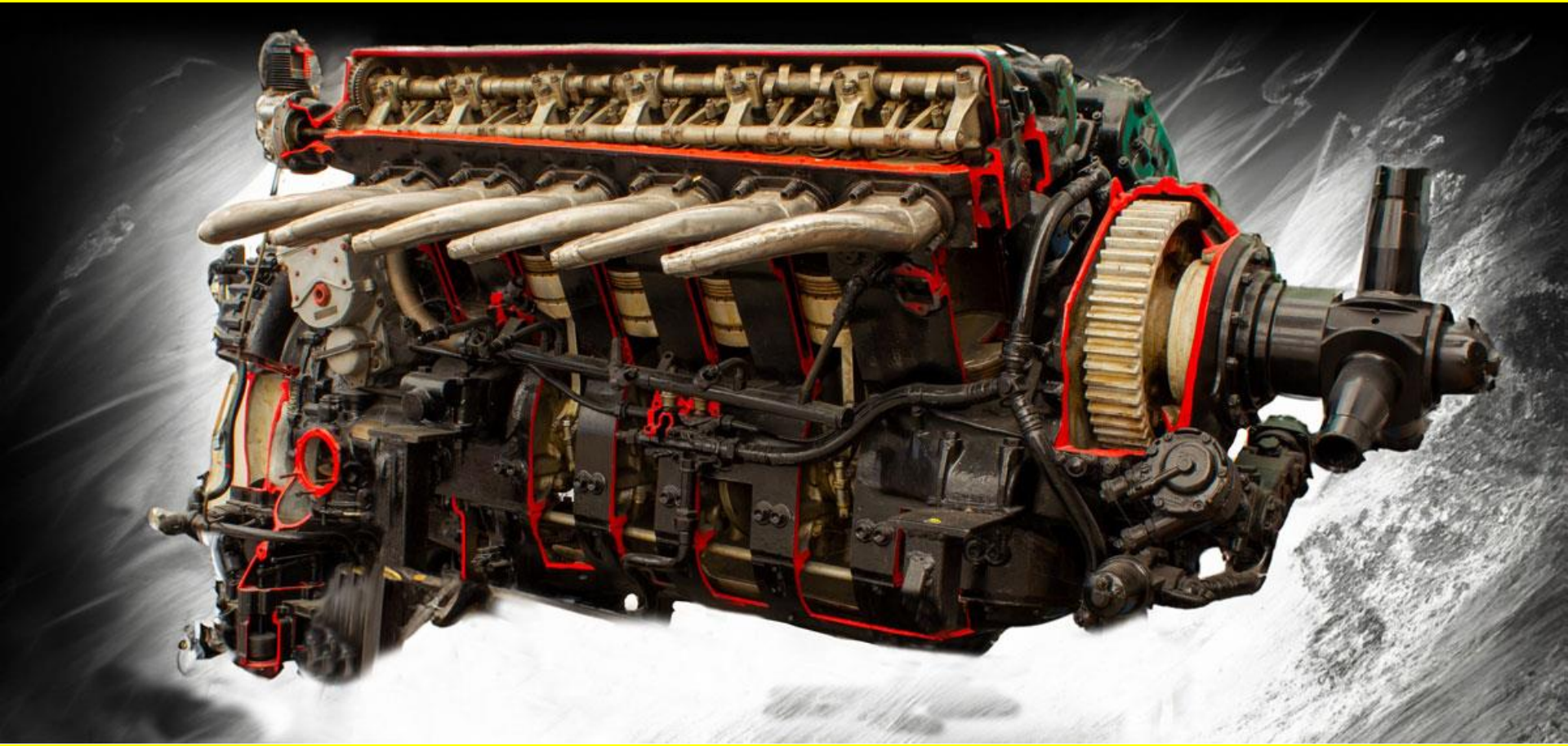
MERLIN



The Engine That Saved the World

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Part 1

A Series of Fortunate Events

Rendezvous With Destiny

The course of World War II would have been very different without Rolls-Royce's immortal Merlin engine

historynet.com

RE: introduction to an article written by *Nicholas O'Dell* entitled: "The Engine That Won World War II"

Very Hush, Hush

“THE British Overseas Airways Corporation flight from Stockholm, Sweden, landed at an airfield in Leuchars, Northern Scotland, one of several hundred round trips the airline made between the two cities. But this was no ordinary flight…”
historynet.com



"…The year was 1943 and although the plane carried civilian markings and the pilot and navigator were nominally civilian employees of BOAC, it was a de Havilland Mosquito bomber…"

historynet.com

<u>Caption</u>: "A de Havilland Mosquito in BOAC civilian markings at Leuchars, Scotland"



"…The passenger who emerged, stiff from being crammed into an improvised bunk in the bomb bay of the unpressurized aircraft, was physicist Niels Bohr, 1922 Nobel Prize winner and pioneer in nuclear fission research…"

historynet.com

RE: Bohr (left), equipped with parachute, flying suit and oxygen mask spent the 3-hour flight lying on a mattress in the air-crafts bomb bay. During the flight, Bohr did not wear his flying helmet since it was too small and, consequently, did not hear the pilot's intercom instruction to turn on his oxygen supply when the aircraft climb-ed to high altitude to overfly Norway. He passed-out from oxygen starvation and only revived when the aircraft descen-ded to lower altitude over the North Sea.

In 1913, *Niels Bohr* achieved worldwide fame in the field of physics by publishing a series of essays in which he revealed his model of the structure of the atom. In 1922, Bohr won the Nobel Prize "for his research into the structure of atoms and the radiation emanating from them." In the 1930s, Bohr spent long periods in the U.S. where he brought the first news of nuclear fission, which was discovered in Berlin, in 1938, by *Otto Hahn* and *Fritz Strassmann.*

Father of the Bomb



"…Bohr had determined that the uranium isotope U-235 could create a chain reaction and therefore, could be used to construct a powerful atomic bomb; findings he detailed at a January 1939 conference in Washington, D.C…"

historynet.com

<u>Caption</u>: "Neils Bohr (left) and Albert Einstein (right), pictured on 11 December 1925, had a long-running debate about the metaphysical implication of quantum physics"

"…By 1943 the Nazi roundup and deportation of Jews in Denmark put Bohr at great risk, as his mother was Jewish. Word leaked that he was about to be arrested and would face a stark choice: Join Adolf Hitler's atomic weapon project or be sent with his wife and son to almost certain death in a concentration camp…"

historynet.com

RE: in September 1943, word reached Bohr and his brother, Harald, that the Nazis considered their family to be Jewish since their mother was Jewish and that they were therefore in danger of being arrested. The Danish resistance helped Bohr and his wife escape by sea to Sweden on September 29, 1943. When the news of Bohr's escape reached Great Britain, Lord Cherwell sent a telegram to Bohr asking him to come to Britain. Bohr arrived in Scotland on October 6, 1943 in a de Havilland Mosquito operated by the *British Overseas Airways Corporation* (BOAC).

"…With the help of the British Secret Service, Bohr had been smuggled to neutral Sweden. On December 6th he flew from England to the United States to join the Manhattan Project…"

historynet.com

RE: on December 8, 1943, Bohr arrived in Washington, D.C., where he met with the Director of the Manhattan Project; Brigadier General *Leslie R. Groves Jr.* He visited Einstein and Pauli at the *Institute for Advanced Study* in Princeton, NJ, and went to Los Alamos, in New Mexico, where the nuclear weapons were being designed. For security reasons, Bohr went under the name "Nicholas Baker" while in the U.S.

The Need for Speed

"…The Mosquito was the only aircraft fast enough to evade German fighters patrolling the North Sea to intercept the BOAC flights, which conveyed clandestine personnel and precision supplies such as ball-bearings…"

historynet.com

RE: BOAC Mosquitos were unarmed, high-speed bomber aircraft that had been converted to carry small, valuable cargos and/or important passengers, such as Bohr. By flying at high speed and high altitude, they could cross German-occupied Norway while avoiding German fighters.

What Might Have Been

"…The Nazi atomic bomb project ultimately fizzled, but it might have ended differently if Bohr had been in-charge, coerced by threats to his family…"

historynet.com

RE: Bohr was aware of the possibility of using uranium-235 to construct an atomic bomb, referring to it in lectures in Britain and Denmark shortly before and after the war began, but he did not believe that it was technically feasible to extract a sufficient quantity of Uranium-235. In September 1941, *Werner Heisenberg,* who was head of the German nuclear energy project, visited Bohr in Copenhagen. During this meeting the two men took a private moment outside, the content of which has caused much speculation.

Finest Hour



"…Of course, he might never have been rescued if Britain had lost the ferocious aerial struggle for its existence in the summer of 1940…"
historynet.com

<u>Caption</u>: "Pilots of No. 601 (County of London) Squadron run to their waiting Hawker Hurricane fighter aircraft at RAF Northolt during the Battle of Britain"

Unimaginable



"…If the close-run Battle of Britain had gone the other way, Great Britain, with much of its armor, trucks and heavy weapons left behind in the evacuation of Dunkirk, would have been in a precarious position. The effect of a possible British capitulation on subsequent events in Russia, North Africa, Normandy and the Far East can only be imagined…"

historynet.com

<u>Caption</u>: "British soldiers evacuated during the Battle of Dunkirk, 1940"

Little Friends



"…Two months after Bohr's harrowing flight, on December 13, 1943, North American P-51B Mustang fighters accompanied 710 U.S. Army Air Forces bombers on a mission to Kiel, Germany. The 980-mile round-trip was the first fully escorted long-distance raid of the war and the beginning of successful daylight precision bombing and the progressive destruction of the Luftwaffe…"

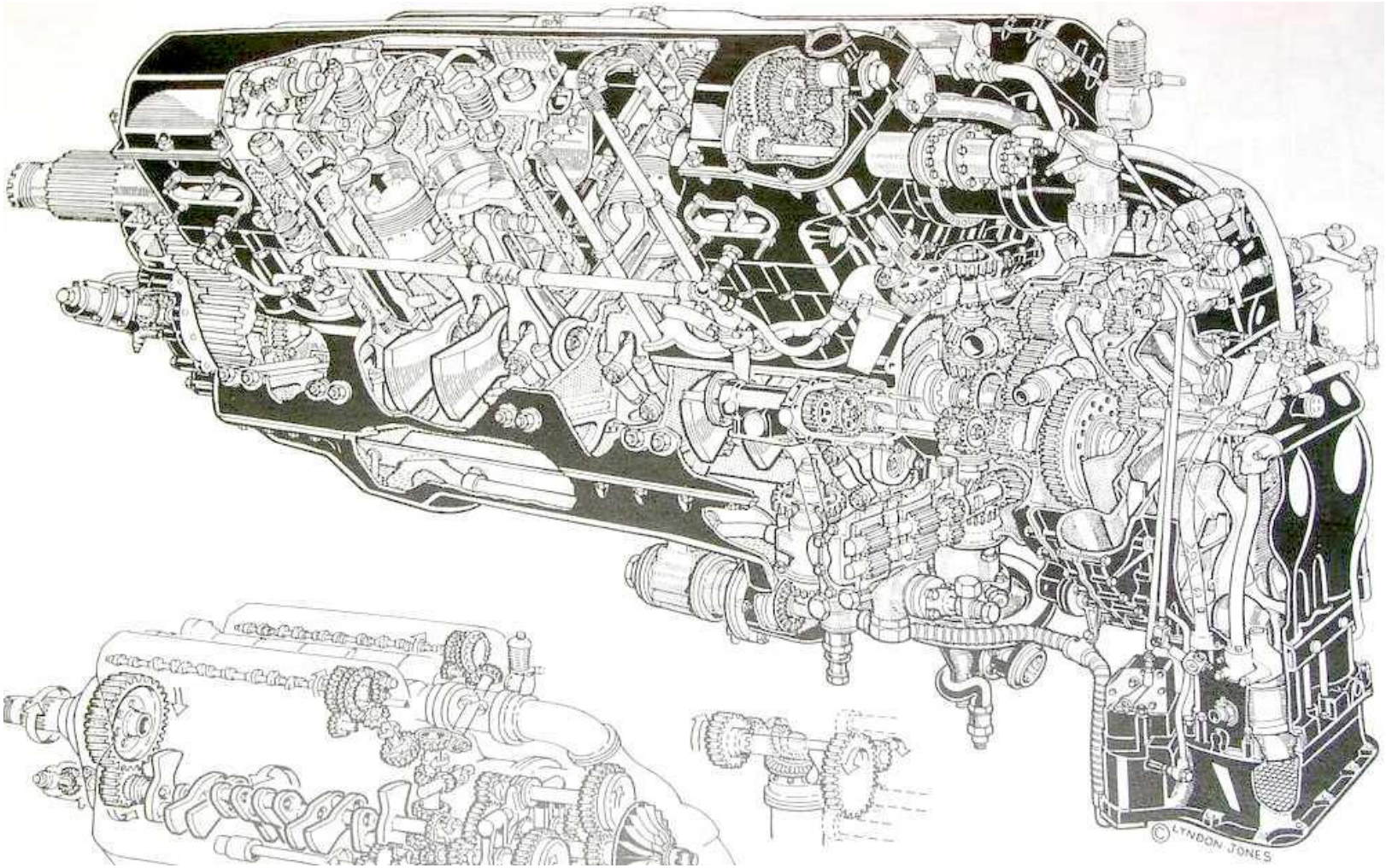
historynet.com

<u>Caption</u>: "B-17 escorted by two P-51B Mustang fighters"



<u>Above</u>: in 1943, the U.S. and Great Britain launched a bombing campaign against Germany that lasted until the end of the war. After heavy initial losses, it became apparent that, for the raids to be truly successful, long-range escort fighters, such as the Mustang, were necessary.

Troika



"…These three momentous events - Bohr's rescue, Germany's defeat in the Battle of Britain and America's long-distance fighter escort missions - had one thing in common: They were all made possible by the same aero-engine; the magnificent Rolls-Royce Merlin…"

historynet.com

<u>Caption</u>: "Cut-away rear view of the Rolls-Royce Merlin engine"

So Much to So Few

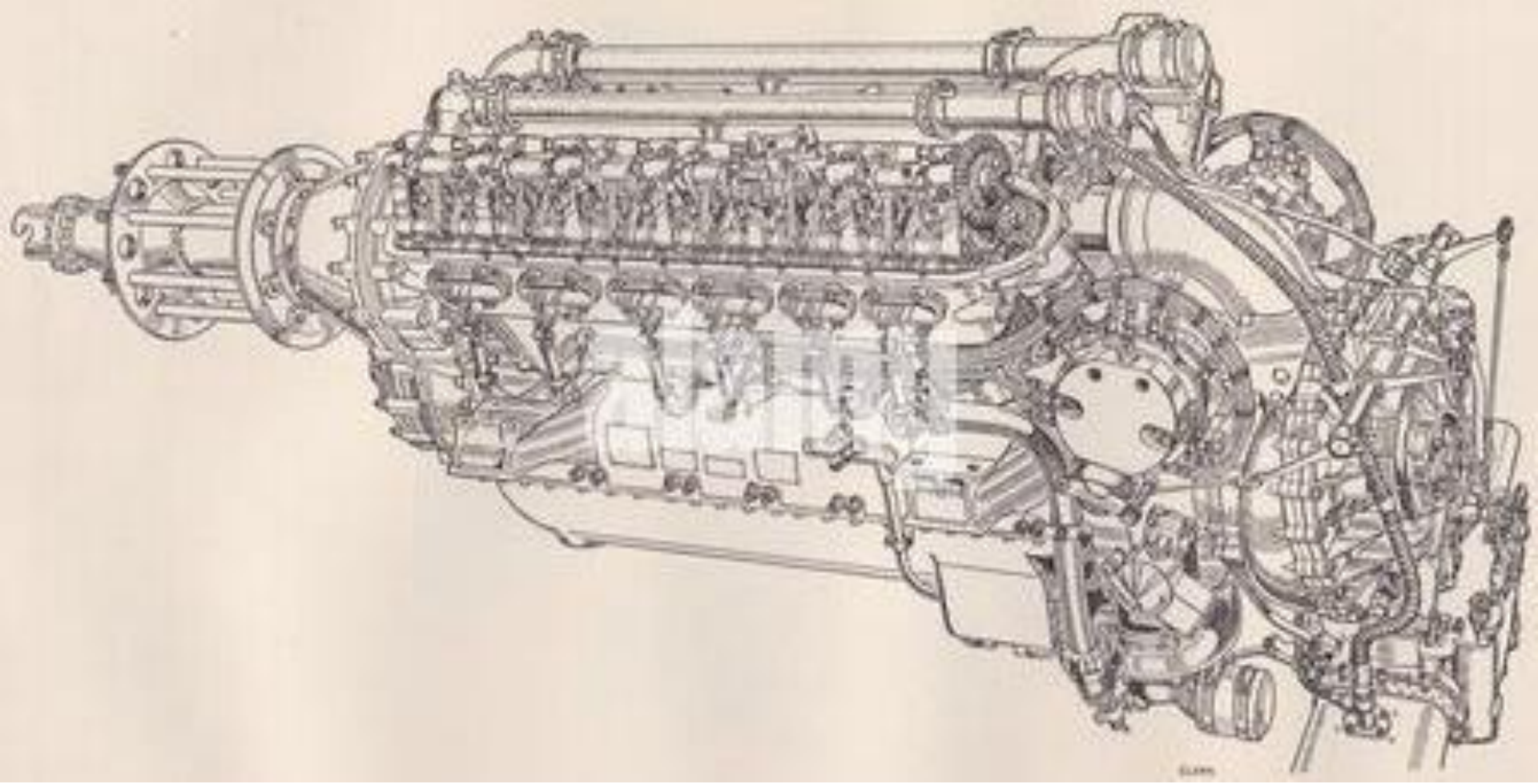
"…Without the inspired genius of a gifted Mathematician and the dedication of a small group of Engineers who developed the Merlin, the world today might be a very different place…"
historynet.com

Origins

"…The Merlin's origins date back to the 1920s, with the 21-liter V-12 Kestrel; the first Rolls-Royce production engine to be supercharged…"

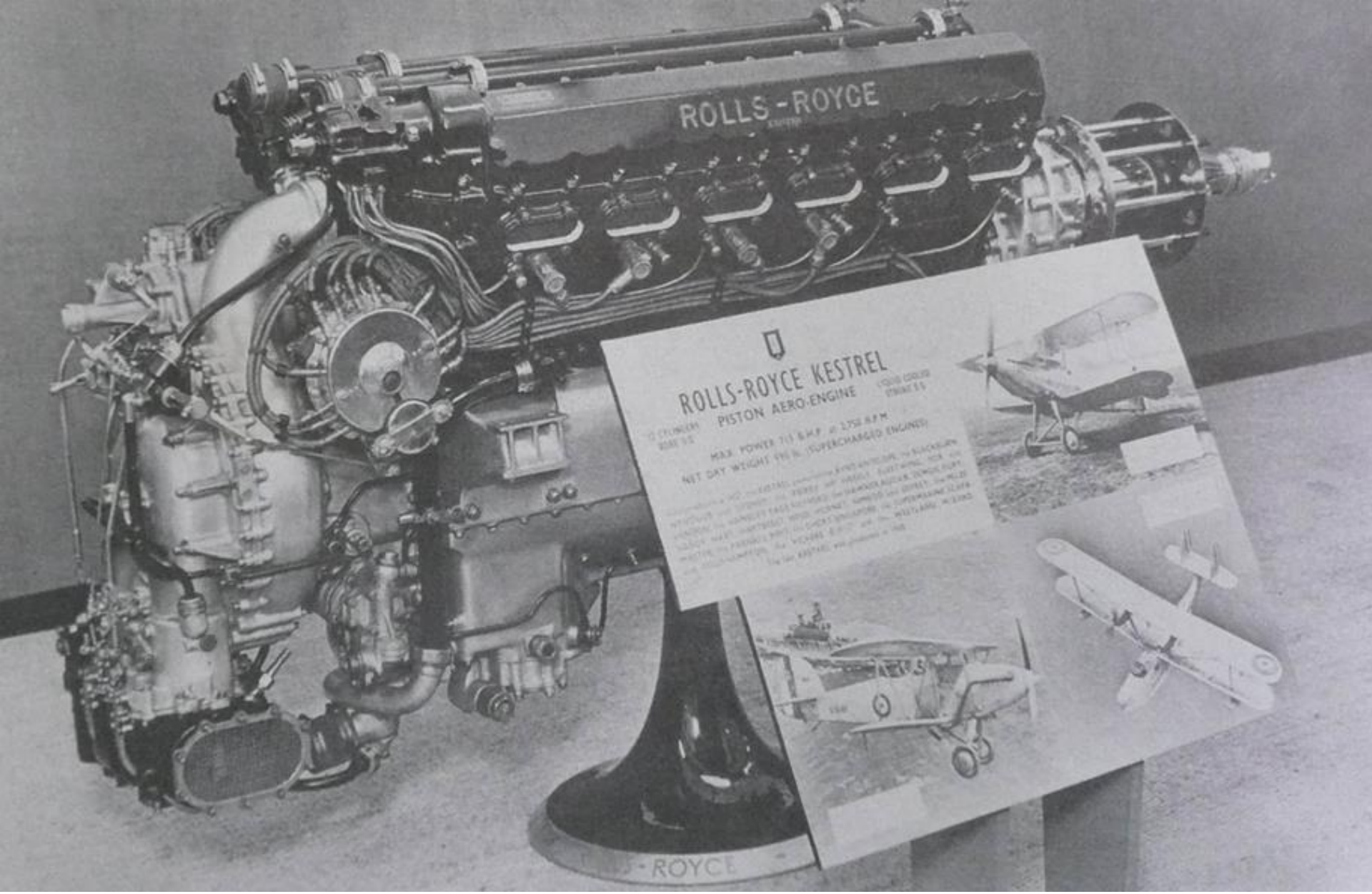
historynet.com

RE: the Kestrel was a V-12, supercharged liquid-cooled aero-engine that developed from a 1920s Air Ministry tasking of R-R and *Napier and Sons* to produce an aircraft engine that was superior to the American Curtiss D-12; a V-12 liquid-cooled engine that was, at the time, the most powerful aircraft engine (450 hp). With the use of cast-aluminum cylinder blocks instead of the contemporary use of individual steel cylinders attached to the crankcase, it was lighter and made for a stronger engine structure. Napier's Chief Design Engineer left the firm and, upon joining R-R, designed what became the R-R Kestrel V-12 engine.



The new engine featured a pressurized cooling system that prevented the coolant boiling with altitude against falling air ambient air-pressure by heating the coolant to 160-degrees C that had the advantage of increasing the boiling point of the coolant at ground level. A supercharging system that operated from ground level upward produced performance that surpassed that of a normally aspirated engine at all altitudes.

<u>Caption</u>: "Rolls-Royce supercharged 'Kestrel' liquid-cooled horizontal engine"



<u>Caption</u>: "The 715 hp Rolls-Royce Kestrel was the forerunner of the Merlin. It was in production from 1927 till 1938, was used in twenty-five types of RAF planes and was even the engine used in the prototype Messerschmitt 109"



"…Strongly influenced by the Curtiss D-12, the Kestrel's basic design was so sound that its derivatives, in various sizes and versions, were produced to the end of the company's piston engine era…"

historynet.com

<u>Above</u>: the Curtiss R-6 Racers were single-engine, single seat, fully-braced single-bay biplanes with fixed landing gear; developed from the U.S. Navy Curtiss CR. The airplane and its D-12 Conqueror engine were both built by the Curtiss Aeroplane and Motor Co., Garden City, NY.

The CD-12 (Curtiss Direct-Drive) history extended over several years. Development began in 1915 with the K-12, using the design skills of *Charles Kirkham* and in competition with the popular Hispano-Suiza. The high-power and low-weight goal was a significant challenge. Thus, it was not surprising that the aluminum monoblock and several other advanced features, including the reduction gearing, presented substantial problems. Unable to overcome these difficulties, Kirkham left Curtiss in 1919 and his successor, *Arthur Nutt,* produced a de-rated CD-12, without the reduction gearing of the K-12, in 1921.



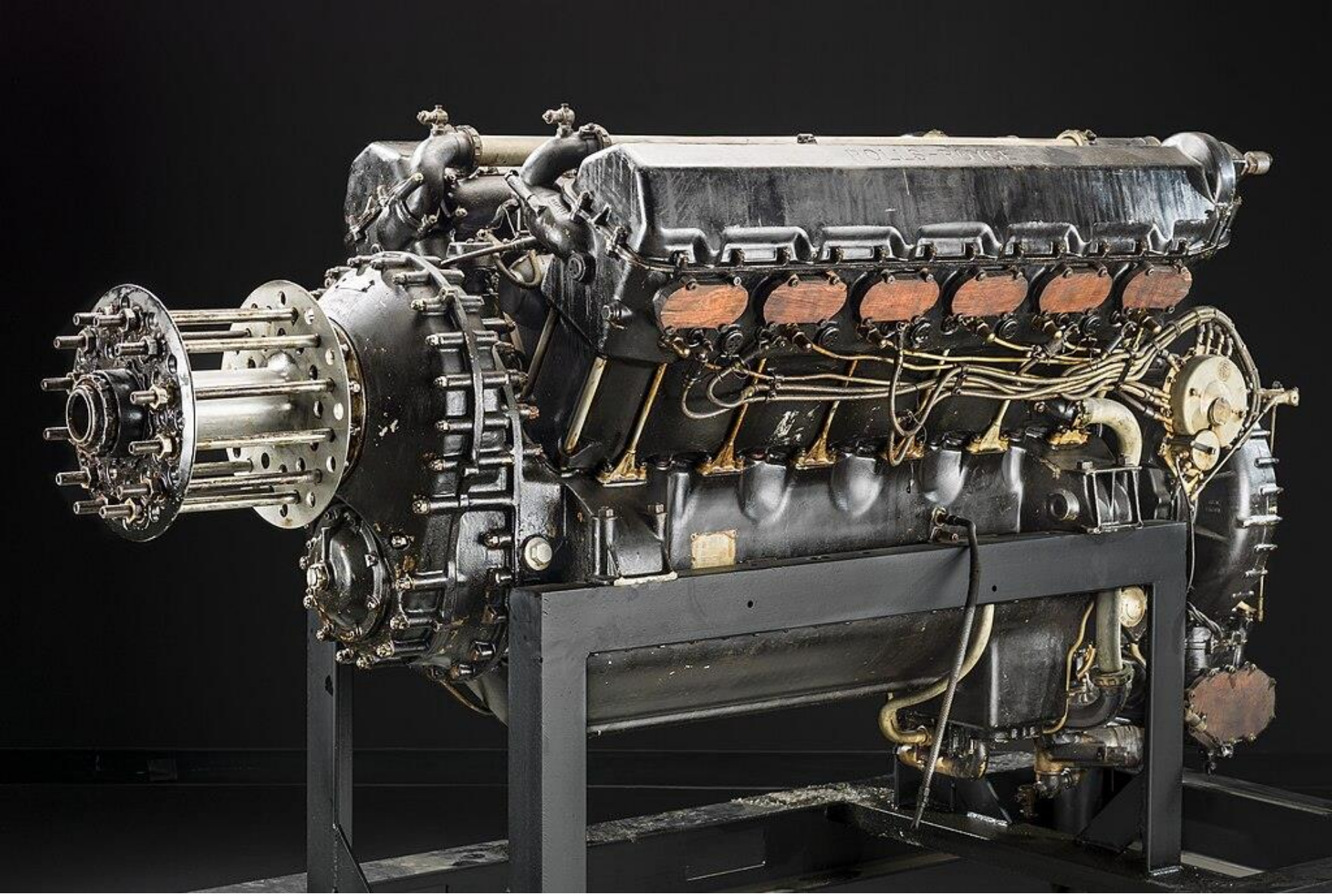
Curtiss CD-12 V-12 Engine

Type-R

"…Its enlargement to 37 liters resulted in the Buzzard, from which a 1929 racing version, called simply 'R' by Rolls-Royce, eventually developed 2,500 hp…"

historynet.com

RE: the R-R "Buzzard" was a piston aero-engine of 2,240 cubic-inch capacity that produced about 800 hp. Designed and built by R-R, it was a V-12 engine of 6 in. bore and 6.6 in. stroke. Only 100 were produced. The Buzzard was developed by scaling-up the R-R Kestrel engine. A further development was the R-R "R" engine – a racing version of the Buzzard engine.



<u>Caption</u>: “Rolls-Royce ‘Buzzard,’ at the National Air and Space Museum”

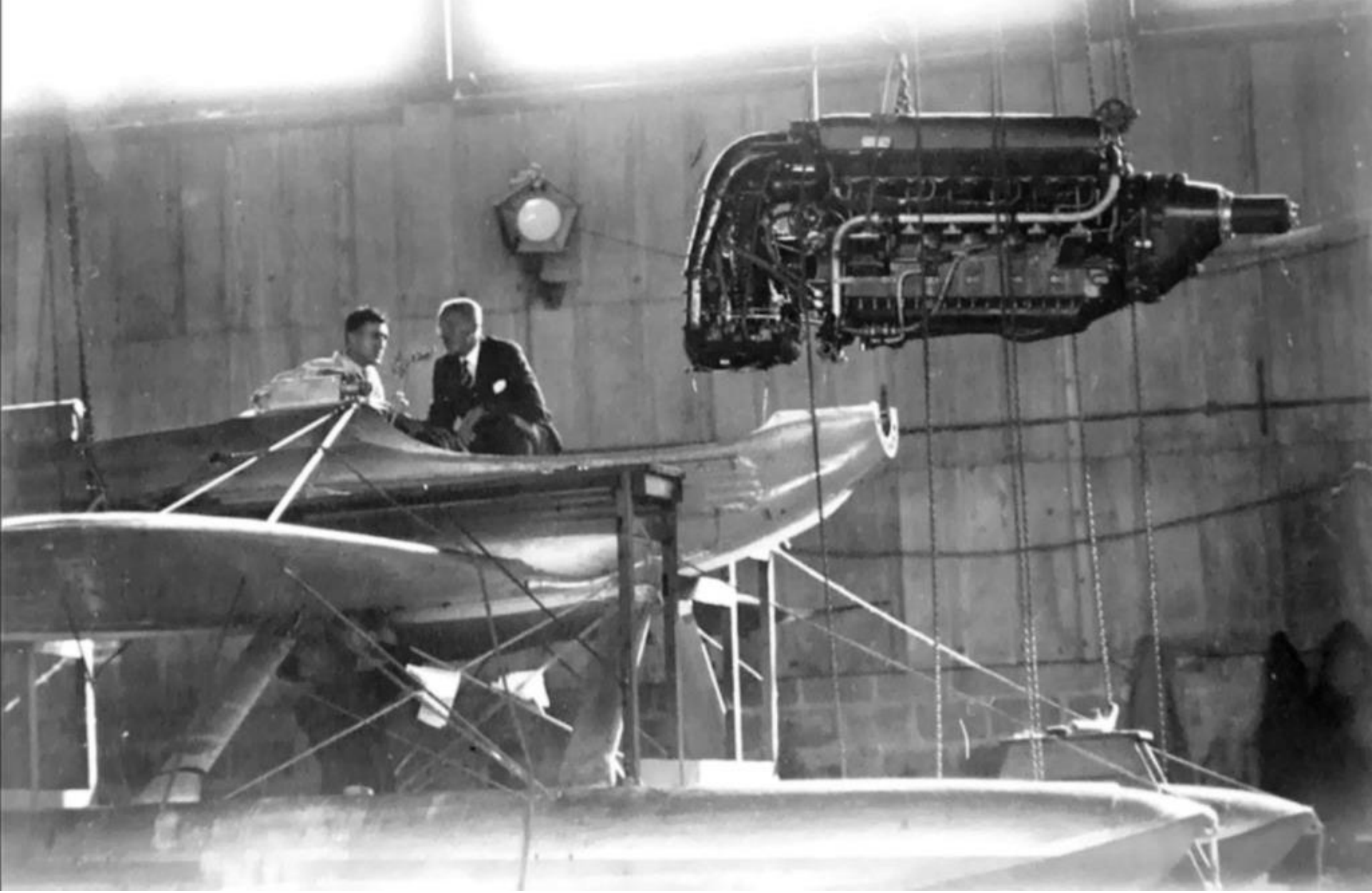




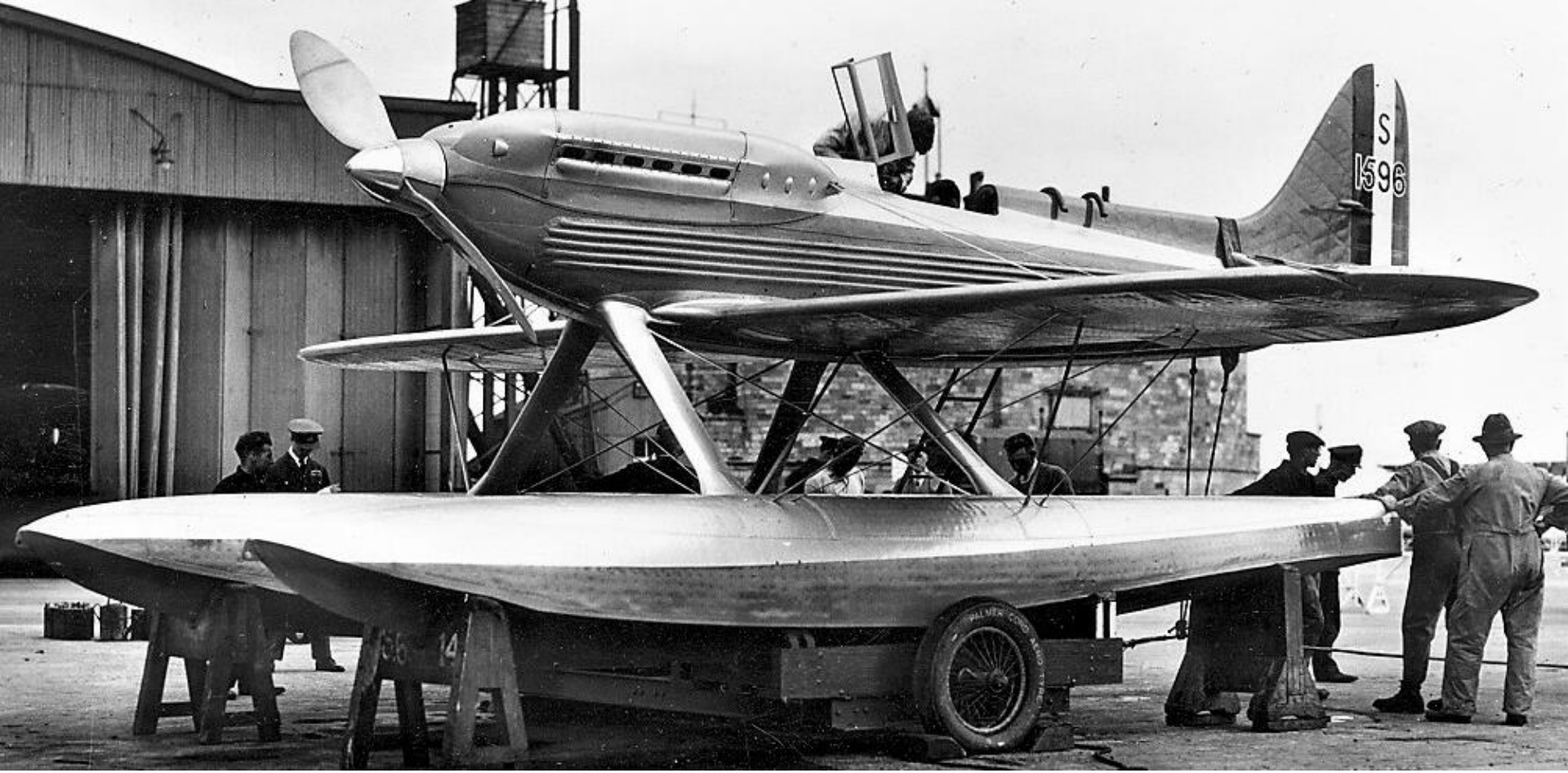
"…The 'R' gave Britain victories in the Schneider Trophy seaplane races three years in a row, a world air-speed record of 407.5 mph and possession of the trophy in perpetuity…"

historynet.com

<u>Above & Left</u>: in September 1929, at the UK's Solent course, Supermarine won again (Flying Officer Henry Waghorn) in the Supermarine S.6B with the new R-R "R" engine with an average speed of 328.64 mph



<u>Caption</u>: "Being installed into a Supermarine S.6B racer, the Rolls-Royce Type R engine helped Supermarine bring the Schneider Trophy to Britain and set the stage for the iconic Merlin"



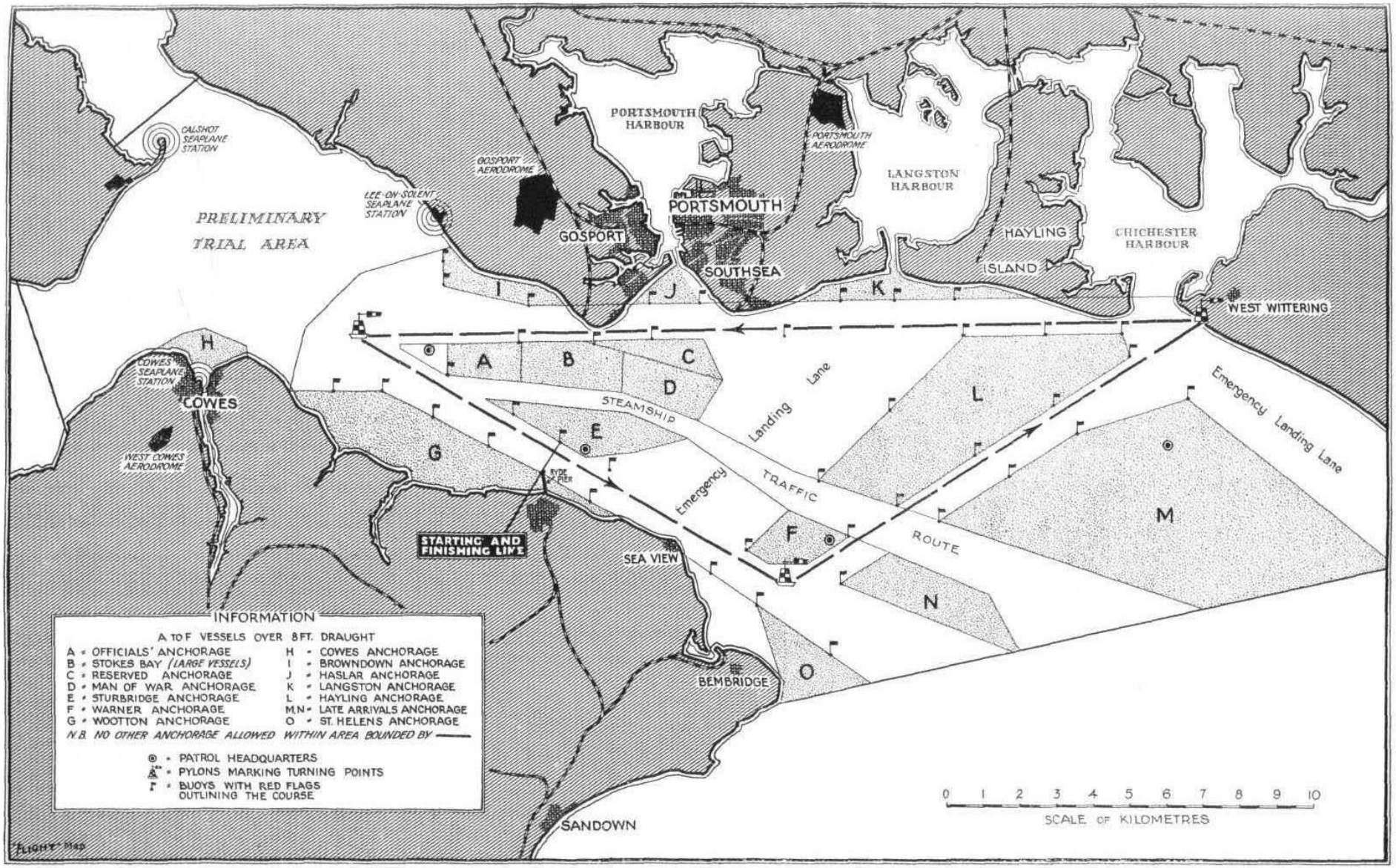
"…Significantly, the winning planes were designed by Reginald J. Mitchell and built by the Supermarine Company…"

historynet.com

<u>Above</u>: the Supermarine S.6B was a British racing seaplane developed by R.J. Mitchell for the Supermarine company to take part in the Schneider Trophy competition of 1931. The S.6B marked the culmination of Mitchell's quest to "perfect the design of the racing seaplane" and represented the cutting-edge of aerodynamic technology for the era.



<u>Above</u>: R.J. Mitchell sits on the running board of his automobile, surrounded by other Supermarine personnel, (from left): Joseph 'Mutt' Summers, H.R. 'Agony' Payne, S. Scott Hall and Jeffrey Quill.



THE 1931 SCHNEIDER TROPHY COURSE: By having a triangular course the number of turns is reduced, but on the other hand some of the turns are sharper than those of the four-sided course of 1929.


THE SCHNEIDER TROPHY
SEPT. 12TH CONTEST - 1931 -
THE ROYAL AERO CLUB
OFFICIAL
SOUVENIR PROGRAMME
6D
Printed and Published by
GALE & POLDEN LTD., LONDON, ALDERSHOT & PORTSMOUTH.


SUPERMARINE
WORLD'S
SPEED RECORD
100 KILOMETRES
1927
281·656 M.P.H
1929
328·63 M.P.H
1931
342·9 M.P.H
INTERNATIONAL SCHNEIDER TROPHY
WON OUTRIGHT BY
VICKERS SUPERMARINE ROLLS ROYCE S.6 B
1931
SUPERMARINE
WORLD'S
SPEED RECORD
1927
283·669 M.P.H
1929
357.7 M.P.H
1931
407·5 M.P.H
HIGH SPEED FLIGHT-ROYAL AIR FORCE
1931
FLIGHT LIEUT. W. F. DAY (ENGINEER)

Setting the Stage



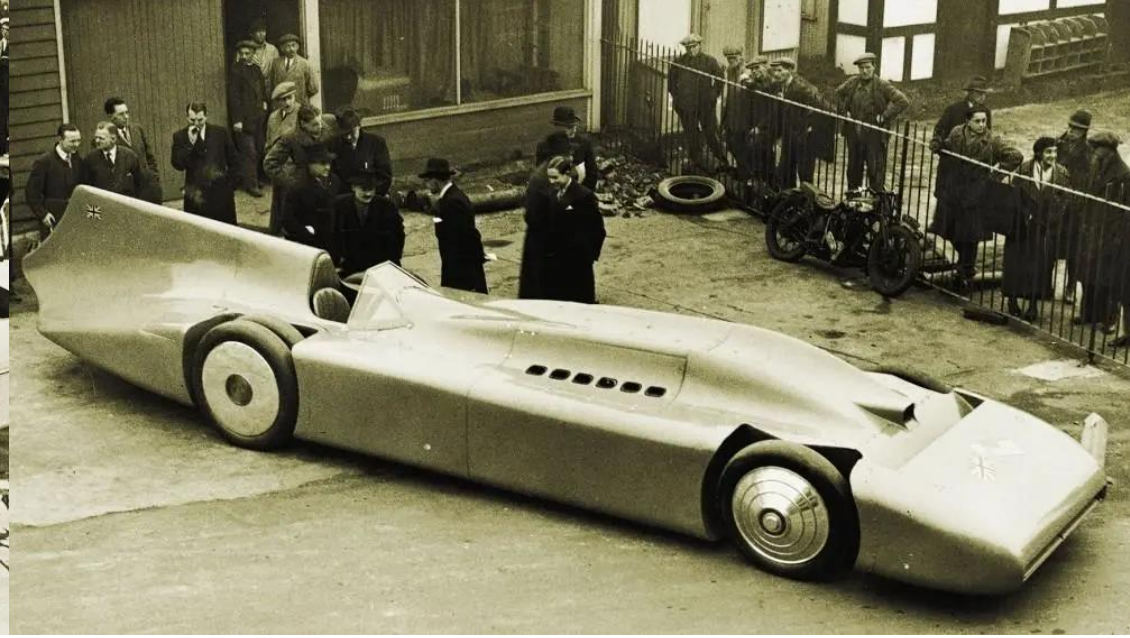
"…Thus, the stage was set for the Engineers and Designers of Rolls-Royce and Supermarine to create, five years later, the immortal Spitfire…"

historynet.com

RE: twenty-five yo Engineer *Reginald J. Mitchell* was appointed Chief Designer of Supermarine Aviation in 1920 and, over the next 16 years, would be responsible for 24 different aircraft: fighters, bombers and flying boats – including the peerless *Spitfire*; hero of the Battle of Britain (above). Supermarine was one of the few British aircraft manufacturers to turn-a-profit during the Great Depression.

Land, Sea and Air

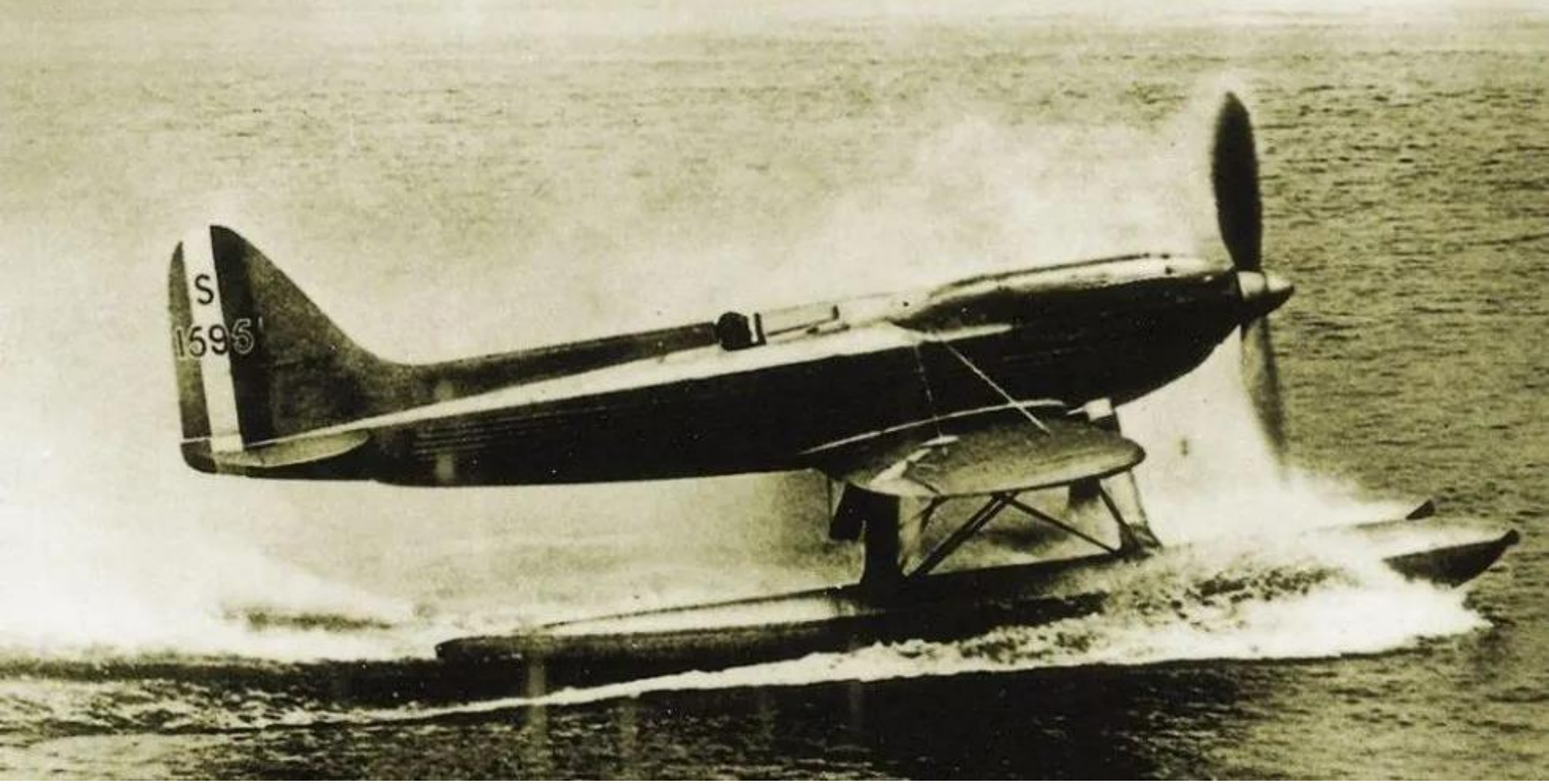




"…The 'R' also powered cars to world land speed records, ultimately achieving 357 mph in 1938 and a boat to a world water speed record of 142 mph, in 1939. As a result, before World War II the engine held or had held all three world speed records; on land, water and in the air…"

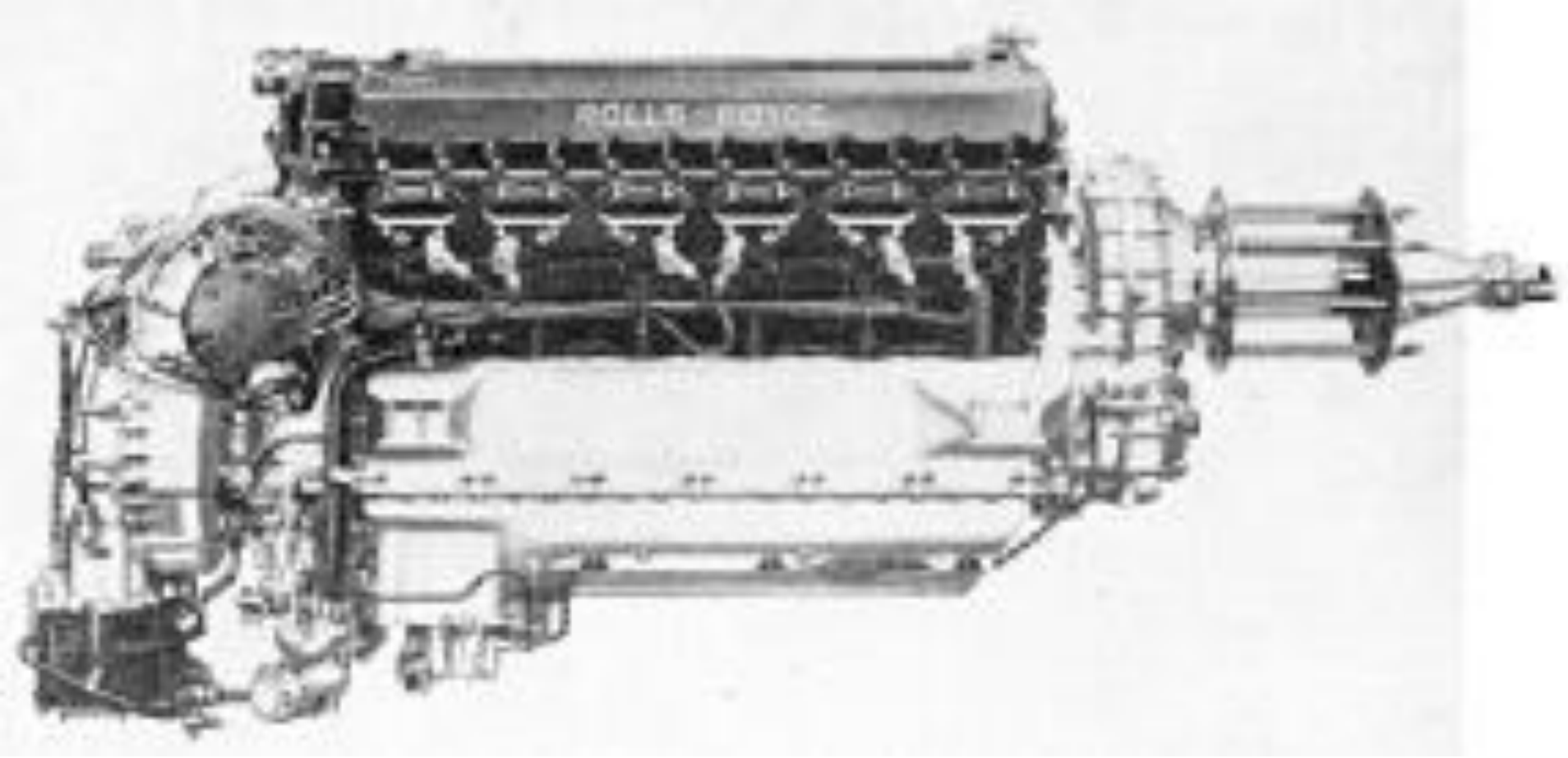
historynet.com

<u>Above L&R</u>: in the 1930s, the R-R Type-R engine ruled the air, land and sea; holding all three speed records simultaneously. In the 1920s and '30s, the pursuit of speed was a worldwide phenomenon. Variously driven by the spirit of adventure, the challenge of engineering, a sense of national pride and/or just outright competitiveness, these dangerous race events held on land, in the air and on the water captured the fascination of people the world over. Even on land and water, big-displacement aviation engines became the go-to powerplants for those individuals seeking speed records.



R-R only made 19 R-Type engines overall, each one serialized with an odd number; an R-R tradition for aero-engines with counter-clockwise rotation (when viewed from the front). Numbered from R1 to R39 (R13 was skipped, another superstition-based R-R tradition), they powered English drivers and pilots to two speed records in the air and eight each on land and water. Several engines were swapped among the handful of planes, cars and boats that set records.

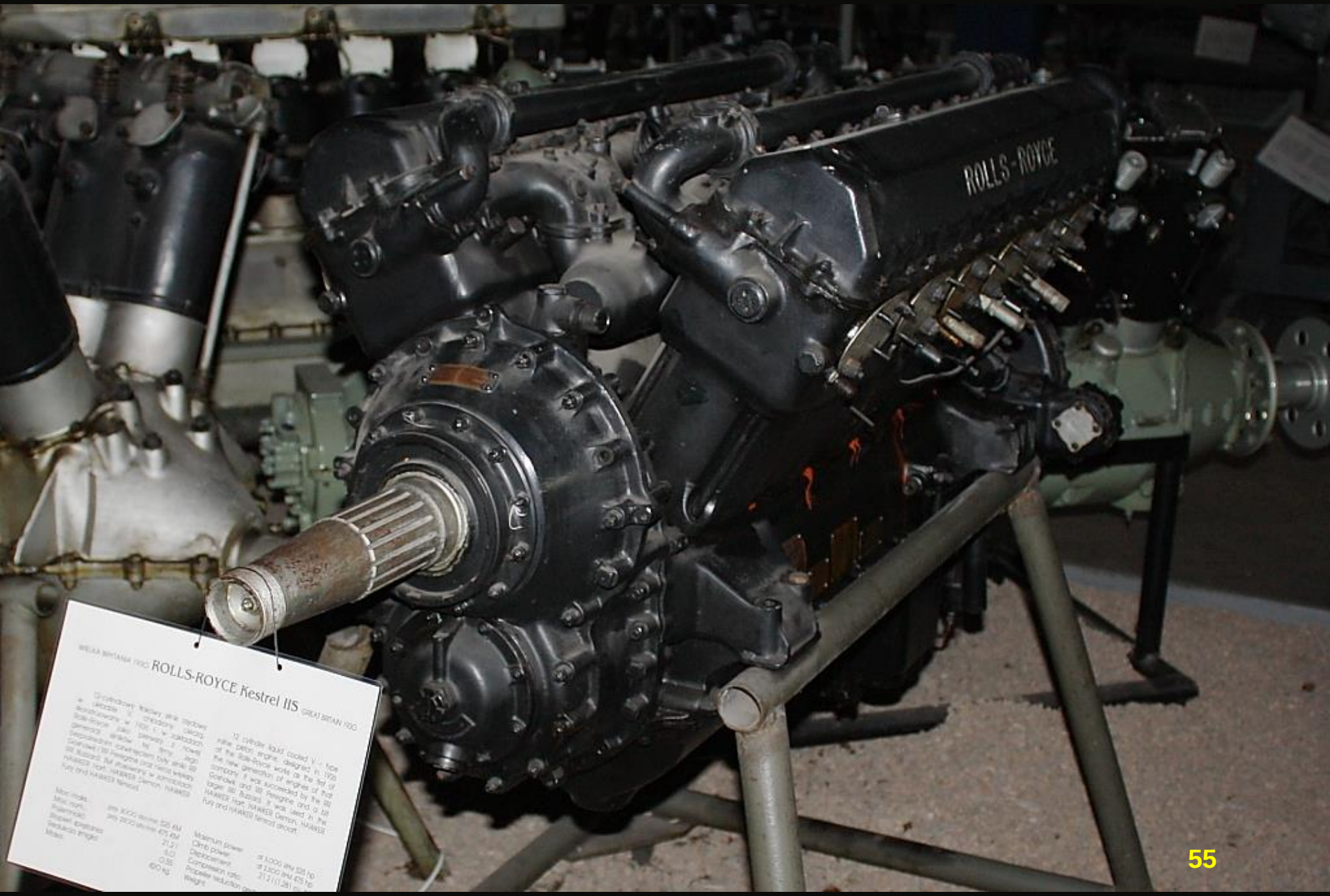
Myth-Busting



"…Despite popular lore, the Merlin was not a de-rated 'R;' instead it was the most important development of the Kestrel, enlarged to 27 liters…"
historynet.com

<u>Caption</u>: "Composite Cooling is a feature of the Rolls-Royce Kestrel engines. In level flight the engines are entirely water-cooled. When climbing a slight amount of boiling is allowed for, thus permitting a smaller radiator to be used than would otherwise be permissible. Reduction gearing for driving the propeller is provided and a choice of three gear ratios is available.

The Kestrel (internal Type-F) was a 21.25 liter V-12 aircraft engine from R-R. It was their first cast-block engine and was used as the pattern for most of R-R's future piston engine designs. Used during the interwar period, it was fitted to a number of British fighters and bombers of the era, including the Hawker Fury and Hawker Hart family and the Handley Page Heyford. The Kestrel engine was also sold to international Air Force customers; in this role it was used to power prototypes of the German Messerschmitt Bf-109 and the Junkers Ju-87 "Stuka" dive-bomber (since the Junkers Jumo 210 engines were not ready to be fitted). Several examples of the Kestrel engine remain airworthy to the present-day.


ROLLS-ROYCE
ROLLS-ROYCE Kestrel IIS GREAT BRITAIN 1930



"…Another myth holds that the engine was named after the wizard of Arthurian legend, but in fact it simply followed Rolls' practice of naming its in-line aero-engines after birds-of-prey. The Merlin is a species of falcon with thin, pointed wings that allow it to dive at high speeds. It was an appropriate choice in view of the engine's future use…"

historynet.com

<u>Above</u>: Merlin's are found throughout the Northern Hemisphere. In North America they're found from eastern Canada and Alaska, south throughout Mexico. Merlin's spend the winter in the southern U.S., Mexico, Central America, northern South America and the Caribbean Islands.

Private Venture



"…The first engines, called PV-12 for 'Private Venture 12-cylinder' (as no government funds had been allocated to the design), were ready for bench testing in 1933, rated at 790 hp. The engine, now uprated to 950 hp, first flew in 1935 in a Hawker Hart; Sydney Camm's last biplane and a forerunner of his Hurricane…"

historynet.com

<u>Above</u>: made famous during the Battle of Britain, the Hawker Hurricane was a single-seat fighter aircraft designed and predominantly built by Hawker Aircraft Ltd. in the late 1930s for service with the RAF. Overshadowed in the public consciousness by the Supermarine Spitfire, the Hurricane nonetheless inflicted 60% of the losses sustained by the Luftwaffe in the engagement and went on to fight in all of the major theatres of operation during WWII.



The R-R PV-12, which was to become the famous Merlin engine, was flown in Hart K3036 on February 21, 1935. Employing a ventral radiator bath similar to that on the Hurricane (the prototype of which was in its early stages of construction), this Hart was delivered to Rolls-Royce Ltd. the following April and was fitted, in-turn, with Merlin "C" and "E" engines, completing over 100 hours flying with each.

Caption: "Hart Mk.I with Rolls-Royce PV12 engine (K3036) APS No. 3471"

Type-Testing

"…Type-testing revealed a host of problems - particularly in the cylinder head design, bearings and gears - which had to be corrected for the engine to become a practical power-plant. By the mid-1930s it was still unreliable; repeatedly failing the civilian 50-hour type-test. It seemed the Merlin would never be successful…"

historynet.com

From Little Acorns…

"…It should be remembered that, at the time, Rolls-Royce was a relatively small company, employing fewer than 7,000 people…"

historynet.com

…Come Mighty Oaks

"…Simultaneously with the Merlin, it was also working on several other piston aero-engines and a marine Merlin for use in fast patrol boats. In 1938 the company would also undertake development of gas turbine (jet) engines. By 1945 Rolls employed more than 55,000 people…"

historynet.com

DT vs. NDT

"…With war clouds gathering and aircraft manufacturers clamoring for the new engine, they continued to improve the Merlin, following Sir Henry Royce's 1915 principle of identifying the weakest link by gradually increasing the engine's speed and load, redesigning the problem component and going on to demand even more, even if this meant running it to destruction…"

historynet.com

RE: *Destructive Testing* (DT) is a method used to assess the strength and durability of materials or products by intentionally damaging or destroying them to determine their failure points. It involves subjecting the test item to extreme conditions or loads until it breaks, providing valuable data on its mechanical properties, performance limits and potential weaknesses. This contrasts with *Non-Destructive Testing* (NDT), which evaluates materials without causing damage.



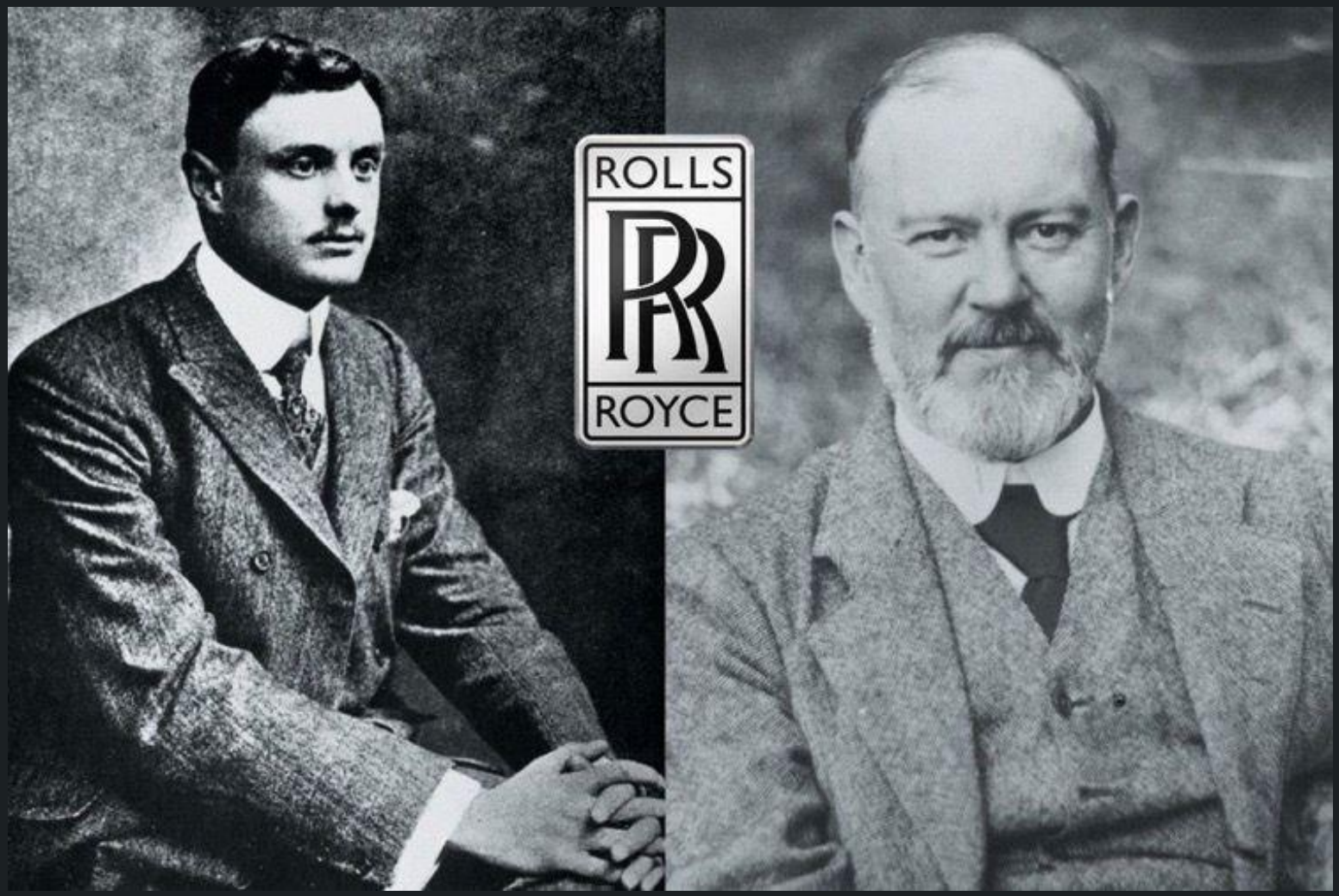
Whatever is rightly done, however humble, is noble. (Quidvis recte factum quamvis humile praeclarum.)

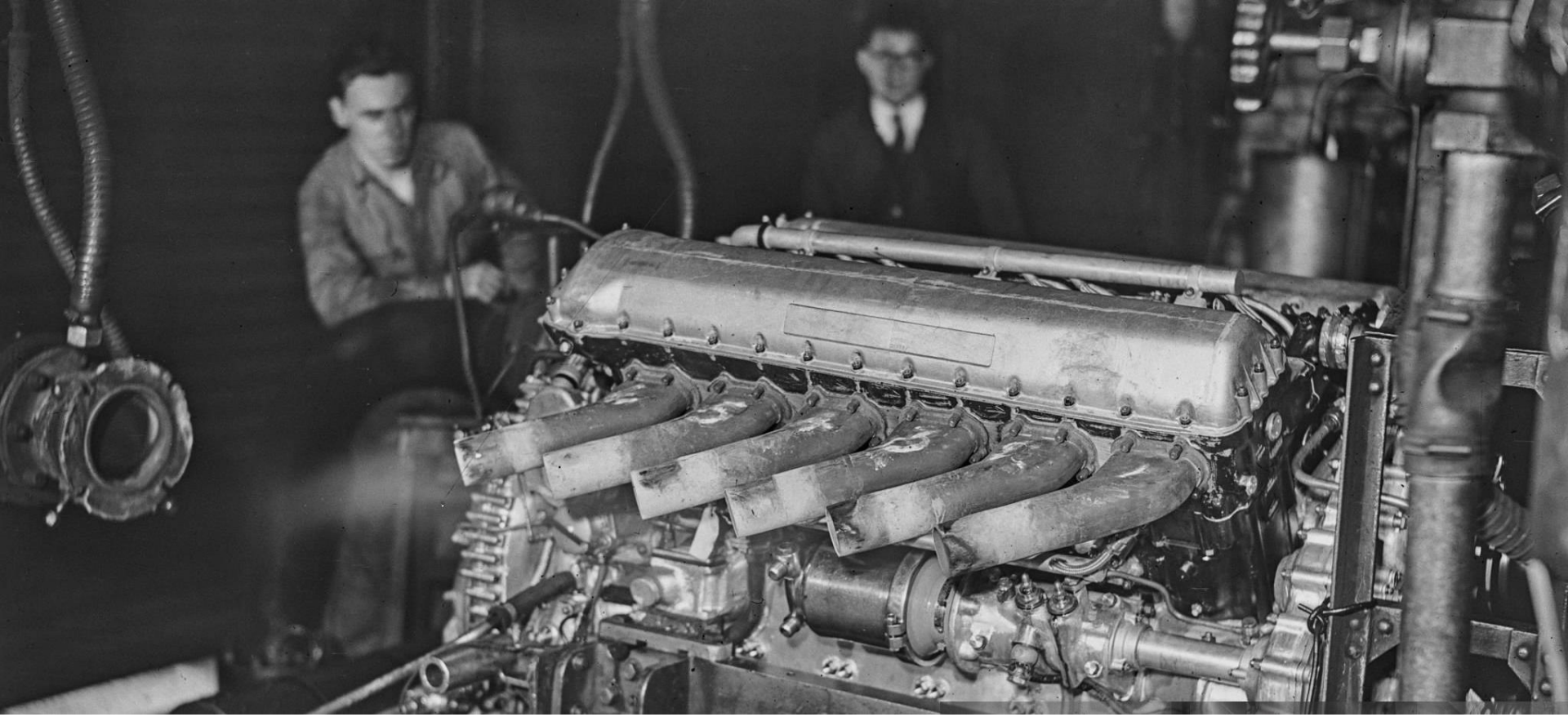
— Henry Royce —

"…Other than dynamometers, instrumentation of the period was rudimentary. But the company had technicians and mechanics of exceptional talent and experience in the testing shops, who, like Royce, had worked their way up through long apprenticeships…"

historynet.com

<u>Above</u>: *Sir Frederick Henry Royce* (1863-1933) was an British Engineer famous for his designs of car and aeroplane engines with a reputation for reliability and longevity. Along with *Charles Rolls* (1877-1910) and *Claude Johnson* (1864-1926), he founded the Rolls-Royce Co.

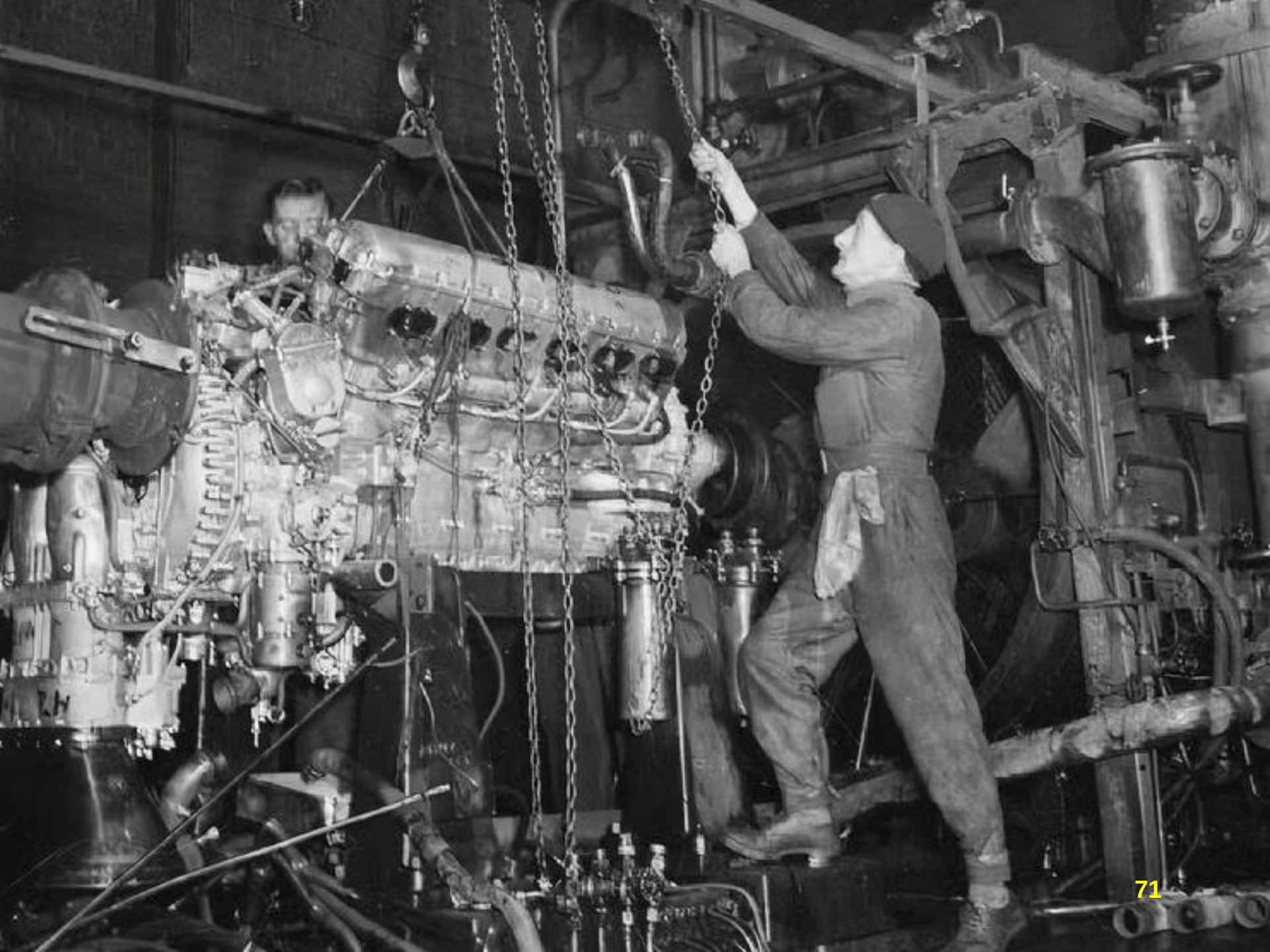

ROLLS
ROYCE



"…They could tell instantly when the sound of an engine changed and detect the onset of detonation (knocking) by holding a short piece of steel between their teeth and resting the other end on the cylinder block of an engine running at full throttle…"

historynet.com

<u>Caption</u>: "A Rolls-Royce Merlin V-12 piston aero-engine undergoes a test-run on a test-bed at the Hillington Rolls-Royce aero-engine factory in Glasgow, Scotland, on Nov. 30, 1942. The Rolls-Royce Merlin engine was produced at plants in Derby, Crewe and Manchester as well as in Glasgow during WWII."



More Than Double



"…Thus, the Merlin experienced a steady increase in power output that, in 12 years, would more than double its original rating while retaining reliability…"

historynet.com

<u>Caption</u>: "Merlin 23 was a Merlin 22 with the direction of coolant flow reversed for Mosquito wing radiator installation"

A Brilliant Mind



"…Rolls-Royce was extremely fortunate in being able to lure the brilliant young Stanley Hooker away from the Admiralty Research Laboratories in 1938. An Oxford graduate in mathematics, he had also done post-graduate work on fluid dynamics and would become, probably, the world's greatest expert in fluid and thermodynamics applied to supercharging..."" historynet.com

Not Much of an Engineer

"…In Hooker's hiring interview at the Derby plant, Works Manager Ernest W. Hives questioned him on a technical point. 'I explained as best I could,' recounted Hooker, 'and then he said, leaning forward, 'You're not much of an Engineer are you?' I had to agree and he replied: 'Never mind, this place is full of the best Engineers in the world and they will teach you…'"

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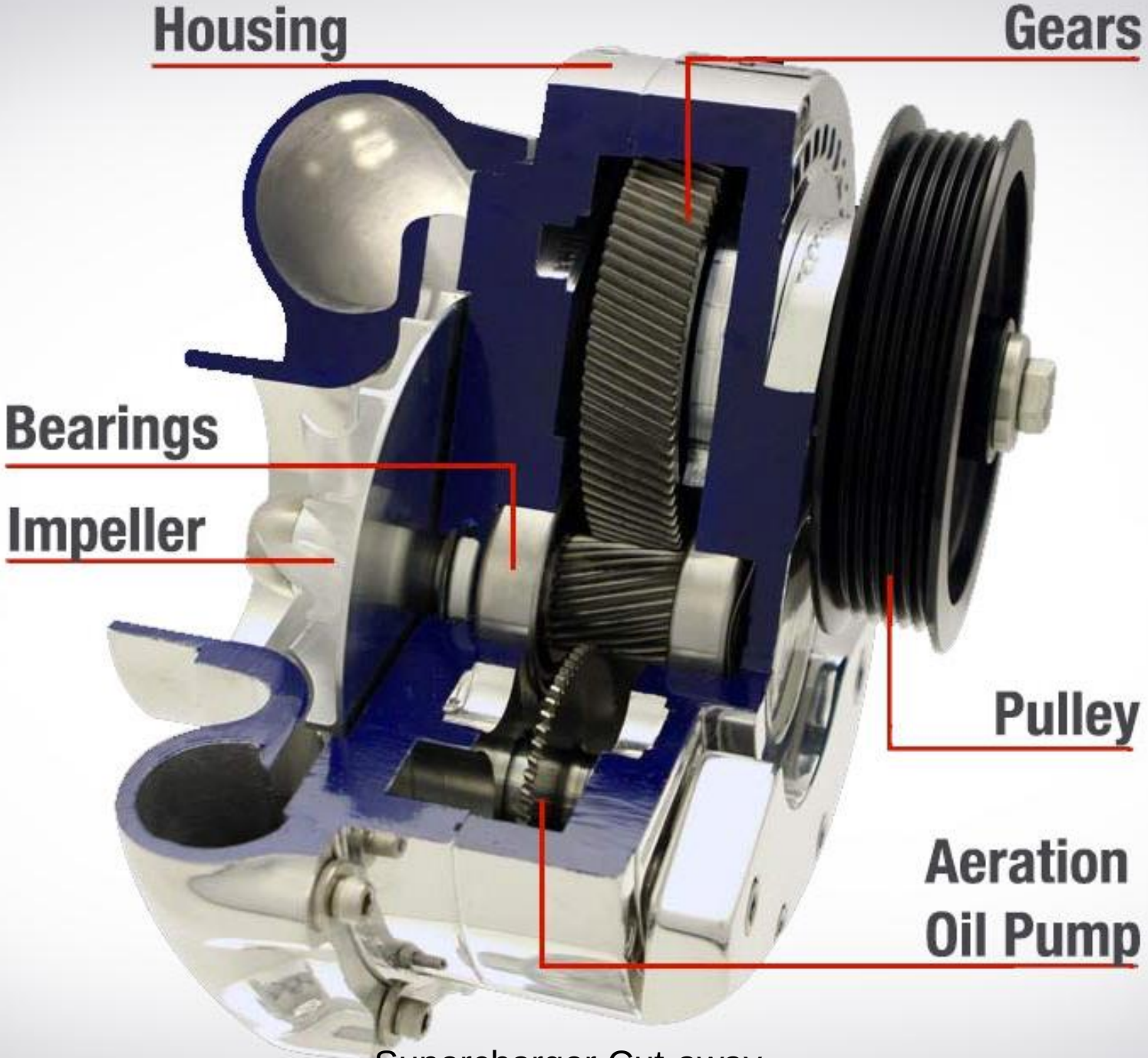
RE: born in 1907, Hooker was a Mathematician/Engineer who, after studying mathematics, hydrodynamics and aerodynamics, went to work for *Ernest Hives* at R-R in 1938. His talents were immediately apparent and he soon he became responsible for analyzing and improving the Merlin engine's supercharger, resulting in an increase in power of 30%. His contribution to the Merlin supercharger program, which he continued throughout WWII, enabled RAF planes to remain competitive in combat against the Luftwaffe. Doubtless, his contribution to the R-R Merlin engine, fitted to the Hawker Hurricane and Supermarine Spitfire airframes, helped win the Battle of Britain. In 1940 he was introduced to *Frank Whittle*, who conceived the first jet engine, and he spent the rest of his career at the cutting-edge of jet-engine design.

Supercharging Science

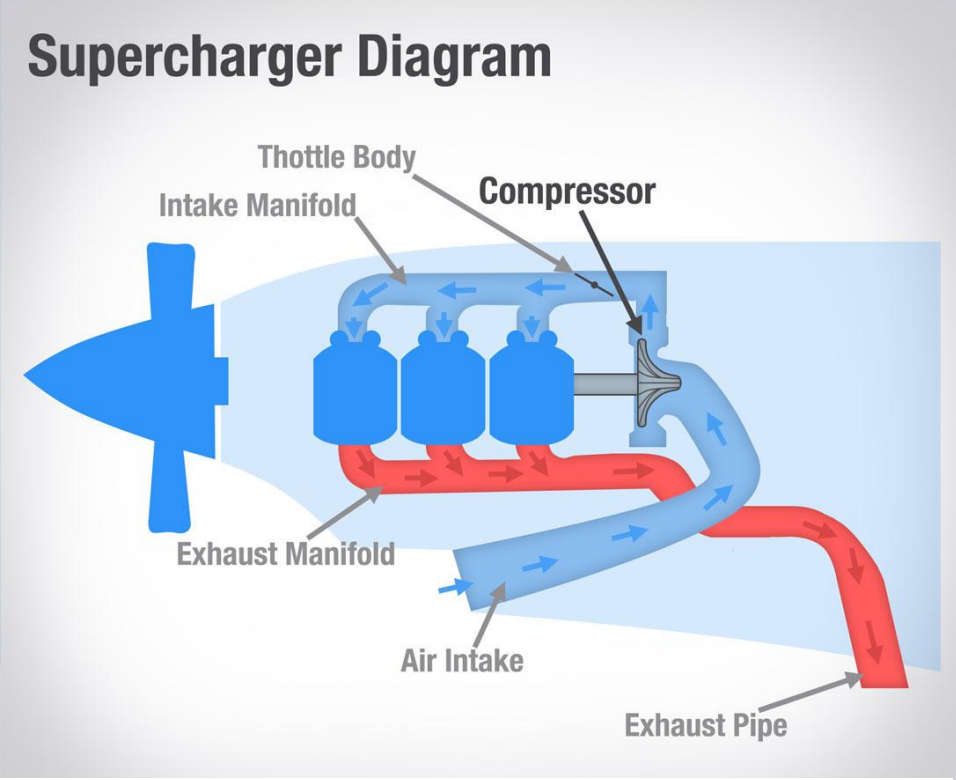
"…On joining Rolls-Royce, Hooker was surprised to learn that supercharging science was scanty, despite aircraft engines having used pressure boost since before World War I…"

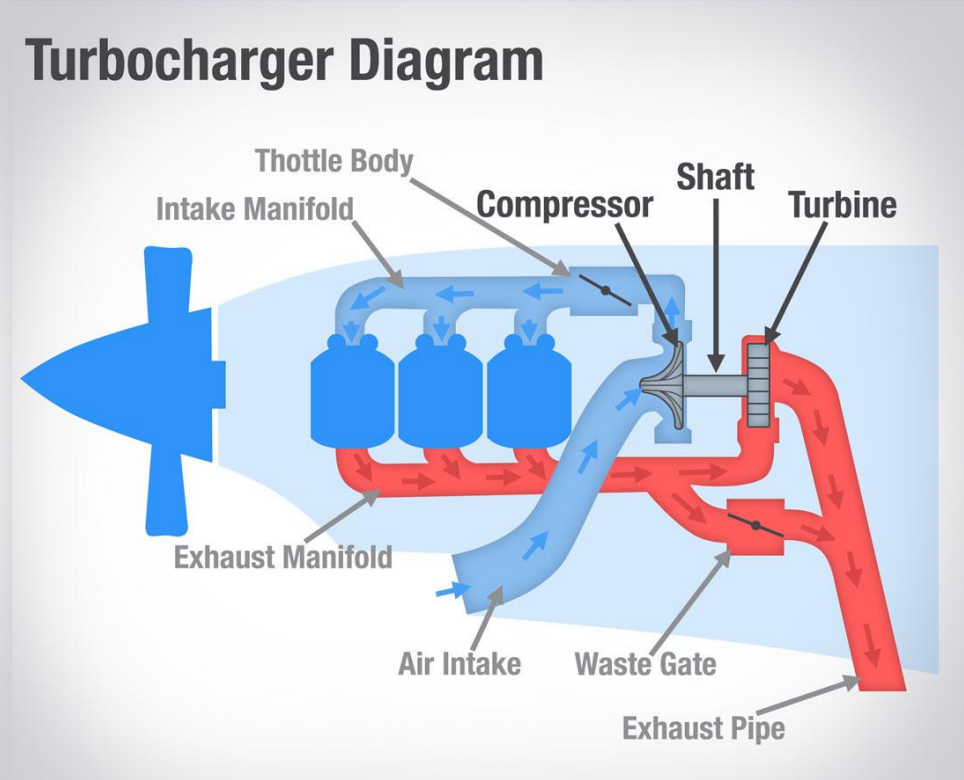
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RE: the first supercharged engine was built in 1878 with use in aircraft engines beginning in the 1910s and use in car engines beginning in the 1920s (German inventor *Gottlieb Daimler* received a patent for supercharging an internal combustion engine in 1885). In piston engines used by aircraft, supercharging was often used to compensate for the lower air density at high altitudes. However, supercharging is less commonly used nowadays since manufacturers have shifted to turbochargers in order to reduce fuel consumption and increase power outputs, especially considering reduced engine displacements. Superchargers are inefficient because they require a lot of engine power to turn; that makes superchargers less fuel efficient than turbochargers and because they use a system of pulleys and gears to turn, there are more parts that can break.



Supercharger Cut-away

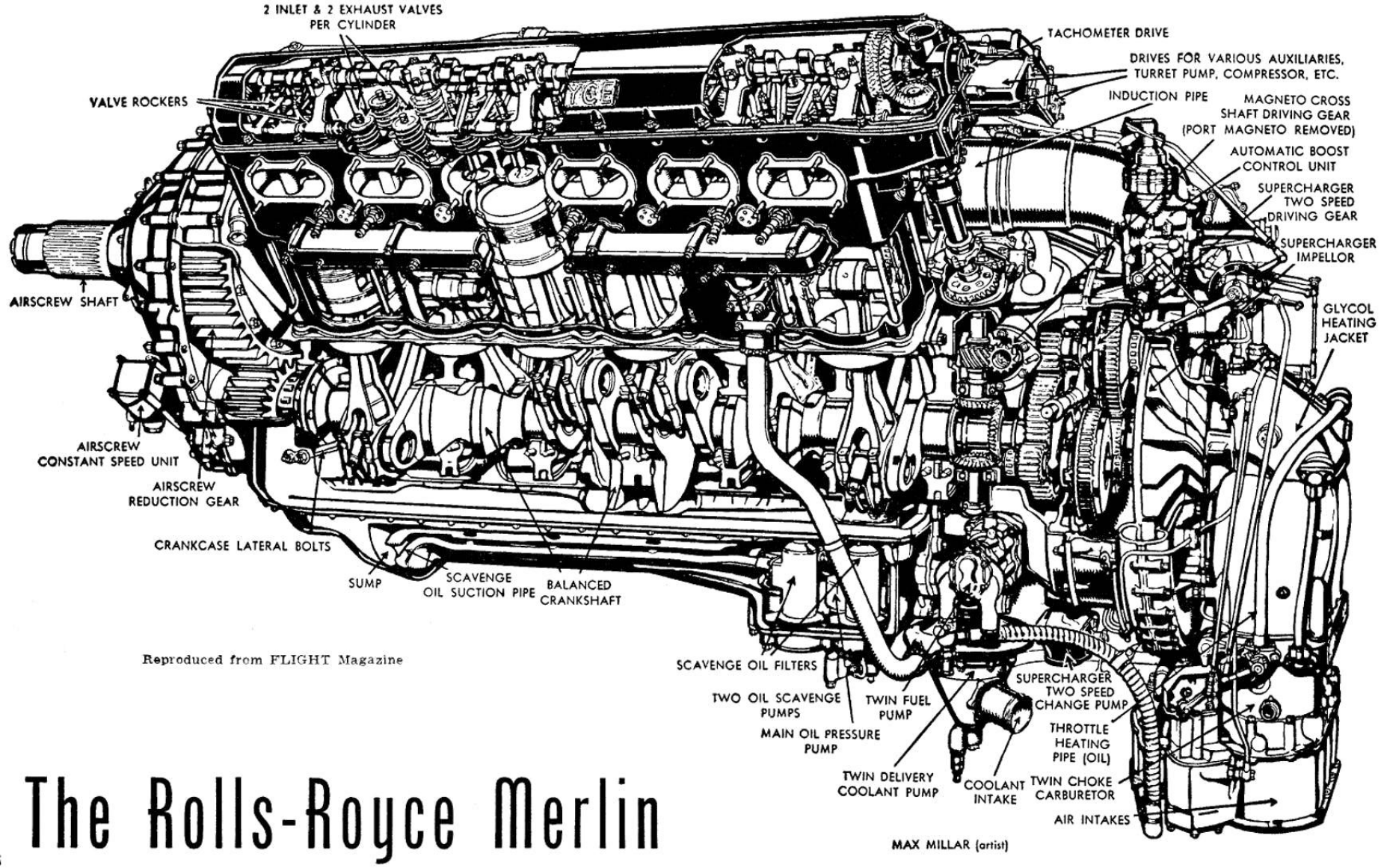




<u>Above L&R</u>: a supercharger (left) is a mechanically driven, forced induction device that is utilized in a piston engine to enable it to produce more power. Its purpose and function is similar to a turbocharger (right) with the principal difference being that it is mechanically-driven by a direct connection to the engine whereas a turbocharger is turbine-driven using engine exhaust gas flow. Turbo-chargers are especially useful at high altitude, where there's considerably less air than at sea-level. In a normally aspirated piston engine, intake gases are drawn into the cylinder by the reduced pressure created by the downward stroke of the piston. The mass of the air that is drawn into the cylinder, in part, limits the power production of the engine. A supercharger requires engine power to run, as opposed to a turbocharger, which runs off of waste exhaust gasses.

"…All the formulas being used to design superchargers were based on parameters derived by the Royal Aircraft Establishment (RAE) that he found to be inaccurate. Hooker approached the head of the Experimental Workshop and asked to see a supercharger. 'Which supercharger?' he was asked. 'Any one will do, because I've never seen one before.' He was then taken to a test rig. 'This is a Merlin engine. This is the front-end where the propeller is bolted on and this contraption at the back-end is the supercharger with the gears that drive it. And it's your job to make it do better'…"

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The Rolls-Royce Merlin

Improving the Baseline



"…As a new employee and a mathematician to-boot, Hooker was at first hesitant to question the work of Rolls Engineers who had produced the giant supercharger that enabled the R engine to win the Schneider Trophy and set a new air-speed record…"

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RE: the Schneider Trophy was first held in 1913, in Monaco, with teams racing time trials around a closed circuit and then the average speed being measured. As the years passed, the Schneider Trophy began to achieve more in progressing the development of airframes. By 1922, Great Britain, thanks to the brilliant mind of *R.J. Mitchell,* saw the Supermarine Sea Lion II achieve an average speed of 145 mph under the power of it's R-R Napier Lion II engine.

<u>Caption</u>: "The Schneider Trophy, on display at the Science Museum, London"

"…He checked and rechecked his calculations: the figures were unassailable. Redesigning the rotor and diffuser would yield an immediate 15-percent increase in efficiency and that would only be the start. Within a few months Hooker, who had never previously seen an aero-engine either, added 30 per-cent more power to the Merlin…"

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TECH NOTES ROLLS-ROYCE MERLIN MK. III

The Merlin III was the major early war production mark (8,456 built). Along with the Merlin II, it powered the Supermarine Spitfire, Hawker Hurricane and Sea Hurricane, Boulton-Paul Defiant and Fairey Battle Mk.Is.

SPECIFICATIONS

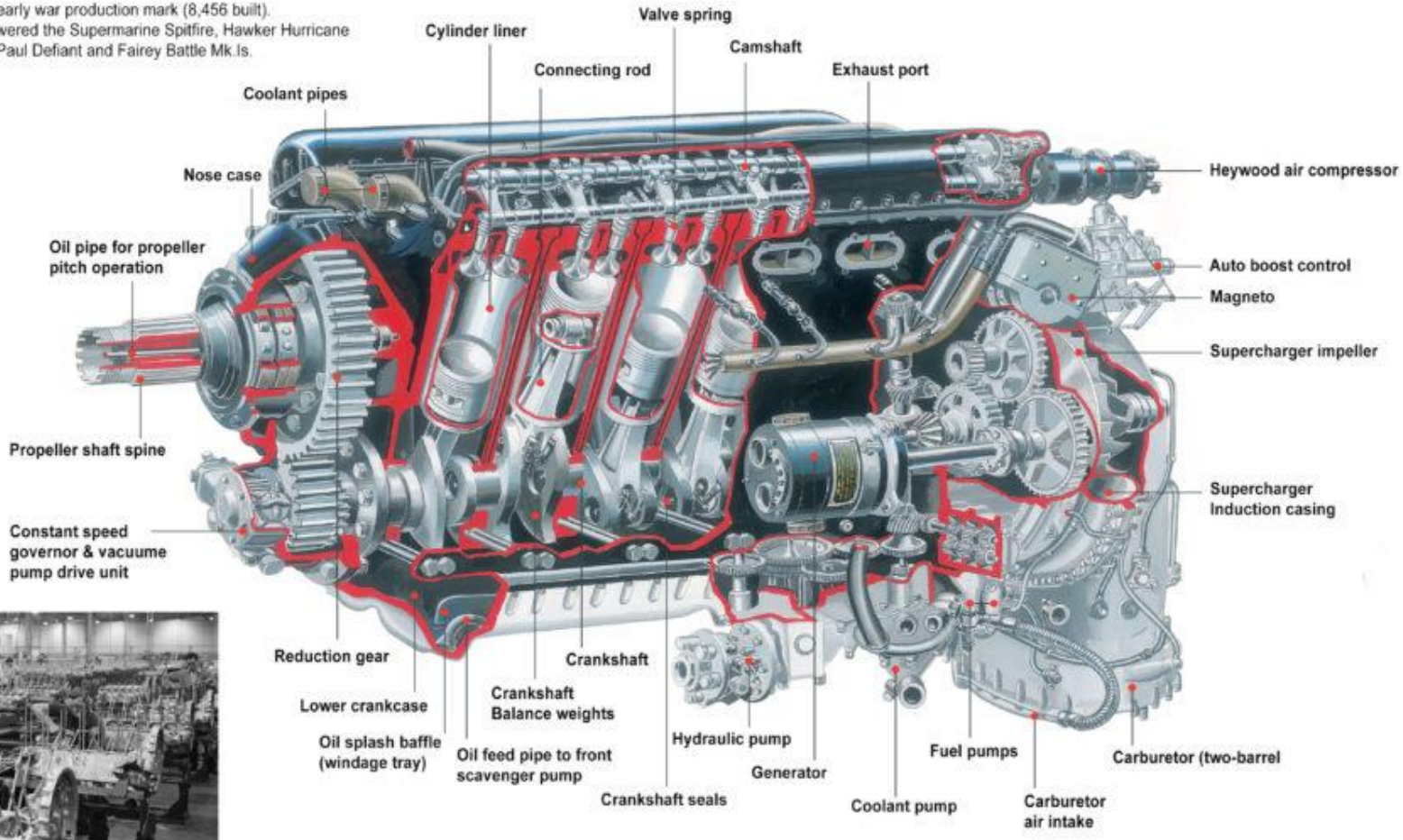
12-cylinder, overhead cam, liquid-cooled, supercharged Vee

POWER RATING
1,030 hp at 3,000 rpm

DISPLACEMENT
1,648 cubic inches (27 liters)

BORE AND STROKE
5.4 inches x 6 inches

WEIGHT
1,440 lbs





Merlin engines under assembly at a Rolls-Royce factory in 1942. (IWM D 12125)

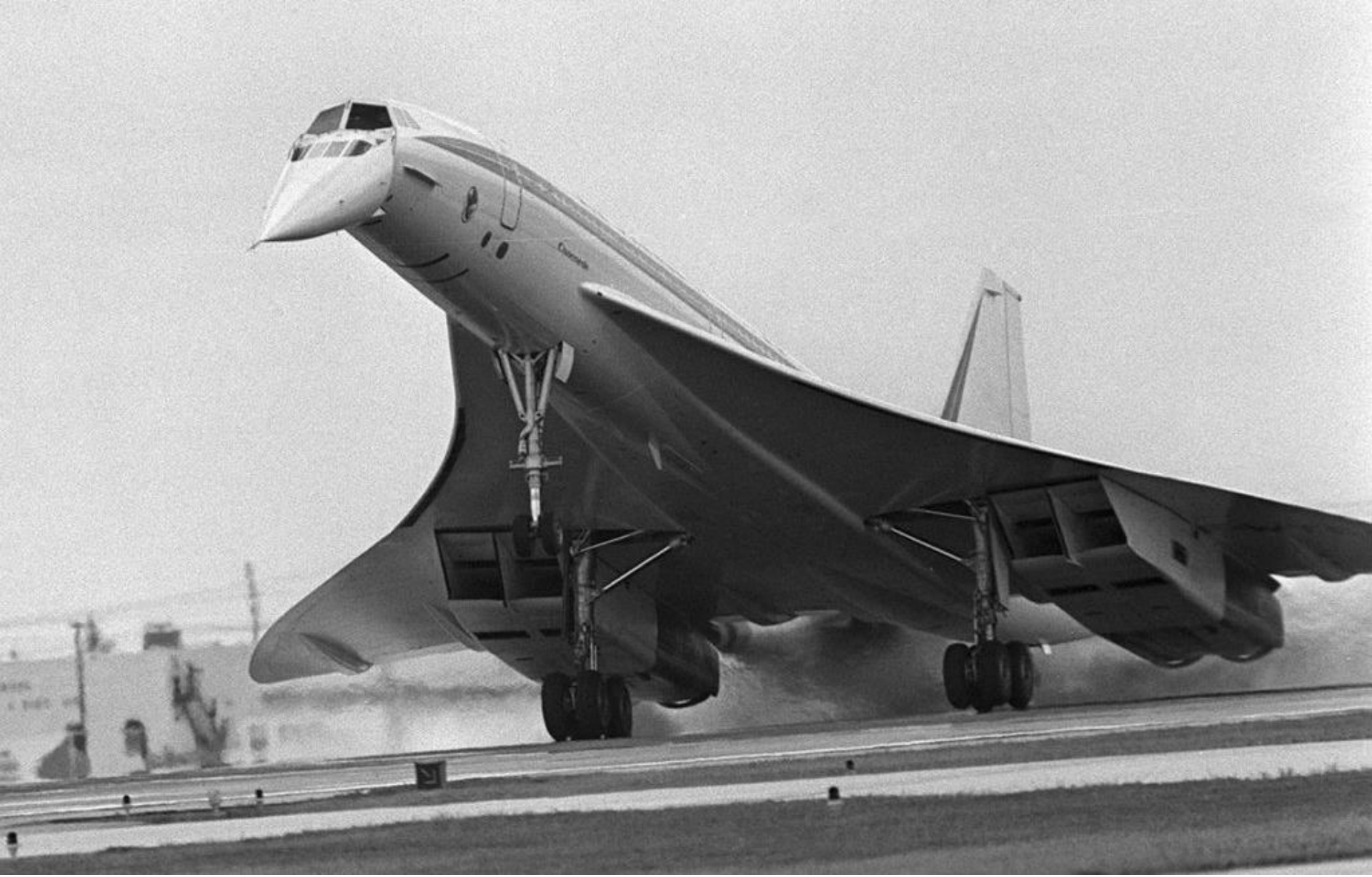
A Well-Spent Life



"…He went on during the war to turn the rudimentary Whittle turbojet into a production engine, raising its thrust from 1,800 pounds to 5,000. By the time he retired in 1967, after being knighted by the Queen, Sir Stanley Hooker had been deeply involved in the design of almost every modern British aero-engine, including those for the Concorde supersonic airliner and the Harrier jump jet)…"

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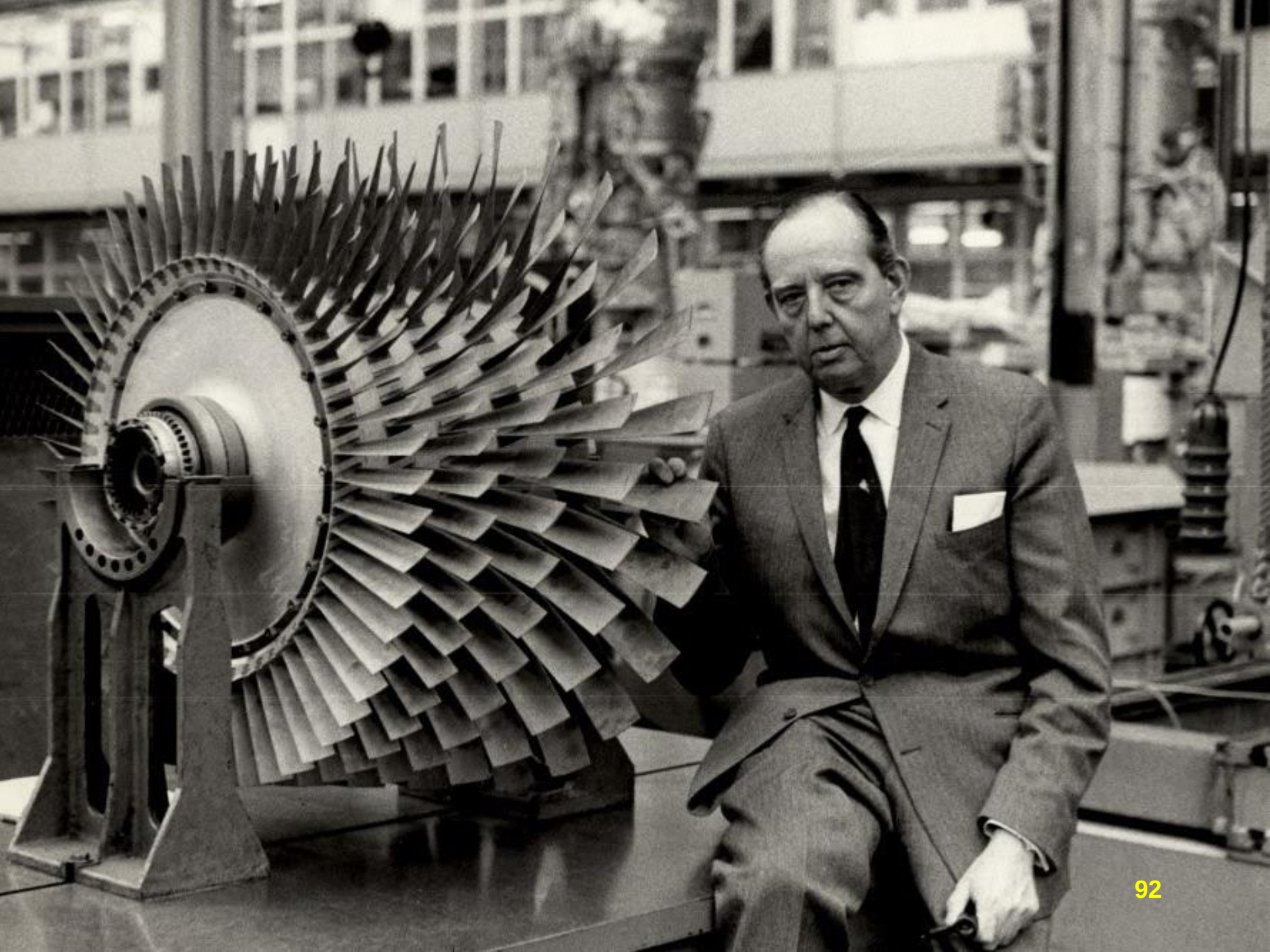
<u>Caption</u>: "Sir Stanley George Hooker (1907-1984)"



<u>Caption</u>: “In this June 14, 1974 photo, the Air France Concorde supersonic airliner touches down at Miami International Airport in Miami, FL. The flight from Boston’s Logan Airport took about 80 minutes.”



<u>Above</u>: the Harrier Jump-Jet is a subsonic, fixed-wing aircraft that can take-off and land vertically due to movable nozzles that can send its thrust downward instead of rearward. A light-attack plane, the Harrier can operate from amphibious ships, aircraft carriers and/or bases close to the enemy. Its armament includes a GAU-12 cannon and it can carry a variety of other munitions as well as external fuel tanks under its wings and fuselage.



"…Many brilliant Engineers worked doggedly and in some cases, into early graves, to develop the Merlin, but it was Stanley Hooker who, by applying advanced scientific principles to the flow and compression of air, was most responsible for boosting its power from 1,025 hp, at the beginning of WWII, to well over 2,000 hp, at the end. The Merlin consistently outperformed considerably larger aero-engines…"

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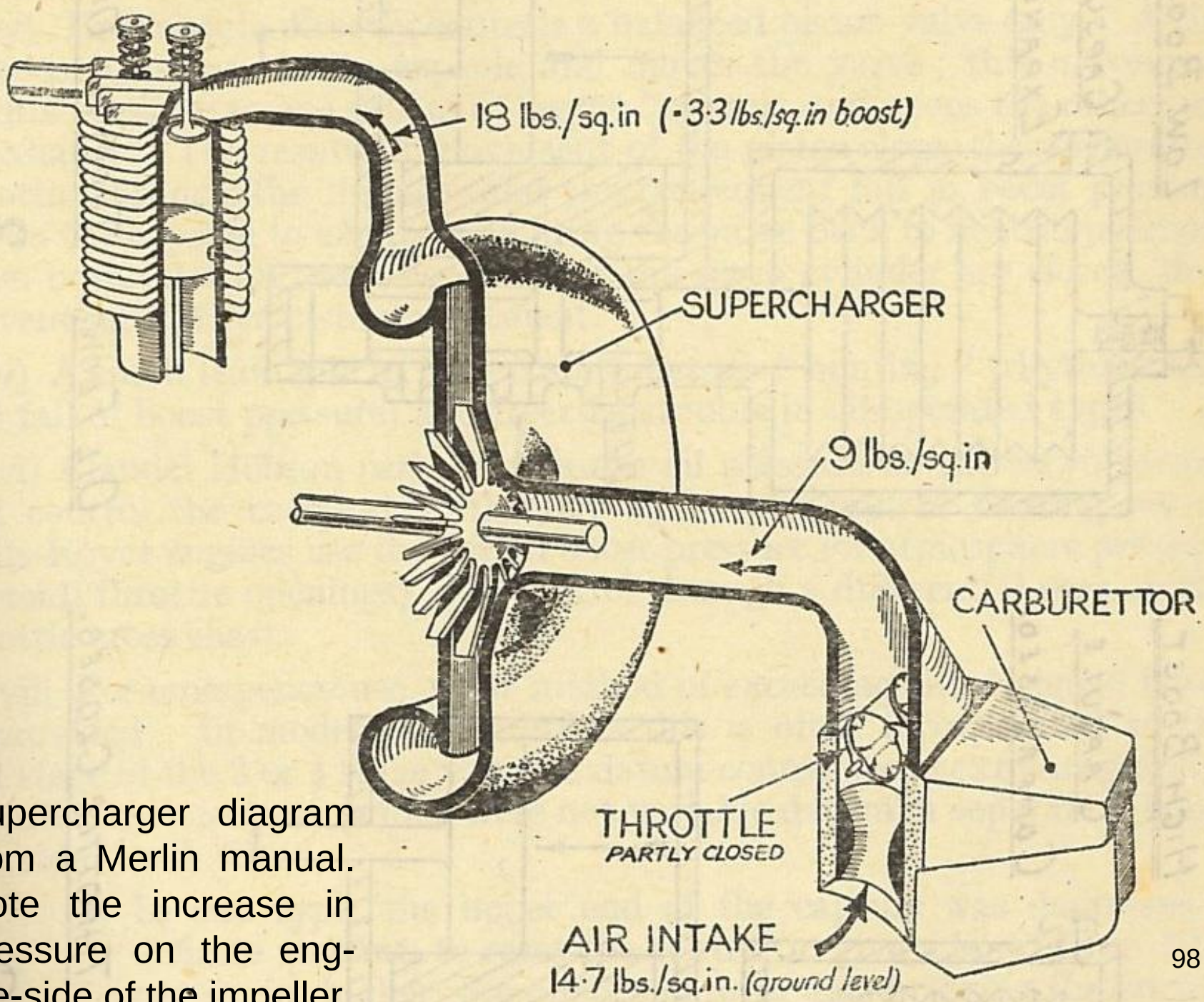
Caption: “Far left, Arthur Rubbra, who was in-charge of the development of the Rolls-Royce Merlin; Gordon Lewis, who was integral to the design team and Sir Stanley Hooker, who is in the middle. Artist, Frank Wootton, who died in 1989, is next who is flanked by Jeffrey Quill, who was the original Spitfire Test Pilot and test flew every Spitfire Mark.”



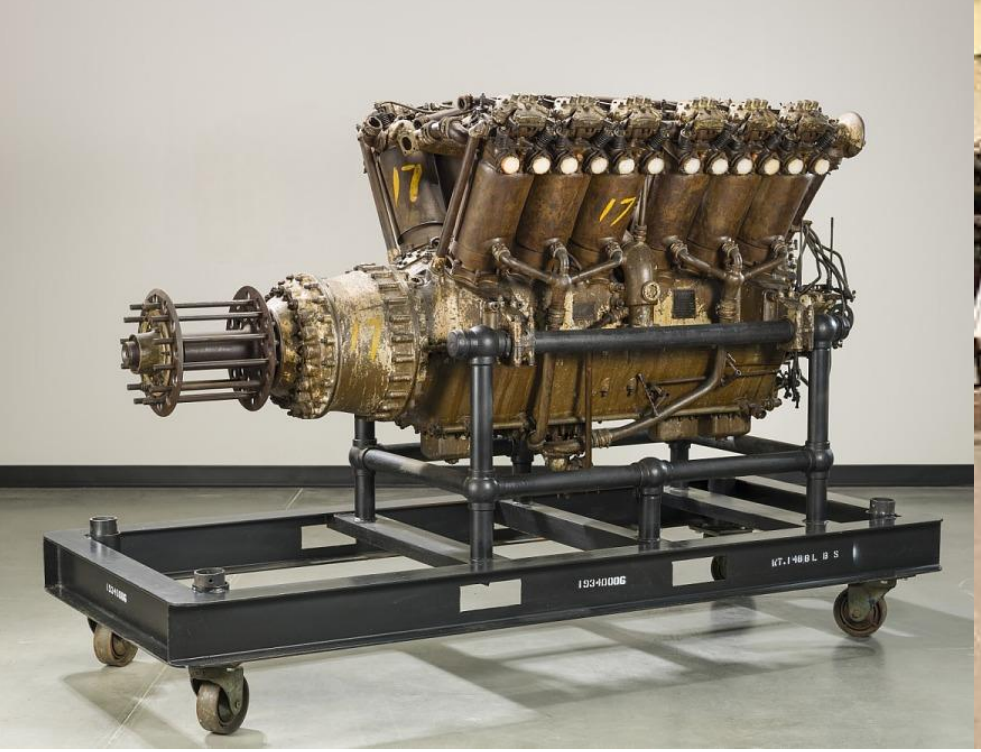
<u>Caption</u>: “Spitfire prototype K5054 being handled by Jeffrey Quill, who gave the Merlin high praise”

Something for Nothing

"…The exhaust-driven supercharger, or turbocharger, seems to offer something for nothing, utilizing otherwise wasted heat energy from the engine's exhaust to drive the supercharger, instead of the power-consuming geared method. It was the preferred system of boost for high-altitude operations for American military radial aircraft engines in WWII…"
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Supercharger diagram from a Merlin manual. Note the increase in pressure on the engine-side of the impeller.





"…Rolls-Royce had experimented with turbocharging on its Condor III engine as far back as 1923…"

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RE: the R-R Condor aero-engine was a larger version of the R-R Eagle; developing up to 675 hp. The engine first ran in 1918; a total of 327 engines were recorded as being built.

<u>Left</u>: the Condor Mk IA (Condor II) was built in 1921. It succeeded the Mk.I and incorporated several design changes, increasing power and speed.

<u>Right</u>: the Condor III (1923-27) developed 650-70 hp and a compression ratio of 6.5:1

Two-stage Supercharging

"…In discussions about its possible use with the Merlin, Hooker pointed-out the lack of suitable locations for a turbocharger on the Hurricane, Spitfire or Mosquito and proposed that exhaust energy could be utilized in a much simpler way. Experiments with exhaust stack designs had produced a short ejector shape imparting reaction ('jet') thrust that added aircraft speed equivalent to an additional 150 hp. This would be lost in turbocharging. …"

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"…He predicted that the turbocharger's main benefit - maintaining power at high altitude - could be obtained by using two superchargers in series, driven by the same engine gears. In fact, the Merlin 61 - the first equipped with a two-stage supercharger, increased the Spitfire IX's ceiling from 30,000 to 40,000-feet and its top speed by 70 mph…"

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RE: the Merlin 61 was fitted with a two-speed, two-stage supercharger providing increased power at medium to high altitudes (+15 psi boost) used in the Spitfire F Mk.IX and P.R Mk.XI



<u>Caption</u>: “RAF mechanics put their backs into their work as they man-handle a damaged Spitfire Mk.IX at a forward airfield in Normandy in June 1944”

Outclassed…

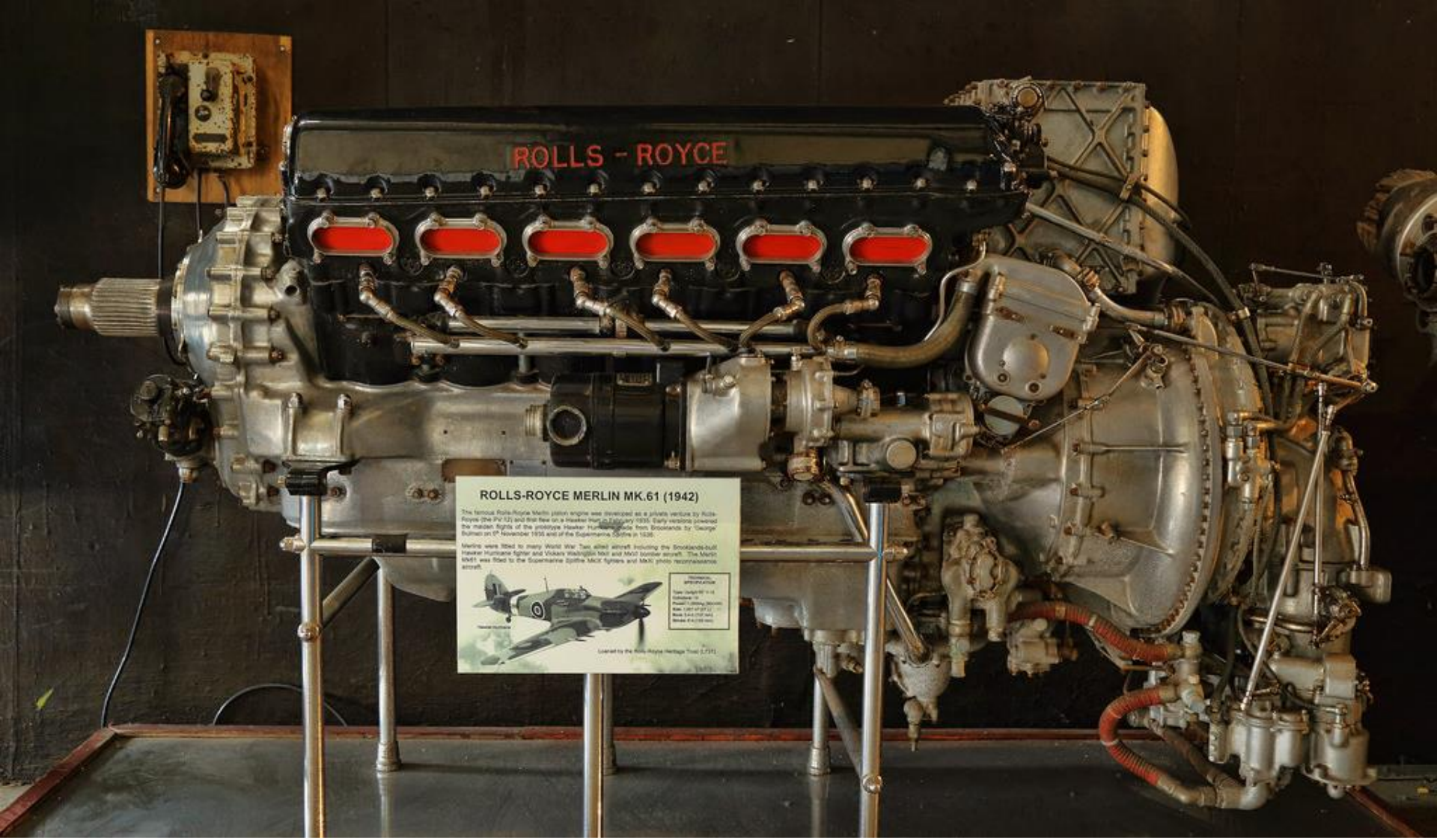


"…The appearance in September 1941 of the new Focke-Wulf Fw-190A, with its 42-liter BMW radial engine, came as a nasty shock to the RAF, as it easily outclassed the Merlin 45-powered Spitfire V in speed and climb…"

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<u>Above</u>: the Fw-190A started flying operationally over France in August 1941 and quickly proved superior in all but turn radius to the Spitfire Mk.V; the main front-line fighter of the RAF, particularly at low and medium altitudes. The Fw-190 made its air combat debut on the Eastern Front, finding much success in fighter wings and specialized ground attack units.

…But Not for Long



"…But within weeks, Rolls was producing the Merlin 61…"
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<u>Caption</u>: "Rolls-Royce Merlin 61 at Brooklands. This version of the Merlin was fitted to the Spitfire Mk.IX and PR.XI and included the prominent 2-speed/2-stage supercharger and intercooler assembly at the rear."



"…Only two-thirds the size of the Fw-190's engine, it nevertheless produced more power, especially at high altitudes, where most of the action took place. Equipped with the Merlin 61, the new Spitfire IX regained the upper-hand, surprising Luftwaffe pilots with its performance surge, since the two Spitfire types looked almost identical…"

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RE: the Fw-190A series' performance decreased at high altitudes (usually 20K ft. and above), which reduced its effectiveness as a high-altitude interceptor. The Fw-190 maintained its superiority over Allied fighters until the introduction of the improved Spitfire Mk.IX. In Nov./Dec. 1942.

<u>Caption</u>: "Supermarine Spitfire IX: Fourth major production fighter variant (Supermarine Type 361) combining Mk.VC airframe with two-stage, two-speed supercharger but lacking other improvements designed for later Supermarine Spitfire Marks. Early Merlin 60 and 61 flight-tested in Spitfire III (from Aug. 1941) and a Spitfire IA, followed by conversion by R-R of two Mk.VCs to Mk.IX prototypes with Merlin 61 engines, early 1942."



"…Air Marshal Sir Harry Broadhurst, a top WWII RAF fighter pilot, vividly recalled his first flight in a Spitfire IX, particularly the astonished look on the face of an Fw-190 pilot as Broadhurst climbed past him with ease…"

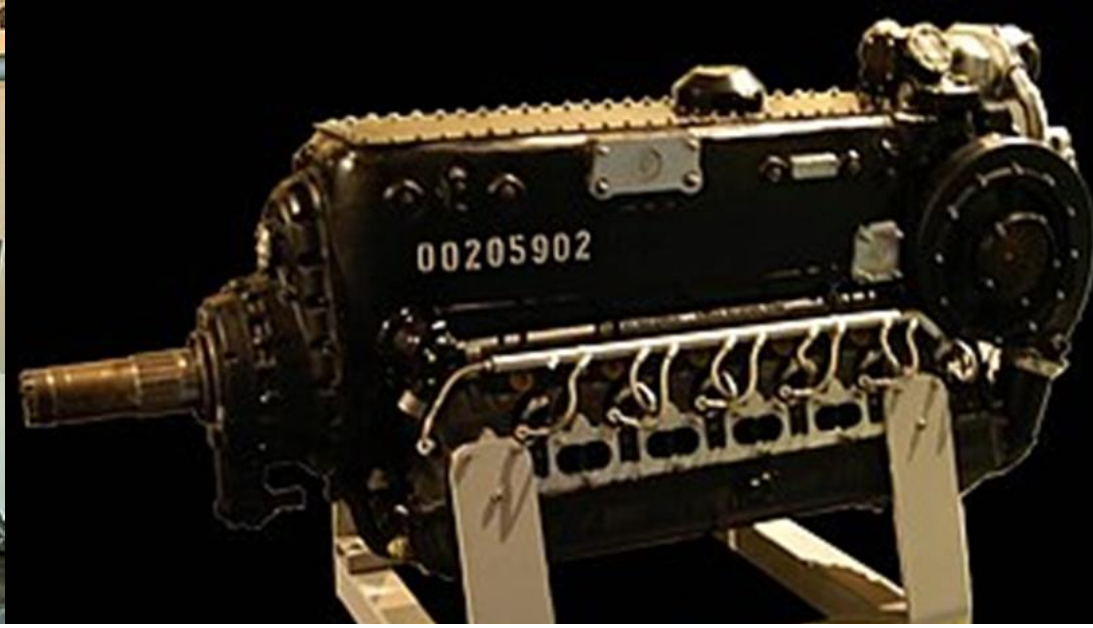
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RE: from the Fw-190's inception, there had been ongoing efforts to address the issue of high-altitude performance in the Fw-190B, C & D models

<u>Caption</u>: "A Supermarine Spitfire Mk.IX of the Texas Flying Legends gaining altitude while performing an aerobatics maneuver at Aviation Nation 2017"

Horsepower Races





"…In a similar horsepower race with the Merlin (and later Griffon), the 34-liter Daimler-Benz DB 601 - which powered the early Spitfires' main adversaries; the Messerschmitt Me-109E and F - grew into the 36-liter, 1,475-hp DB 605 in the 109G. But by then the Spitfire IX's Merlin 61 was producing 1,560 hp, soon to become 1,710 in the Merlin 70. Daimler-Benz finally enlarged the 600 series into the 44.5-liter 603.

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RE: the Daimler-Benz DB 601 (left) was a liquid-cooled, inverted, V12, which powered the Messerschmitt Bf-109E & F, Messerschmitt Bf-110 and many other German aircraft. Approximately 19K 601s were produced before it was replaced by the improved Daimler-Benz DB 605 (right), in 1942. It powered the Bf-109G. Developed from the DB 601, the DB 605 was used from 1942 to 1945 in the Messerschmitt Bf-109 fighter and the Bf-110 and Me-210C heavy fighters.



"…With only 40 more horses than the Merlin 70 and too heavy for any of the Luftwaffe's single-engine fighters, it was relegated to twin-engine aircraft. The similar Jumo 211 V12 from the other major German engine manufacturer, Junkers, fell halfway in size between the DB 601 and 605 at 35 liters, but by 1942 was only yielding 1,400 hp…"

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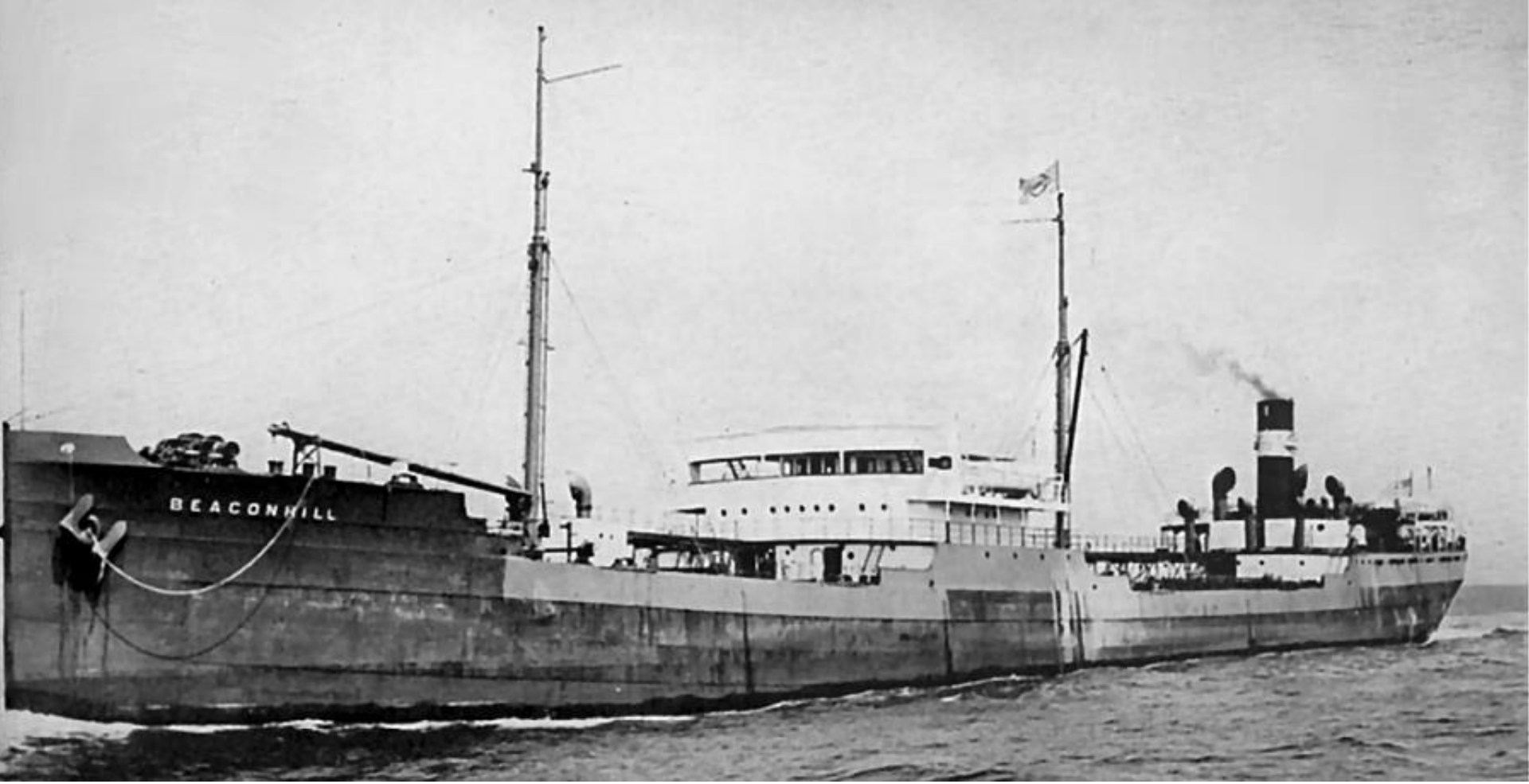
RE: the Jumo 211 V-12 was Germany's first modern aero-engine, with three valves per cylinder; a cast crankcase and supercharger as standard. It was developed by *Dr. Franz Josef Neugebauer* as a scaled-up successor to the earlier Jumo 210.

<u>Caption</u>: "The Me 264 V1 Amerika Bomber contract competitor fitted with four unitized Jumo 211 engines"

A Damn Close-run Thing

"…Germany's comparatively deficient engine power has been mistakenly blamed on the scarcity of high-octane fuel. But Britain entered the war with aviation gasoline of around 87-octane 'regular,' while Germany already had 100-octane. By 1942, the Germans had raised this to 150. Rolls had tested the Merlin with 100-octane gasoline and found it would happily motor-on with manifold pressure raised from 43 to 48-inches of mercury, boosting output by 135 hp, but this was of academic interest as there was no 100-octane fuel in the RAF's storage tanks…"

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"…Fortunately, the Esso tanker 'Beaconhill' arrived from the United States just before the Battle of Britain, bringing enough of the new fuel to serve the Hurricanes and Spitfires throughout the conflict…"

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<u>Caption</u>: "Built as 'Hoven' in 1919, she became 'Beaconhill' in 1926"



"…With higher permissible boost pressures, the additional speed and rate of climb were decisive. Without it, what was in the words of the Duke of Wellington (referring to the 1815 Battle of Waterloo) 'a damned close-run thing' might well have turned the other way…"

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<u>Caption</u>: "A flight of Hawker Hurricane fighters prepares to meet the enemy during the Battle of Britain. Hurricanes dealt, mainly, with the German bombers while the Spitfires tangled with their fighter escorts."

Problem…

"…Direct fuel-injection in the Daimler-Benz engines yielded a temporary advantage…"

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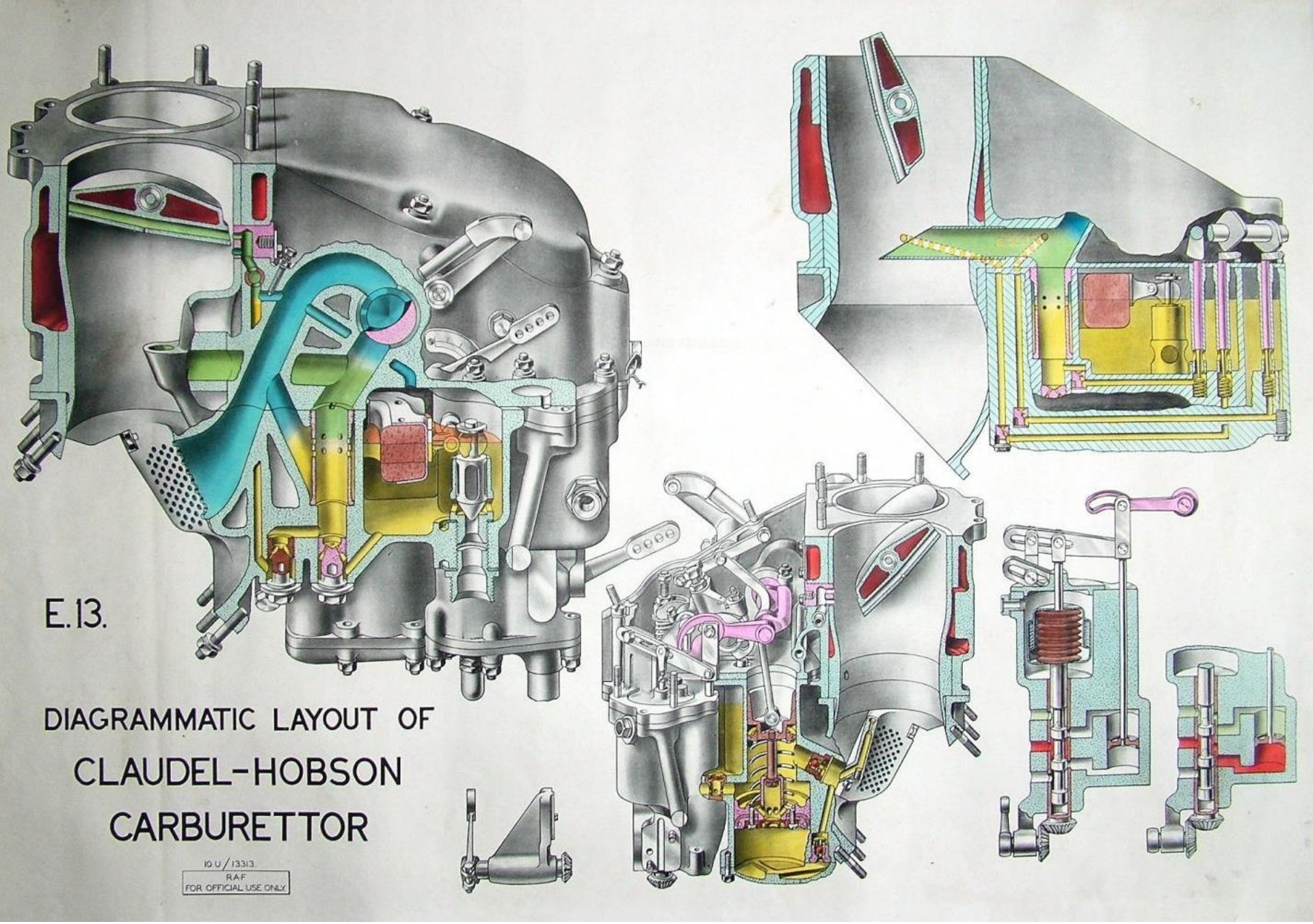
RE: the flow through the carburetor changes in density as an aircraft climbs, however, the density of the fuel does not. Carburetors had been developed on the ground, where most of the very serious problems present in aircraft applications simply do not exist in that they remain parallel to the ground and are used under a tiny range of variations in pressure and temperature, as compared to an aircraft. The development of high altitude flight happened in a very short space of time and was possible since the development of the supercharger outpaced the development of fuel delivery technology. In Germany, development work on petrol fuel-injection had begun in 1928 and subsequently, in 1933, large aero-engines were developed with fuel-injection rather than carburetors. The primary aims of this fuel injection were: to optimize the air/fuel ratio for every engine cylinder; to optimize fuel consumption with large valve overlap; to remove the restricting venturi's from the engine air intake; to simplify pilot workload; to prevent carburetor icing and to prevent fuel mixture upset due to inverted flying or G-effects.

"…In combat, a Messerschmitt pilot, pursued by an early Hurricane or Spitfire, could push the stick forward and dive, while the same maneuver would cause the Merlin to cut-out due to mixture leaning from negative G. The carburetor's float would respond to what it now thought was 'down,' flooding the engine for several seconds - and several seconds can mean life or death in aerial combat. RAF pilots would roll inverted and pull back on the stick to keep positive G, but by that time their quarry had frequently escaped..."

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RE: unfortunately, the issues associated with the float-type carburetors fitted to the Merlin engine remained unresolved until 1941, when a partial remedy was implemented. Further resolution of the problem on new engines; from approximately 1943 onward, occurred with the introduction of pressure carburetion and fuel-injection. In the meantime, by exploiting the stick-forward, nose-down dive and escape advantage of fuel-injection, many a Bf-109 pilot escaped to fight another day.

When R-R designed the new 1K-hp Merlin engine in the early 1930s, they chose to equip the engine with a contemporary aircraft carburetor. Their initial options at that time were limited to the use of a float carburetor - a type which had been used successfully in many of their preceding aero-engines. The Merlin was conceived as a supercharged V-12 engine, laid-out similarly to the R-Type racing engines, with the carburetor placed before the supercharger air intake, albeit offset slightly below the intake to reduce engine length and thus being an updraft carburetor. This layout also closely resembled that of the successful supercharged Kestrel engines. The Kestrel carburetors had generally used design features of the Claudel-Hobson type, where fuel jetting was largely adjusted for altitude and power levels by the physical adjustment of the carburetor fixed jets, mostly operated by the pilot-controlled mixture lever and throttle position. There was also a requirement to ease pilot workload thus, automatic carburetor control was desirable, where possible.



Claudel-Hobson Carburettor

The attitude and acceleration effects on the float-type carburetor are principally due to the use of a simple float regulated fuel supply in a float chamber. The various fuel feeds to the intake venturi from the float chamber rely on the upright and unaccelerated condition of the carburetor; in any deviation from the straight and level attitude a simple float-type carburetor will suffer from effects upon its fuel metering ability. Despite the obvious complexity of these float-type carburetors, their weaknesses in operation with a vulnerability to malfunction during upset in flight and acceleration or negative G-effects were recognized but unresolved.

…Solution



"…Beatrice 'Tilly' Shilling, a Scientist at the Royal Aircraft Establishment, designed a simple flow restrictor to solve the problem…"

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RE: *Beatrice Shilling* (known as "Tilly" to her friends) was a gifted British Engineer who, in 1936, was recruited to serve as a Scientific Officer in the RAE; a position she held until her retirement in 1969. Shilling earned an engineering degree from Manchester University. In doing so, she became one of the first two women to study engineering at that institution. With jobs scarce during the Depression, she went on to earn a Master's Degree, focusing her research on combustion engines. Shilling became a proficient motorcycle racer in the 1930s, lapping Brooklands at 106 mph on her Norton M30 500 to earn a gold star.

<u>Caption</u>: "RAE Engineers (left-to-right) Margaret Rowbotham, Beatrice Shilling and Margaret Partridge"



<u>Caption</u>: “Miss Beatrice Shilling astride her Norton at Brooklands in July, 1935”

"The Air Ministry, having had some experience of women's work in the First World War, were not entirely unsympathetic, and I was offered a job as an assistant in the Technical Publications Department at the Establishment."

Beatrice Shilling

RE: recalling, in a 1969 letter, her arrival at the RAE in 1936. After spending eight months writing aero-engine handbooks, she was transferred to the Engine Department, where she specialized in research and development on carburetors; a much better match for her skills and interest.

The initial Merlin production Carburetor type SU AVT 32/135 was a twin-choke updraft-type with twin venturi, each 3.3-inches in diameter. The left choke incorporated the aneroid controlled altitude needle/jet while the right choke had the aneroid controlled boost needle/jet enrichment with a manual Rich/Weak datum control. The carburetor had an automatic accelerator pump and idle running circuits. The pilot controlled the throttle position. However, the R-R boost controller fitted to the production Merlin could limit throttle plate movement via a linkage and differential; to control the throttle plate position and so impose the engine boost limits. The boost controller also had various styles of override cut-out to allow over-boosting in emergency by disabling the boost control influence on throttle plate position when the pilot operated the override.

Unfortunately, this carburetor was vulnerable to adverse function in several respects. Due to the fact that float-type carburetors rely on a relatively weak air-pressure effect to raise the fuel into the venture; they are badly effected by any positional deviation from the straight and level datum that thereby alters the float chamber fuel-level relative to the outlet into the venturi. The internal operating levers of the carburetor may also suffer from influence under G-effects if they are not designed to avoid it. Perhaps the worst problem is that under negative-G the fuel supply held in the carburetor float chamber could become totally inverted in the chamber, with uncontrolled effects on fuel mixture to the engine.

These weaknesses in the operation of float-type carburetors in maneuvering aircraft were known at the time. The positive G-effects and short periods of negative-G flight were common in fighter-type aircraft of the early 1930s, but little effective work seems to have been done in the UK to solve these weaknesses in the aircraft float-type carburetor. At high speeds, an aircraft does not need to be inverted to experience negative-G; simply pushing the nose down in manoeuvers at high speed will generate negative-G forces. Action to prevent the worst of these negative G-effects on the RR/SU float-type carburetor was not effective until 1941.

Another issue was carburetor icing. The temperature drop due to evaporation of the fuel causes ice formation from any water vapor in the air passing through the carburetor. This carb icing presents a dire threat to the aircraft even in warm climates and the ice formed inside the carburetor can restrict airflow sufficiently to stop the engine. The SU carburetors prevented carb icing by having hot engine oil fed inside the carb throttle plates and hot engine coolant was circulated around the choke tubes. These arrangements were effective to prevent carb icing but, incurred wasteful heating of the intake charge and the additional oil and coolant circuits were unwanted vulnerabilities that could contribute to engine failure. Other considerations were backfires and unequal cylinder mixture strengths. R-R used SU carburetors on Merlins I, II, III, IV, V, VIII, X, XII and 30. The function of this SU AVT 32/135 carburetor is easy to understand from Fig 2.

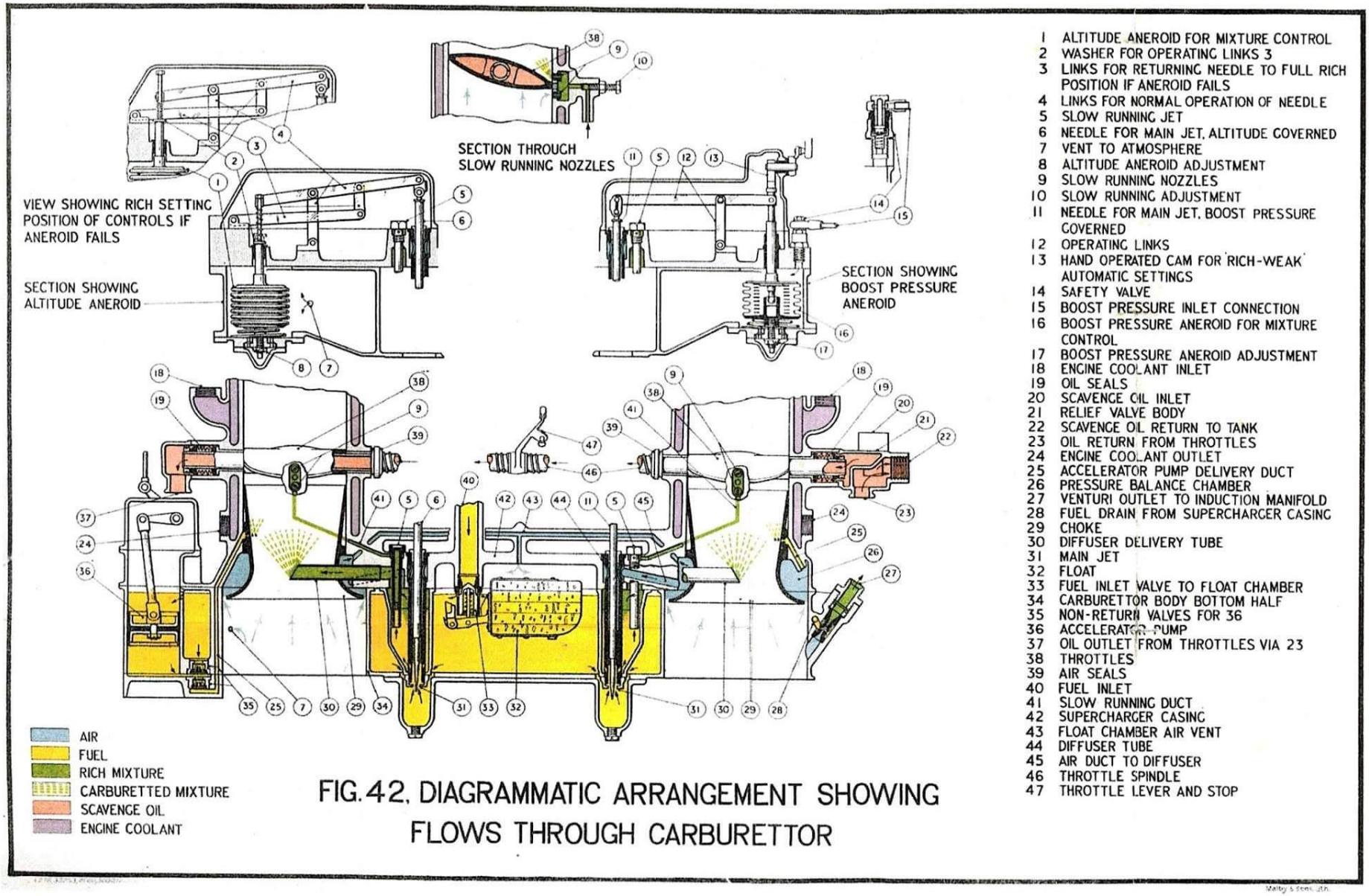


FIG. 42. DIAGRAMMATIC ARRANGEMENT SHOWING FLOWS THROUGH CARBURETTOR

Figure 2: Merlin SU AVT 32/132 Carburetor

The fuel supply is controlled by the float to maintain a level slightly lower than the diffuser tubes, one in each venturi. The fuel is available to the idle jets, the accelerator pump and the main jets (both aneroid regulated), one for altitude the other for boost enrichment, with a selectable rich-weak datum bias. The float chamber air vent (43) is important as it balances the pressure in the float chamber with that in the carb intake at the entrance to the venturi. At Idle, the closed throttle valve (38) has generated a higher depression at the slow running nozzles (9), enough to raise the fuel up to them from the idle jets (5). As the throttle is opened airflow increases and the depression in the venturi also increases until it is strong enough to lift fuel through the two variable main jets and into the diffuser tubes (30) as an emulsion. When the throttle is moved in an open direction, the accelerator pump also pushes a linked volume of fuel up the passages to the delivery ducts (25) and into the airflow, thus preventing hesitation or weak cutting that would occur if the throttle is opened quickly. Problems with unequal fuel distribution to the cylinders were partially cured by careful intake design but, the general solution to poor fuel distribution was to richen the overall mixture setting until the weakest running cylinder was at an acceptable setting. Engine damaging backfires at increasing boost pressures were controlled by fitting flametraps in the inlet manifolds at the inlet ports.

Fuel-injection was not favored by the RAF and other advances in carburetor technology seem to have been ignored, notably some from the U.S. Other than fuel-injection, the greatest advance was the development by Bendix-Stromberg of their pressure carburetor system, which replaced the vented float chamber, float valve and the diffuser into the venturi, with a pressure regulated and metered fuel flow that was sprayed into the airstream just before the supercharger. This new fuel system removed virtually all of the difficulties that float carburetors had suffered with G-effects and inverted flight. Also, the fact that the fuel was sprayed into the air-stream after the pressure sensing venturi and the throttle plates straight into the supercharger intake removed almost all risk of carburetor icing. This new Bendix PD12 type of carburetor was successfully tested and fitted to the Allison V1710 C10 in 1938.



Caption: “Mechanics preparing an Allison V-1710 engine to be installed on a Lockheed P-38 Lightning”

At the time of the Battle of Britain, the Spitfire and Bf-109 were closely matched in performance. The Bf109's DB601A engine was fitted with direct fuel-injection that provided uninterrupted engine running in all attitudes, even in fully negative G-conditions for short periods. The Merlin engine, with the float carburetor, suffered various carburation faults in unusual attitudes and would cut completely under negative-G. As the desperate fighter vs. fighter combat tactics developed during the battle, the tactical disadvantage of the carburetor problems in Merlin engines became a high priority for improvement. German pilots could push their aircraft into negative-G with their engines running normally however, the Spitfire and Hurricane would fluff and rich-cut if they tried to do the same. This problem was more than a nuisance; lives were lost in combat as a result.

Utilizing 100-octane fuel to increase boost and increase engine output to 1,310 hp, the Merlin-powered Hurricanes and Spitfires were very fast, but the Merlin's Skinners Union (SU) AVT35/135 carburetor would suffer a "fluff" when entering a steep dive. The negative G-forces would momentarily throw the fuel to the top of the float chamber and starve the jet of fuel for 1.5 seconds. Although the carburetors would regain function, the situation was potentially disastrous.

At about this time, R-R was bringing the Merlin XX into production. The improved engine featured a new version of the R-R/SU carburetor; the AVT 40/193. This carburetor featured larger chokes with 3.75-inch diameter venturi for greater airflow in the more powerful engine and twin float chambers that made some attempt to reduce the fuel flow problems that these float-type carburetors suffered when angled away from straight and level. However, this carburetor was still unable to function in negative-G. The AVT 40/193 carburetor was designed for use on the Merlin XX, 21, 45, 46 and 47 and is shown in Fig 3.

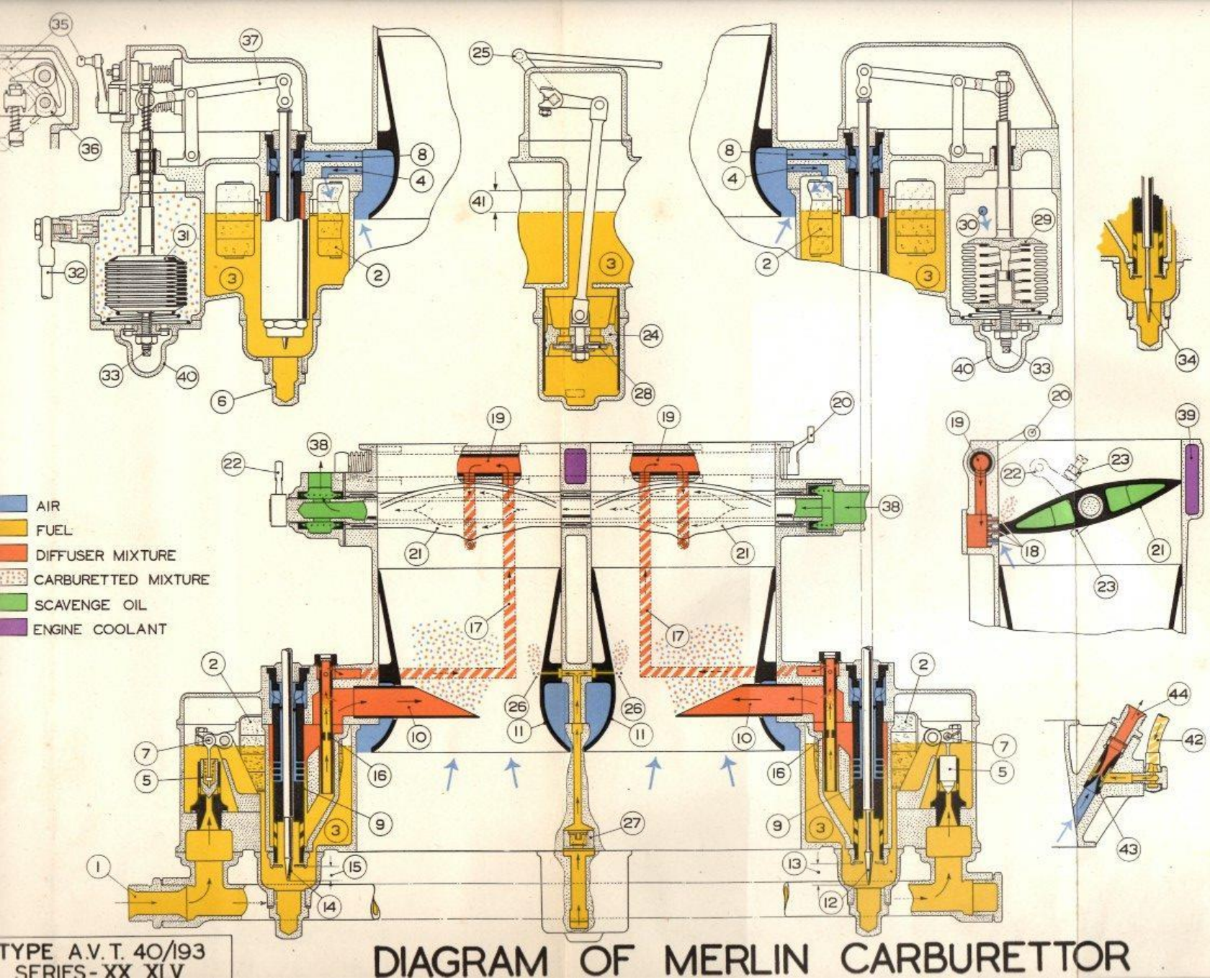


Figure 3: AVT 40/193 – Merlin Series XX

Miss Tilly's Orifice

"…Resembling a metal washer, it allowed a maximum fuel flow of what was required at full throttle. The device became known at the Rolls factory by the somewhat indelicate name 'Miss Tilly's Orifice'…"

historynet.com

RE: RAE Scientist and Engineer *Beatrice Shilling* is credited with successful work to cure some of the faults with the float carburetors. Well aware of the negative-G problems, she developed a fuel line restrictor to limit the maximum fuel flow to the carburetor to equal the maximum fuel flow that the engine required. This flow limit only restricted the fuel flow when the false excess demand from a flooding carburetor in negative-G would otherwise cause a rich cut-out. The restrictor was tested and provided a partial cure, so a crash modification program began in the beginning of 1941. Known as "Miss Tilly's Orifice," it was not fitted during the Battle of Britain, but even when it was later, the result was not a complete solution to the problem.

"…Luftwaffe pilots, accustomed to escaping by diving, now experienced a nasty surprise on finding the pursuing Hurricane or Spitfire still behind them. Later models of the Merlin used in fighters utilized Bendix or Rolls-Royce single-point fuel-injection into the eye of the supercharger impeller and Miss Tilly's Orifice eventually passed into legend…"

historynet.com

RE: the restrictor was fitted in the fuel inlet of the carburetor and was correctly named the "RAE Restrictor." The initial version of restrictor for the AVT 32/135 was a thimble-like pressing with a hole at the end that was simply fitted like an olive between the carburetor fuel inlet union and the fuel feed pipe of the Merlin II, III, IV, V, VIII, X, XII and 30. In later versions, the restrictor was formed as a disc with a central hole and was incorporated into the actual fuel inlet union fitting of subsequent Merlins with standard float carburetors. R-R Merlin engines were being developed at a great pace and flow restrictors to suit the various versions of the engine were designed and installed.

Carburation Evolution

R-R was keen to further improve the unusual attitude and negative-G performance of the Merlin fitted with the AVT 40/193 carburetor. A redesign was performed by R-R and SU that replaced the simple float controlled inlet fuel valve with a weight-balanced diaphragm controlled fuel inlet. This considerable work resulted in a new carburetor; the RR/SU AVT 40/213. This was designed for the Merlin 45, 46, 47, 50 and 56 engines and was intended to perform correctly under positive and negative-G conditions. The balanced diaphragm was intended to provide the correct basic fuel flow into the carburetor in positive and negative-G. Unfortunately, service trials with two squadrons of Spitfire Mk.Vs using this new carburetor were unsatisfactory and, in a major upset to Merlin development, the AVT 40/213 carburetor was withdrawn from use. A diagram of the AVT 40/213 carburetor is shown in Fig 4.

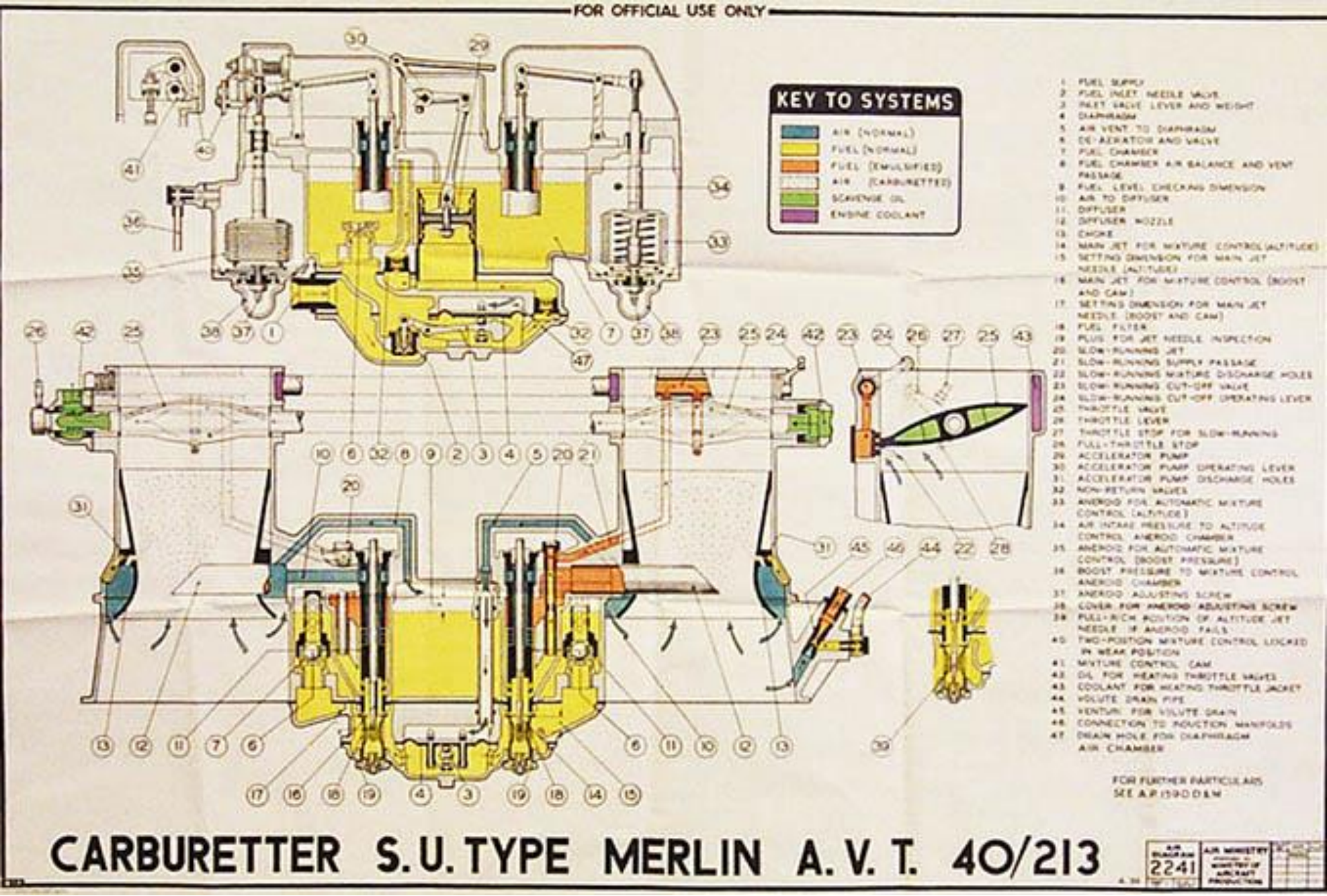


Figure 4: Merlin AVT 40/193 Carburetor

Further development to resolve the negative-G problems with the Merlin AVT 40/193 carburetors had been ongoing at the RAE. This type of carburetor was to remain important and in heavy use as it was used in many aircraft and their Merlin engines. It appears that the RAE chose to attack the specific problems that this float-type carburetor suffered under negative-G while retaining the basic layout and functions of the float design. The modifications were designed to cure three internal problems during negative-G; the flooding flow of fuel in the air balance and vent lines; the interrupted flow of fuel to the main jets and the excessive flow of fuel through the fuel inlet valves due to float malfunction in negative-G which caused continued flooding.

The air balance and vent lines were prevented from allowing fuel back flowing by fitting ball valves. The flow of fuel to the main jets was maintained by isolating the jet orifice in a chamber formed by a plate and fed with fuel from shroud tubes that acted as standpipes, feeding fuel when either upright or inverted. Excessive fuel flow, due to the floats rising when inverted in the displaced fuel, was limited to maximum engine demand flow, by fitting *pintles* on the float valves and maximum flow rate stops on the levers, that limited the maximum travel of the floats and hence maximum fuel flow; in a similar but more complicated way than the RAE Restrictor. These combined modifications prevented the worst combinations of rich-cutting and/or weak-cutting that unmodified carburetors had suffered. The new carburetor was identified as the AVT40 anti-G. It also seems that carburetors modified in this way are referred to as an "RAE Anti-G carburetor." The comprehensive diagrammatic illustration of the AVT 40 Anti-G is shown in Fig 5.

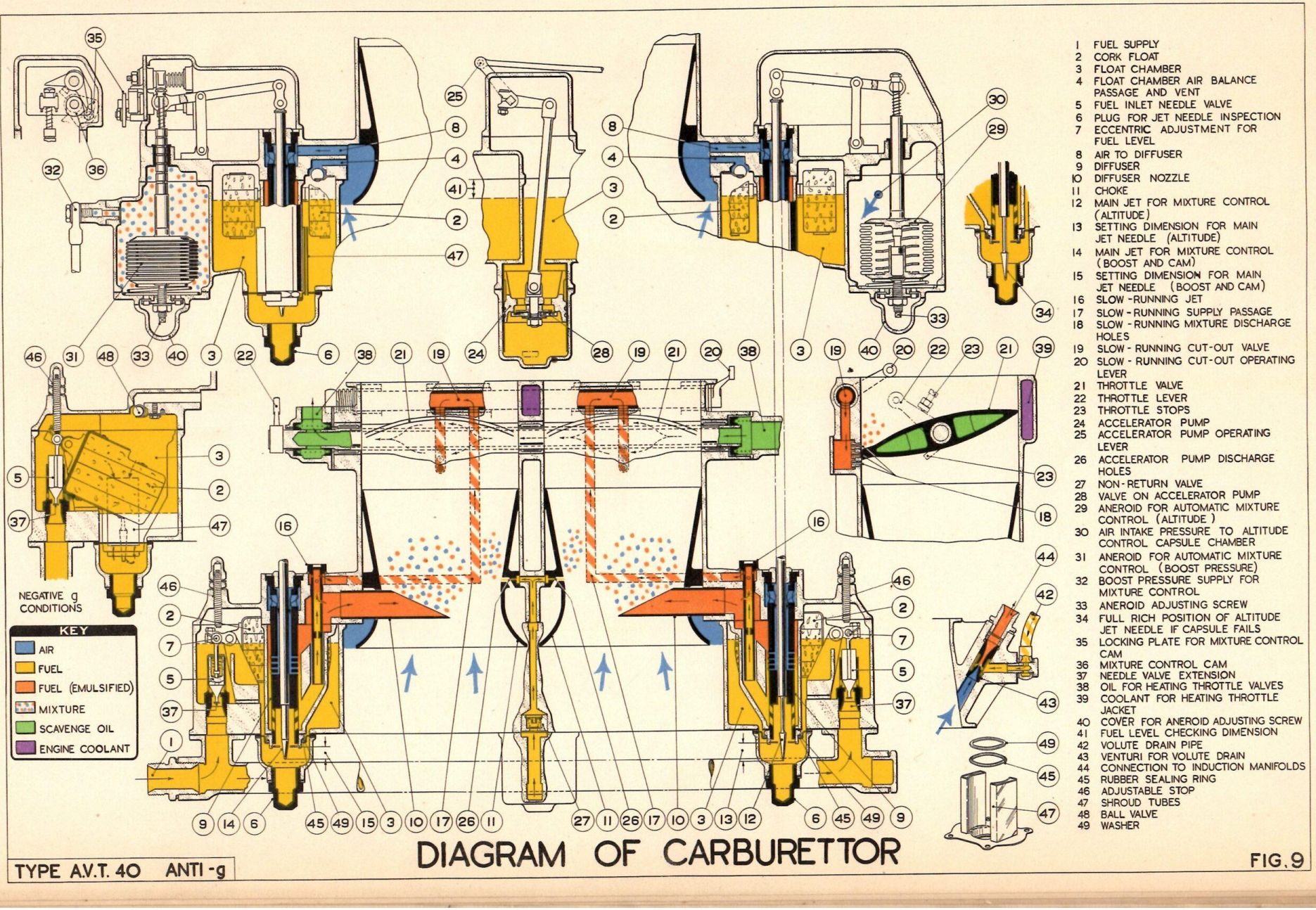


Figure 5: AVT 40 Carburettor (AVT 40/216)

Merlin engine development continued at pace and the up-coming 2-speed, 2-stage 60 series Merlin engines required a larger carburetor for their greater airflow and power. The new carburetor was the RR/SU AVT 44/199/1 (see Fig. 6).

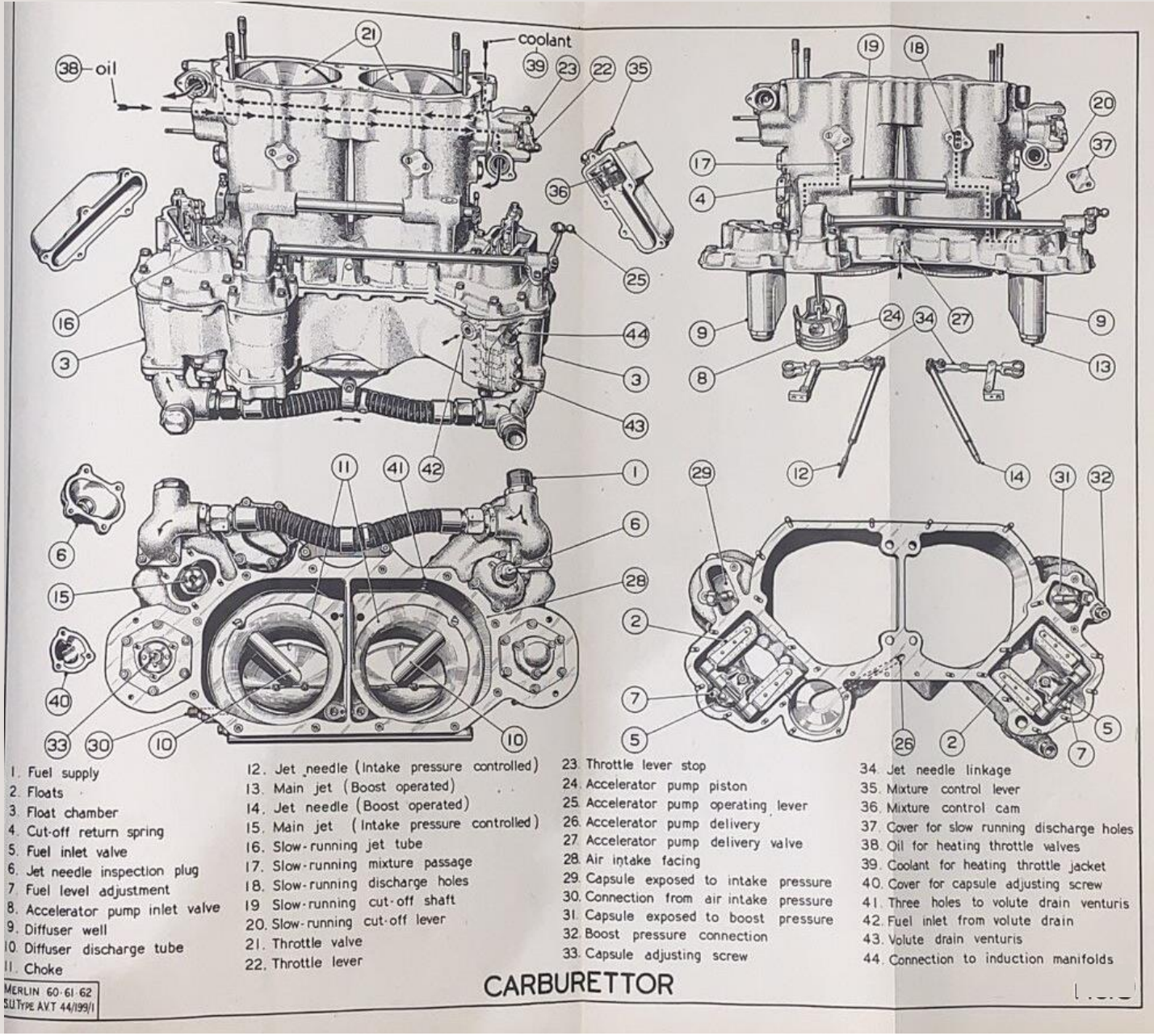


Figure 6: AVT 44/199/1 Carburetor Illustration

The Merlin 61, 63 and 64 were fighter engines and the RAE were, no doubt, desperate for the improvement of the fully modified anti-G carburetor. The fully modified Anti-G type of carburetor for these engines was introduced as the AVT 44/208 Anti-G. Spitfire IX trials with these different carburetors illustrate the importance of the carburetor function under negative-G. A service trial of AB505 in April 1942 notes that the "Merlin 61 fitted with the latest Anti-G carburetor" was able to "change rapidly from climb to dive without the engine cutting." Conversely, a July 1942 trial of a Spitfire IX without an Anti-G carburetor flown against a Fw-190 had "great difficulty following" a diving turn as, "this type of engine with ordinary carburetor cuts-out very easily." An illustration of the AVT 44/199/1 is shown in Figure 6 and a diagram in Fig. 7.

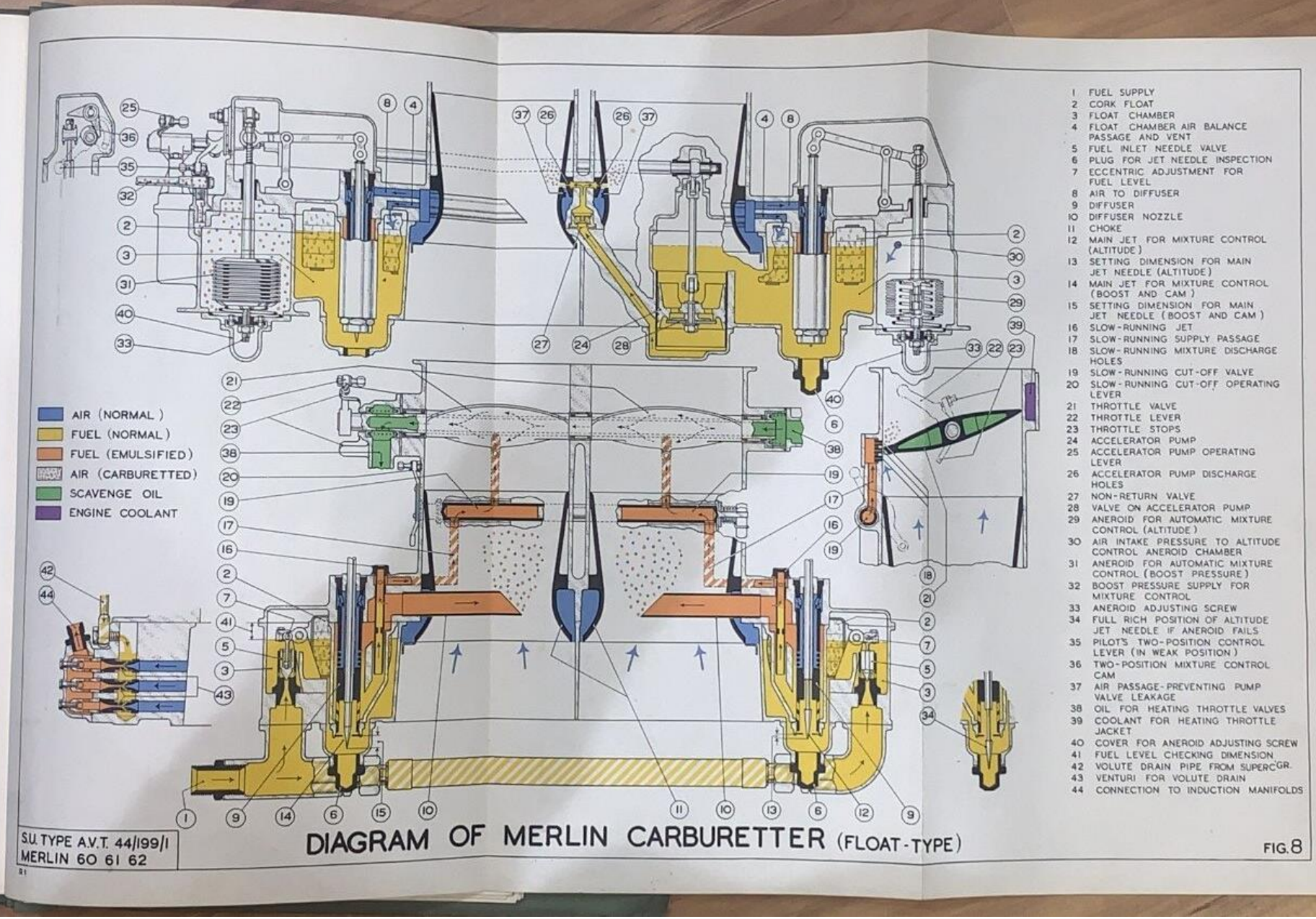
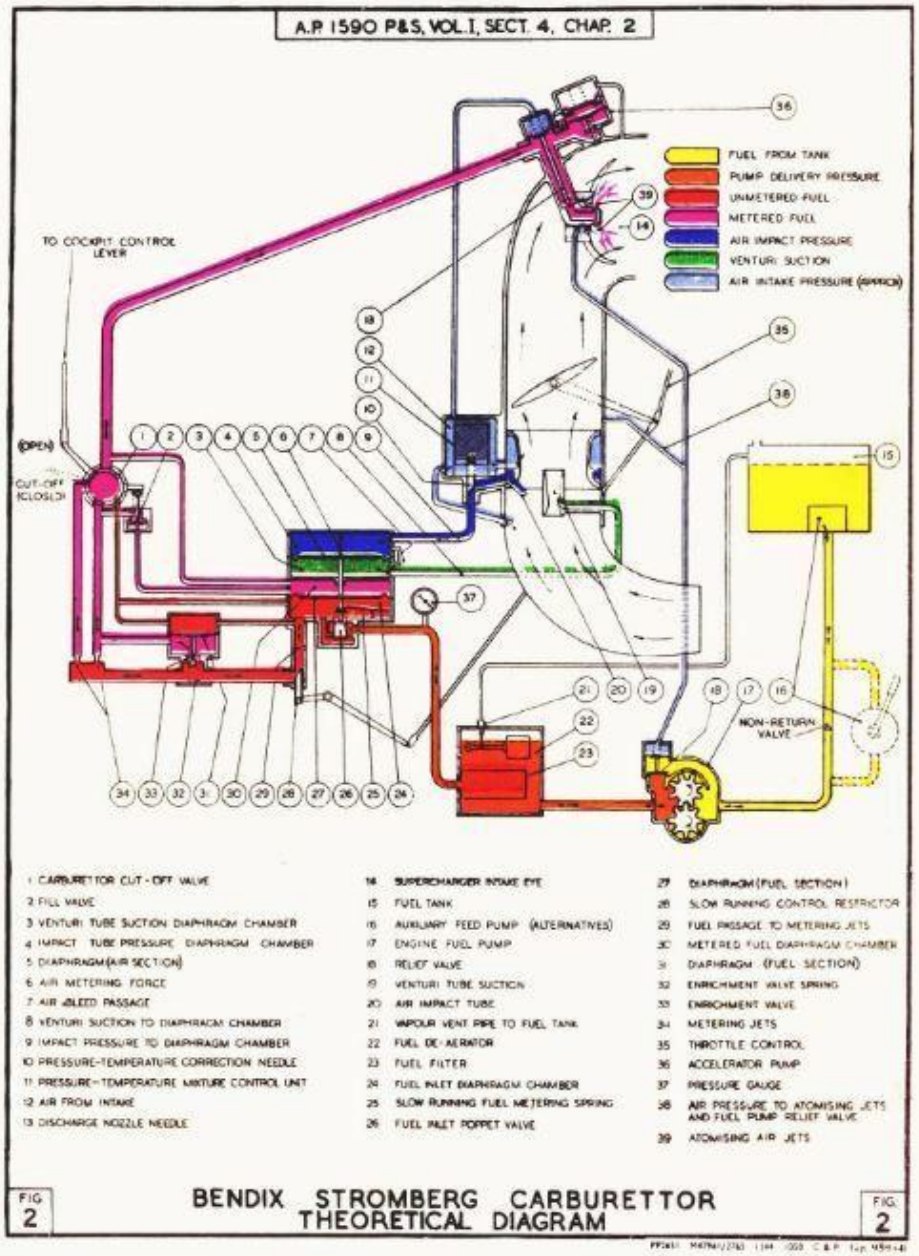


Figure 7: AVT 44/199/1 Carburetor Diagram

For the powerful Merlin 66 engine, R-R decided to use the Bendix-Stromberg Injection carburetor. This pressure carburetor was developed in the mid 1930s and was in production from 1938. This carburetor was designed to operate as a fully pressurized fuel system that dispensed with the problematic float-controlled fuel level with its emulsion tubes and diffusers. Negative-G had no effect on fuel flow or carburetor function. Notably, Packard built their Merlins in the U.S. with a version of the Bendix PD16 from the very start of Packard Merlin production. Packard built their versions of the Merlin 66; the 266 and V-1650-7, with a very similar Bendix PD18. These Bendix-Stromberg PD pressure carburetors were a step towards fuel-injection and were sometimes referred to as "injection carburetors." A diagrammatic illustration of the 8D44/1 carburetor is shown in Figure 8.



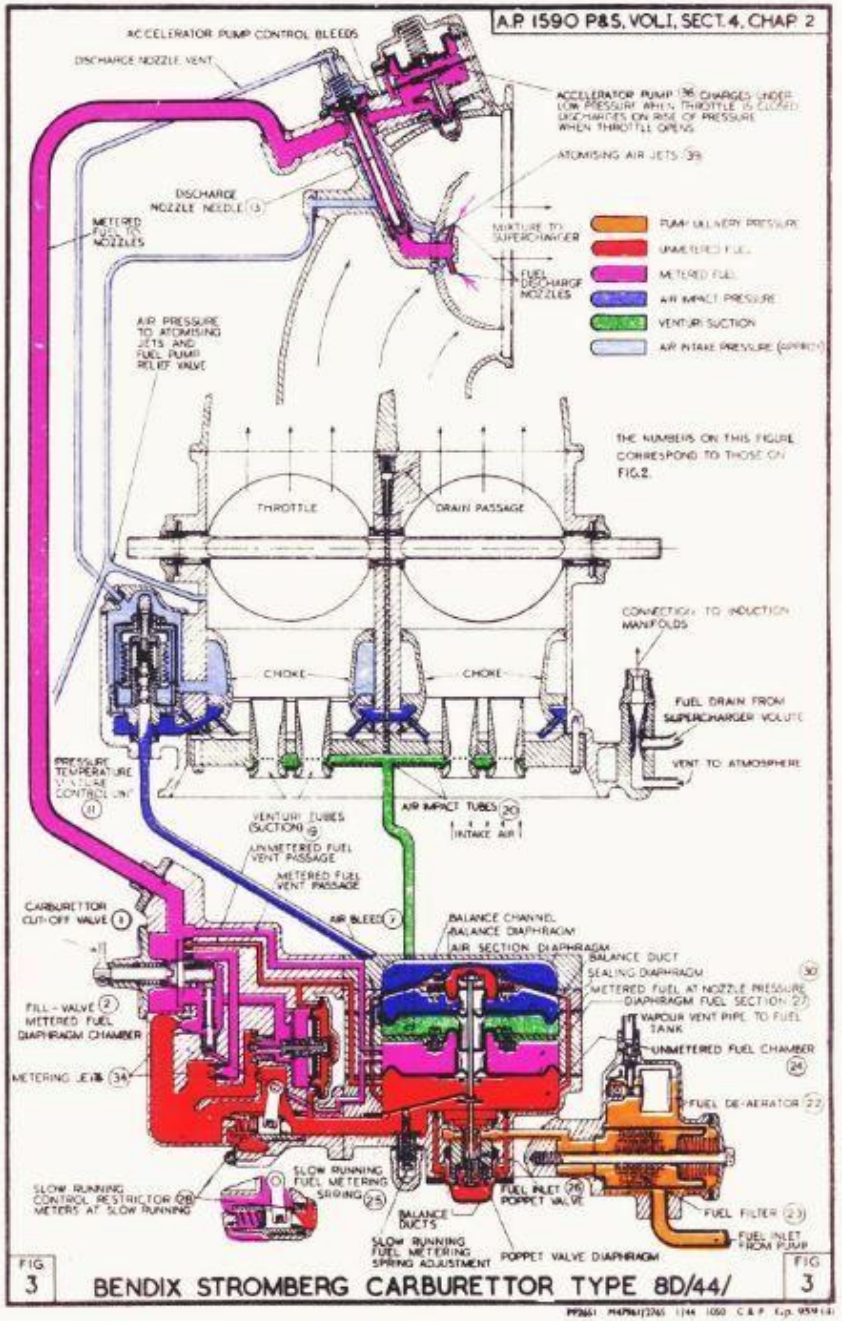
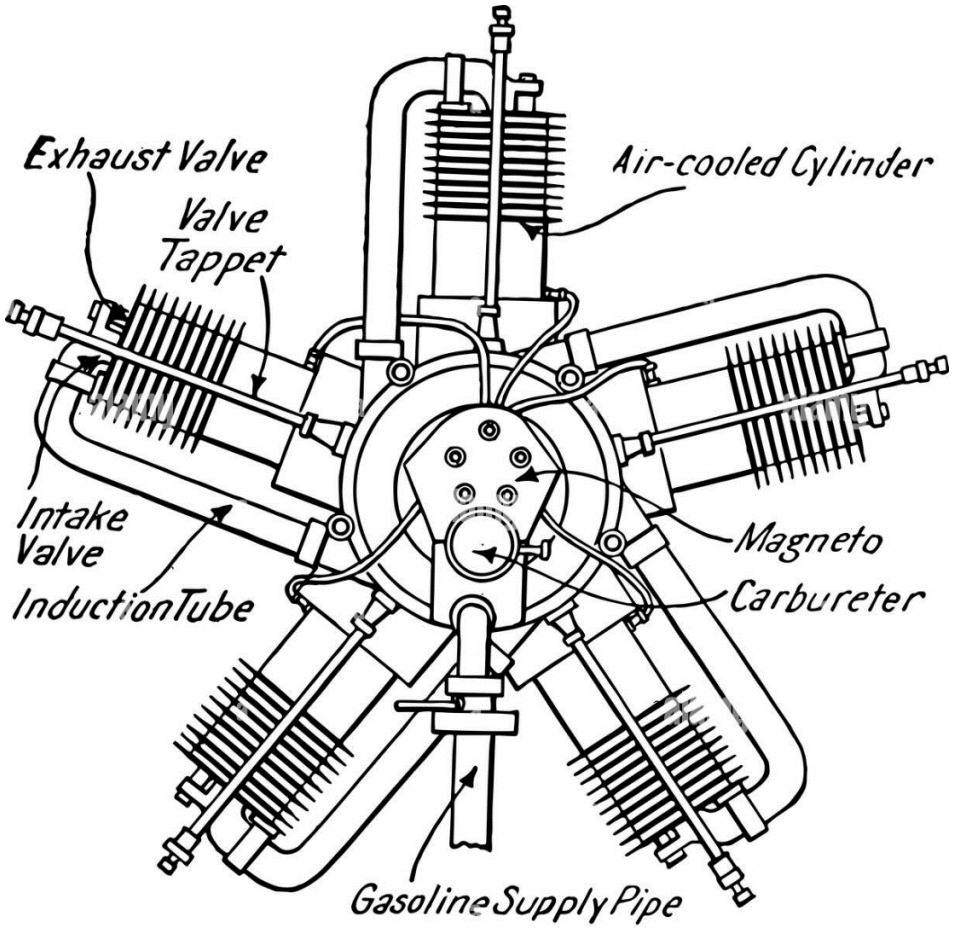


Figure 8: 8D/44/ Bendix Stromberg Injection (a/k/a ‘Pressure’) Carburetor



In further UK developments of the Merlin engine, the Bendix Pressure carburetor was replaced with an SU-developed single point fuel-injector with a variable output swashplate-type injection pump. Finally, R-R developed their own simplified gear pump single point fuel-injection that was cheaper to produce. This system missed the last Merlin engines, however, it was featured on late Griffon engines-serving operationally with the RAF until 1991, when the Avro Shackleton (above) was retired from service.

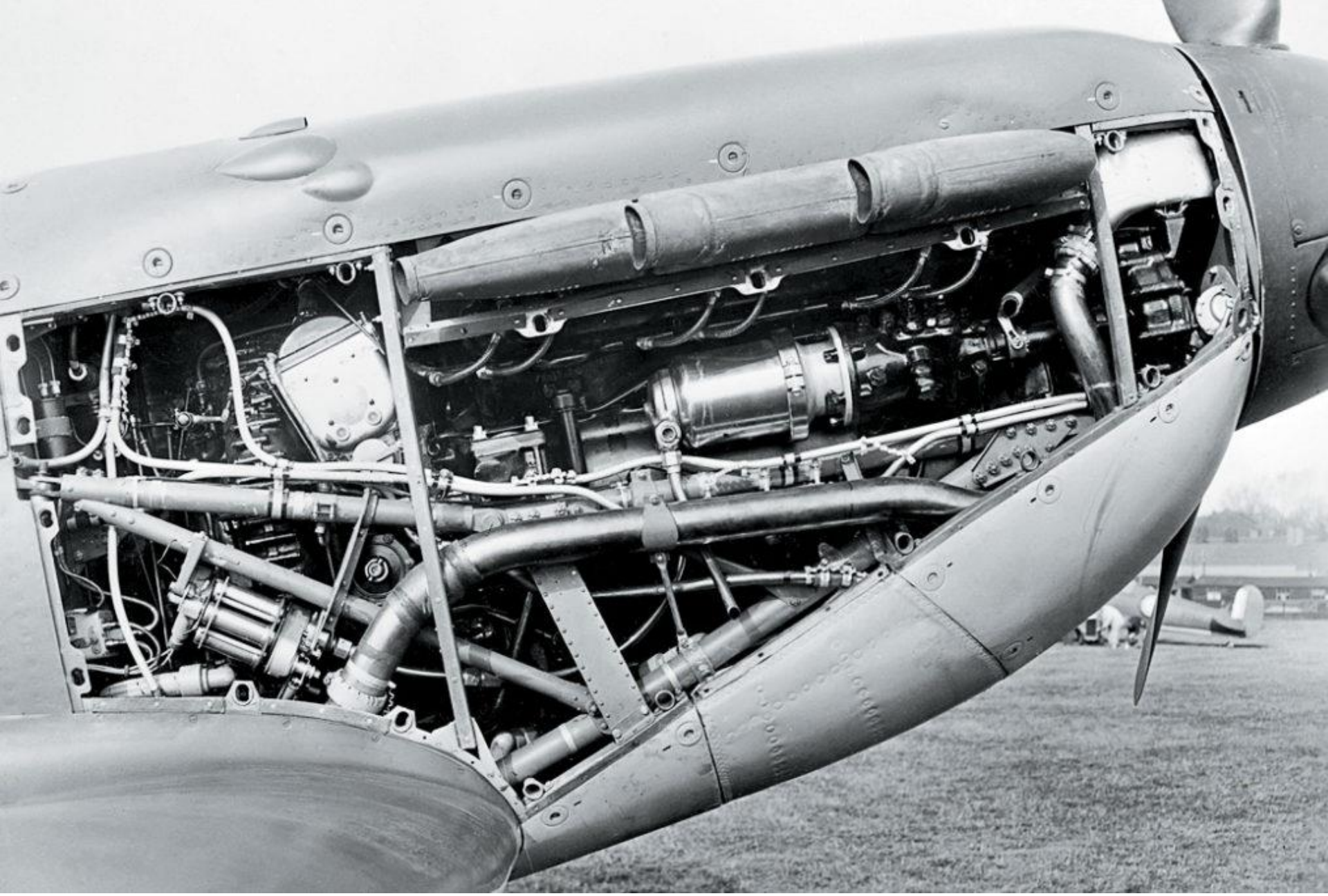
Straight vs. Round



Anzani Radial Motor, with Stationary Cylinders.

"…Radial engine proponents point out that liquid-cooled power plants are more vulnerable to battle damage: while a radial often continued to run even with a cylinder shot completely off the crankcase, a bullet in the cooling system of its in-line counterpart could bring the flight to a rapid end…"

historynet.com



<u>Caption</u>: “A close-up of a Merlin IX in a Spitfire Mk.IIa reveals its Achilles’ heel; the large, curving coolant pipe”

Advantages of Radial Engines



- **Air-Cooled & Lightweight** – No radiators needed, reducing aircraft weight.
- **Durable** – Simple design with fewer moving parts makes them tough.
- **Reliable** – Minimal vibrations ensure smooth operation and fewer failures.
- **High Power** – Generates strong horsepower, ideal for heavy aircraft.
- **Easy to Maintain** – Open cylinder access simplifies repairs.

"…But well-designed liquid-cooled engines like the Merlin could run for long periods beyond normal operational limits without overheating, as liquid-cooling is more efficient than air cooling, particularly for the cylinder head and valves. And they could operate at higher altitudes, reducing risk from anti-aircraft fire…"

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Time-and-Again



"…Far from being delicate and temperamental, as some 'round engine' devotees maintain, the Merlin proved time-and-again that it could take abuse and still bring wounded aircraft home. Accounts of its fortitude are legion, including heavy bombers returning with half their engines disabled by flak or fighters, using throttle and boost far beyond the specified maximums for hundreds of miles…"

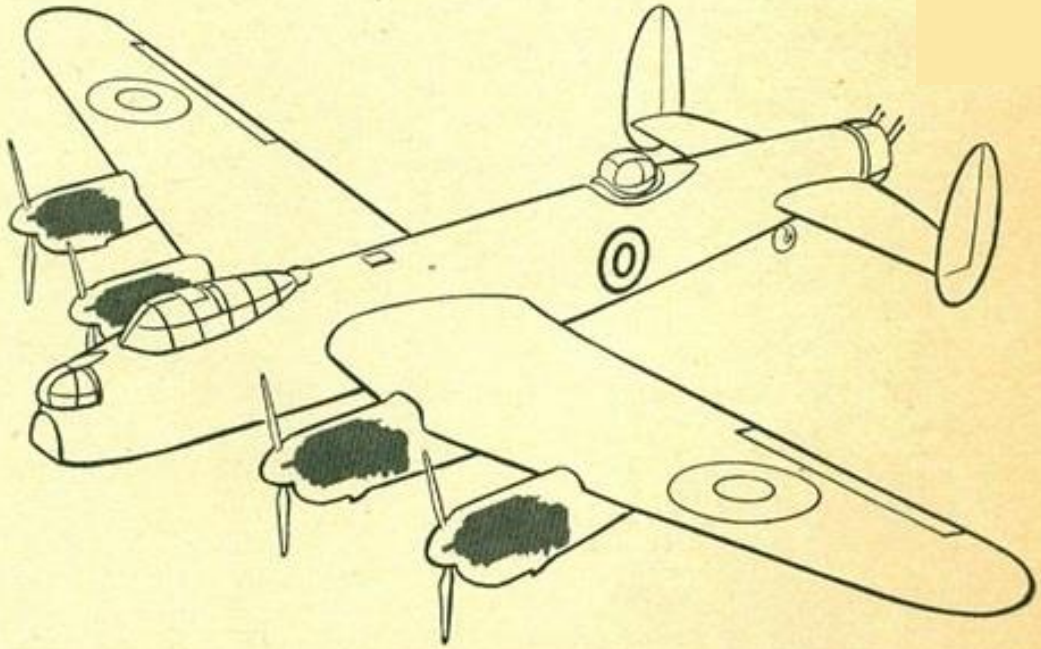
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<u>Caption</u>: " Battle damage to a Lancaster bomber's starboard-inboard engine"

"…For example, one bomber pilot wrote, 'I had to return from Nuremburg in a Wellington on one engine and used maximum boost and revs on a Merlin X for five hours with no sign of distress.' In another incident, an Avro Lancaster pilot who lost an engine just after take-off pressed on to Stuttgart, fully loaded with fuel and bombs, using climb power on three engines for the whole trip…"

historynet.com

RE: the Lancaster heavy bomber began life in 1941 when the Mark I was developed from the ill-fated Manchester and was fitted with four Merlin XX engines of 1,280 hp/each. By the middle of 1942, R-R could not supply sufficient engines to meet the demand; even the 18K per-year rate by 1943 was insufficient. The Ford Motor Co. was approached, but they would not agree to help and, eventually, Packard stepped-in. The drawings were already in the U.S., having been sent there after the Fall of France; but much work remained to be done before production could commence and the drafting staff worked tirelessly to prepare working drawings from the master copies. When Packard started to make the Merlins they had great difficulty in working to R-R tolerances, but persevered and managed to produce their first engine within a year.



"To Berlin—with the compliments of Coventry" might well have been scrawled on the block-busters dropped by England's multi-ton Lancasters. These four-motored giants depend on Packard-built Rolls-Royce engines on their nightly sweeps over German targets.

PACKARD

Precision-built Power

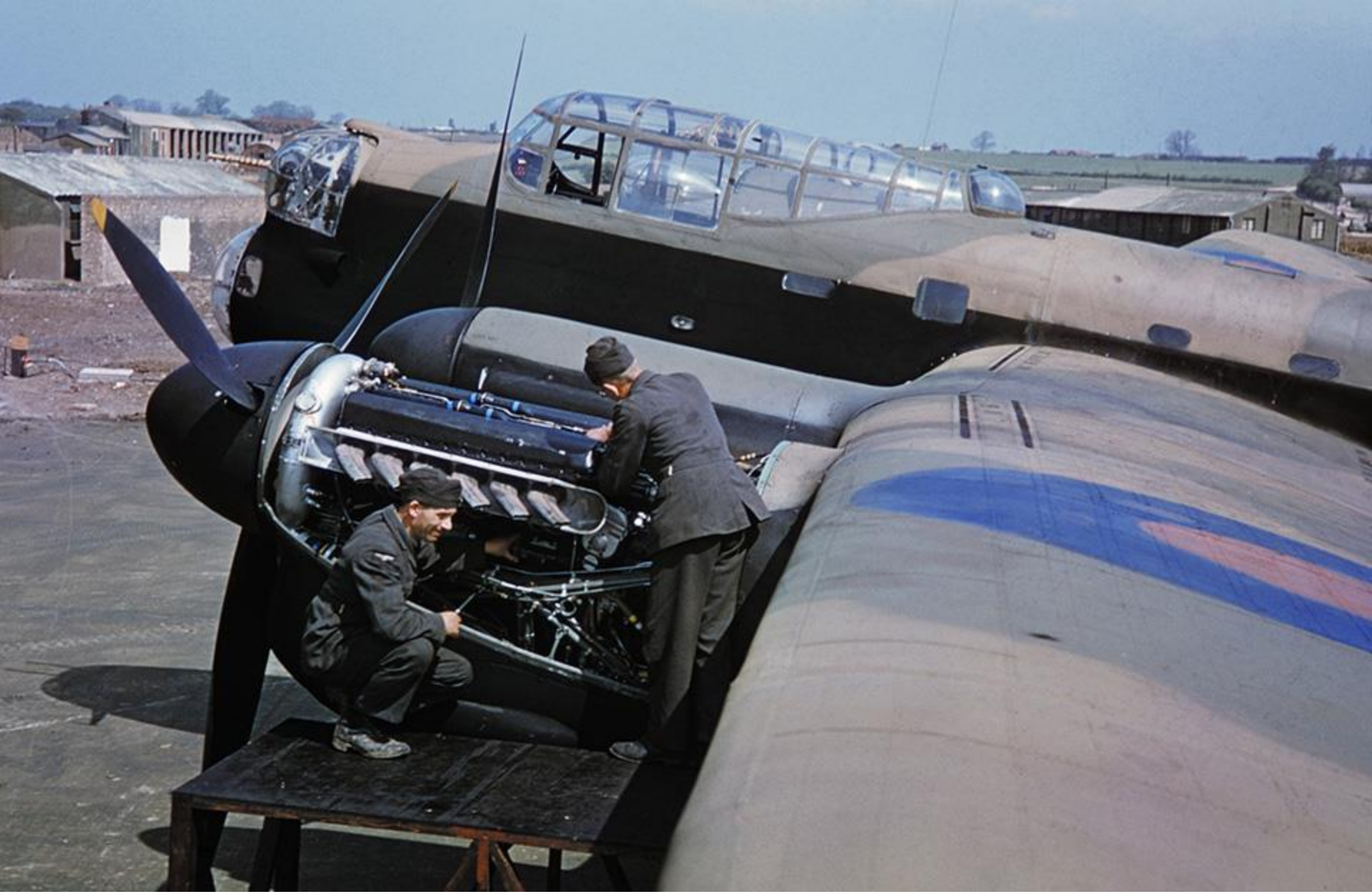
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ASK THE MAN WHO OWNS ONE

The American Merlins developed 1,460 hp and were designated "Merlin XXVIII." At first they were fitted with a Bendix carburetor because the British SU could not be produced in-time, but eventually the Stromberg carburetor became standard. Another important difference with the introduction of the Packard engine was the use of rounded-end propellers (a/k/a "paddle blades"). These props improved performance, particularly in the climb and they were later adopted on all Lancasters.

The original design and manufacture of the Canadian Lancaster Mk.X's were identical to the British Lancaster Mk.III. The first 75 aircraft (serial nos. KB700 to KB774) received the Packard-built R-R Merlin 38 engines, which produced 1,390 hp at 3K rpm. Lancaster Mk.X serial no. KB775 onwards were installed with the Packard-Merlin 224 engines. These were manufactured in Detroit by Packard and based on the British R-R Merlin 24. They were given the "2" prefix and became the Packard-Merlin 224, producing 1,620 hp at 3K rpm.

With the Merlin XXVIII came excellent tool sets, which were greatly appreciated by ground crews. The Lancaster manufacturers were allotted specific quantities of British and American engines so that, in general, the serial numbers of the aircraft were a guide to the initial engine installation, although in service, when an engine was changed, it could have been replaced by either type (British or American). The aircraft was originally designated a Mk.I or Mk.III respectively. A Lancaster Mk.II was also introduced during 1942, this version being fitted with Bristol Hercules radial engines (as an insurance against delay in supplies of Merlins from the U.S.).



Caption: “Mechanics work on one of four Merlins powering an Avro Lancaster bomber of No. 207 Squadron at RAF Bottesford airfield, Lincolnshire, in June 1942”





Continuous improvements made to the Merlin engine allowed it to, eventually, produce over 2K hp. Thus, each succeeding modification allowed the Lancaster to go faster, higher and/or carry a heavier bomb load, but never was it more apparent than on take-off when the boost-pressure was increased from +12, in 1942, to +18, in 1945 (a 50% increase).

Left: caption "An Avro Lancaster's bomb load; five rows of 500 lb. bombs, four per row"

Above: caption: "A Lancaster releasing its bomb load"

V-1650

"…The Merlin served in all war theaters, with all Allied air forces - including the Soviets - and was the only British engine to be used in American warplanes. In fact, it was in the P-51 Mustang that the Merlin, produced under license as the V-1650 by the Packard Motor Car Company, gained perhaps its greatest renown…"

historynet.com

RE: the P-51 was conceived early in 1939, when Britain, anticipating war and having ordered more P-40 Warhawks from Curtiss than the company could rapidly produce, approached North American Aviation (NAA), from whom they had been buying AT-6 trainers (a/k/a "Harvards") with a proposal that NAA set-up a second P-40 production line. NAA offered a counterproposal: they would create a new, superior fighter of their own. The engine type was preordained: the same mediocre 1,140-hp Allison V-12 that powered the P-40. *Edsel Ford* was working on an aircraft contract with R-R, but his father, Henry, declined. His stated reason was that he wished only to produce materials for defense of the American mainland, not warcraft, but others have suggested Ford did not have the precision engineering capability to build the complex design of the Merlin engine.

SISTERS UNDER THE SKIN!



Heart of the Water Wasps—incorporating the latest in science and metallurgy, this 1350 horsepower Packard engine is the newest ultra-modern type of 60-degree V-12 liquid-cooled, super-charged design.



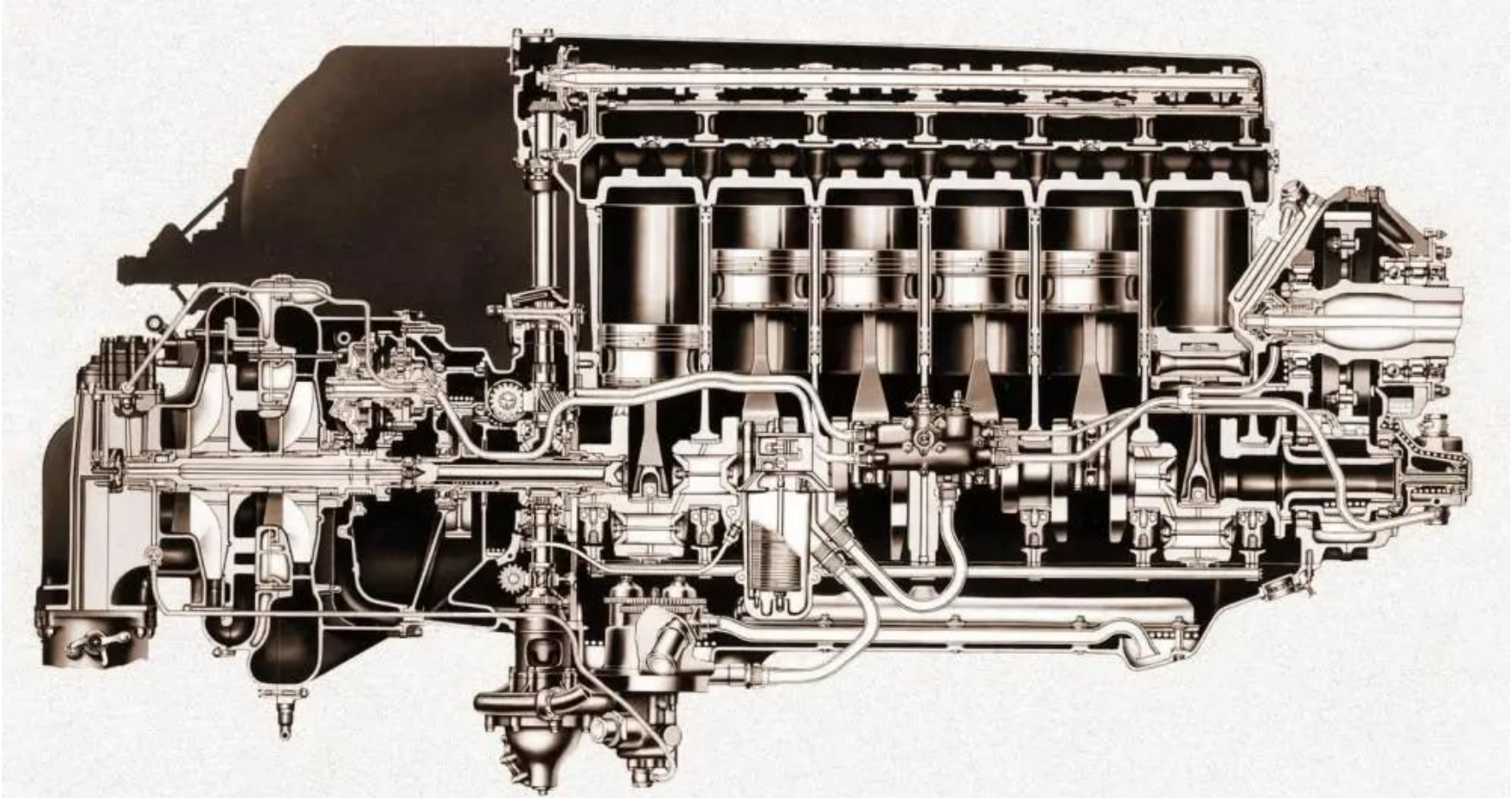
Heart of your Packard—one of the most dependable motors of all time. Despite its size, power, and fiery performance, its all-around thriftiness compares favorably with small "economy" cars, owners say.

Packard's first major WWII contract came in 1939, for marine engines to power the entire American "Water Wasp" torpedo boat fleet. That design was the V-12 R-R Merlin, which they had been building domestically since 1935. The most famous ELCO-constructed PT (Patrol-Torpedo) boat with a Packard Marine engine was launched on June 20, 1942 and designated "PT-109," skippered by a USN junior officer by the name of *John F. Kennedy.*



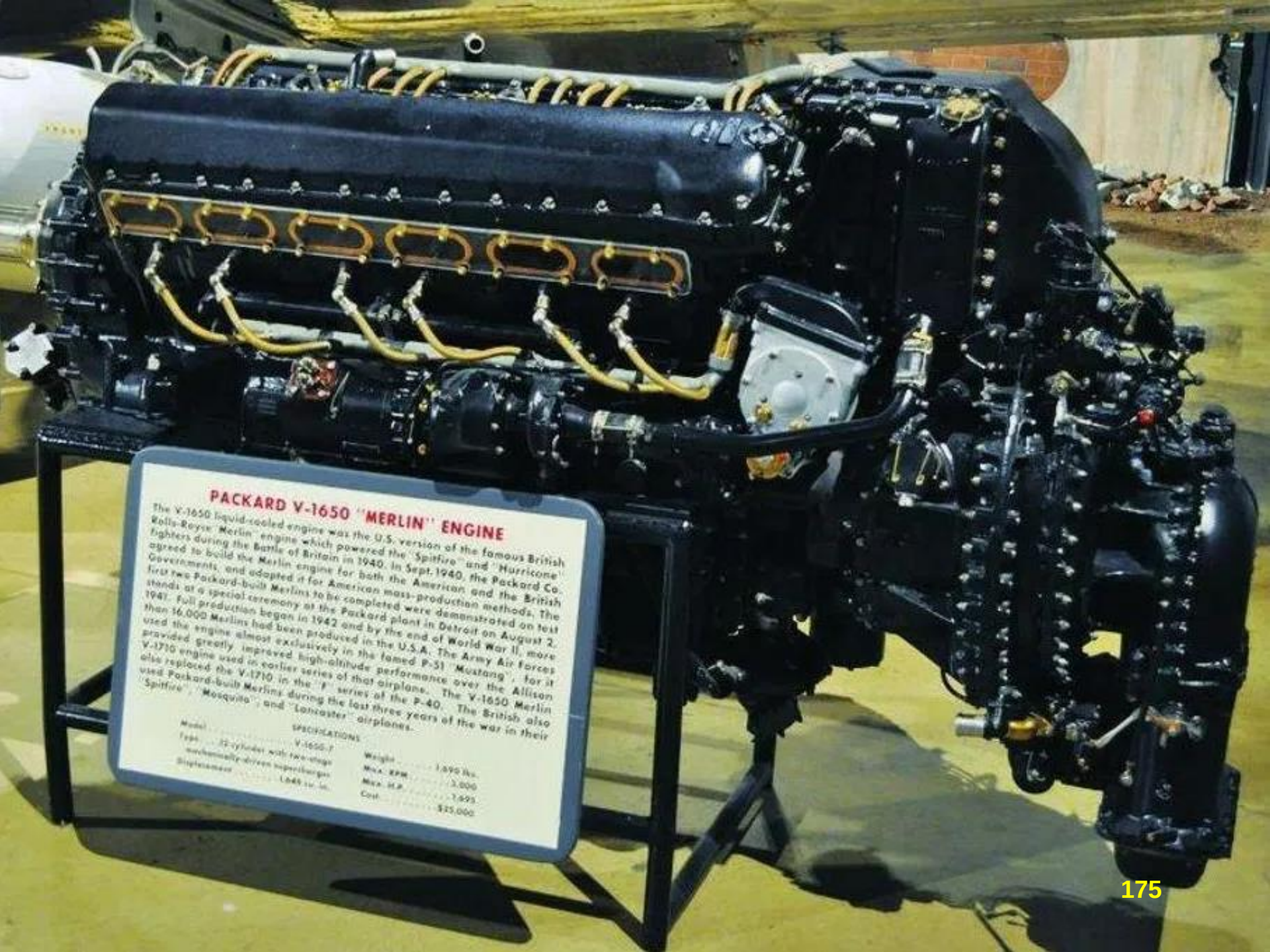
Packard powers the Water Wasps!

After British officials toured a number of American manufacturers, Packard received the $130-million contract based on their machining abilities. The Packard version incorporated several improvements aimed at durability and reliability, but the candle-on-the cake was an improved automatic supercharger, which kept power output above 1,200-hp at high altitudes. A water-to-air intercooler circulated an independent ethylene glycol supply to cool the intake charge between the two impellers of the supercharger, but the fuel-air mixture could still reach around 400-degrees C, so Packard used an additional after-cooler ahead of the intake manifold; a second complete cooling system. One single aluminum-block Merlin engine contained about 14K separate parts, with operating tolerances in the supercharger of 0.0001-inch



<u>Above</u>: where Packard could cast an automotive block in just five hours, the Merlin block took 110 and a set of its con rods required 31 hours to machine. Over the course of 70 assembly stations, the engine and its components received 70K different inspections. The result was a 1,649-cu. in. (27-liter) engine that weighed 1,690 pounds fully dressed and at full take-off power made 1,380-hp at 3K RPMs. Another 220-hp were on tap when the blower kicked-in. Merlins became more powerful as the war progressed.

Packard ran the first two V-1650-7 engines on test stands in Detroit on August 2, 1941 and began full production the following winter. At $25K/each, they built 54,714 units and in the U.S., went into, primarily, P-51 Mustangs, which cruised at 275 mph and could hit 437 mph. In wartime, the only comparable combination was the Messerschmitt 109 series, with variants on the 1K-hp, 2,069-cu.in. Daimler-Benz DB-601.


PACKARD V-1650 "MERLIN" ENGINE
The V-1650 liquid-cooled engine was the U.S. version of the famous British Rolls-Royce "Merlin" engine which powered the "Spitfire" and "Hurricane" fighters during the Battle of Britain in 1940. In Sept. 1940, the Packard Co. agreed to build the Merlin engine for both the American and the British Governments, and adapted it for American mass-production methods. The first two Packard-built Merlins to be completed were demonstrated on test stands at a special ceremony at the Packard plant in Detroit on August 2, 1941. Full production began in 1942 and by the end of World War II, more than 16,000 Merlins had been produced in the U.S.A. The Army Air Forces used the engine almost exclusively in the famed P-51 "Mustang", for it provided greatly improved high-altitude performance over the Allison V-1710 engine used in earlier series of that airplane. The V-1650 Merlin also replaced the V-1710 in the "F" series of the P-40. The British also used Packard-built Merlins during the last three years of the war in their "Spitfire", "Mosquito", and "Lancaster" airplanes.
SPECIFICATIONS
Model ... V-1650-7
Type ... 12-cylinder with two-stage mechanically-driven supercharger
Displacement ... 1649 cu. in.
Weight ... 1,690 lbs.
Max. RPM ... 3,000
Max. H.P. ... 1,695
Cost ... $25,000



"…American precision daylight bombing of key targets deep inside Germany, by unescorted heavy bombers of the Eighth Air Force, began badly. By late spring of 1943, Luftwaffe strength was growing and its fighter tactics were improving. Bomber losses reached 14 percent during the April 17 raid on Bremen. In July 128 bombers were shot-down, with 1,280 crewmen either killed or taken prisoner and half the surviving aircraft had suffered battle damage…"

historynet.com

<u>Caption</u>: "A USAAF B-17 flies through heavy flak during a raid on Ludwigshaven, Germany, in September 1944"

History Rhyming

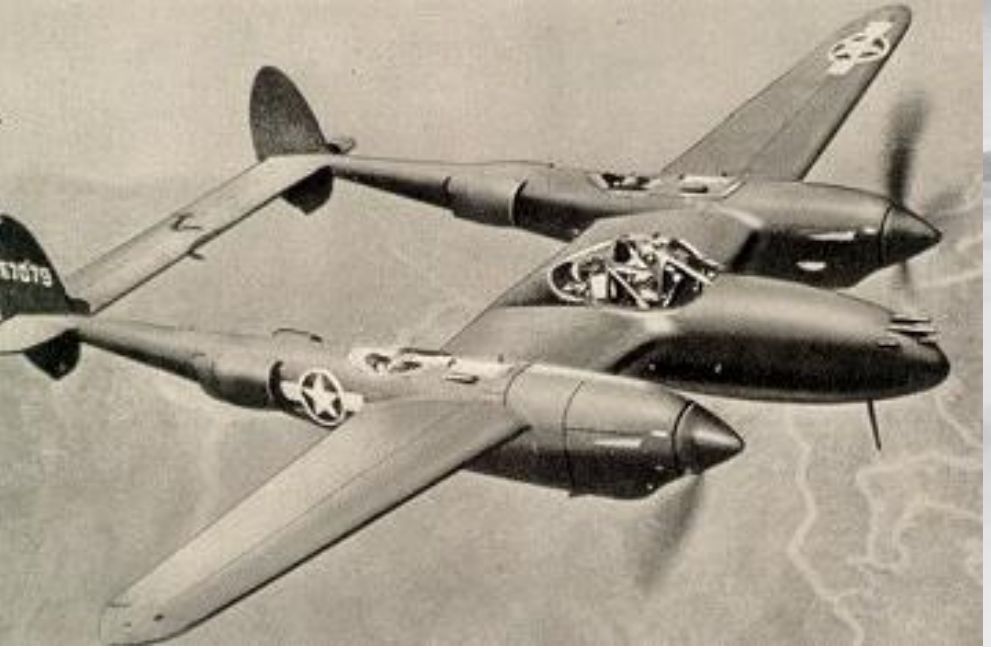
“History never repeats itself, but it often rhymes”
Mark Twain



"…The assumption that bombers, flying in mutually defensive formations, could penetrate Germany without fighter escort all the way to the target was proving to be a disastrous repeat of the Luftwaffe's experience against Britain three years earlier. It persisted in the face of all the evidence for the same reason: there were no suitable long-range fighters…"

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<u>Caption</u>: "The remains of a Luftwaffe bomber brought down on the southeast coast of England, July 11, 1940, during a night air raid. Forty Luftwaffe planes were brought down in three days by the work of RAF fighters and anti-aircraft defenses."





"…The Republic P-47's radius, even with drop tanks, was only 400 miles. The twin-engine Lockheed P-38 had the range, but in a dogfight was outperformed by well-handled single-engine fighters, just as the Messerschmitt Me-110 had been in 1940…"

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Left: the first airplane developed from the get-go as a military-type by Lockheed; the P-38, was designed to meet a U.S. Army Air Corp specification issued in 1936

Right: nicknamed "Jug," the P-47 was used as both a high-altitude escort fighter and a low-level fighter-bomber

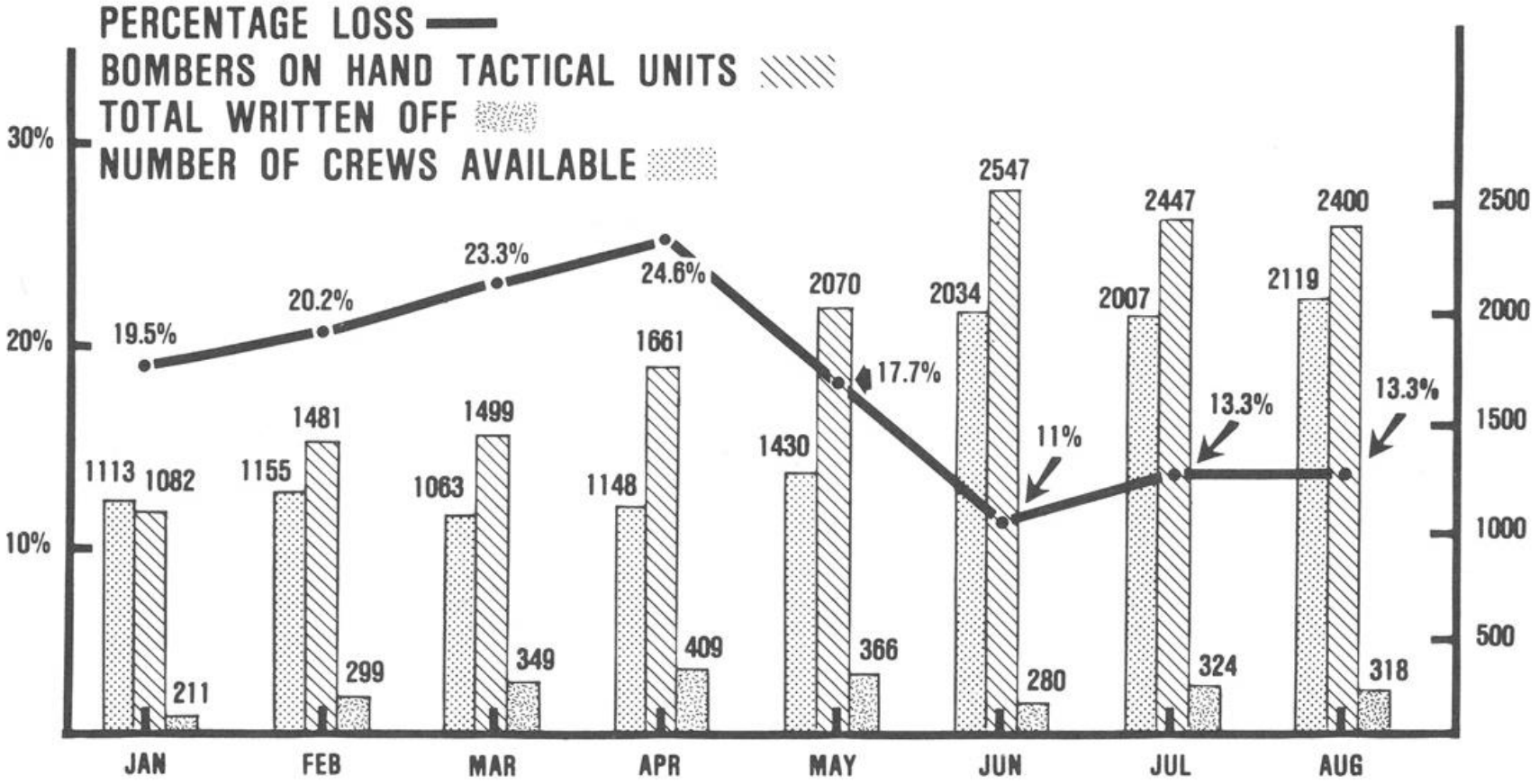
An Intolerable Situation

"…Losses in raids on Schweinfurt and Regensburg on August 17 reached as high as 20 percent and a return raid on Schweinfurt on October 14 resulted in an intolerable 27 percent loss - 34 percent if planes scrapped on their return were counted - forcing the Eighth Air Force to suspend raids until a solution could be found…"

historynet.com

RE: the USAAF's 8th Air Force suffered significant losses during WWII, particularly during daylight bombing raids over Europe. While achieving considerable success, their casualty rate was exceptionally high; with over 26K airmen killed and an additional 28K becoming POWs. Thus, two-thirds of 8th Air Force personnel involved in combat operations could expect to become a casualty.

AIRCRAFT WRITTEN OFF: EIGHTH AIR FORCE 1944 (HEAVY BOMBERS)





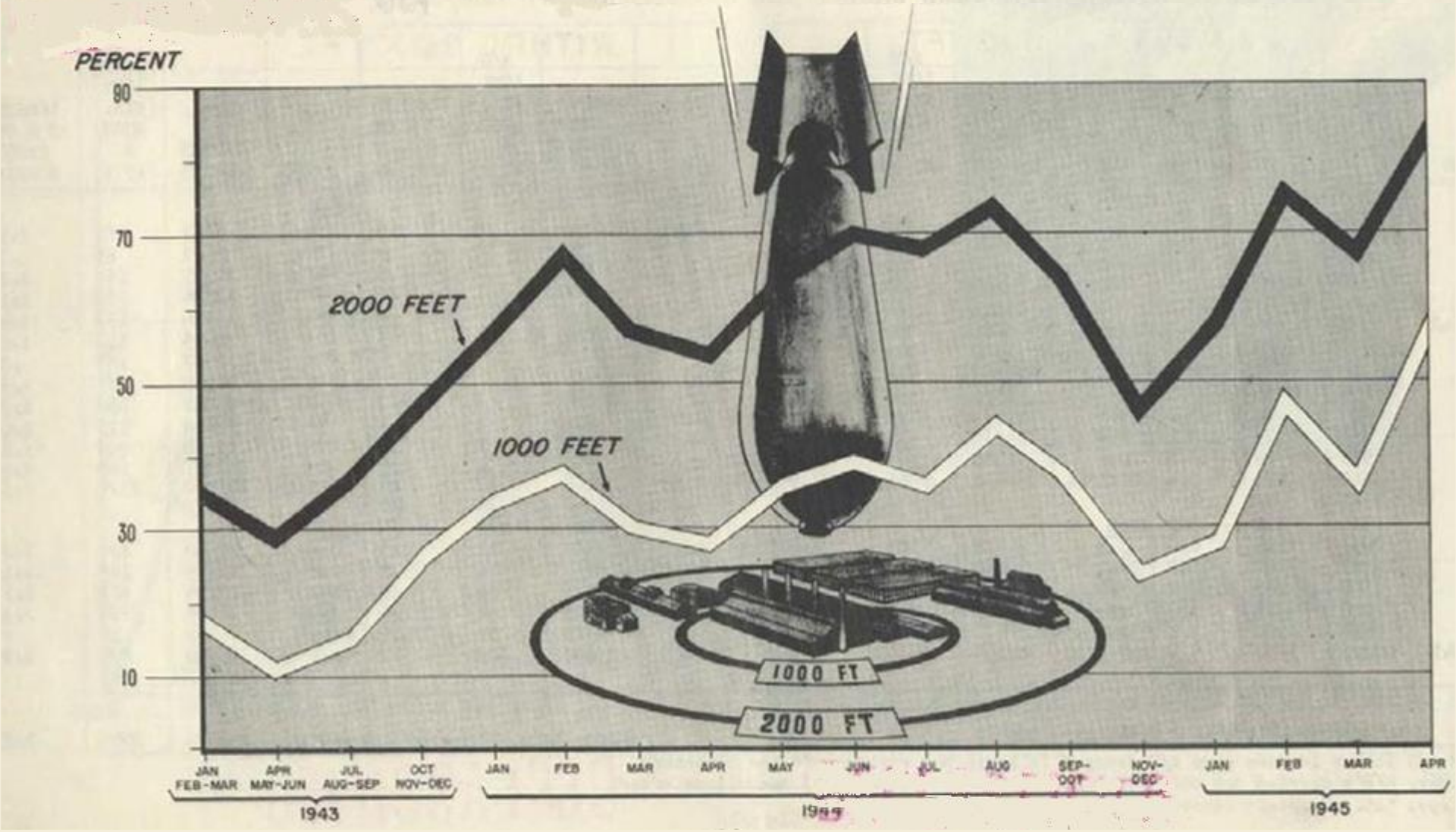
"…Even if a factory was hit, it was almost impossible to destroy the vital machine tools and presses. Once wreckage was cleared away, production often restarted within days…"

historynet.com

<u>Caption</u>: "A tight formation of Eighth Air Force B-17s releases its bomb loads during a daylight raid over Betzdorf, Germany, March 12, 1945"

BOMBING ACCURACY

AVERAGE PERCENT OF BOMBS DROPPED WHICH FELL WITHIN 1000 FT. AND 2000 FT. RESPECTIVELY OF PRE-ASSIGNED MPI'S ON VISUAL MISSIONS UNDER CONDITIONS OF GOOD AND FAIR VISIBILITY





Decentralization

"…Despite temporary disruptions, German fighter production continued to increase until the war's last months. The Germans simply decentralized their fabrication and assembly to smaller, satellite plants and cottage industry sites…"
historynet.com

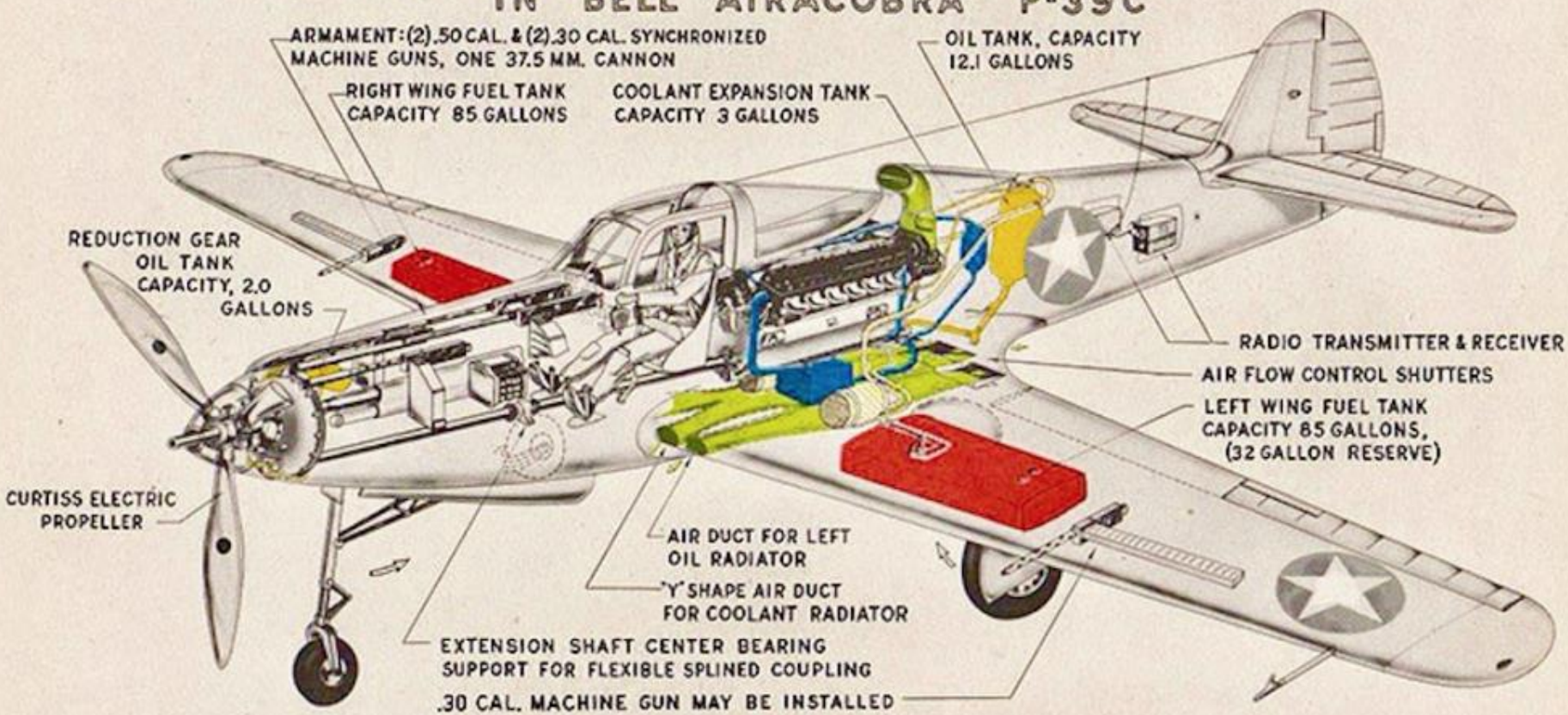
Similar, But Inferior

"…The Allison V-1710, the only American in-line engine used in WWII, was very similar to the Merlin in several ways, but lacked the power development potential and altitude capability, relegating the RAF's early Allison-powered Mustangs to low-level photo-reconnaissance…"

historynet.com

RE: the only American liquid-cooled engine to see service in WWII was the Allison V-1710. It was one of the most important large U.S. aero-engines, with over 70K produced from the time of the first, in 1931, to the last, in 1948. The engine was produced for several important WWII fighters, including the P-38 Lightning, P-39 Aircobra, P-40 Warhawk, P-51A Mustang, P-63 Kingcobra, P-82 Twin Mustang and the Consolidated XA-11A (an experimental attack version of the Consolidated P-25). Allison was an Indianapolis firm that had done well with Liberty engine modifications and with reduction gears for other manufacturer's engines.

ALLISON E-4 V-1710-35 INSTALLATION IN BELL "AIRACOBRA" P-39C



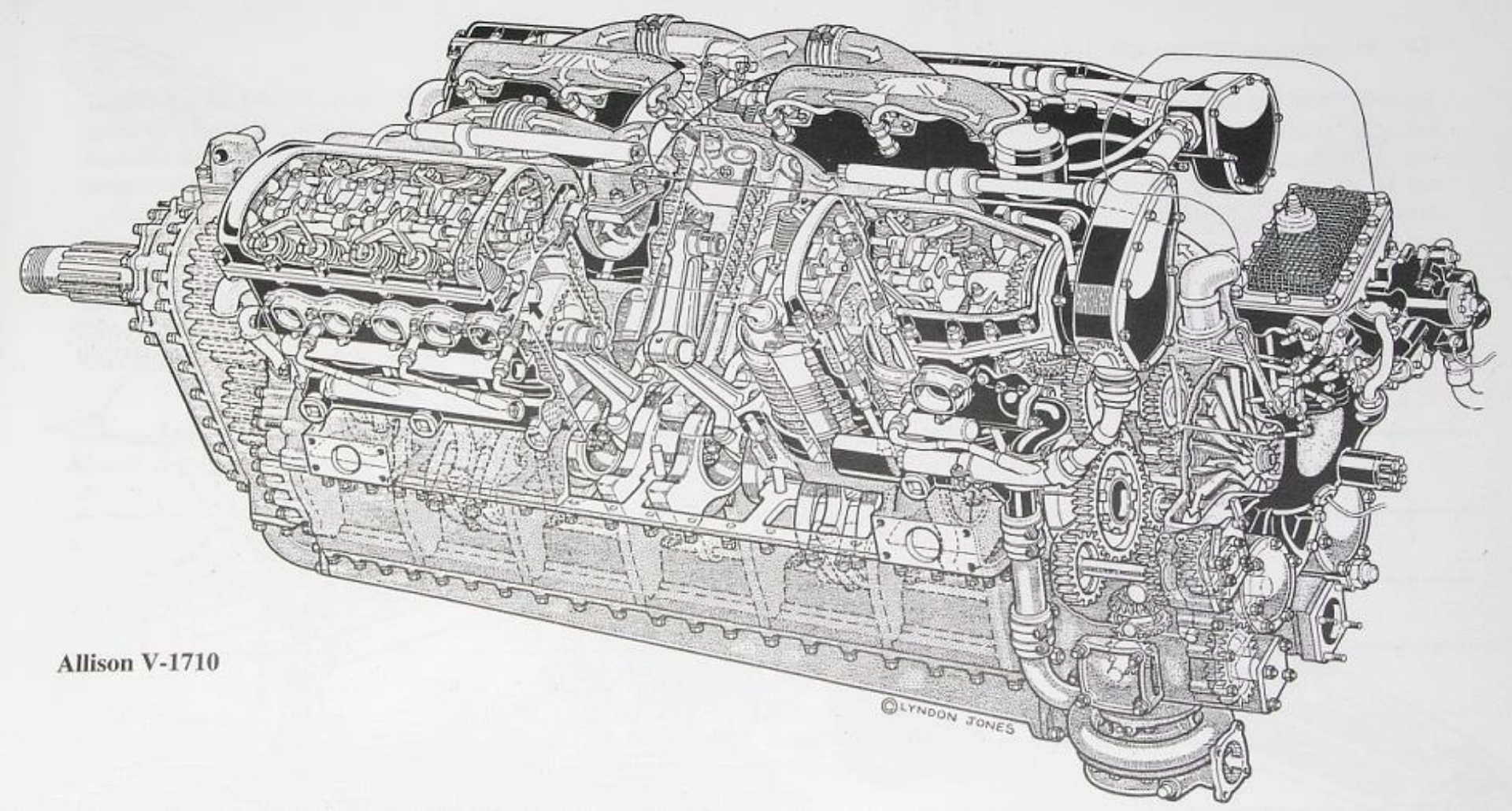
COLOR KEY

GASOLINE — COOLANT — ENGINE & REDUCTION GEAR OIL (PRESSURE) — (SCAVENGE)

BREATHER & VENT LINES — FREE AIR FLOW



<u>Caption</u>: “Mechanics preparing an Allison V-1710 engine to be installed on a Lockheed P-38 Lightning”



<u>Above</u>: the Allison V-1710 turned-out to be a sturdy and reliable powerplant. However, its inability to deliver power at high-altitudes diminished its greatness. This was the result of a USAAC decision to rely on turbo-supercharging to obtain adequate power at combat heights. A turbo-supercharged Allison was as good as any high-altitude engine; the trouble was the wartime shortage of alloying materials, particularly tungsten, which made it impossible to make enough turbo-superchargers for the entire Allison V-1710 production.



<u>Above</u>: a British North American NA-73 Mustang Mk.I being test-flown at Inglewood, Calif., ca. Oct. 1942. Equivalent to a P-51A, the aircraft's Allison engine installation is easily identified by the different contour of the tight cowling without chin inlet beneath the propeller hub and the carburetor air-intake on top of the engine cowling. This plane was one of the original batch of 300 aircraft ordered by the RAF in Dec. 1940, before the Lend-Lease Act.

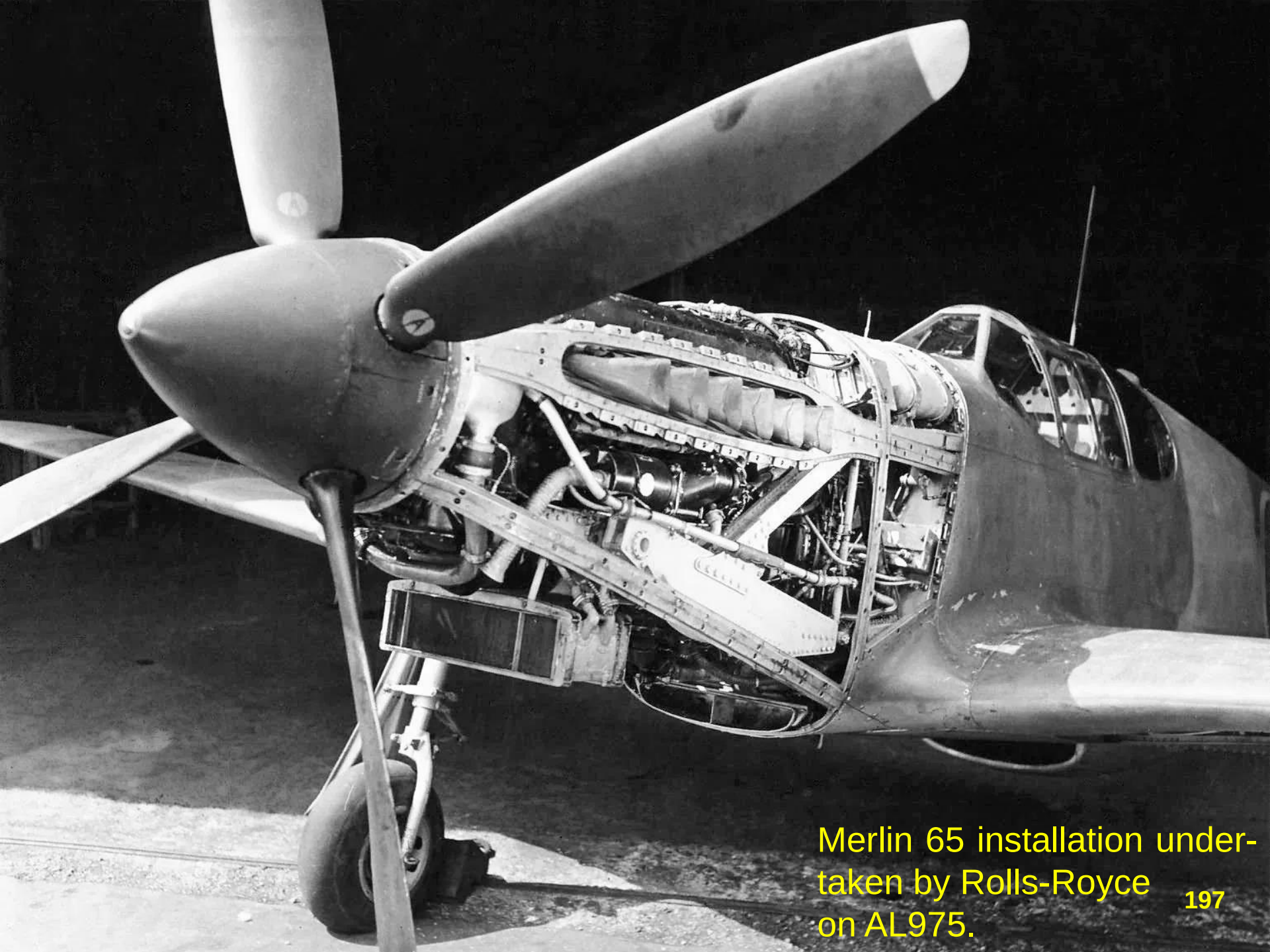
A Marriage Made-in-Heaven



"…In a marriage made-in-heaven, five P-51s were fitted with Merlin 65s at Rolls-Royce's research airfield at Hucknall in 1942, transforming a good fighter into a superb one, faster than the Fw-190 and Me-109 at all altitudes and superior to both in virtually all respects…"

historynet.com

<u>Caption</u>: "An aerial photograph of the Hucknall Flight Test Establishment"



Merlin 65 installation undertaken by Rolls-Royce on AL975.

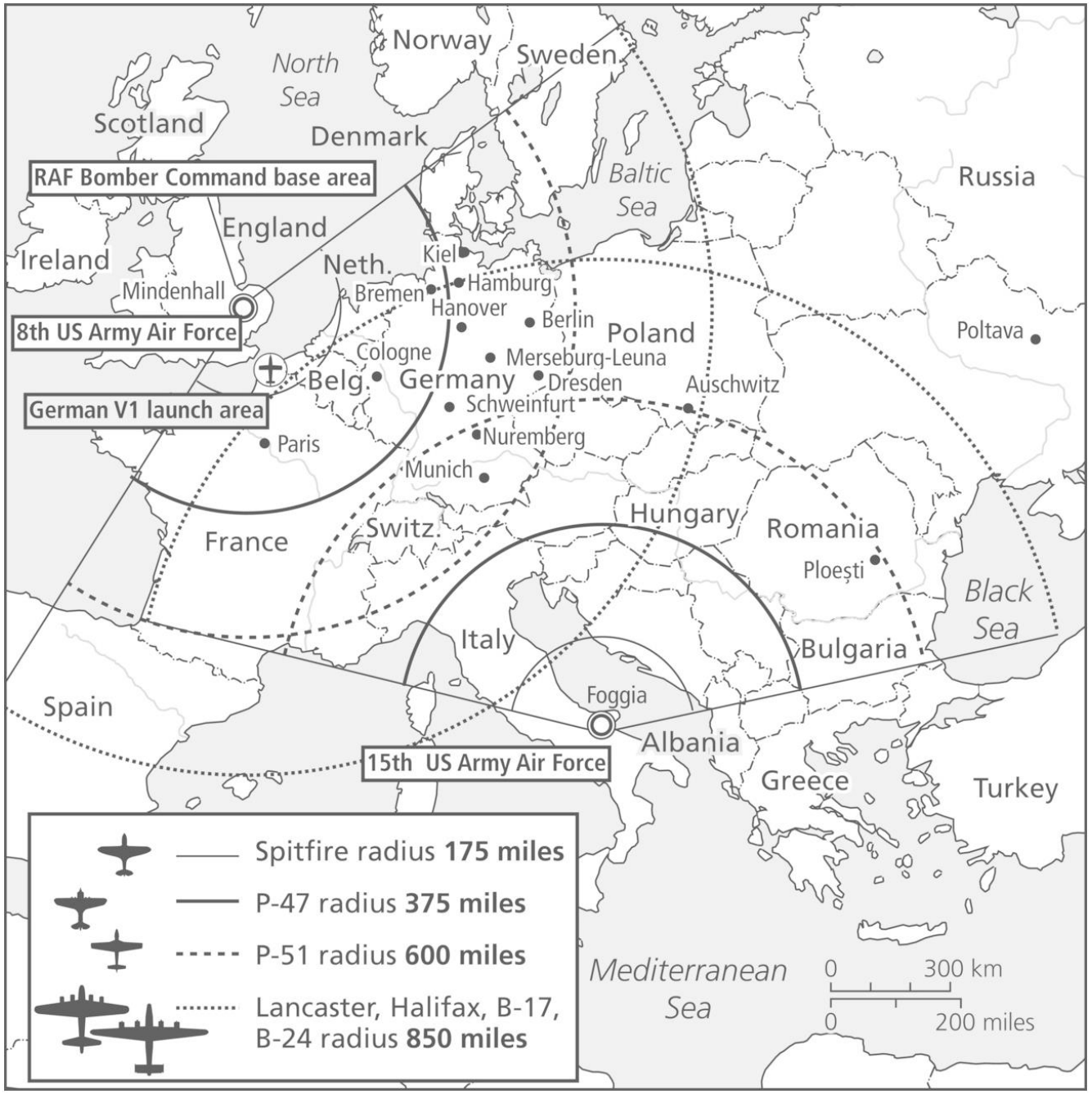
The Jig Was Up



"…Carrying 270 gallons of fuel internally and two 75-gallon drop tanks, the Packard Merlin-powered Mustangs had an endurance of 7-1/2 hours. They could escort the B-17s and B-24s to any target in Germany and outfight any Luftwaffe plane on the way there and back…"

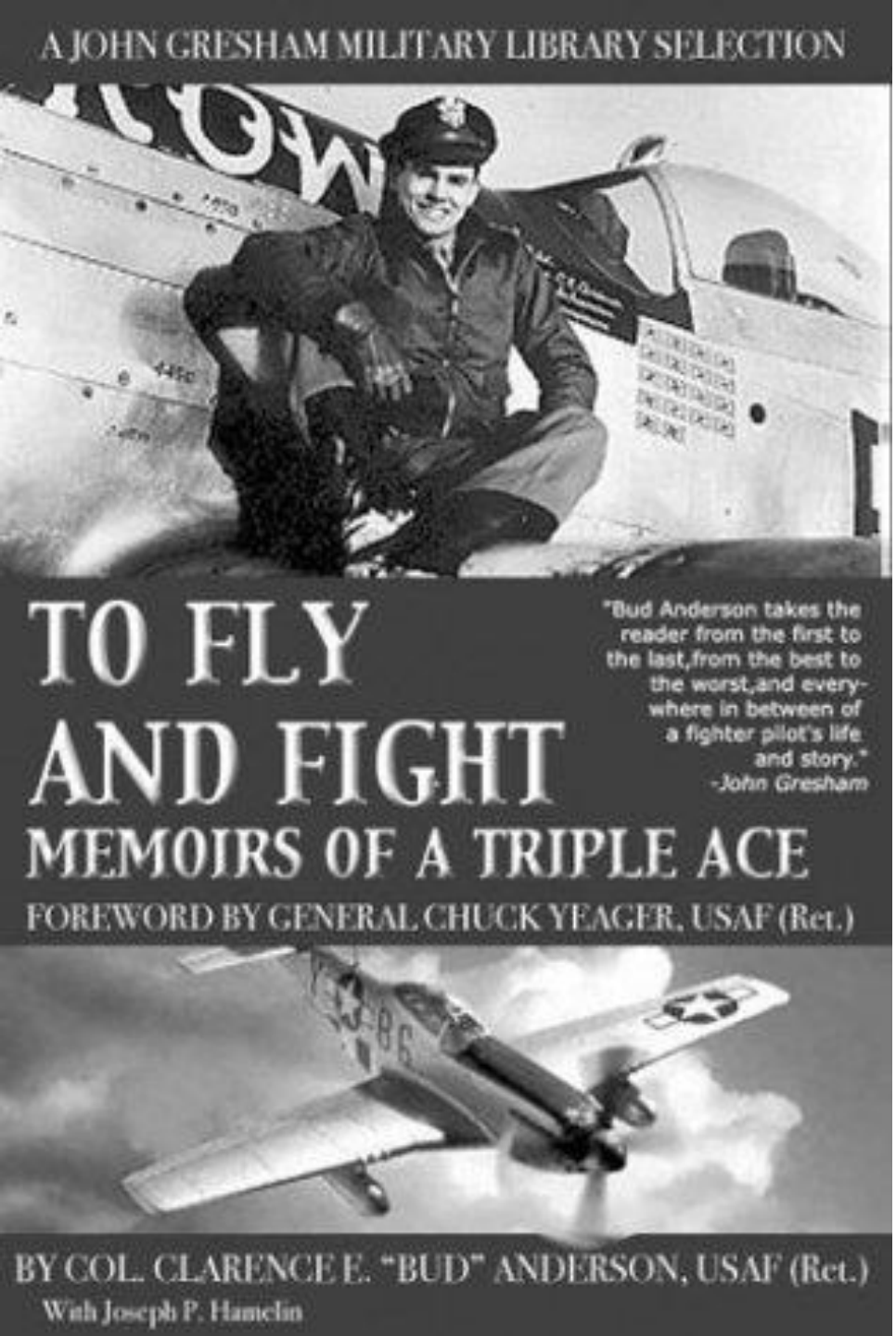
historynet.com

<u>Caption</u>: "Different models of Merlin Mustang in service with the 375th Fighter Squadron, 361st Fighter Group: three P-51Ds lead a single P-51B, all toting long-range fuel tanks"


Norway
Sweden
North Sea
Scotland
Denmark
RAF Bomber Command base area
Baltic Sea
Russia
England
Ireland
Neth.
Kiel
Hamburg
Mindenhall
Bremen
Hanover
Berlin
8th US Army Air Force
Poland
Poltava
Cologne
Merseburg-Leuna
Belg.
Germany
Dresden
Auschwitz
German V1 launch area
Schweinfurt
Nuremberg
Paris
Munich
Hungary
Romania
Switz.
France
Ploești
Black Sea
Italy
Bulgaria
Foggia
Spain
Albania
15th US Army Air Force
Greece
Turkey
Spitfire radius 175 miles
P-47 radius 375 miles
P-51 radius 600 miles
Lancaster, Halifax, B-17, B-24 radius 850 miles
Mediterranean Sea
0
300 km
0
200 miles

"When I saw mustangs over Berlin, I knew the jig was up"
***Hermann Göring,* Luftwaffe Reichsmarschall**

True Believers



"…Legendary 357th Fighter Group ace Clarence 'Bud' Anderson wrote of the Merlin-equipped Mustang in his memoir 'To Fly and Fight,' 'The Merlin had great gobs of power and was equally at home high or low, thanks to a two-stage, two-speed supercharger'…"

historynet.com

Caption: "Touching, thoughtful, and dead honest, *To Fly and Fight* is the story of a boy who grew up living his dream. During WWII Anderson flew with Chuck Yeager in the famed 357th Squadron where he became a triple ace by shooting out of the sky fifteen enemy planes…"



MUSTANG ACE

MEMOIRS OF A P-51 FIGHTER PILOT

ROBERT J. GOEBEL

Copyrighted Material

"…Bob Goebel, who flew Mustangs with the 31st Fighter Group in the Mediterranean theater, explained the supercharger's operation in 'Mustang Ace:' 'The P-51 had a two-stage blower in the induction system that was controlled automatically with a barometric switch. Around 17,000-feet, when the throttle had been advanced almost all the way forward just to maintain normal cruise, the blower would kick into high, the manifold pressure would jump up and the climb could be continued to 30,000-feet'…"
historynet.com

<u>Caption</u>: "…Just as Goebel was about to join the leading fighter group in the Mediterranean Theater of Operations, the 31st turned in its British-made Spitfire fighters for new P-51 Mustang fighters. Within weeks, Bob Goebel had flown his first combat missions…"

The First Duty

"…Although bomber losses dropped dramatically with the Mustang escorts, Maj. Gen. James H. 'Jimmy' Doolittle believed the Eighth Air Force was committing the same mistake Hermann Goring had in the Battle of Britain - compelling the escorts to stay close to the bombers instead of allowing them to range free, around and ahead of the formation…"
historynet.com



<u>Caption</u>: “U.S. Army Air Forces North American P-51C Mustang fighters of the 332nd Fighter Group take-off from Ramitelli airfield, Italy, to escort heavy bombers sent to bomb a German refinery for synthetic oil at Blechhammer (today Blachownia Śląska, Poland), on 7 August 1944. Note the P-51s have wing tanks for the extra fuel needed for such long missions.”

"…On assuming command of the Eighth on January 6, 1944, he noticed a sign at VIII Fighter Command headquarters: THE FIRST DUTY OF THE EIGHTH AIR FORCE FIGHTERS IS TO BRING THE BOMBERS BACK ALIVE. Doolittle ordered it changed to: THE FIRST DUTY OF THE EIGHTH AIR FORCE FIGHTERS IS TO DESTROY GERMAN FIGHTERS. The bombers would be bait to trap the Luftwaffe, the objective being the total destruction of its fighter arm and the achievement of Allied air superiority over Europe, in preparation for D-Day and to enable U.S. and British aircraft to bomb key targets at will…"

historynet.com

"Adolf Galland said that the day we took our fighters off the bombers and put them against the German fighters, that is, went from defensive to offensive, Germany lost the air war. I made that decision and it was my most important decision during World War II. As you can imagine, the bomber crews were upset. The fighter pilots were ecstatic."

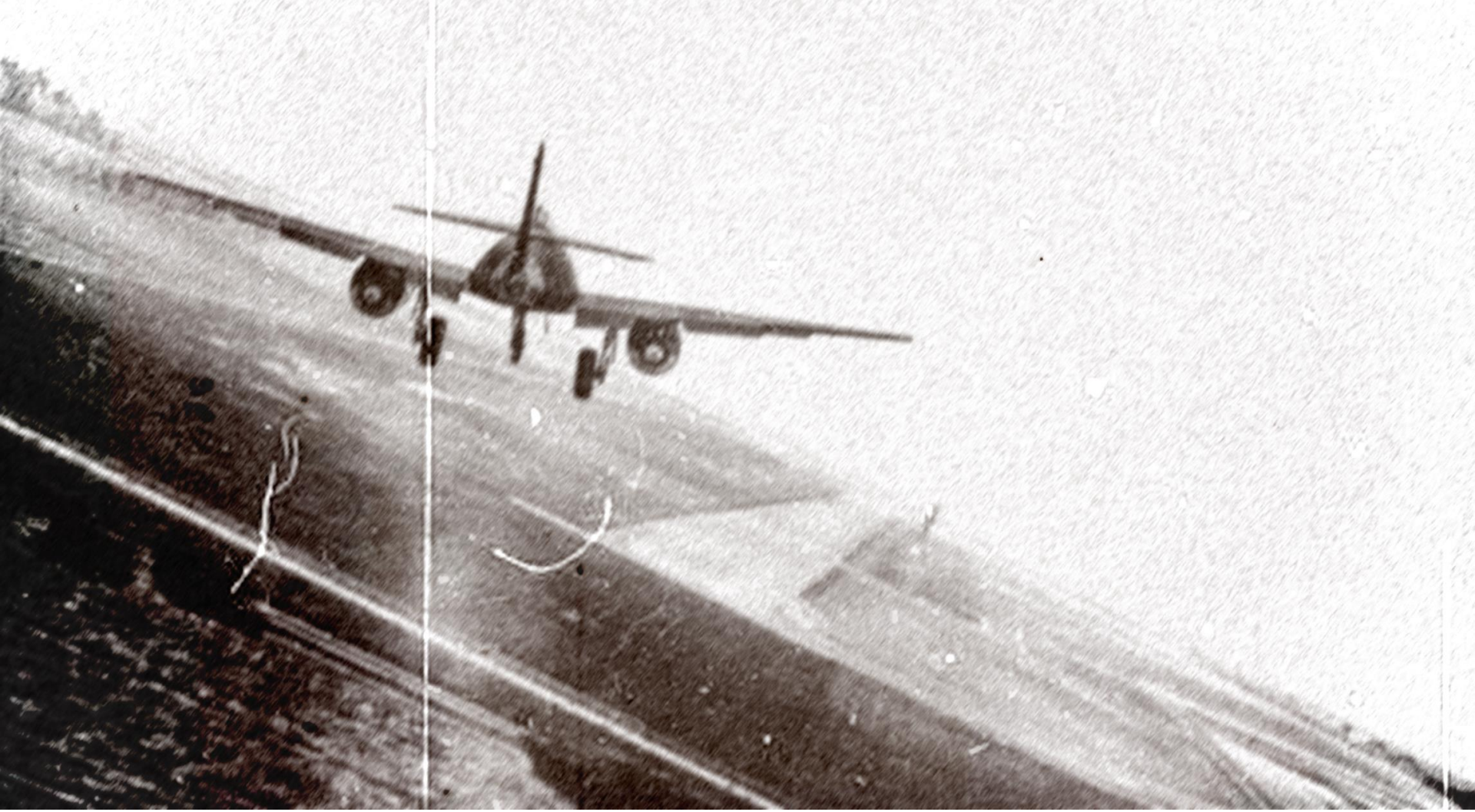
Maj. Gen. James H. Doolittle


LOUIE

Free-Ranging

"…Soon whole fighter groups were allowed to freelance and the Luftwaffe hunters became the hunted. Communication experts in England monitored German radio transmissions and vectored the Mustangs in to attack enemy fighters as their formations assembled…"

historynet.com



"…Free-ranging Mustangs destroyed German fighters, including Messer-schmitt Me-262 jets, on the ground or during take-off and landing. In February and March 1944, the Luftwaffe lost 4,236 aircraft…"

historynet.com

<u>Caption</u>: "Me262 captured on P-51 gun camera as it's coming down on an airfield, 1945"

War of Attrition

"…Although German fighter production rose from 24,807 in 1943 to 44,000 in 1944, lack of fuel and relentless pressure by the Allied Air Forces overwhelmed the Luftwaffe. Pilots were being killed faster than they could be replaced and by the time of the last major Allied raid on April 25, 1945, the once-dominant force had virtually ceased to exist…"

historynet.com

What Might Have Been



"…Without the P-51 Mustang, and its Merlin engine, the Allies could not have achieved air superiority over Europe in 1944. The Normandy invasion might have been delayed or even failed and the war could have dragged on into 1946…"

historynet.com

<u>Caption</u>: "P-51 Mustang over Berlin, 1945"



"…The prospect of a strong Luftwaffe, equipped with thousands of piston engine and jet fighters - not to mention scores of Arado Ar-234 jet bombers - is unpleasant to contemplate. Instead, as Albert Speer, Hitler's Armaments Minister, told the Japanese ambassador at the outset of the escorted bombing campaign, 'For the first time . . . raids, which might deal a really fatal blow to Germany, have begun'…"

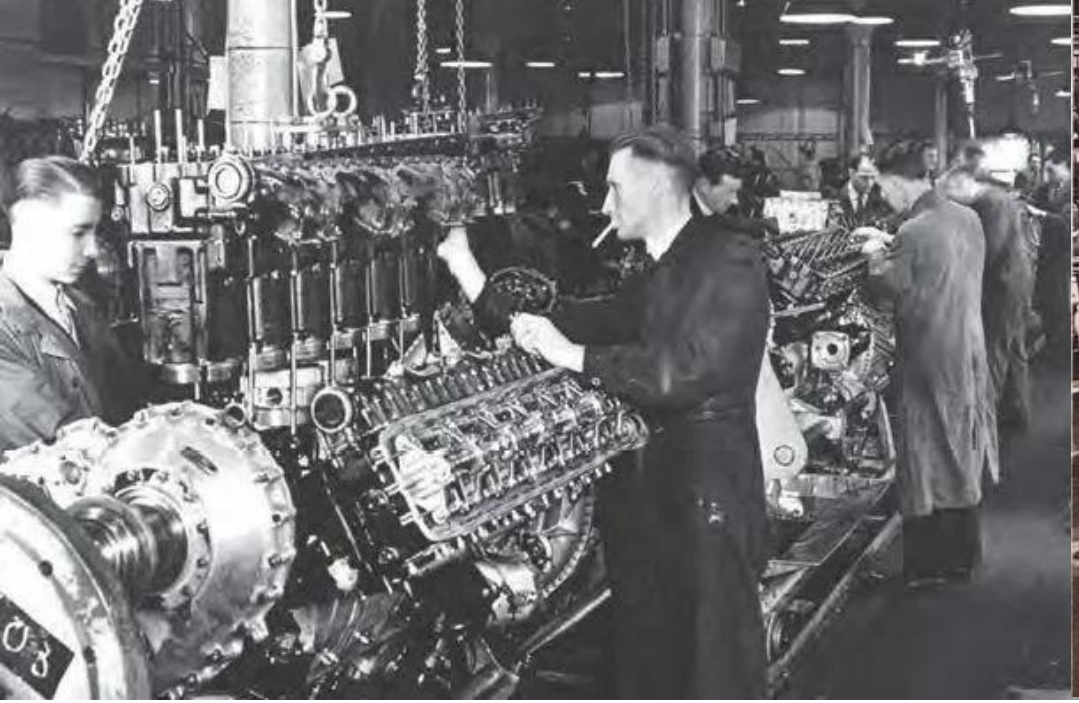
historynet.com

<u>Above</u>: the Arado Ar-234 *Blitz* (Lightning) was the world's first operational turbojet-powered bomber, seeing service during the final months of WWII. The Ar-234 was produced in small numbers, despite plans for production of 500 per-month by late 1945. This was partly due to a lack of available jet engines and other critical materials for which the aircraft had to compete with other types, such as the Messerschmitt Me-262.

Peerless

"…The 1939 Merlin Mk.I was rated at 950 hp. By 1945 the Merlin RM17SM had been flight-tested at a continuous 2,200 hp, with 2,640 hp available for short periods. No other engine achieved such a remarkable power increase while continuing to run reliably…"

historynet.com





"…Some 160,000 Merlins were produced during WWII, more than 100,000 in Britain, the rest by Packard in the U.S. They were used in more applications - air, marine and land - and appeared in more marks (50) and power ratings (21) than any other engine. They powered aircraft of more purposes (nine) and types (31)…"

historynet.com

<u>Left</u>: caption: "Merlins on the line in Nottingham. Rolls-Royce learned much about modern production techniques during the 1930s"

<u>Right</u>: caption: "Packard Merlin engine factory floor, Detroit"



"…Today Merlins continue to propel many warbirds in the U.S., Britain and elsewhere and the engine's throaty growl can still be heard at air-shows around the world…"

historynet.com

<u>Caption</u>: "Merlin-powered Supermarine Spitfire and North American P-51 Mustang fly in tight formation at an air show"



<u>Caption</u>: “RAF Museum London; Rolls-Royce Merlin engine display at air pageant celebration”

Last Hurrah



"…In an ironic coda to the Merlin story, the final variant of the Me-109, the Spanish-built Hispano Aviacion HA-1112-M1L Buchon, was equipped with the 1,600-hp Merlin 500-45 engine. Remaining in service until December 1965, it was later used, disguised as Me-190Es and Gs, in films such as 'Battle of Britain,' 'Memphis Belle' and 'The Tuskegee Airmen'…"

historynet.com

<u>Caption</u>: "One of the last HA-1112-M1L Buchóns, repainted to represent a German Bf-109, with Luftwaffe markings and still flying. It can be recognized by the exhaust pipes at the top of the nose, like the Spitfire (tri-blade propeller retrofitted)."

Completing the Circle



"…And so the circle was completed: 30 years earlier, a Rolls-Royce Kestrel had powered the prototype Messerschmitt Bf-109V1."

historynet.com

RE: on May 28, 1935, test pilot Hans-Dietrich Knoetzsch took the prototype Bf-109 V1 fighter on its first flight. The new fighter was designed by *Wilhelm Emil Messerschmitt, Walter Rethel* and *Robert Lusser.* It was a light-weight, single-seat, single-engine, low-wing monoplane with retractable landing gear. Because the Junkers Jumo 210 inverted V-12 engines planned for the new fighter were not yet available, a liquid-cooled, supercharged, 1,295.91 cu.-in. displacement (21.24 liter) Rolls-Royce Kestrel VI single overhead cam 60-degree V-12 was installed.

<u>Caption</u>: "BKW Bf 109 VI D-IABI prototype, left profile"

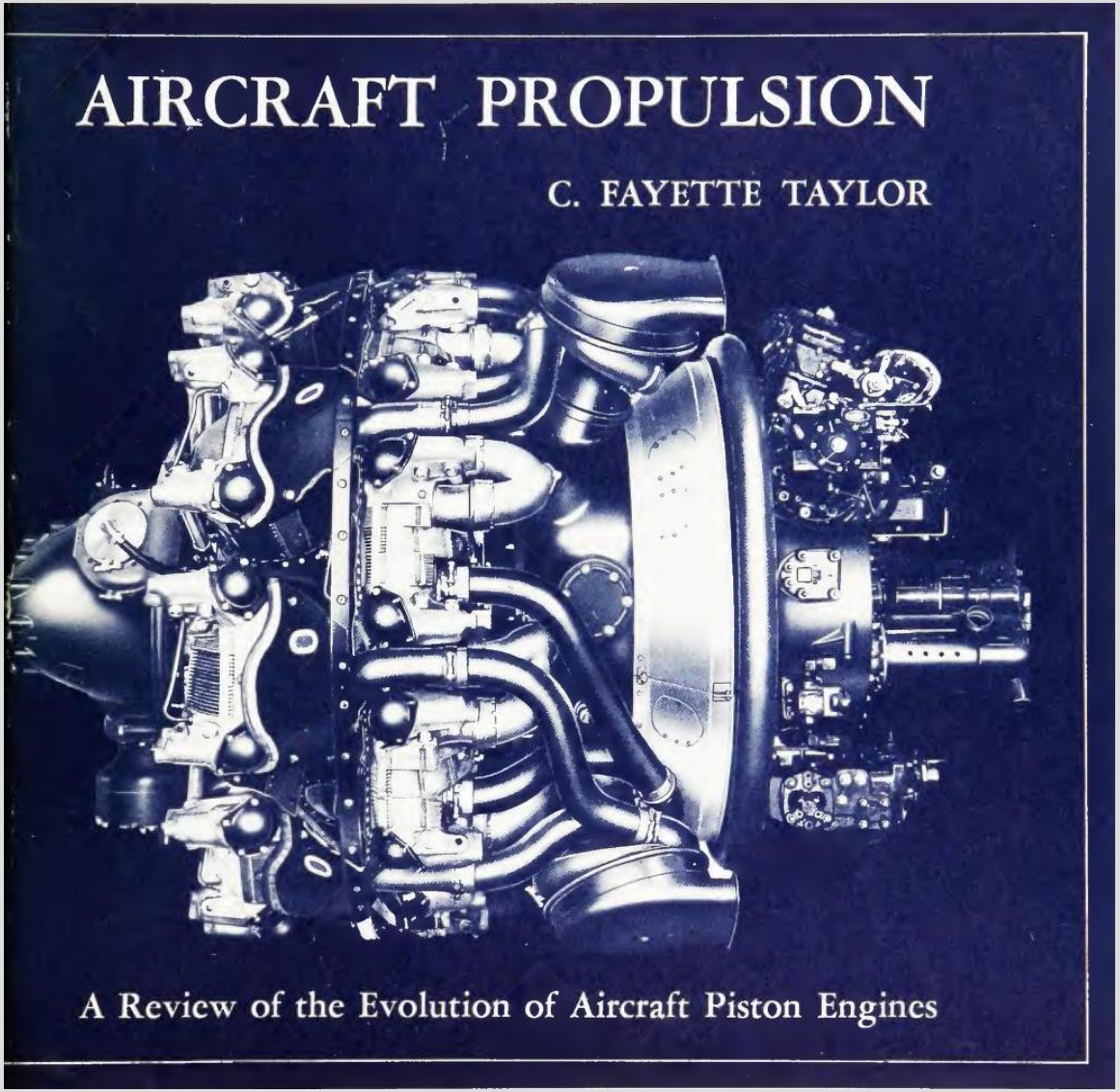
Part 2

Evolution

"Ah, but a man's reach should exceed his grasp, or what's a heaven for?"

***Robert Browning,* Poet**

RE: excerpt from his poem: "Andrea del Sarto." The Victorian poet's quote sought to encourage aspiration and striving for higher, more ambitious goals, even if they seemed to be out-of-reach.


AIRCRAFT PROPULSION
C. FAYETTE TAYLOR
A Review of the Evolution of Aircraft Piston Engines

SMITHSONIAN ANNALS OF FLIGHT
VOLUME 1 • NUMBER 4 • (END OF VOLUME)

AIRCRAFT PROPULSION

A Review of the Evolution Of Aircraft Piston Engines

C. FAYETTE TAYLOR

Professor of Automotive Engineering Emeritus
Massachusetts Institute of Technology



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CITY OF WASHINGTON • 1971

Foreword

This, the fourth number of Smithsonian Annals of Flight, was the Fourth Lester B. Gardner Lecture, delivered at the Massachusetts Institute of Technology, March 8, 1962, and at the Smithsonian Institution, October 5, 1962. Subsequently it was published in the General Appendix to the Annual Report . . . *of the Smithsonian Institution . . . for the Tear Ended June 30, 1962* (1963).

As presented here, the text has been revised, enlarged and updated. Its 72 illustrations, many of them new, include a number of engines, aircraft and the materials in the collections of the National Air and Space Museum.

With it, for the first time, appears the bibliography which accompanied the original manuscript and which, for lack of space, could not then (1963) be printed. This has since been edited and expanded to approximately double its original length by Dr. Richard K. Smith while he was serving on the Museum staff. Its nearly 600 entries, most of them contemporary accounts, cover the whole range of engine development and related activities from the early beginnings. This bibliography should be a useful and welcome tool, both for the airplane enthusiast and for the Historian of aviation technology.

The active connection of the Author, C. Fayette Taylor, with aircraft power started with his appointment in 1917 as officer-in-charge of the (aircraft) Power Plant Laboratory of the United States Navy, Washington, D.C. Here the engines of World War I, both foreign and domestic, were tested and improved. From 1919 to 1923 he was Engineer-in-Charge of the Power Plant Laboratory of the Army Air Service at McCook Field, Dayton, Ohio. Pioneer work on engines and fuels was done during this period. From 1923 to 1926 he was Engineer-in-Charge of Design and for a short while Chief Engineer at Wright Aeronautical Corporation, Paterson, New Jersey, concentrating on the development of air-cooled radial engines. Since 1926, he has been Professor of Automotive Engineering at the Massachusetts Institute of Technology, retiring from active duty there in 1965. He is still an active consultant in the field of internal-combustion engines.

Professor Taylor is Author, with Charles Chatfield and Shatswell Ober, of *The Airplane and Its Engine* (McGraw Hill, 1928, 1932, 1936, 1940, 1948); with E. S. Taylor, of The Internal Combustion Engine (International Textbook Co., 1938, 1948, 1961); and of *The Internal Combustion Engine in Theory and Practice* (M.I.T. Press, Cambridge, Mass., 2 vols., 1960, 1968). He has also published numerous papers and articles in professional journals.

S. Paul Johnston, Director
National Air and Space Museum

July 1, 1969

Acknowledgements

This publication is based chiefly on the Author's close personal connection with the development of aircraft engines during the period 1917-1950. Important editorial assistance by members of the staff of the National Air and Space Museum is gratefully acknowledged. Especial thanks are due to Mr. Robert B. Meyer, Jr., Curator, Propulsion. The bibliography has been edited and arranged by Dr. Richard K. Smith.

C. Fayette Taylor

Early Attempts at Propulsion

Man’s muscles, usually attached to flapping wings, were the earliest and most obvious source of power suggested for flight. In spite of innumerable attempts, there is no record of heavier-than-air sustained flight having been made with this kind of power until 1861, when Derek Piggot, in Hampshire, England, was reported to have flown 70 yards in a monoplane that was powered by a pedal-driven propeller. On the other hand, many early balloons were equipped with oars or paddles and at least two dirigible balloons; that of Charles E. Ritchel at Hartford, Connecticut, in 1878, and that of deLome, in Paris, 1863, were equipped with propellers driven by pedals and a manned windlass, respectively. As late as 1907, Cromwell Dixon of Seattle, Washington, demonstrated a dirigible-airship powered by a pedal-driven propeller.

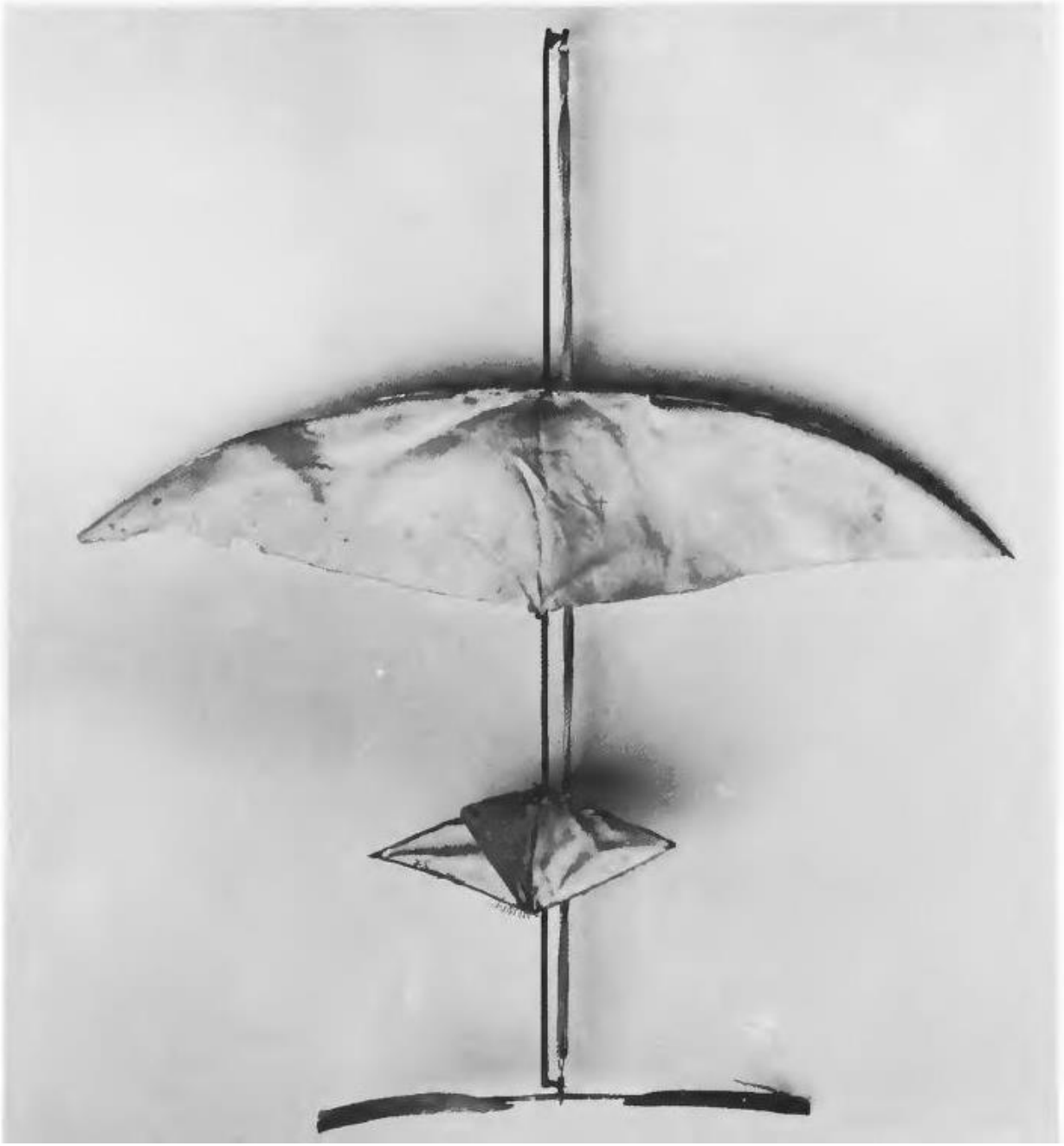
The first successful free flights by a man-made heavier-than-air contrivance seem to have been by model helicopters whose counter-rotating propellers, usually made of bird feathers, were driven by a wooden or whalebone bow (fig. 1).



Figure 1.—Reproduction of Launoy and Bienvenue helicopter (NASM 1930–15), using bent-bow propulsion, 1784. (*Photo A–18232*)

Charles H. Gibbs-Smith, in his excellent historical account *The Aeroplane,* credits the Chinese with this invention, as early as the 4th or 5th century, A.D. A French painting of such a device is dated 1460. Models of this type were flown by Launoy and Bienvenu in France in 1784 and by Sir George Cayley, “Father of Aerial Navigation,” in 1792. Alphonse Penaud (1851-1880) improved on Cayley’s design by using twisted rubber bands, both for model helicopters and for a near-conventional model monoplane (fig. 2)..

Figure 2.—Pénaud's Planaphore (NASM 1930–17), using rubber-band propulsion, 1871. (*Photo A–19627*)



This system of propulsion remains to this day the most important source of power for small airplane and helicopter models and even today, probably powers many more “airplanes” than any other type of power-plant. It is of historical interest to note that in the first detailed account of their pioneer flights the Wright Brothers attribute their early interest in flying to toy helicopters powered by rubber bands.

The first successful flight by a model airplane powered by means other than rubber bands is said to be that of Felix DuTemple in France, 1857-1858, using a clockwork motor. Steam power was later used by this same inventor, but there is no authentic record of successful flight. A compressed-air-driven model by Victor Tatin (France) made circular tethered flights in 1879.

Odd sources of power that have been proposed included tethered gryphons (birds were evidently considered inadequate), sails and horses on a treadmill (obviously at least 1,000 pounds per-horsepower). Some of these sources were even tried. The prize for ingenuity in the unconventional category might go to Portuguese reports, published about the year 1700, which described an aircraft sustained by magnets acting on electrified amber and propelled by a hand-power bellows blowing on its sails.

Sir George Gayley built and tested a gunpowder engine in 1807 and in 1850 designed a model airplane powered by this means, but it was never built. A model ornithopter with wings operated by gunpowder, built by Trouve, is said to have risen from the ground in 1870.

There are records of two flights of dirigible airships using electric motors with batteries, namely, that of Tissandier at Auteuil in October1883, and that of Charles Renard and Arthur Krebs near Paris, in August 1884. The latter machine was considered quite successful.

Rocket power, inspired by the Chinese invention of the ballistic rocket in the 12th century, was suggested by Gerard in 1784. An English cartoon of 1825 shows a proposed rocket, propelled by a steerable steam jet, in flight to the moon. For man-carrying powered flight, the first use of rockets was by Fritz von Opel (Germany) in 1928. The first jet-engined flight was that of the Heinkel-178 airplane in Germany, 27 August 1939, powered with the HeS-3B gas-turbine engine of 1,100-lbs thrust, developed by Pabst von Ohain.

Steam power became a popular proposal for aerial navigation in the early 19th century soon after it had been successfully demonstrated in ships, locomotives and road vehicles. A model helicopter by W.H. Phillips (England) rose from the ground under steam power in 1842. Steam jets located in the wing tips were a remarkable anticipation of a modern application of jet power.

Contrary to most historical statements, the steam-driven airplane models of Henson and Stringfellow were apparently not capable of sustained rising or level flight. In the short indoor flights of record, take-off was from a horizontal wire somewhat higher than the landing point. Thus, these flights were what may be called “powered glides.” The power-plants used are of interest, however, because of their advanced design. Gibbs-Smith attributes the power-plant design to Henson, stating that Stringfellow was more the skilled mechanic than the inventor. The 20-ft.-span model built by Henson but never flown was said to include a well-designed steam plant, but details are difficult to find. Stringfellow’s “flying” model was a 10-ft-span monoplane equipped with a double-acting steam engine of 3/4 x 2-in. bore and stroke driving two mid-wing 16-in. propellers geared to turn at three times engine speed. Its best powered glide was for about 120 ft. indoors. A Stringfellow engine and boiler of 1868, a multi-bulb affair, is now at the National Air and Space Museum of the Smithsonian Institution (fig. 3).

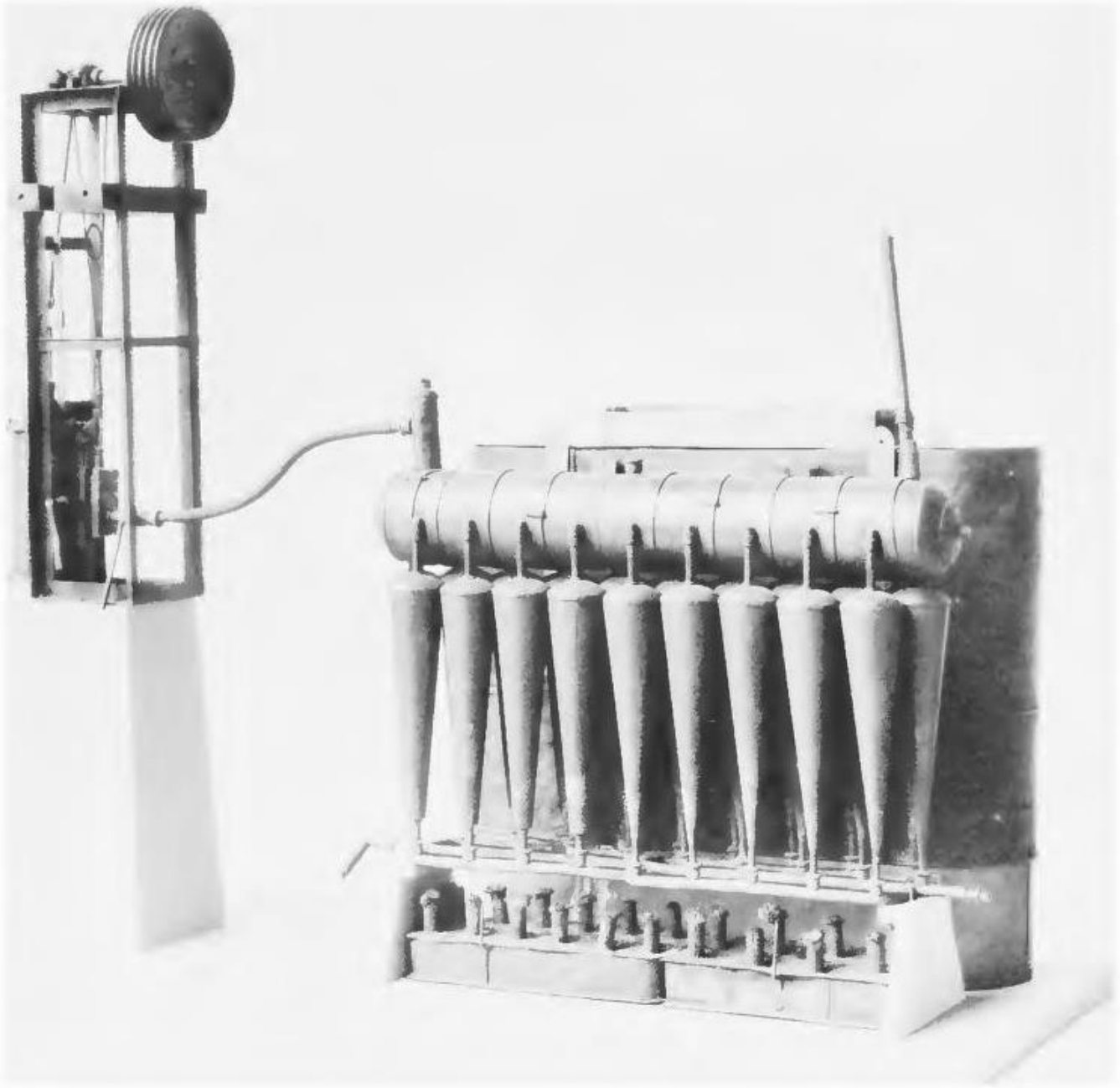


Figure 3.—Stringfellow engine and boiler (NASM 1889-1), 1868. (*Photo A-20030*)

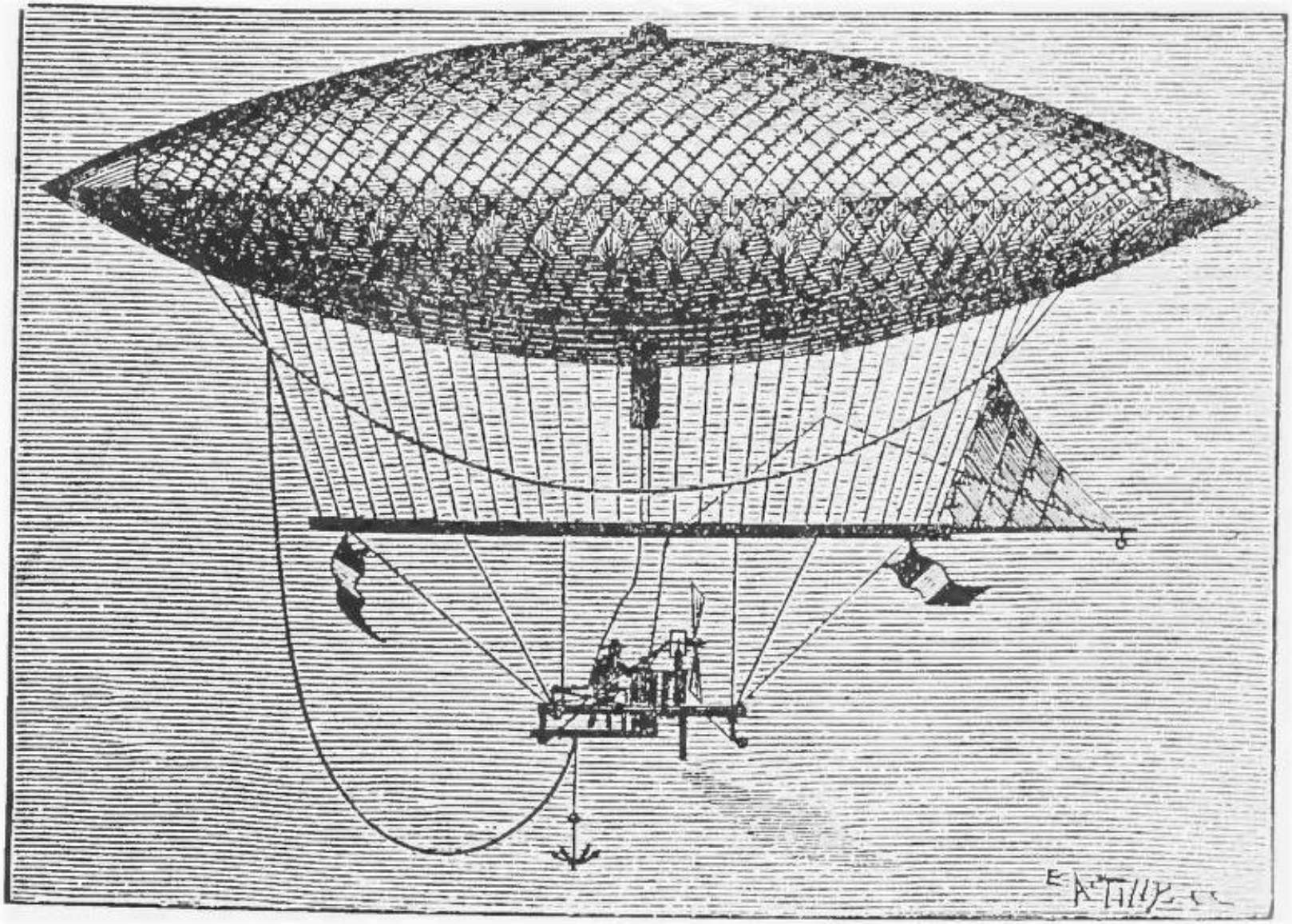


Figure 4.—Giffard airship, steam-engine powered, 1852. (*Photo A-19889*)

A dirigible airship with a 3-hp steam plant weighing 351 lbs. was flown by Henri Giffard from Paris to Trappes in 1852 (fig. 4).

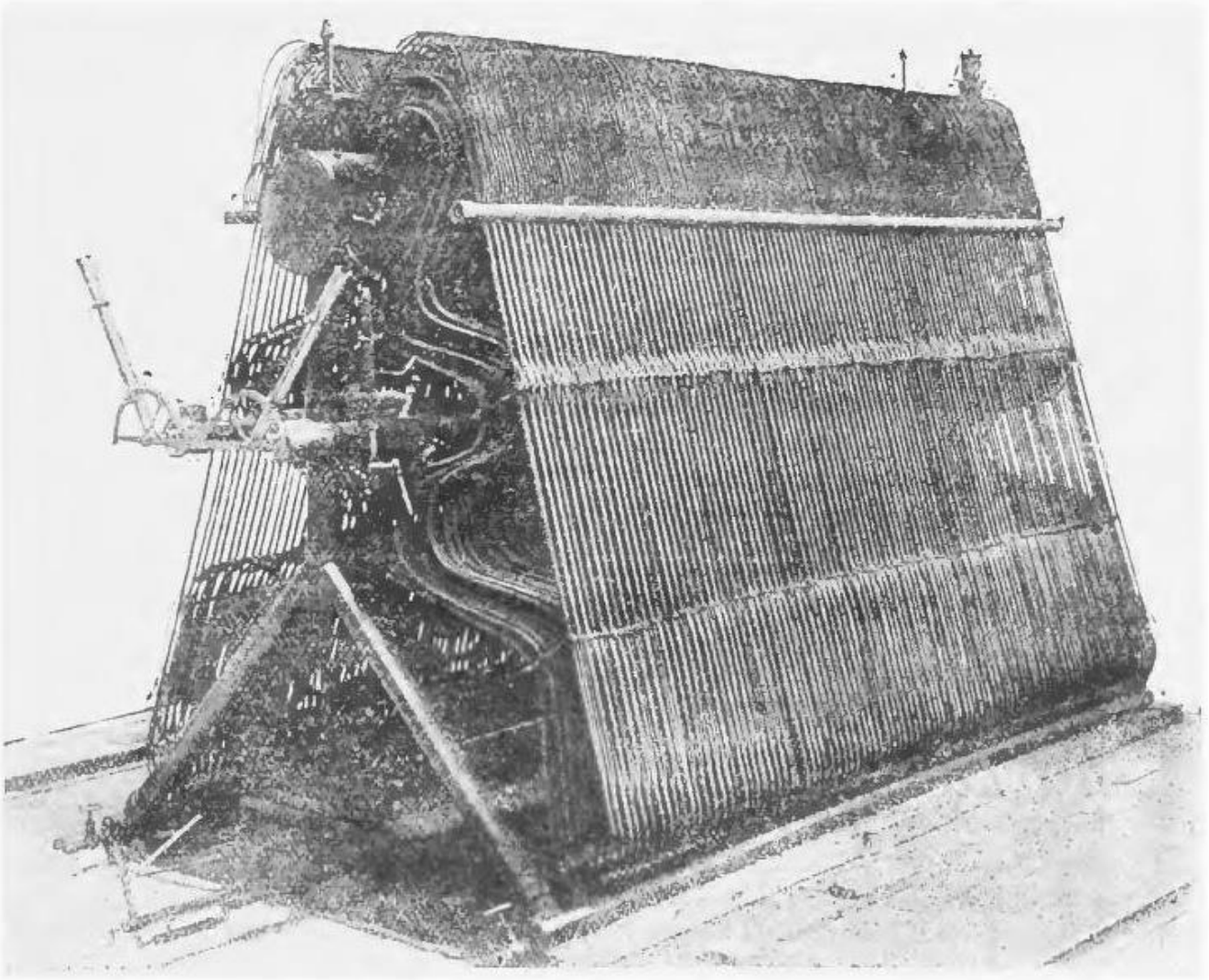
I have not found a technical description of this single-cylinder vertical engine. In spite of earlier and later designs for steam-driven dirigible balloons, that of Giffard seems to be the only one which made successful flights. Alexander F. Mozhaiski in Russia, in 1884 and Clement Ader, in 1890, both built and tested full-scale steam-powered airplanes. At most, these machines made short uncontrolled “hops,” although Ader’s machine seems to have had the ability to lift itself without external assistance. No engine details seem to be available. The “Chauve-Souris,” Clement Ader’s “Avion III,” of 1897, on display at the Conservatoire National des Arts et Metiers, Paris, France, is equipped with two 20-hp steam engines.

The best-known full-scale attempt at flight with steam was that of Sir Hiram Maxim, in 1894. Maxim was an experienced Steam Engineer and his powerplant was far more advanced than the aircraft to which it was applied. Its two twin-cylinder compound engines (fig. 5) each drove a pusher propeller.



Figure 5.—Sir Hiram Maxim with his twin-cylinder compound steam engine, 1894. (*Photo A-42378*)

Figure 6.—Maxim's steam boiler, feed-water heater, and burner, 1894. (From *Journal of the Society of the Arts* (30 November 1894), vol. 43, p. 22.)



The power-plant was rated at 363 hp and weighed complete, 1,800 lbs., or 5 lbs./hp, an extraordinarily light weight for its day. The boiler, (fig. 6) was of the multiple water-tube type, very much like modern marine steam boilers.

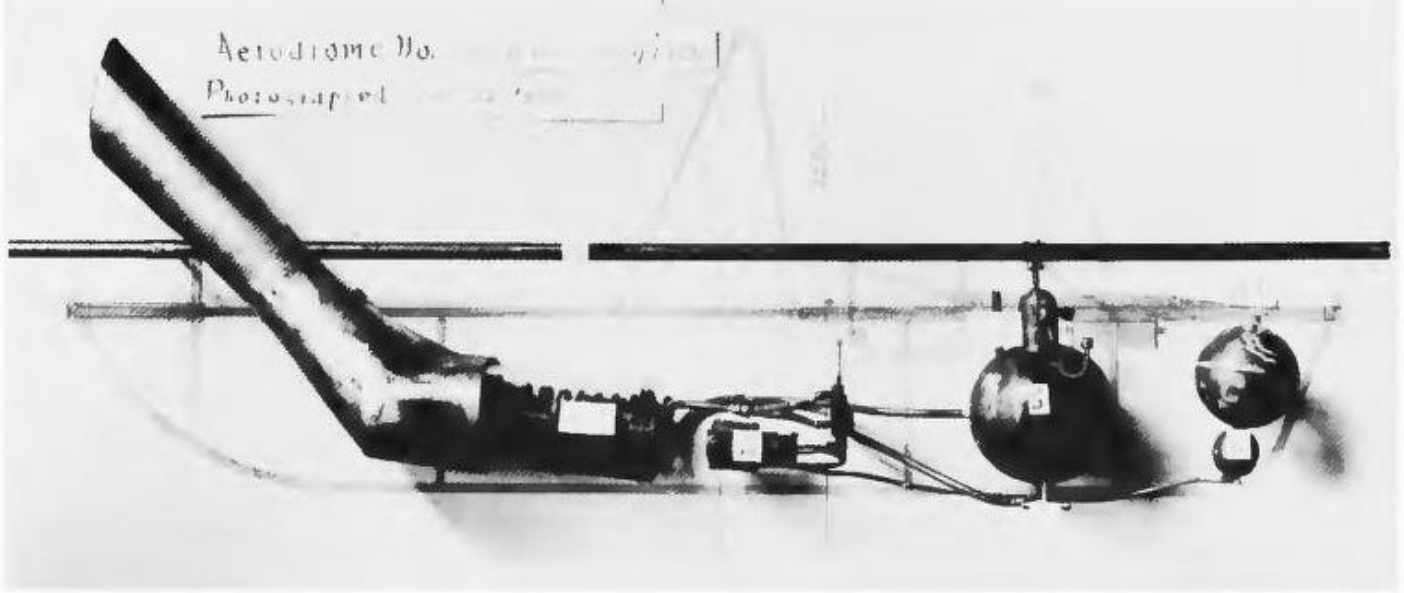


Figure 7.—Steam engine used by Samuel P. Langley in his 14-ft-span Aerodrome No. 5 (NASM 1905–1), 1896. (*Photo A–12555*)

Operation along rails indicated that this engine could furnish the power necessary to lift even the monstrous contraption in which it was installed. Lack of success with this machine was not the fault of the power-plant.

Any discussion of steam power for aircraft should include the work of Dr. Samuel P. Langley, Secretary of the Smithsonian Institution, who built and successfully flew unmanned steam-powered models of 14-ft span in 1896. Fortunately, Langley's records are complete and full technical details are available. The most notable feature of Langley's steam power-plants (fig. 7) was the use of "flash" boilers; that is, boilers consisting of one or more long coiled tubes with water pumped in at one end and steam issuing from the other.

This type later was used successfully in the White automobile and is probably the type which would be used today if no alternative to steam power were available. Langley's steam plants weighed in the neighborhood of 7 lbs./hp. He was perhaps the first to grapple with the problem of "flameout" in an aeronautical burner. A sentence from his memoirs reads in part, "Unfortunately there is a limit to this process [increasing the air flow through the burner] of increasing the air supply . . . a certain speed of efflux cannot be exceeded without putting the flame out." The early jet engines encountered this same problem.

Of course, steam ceased to be of importance for aircraft after flights by the Wright brothers and others had demonstrated the superior qualities of the internal-combustion engine, but it continued to have an emotional appeal to many people well into the 1930s. A Travelair biplane powered with a steam engine designed by William Besler was actually flown by the designer in California in 1932. A replica of this engine is in the Smithsonian's National Air and Space Museum (NASM 1965-253).

Steam was probably given the *coup de grace* by Commander Eugene Wilson of the Navy Bureau of Aeronautics; a Naval Officer trained in steam power for ships, who reported in 1926, “On the basis of these three considerations [weight, economy, air-resistance] they [steam power-plants] are absolutely impossible.” My own opinion is not so extreme. If steam power was without competitors we would have successful steam aircraft today, but at a considerable sacrifice in performance and perhaps also in safety.

Early Internal-Combustion Engines

The earliest successful aeronautical application of the internal-combustion engine appears to be in a dirigible-balloon flight by Paul Haenlein in Germany in 1872. A 4-cylindcr 5-hp (40 rpm) Lenoir engine using coal-gas fuel was used. The Lenoir engine was the first commercial internal-combustion engine. The cylinders drew in air for half the stroke and fired at atmospheric pressure at mid-stroke. Efficiency was low - about 5 percent.

The relatively lightweight and relatively efficient “Otto-cycle” gasoline engine began with developments in England and Germany in the 1880s, stimulated by automobile development. Its application to aircraft came soon after. The first flight with this type of engine was apparently that of a dirigible airship designed by David Schwartz. The flight took place in Germany in 1897.

Alberto Santos-Dumont, in Paris in 1898, flew a dirigible equipped with a pair of “tricycle” engines in tandem, rated together at 3-1/2-hp and weighing, it is said, 66 lbs, or 19 lbs./hp. These engines were probably forerunners of the 3-hp Clement engine used by Dumont for his one-man dirigible airship flown during the summer of 1903. This engine was a 2-cylinder V-type, air cooled and weighed 8.8 lbs./hp. It is on exhibit at the Smithsonian’s National Air and Space Museum (NASM 1908-1).

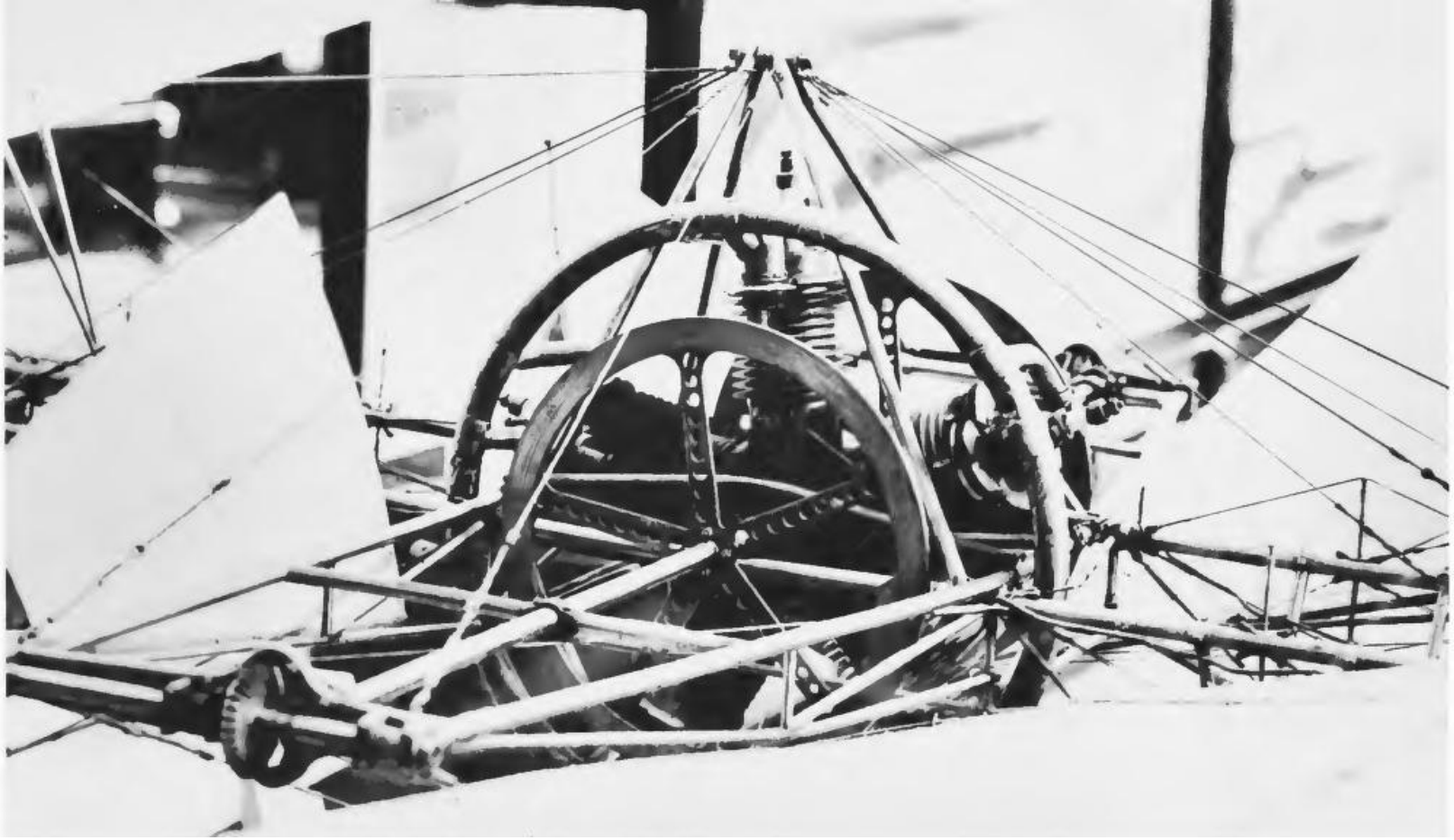


Figure 8.—Gasoline engine used in Langley's quarter-size model aerodrome (NASM 1950–3); 3.2 hp at 1800 rpm, 7 lb (without battery), 1901. (*Photo A–23759*)

The first successful heavier-than-air flight powered by a gasoline engine was that of Langley's 1/4-size model, which flew 350 ft. on 18 June 1901 and 1,000 ft. on 8 August 1903. The engine (fig. 8) was a 5-cylinder air-cooled radial, designed and built by Stephen M. Balzer and redesigned and rebuilt by Charles M. Manly. It produced 3.2-hp at 1800 rpm with a weight of 7 lbs. (see table 1 for other data).

TABLE 1.—Engines of Historical Importance

Engine	Year [a]	Type	No. cyl.	Bore (in.)	Stroke (in.)	Displ. (cu. in.)	Horse-power [b]	Rpm	Weight [c] lb	Weight [c] lb/hp	Bmep (psi)	Piston speed (ft/min)
Water-cooled												
Langley	1901	radial	5	5	5.5	687	52	950	135	2.6	63	870
Wright	1903	horizontal	4	4	4	200	[d] 16	1,090	179	11.2	58	725
Antoinette	1906	V	8	3.15	3.15	196	32	1,400	93	2.9	91	735
Darracq	1909	opposed	2	5.2	4.72	194	24	1,500	121	5.04	65	1,180
Curtiss OX–5	1910	V	8	4	5	503	90	1,400	320	3.55	101	1,170
Mercedes	1915	vertical	6	5.51	6.3	901	160	1,400	618	3.86	100	1,470
Hispano-Suiza	1915	V	8	4.72	5.11	718	150	1,450	467	3.1	114	1,235
Liberty	1917	V	12	5	7	1,650	420	1,700	856	2.04	118	1,985
Curtiss D–12	1922	V	12	4.5	6	1,145	325	1,800	704	2.16	125	1,800
Rolls Royce Kestrel VI.	1930	V	12	5	5.5	1,296	560	2,500	992	1.77	137	2,290
Rolls Royce Merlin I	1936	V	12	5.4	6	1,650	1,030	3,000	1,320	1.28	165	3,000
Packard-Merlin	1945	V	12	5.4	6	1,650	2,250	3,000	1,740	.78	360	3,000
Air-cooled												
Langley (model)	1901	radial	5	2.06	2.75	46.5	3.2	1,800	7	2.2	30	825
Anzani	1909	fan	3	4.13	5.12	206	24.5	1,600	145	5.9	59	1,360
Renault	1908	V	8	2.76	4.72	226	35	1,400	242	6.9	88	1,100
Gnome	1909	rotary	7	3.93	3.93	335	50	1,150	165	3.3	103	753
Jupiter	1920	radial	9	5.75	7.5	1,753	400	1,650	700	1.75	109	2,060
Jaguar	1922	2-row-radial	14	5	5.5	1,512	360	2,000	910	2.53	94	1,830
Lawrance J–1	1922	radial	9	4.5	5.5	787	200	1,800	476	2.38	112	1,650
Pratt & Whitney Wasp.	1926	radial	9	5.75	5.75	1,344	425	1,900	650	1.53	132	1,820
Wright 1820	1930	radial	9	6.13	6.88	1,823	575	1,900	940	1.64	.....	2,180
	1945	radial	9	6.13	6.88	1,823	1,525	2,750	1,376	.90	245	3,150
Continental A–65	1938	opposed	4	3.88	3.63	171	65	2,350	155	2.38	128	1,420
Pratt & Whitney 2800.	1940	2-row-radial	18	5.75	6.0	2,804	2,000	2,700	2,300	1.15	209	2,700
	1945	2-row-radial	18	5.75	6.0	2,804	2,800	2,800	2,327	.83	305	2,800
Pratt & Whitney 4360.	1948	4-row-radial	28	5.75	6.0	4,363	3,500	2,700	3,470	.99	235	2,700
Wright 3350	1941	2-row-radial	18	6.13	6.31	3,347	2,000	2,400	2,848	1.43	197	2,550
	1955	2-row-radial	18	6.13	6.31	3,347	3,700	2,900	3,560	.96	302	3,070

[a] Refers to year of first general use (except for Langley engine). Where two dates are given, they refer to typical early and late models of the same basic engine.

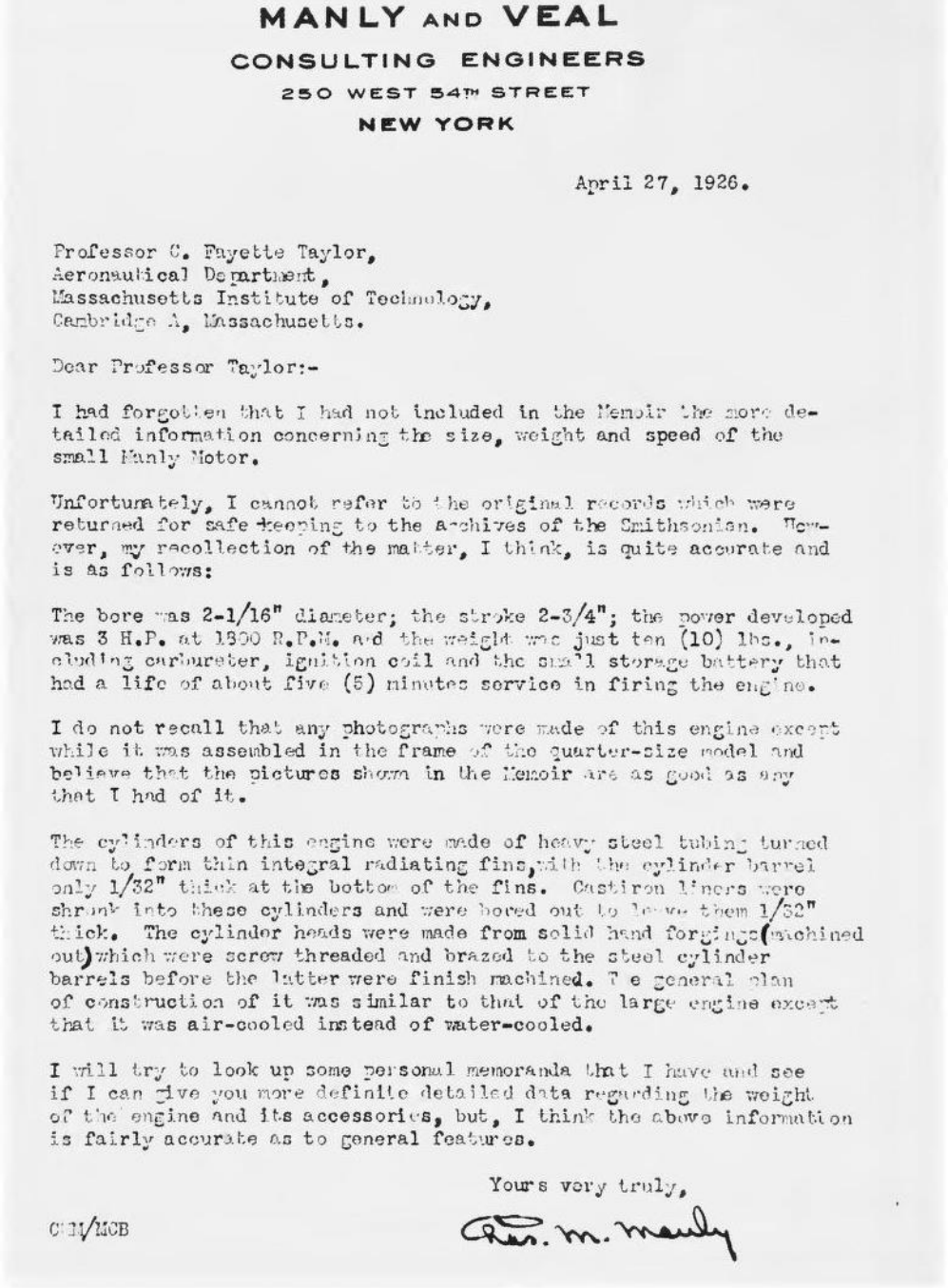
[b] Maximum rated, or takeoff power.

[c] Radiator, cowling, and coolant are not included in the weight of liquid-cooled engines Cowling is not included for air-cooled engines.

[d] Dropped to 12 hp after 1 min.

All liquid-cooled engines later than Curtiss D–12 are supercharged.

All air-cooled engines later than Lawrence J–1, except Continental, are supercharged.



MANLY AND VEAL
CONSULTING ENGINEERS
250 WEST 54TH STREET
NEW YORK

April 27, 1926.

Professor C. Fayette Taylor,
Aeronautical Department,
Massachusetts Institute of Technology,
Cambridge A, Massachusetts.

Dear Professor Taylor:-

I had forgotten that I had not included in the Memoir the more detailed information concerning the size, weight and speed of the small Manly Motor.

Unfortunately, I cannot refer to the original records which were returned for safe keeping to the Archives of the Smithsonian. However, my recollection of the matter, I think, is quite accurate and is as follows:

The bore was 2-1/16" diameter; the stroke 2-3/4"; the power developed was 3 H.P. at 1800 R.P.M. and the weight was just ten (10) lbs., including carburetor, ignition coil and the small storage battery that had a life of about five (5) minutes service in firing the engine.

I do not recall that any photographs were made of this engine except while it was assembled in the frame of the quarter-size model and believe that the pictures shown in the Memoir are as good as any that I had of it.

The cylinders of this engine were made of heavy steel tubing turned down to form thin integral radiating fins, with the cylinder barrel only 1/32" thick at the bottom of the fins. Castiron liners were shrunk into these cylinders and were bored out to leave them 1/32" thick. The cylinder heads were made from solid hand forgings (machined out) which were screw threaded and brazed to the steel cylinder barrels before the latter were finish machined. The general plan of construction of it was similar to that of the large engine except that it was air-cooled instead of water-cooled.

I will try to look up some personal memoranda that I have and see if I can give you more definite detailed data regarding the weight of the engine and its accessories, but, I think the above information is fairly accurate as to general features.

Yours very truly,

CMM/MCB

Chas. M. Manly

Figure 9.—Letter from Charles M. Manly describing the small gasoline engine of figure 8. (*Photo A-51010*)

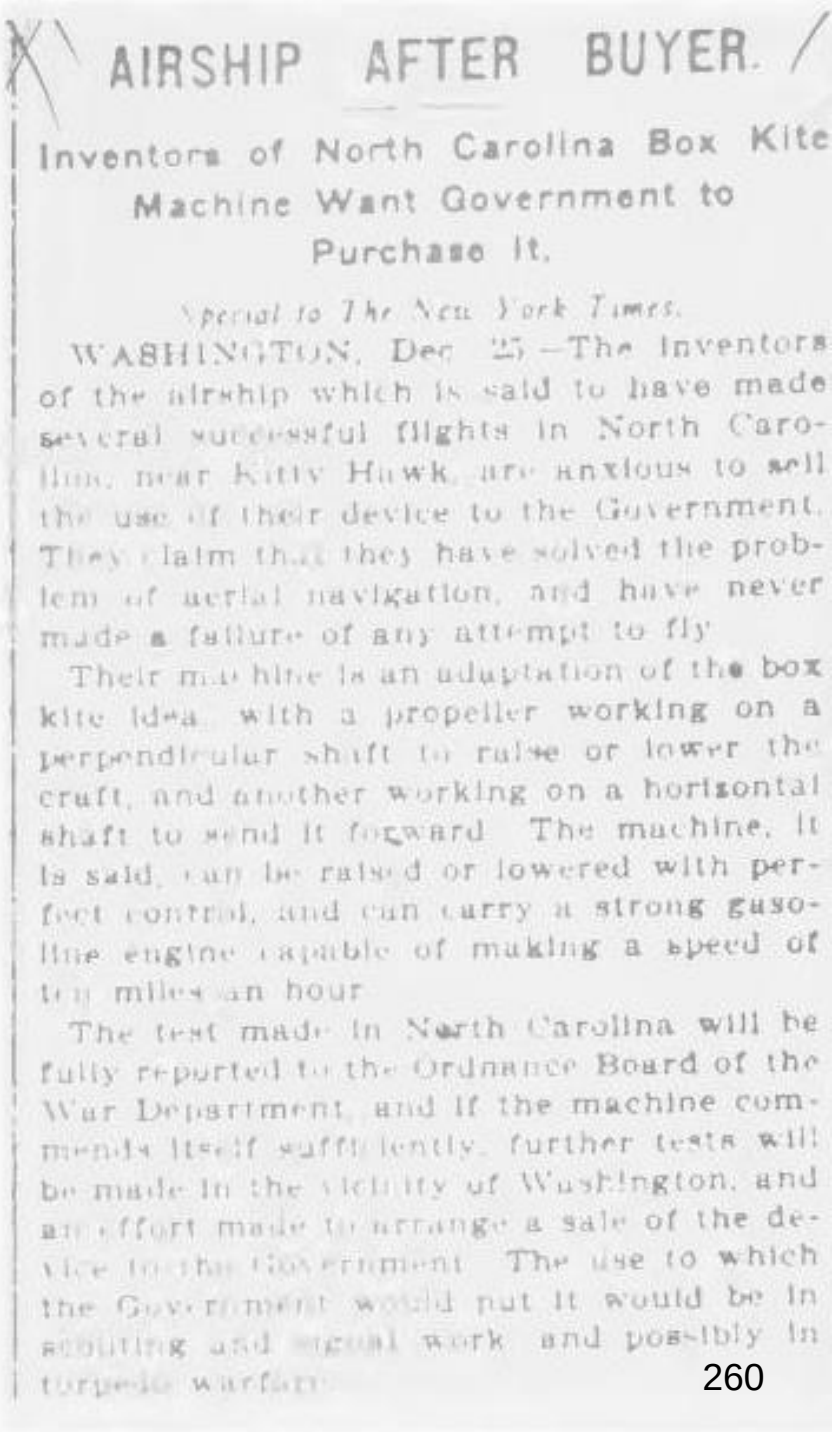
At 2.2 lbs./hp, this engine can legitimately be described as remarkable for its time. Figure 9 shows a letter from Manly giving some data on this engine that were not published in the *Langley Memoir.*

There is still some controversy, however academic and futile, about who made the first man-carrying powered flight. If short straight-ahead “hops” are counted as “flights,” then the claims of Ader and Du Temple pre-date the well-documented flights of the Wright brothers in 1903. These were also short hops but they demonstrated good control and were followed soon after by sustained flights. Certainly the Wright brothers developed the first practical, controllable airplane; and their flights at Kitty Hawk, North Carolina, on 17 December 1903, mark the beginning of this revolutionary achievement. Also, the engine they used in 1903 and in their subsequent flights was their own design.

The Wright engine of 1903 and the Langley full-scale engine completed late in 1901 and tested in 1902, 1903 and 1904, may be taken as the real beginning of the age of the reciprocating internal-combustion engine in aeronautics. As such, these engines are worthy of some detailed attention.

Wright Brothers' Engine, 1903

Little was known about the accomplishments of the Wright brothers until some years after their flights of 17 December 1903. Figure 10 shows a short and amusingly inaccurate report in *The New York Times* of 26 December 1903, which attracted little attention.



AIRSHIP AFTER BUYER.

Inventors of North Carolina Box Kite Machine Want Government to Purchase It.

Special to The New York Times.

WASHINGTON, Dec. 25.—The inventors of the airship which is said to have made several successful flights in North Carolina, near Kitty Hawk, are anxious to sell the use of their device to the Government. They claim that they have solved the problem of aerial navigation, and have never made a failure of any attempt to fly.

Their machine is an adaptation of the box kite idea, with a propeller working on a perpendicular shaft to raise or lower the craft, and another working on a horizontal shaft to send it forward. The machine, it is said, can be raised or lowered with perfect control, and can carry a strong gasoline engine capable of making a speed of ten miles an hour.

The test made in North Carolina will be fully reported to the Ordnance Board of the War Department, and if the machine commends itself sufficiently, further tests will be made in the vicinity of Washington, and an effort made to arrange a sale of the device to the Government. The use to which the Government would put it would be in scouting and signal work, and possibly in torpedo warfare.

Figure 10.—Account of Wright brothers' first airplane in *The New York Times*, December 25, 1903.

In spite of the fact that the flights near Dayton in 1904 and 1905 were witnessed by numerous people, the press ignored them. The first eyewitness report published was a letter in *Gleanings in Bee Culture,* Medina, Ohio, 1 January 1905, by its publisher, A.I. Root, under the title “What God Hath Wrought.” This article is reproduced by Gibbs-Smith in his book *The Aeroplane*.

An early public report by the Wrights themselves appeared in the September 1908 issue of *Century Magazine,* a publication similar in content and format to *Harper’s* and the *Atlantic Monthly,* I recall discovering this article when our copy arrived at home and I remember that my father, in spite of the many photographs of the machine in flight, refused to believe that human flight had been achieved. This attitude, five years after the Wright’s first flight, was pretty general at the time; partly on account of the great number of false claims of flight which had been made in the past. These spurious claims also account for the seemingly incredible absence of reports by the Dayton press, whose representatives, after witnessing two unsuccessful attempts at flights made in 1904, failed to report eyewitness accounts of the many flights made in 1904 and 1905, or even to go eight miles out of town to see for themselves!

The *Century* article is extraordinary for its simple and beautiful expository style, and for its evidence of the almost excessive modesty of the brothers Wright, together with their rationality and persistence. I believe that it should be rated as a classic in American scientific literature.

The 1903 Wright engine (fig. 11) was designed by the brothers and built with the assistance of their faithful mechanic Charles E. Taylor (fig. 12; he is not related to the writer).

Figure 11.—Engine from Wright brothers' 1903 airplane (NASM 1961-48); 12 hp at 1090 rpm, 179 lb. (*Photos A-38626-B*)

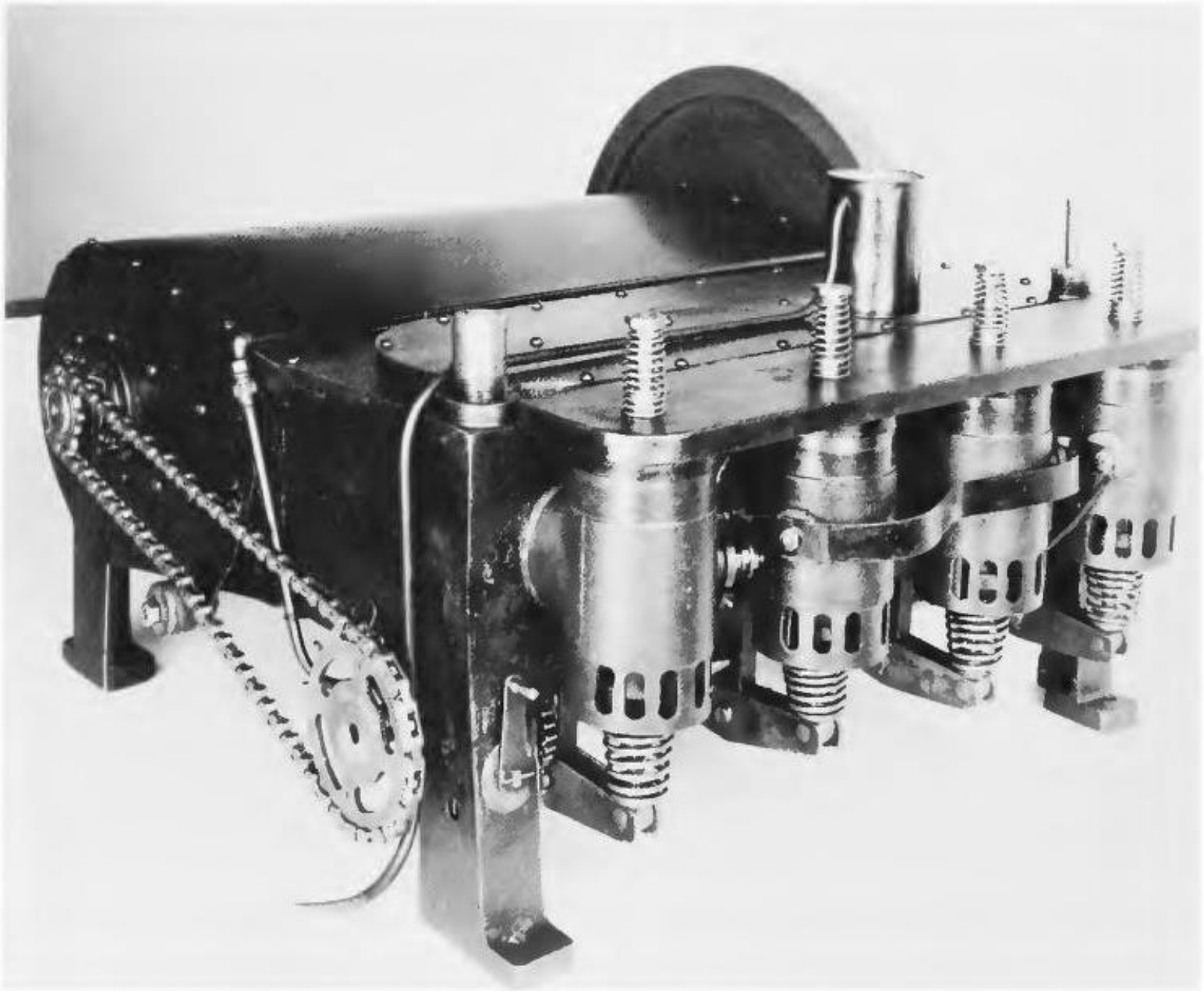


Figure 12.—Wright brothers' mechanic Charles E. Taylor (left), who helped to build Wright 1903 engine, with a later model Wright brothers' engine. (From *Airway Age*, vol. 9, no. 12 (December 1928), p. 38)



This engine is especially well described by Robert B. Meyer in the *Annual Report of the . . . Smithsonian Institution . . .for the year ended June 30, 1961*. It was a 4-cylinder water-cooled, horizontal engine of 200-cu-in. displacement, with automatic inlet valves. Fuel was supplied by gravity from a small can on top of the engine. From there it flowed through an adjustment valve to a surface carburetor in the intake manifold, which was heated by the cylinder water jacket. Ignition was by a low-tension magneto with “make-and-break” spark contacts in the cylinders. The engine would give 16-hp for a minute or so, after which it gave a steady 12-hp. Control, such as it was, was by the spark timing. As shown in Table 1, this engine was heavy and of low power compared to the contemporary Langley engine, but it flew! This basic design was later improved by the Wrights so that, by 1910, it was delivering 30-hp for a weight of 180 lbs., or 6 lbs./hp.

The first and subsequent engines followed contemporary automobile practice in cylinder arrangement; however, crankcases were of cast-aluminum and the first engine had an en-bloc cast-aluminum water jacket. These, in use for aircraft engines from the beginning, have just recently come into use for some automobiles. After being in England for a number of years, the first Wright engine, with some alterations made subsequent to the 1903 flight, is now on display in the original airplane in the National Air and Space Museum, Smithsonian Institution.

It was my good fortune to know Orville Wright and to see him frequently during the period from 1919 to 1923 when I was Engineer-in-Charge of the Aircraft-Engine Laboratory of the U.S. Army Air Service in Dayton, Ohio. He had previously retired from active participation in aeronautics and had become a very modest, very quiet, much beloved member of the Dayton community and of the famous Dayton Engineers Club.

Langley Engines, 1900-1903

Considering the state-of-the-art at the turn of the century, the 52-hp 5-cylinder water-cooled radial engine Langley used in his Aerodrome represents one of the most remarkable pieces of engine design and construction ever achieved.

The history of this engine is interesting. In 1898 Samuel P. Langley, then Secretary of the Smithsonian Institution, had accepted a contract to develop a flying machine for the United States Government and, on June first of that year, hired Charles M. Manly, a young graduate of Cornell University, as his assistant to supervise the design and construction of his Aerodrome. On 12 December, Langley contracted with a New York City automobile builder, Stephen M. Balzer, for a 12-hp engine to be completed in three months. Considering that even now, the development of a reliable gasoline engine is a matter of at least two years, this contract must stand as one of the most optimistic on record! Later, he contracted with Balzer for a 1-1/2-hp engine to power a 1/2-size model Aerodrome.

Neither engine had been delivered by 1900 and the slow progress led Langley and Manly to spend three months in Europe seeking even the prospect of an engine to power the full-sized Aerodrome. The search was unsuccessful and it was finally decided that Manly should join in the further development of the Balzer engines, which had failed to produce the power required.

These engines were of the rotating-radial type, but Manly, after further consulting European builders, decided to use the stationary radial principle. His choice was quickly justified. Whereas the full-scale rotary engine had developed only 8-hp and the small engine 1-hp, the first non-rotary versions produced 16 and 2-hp, respectively; an increase largely attributed to better valve action in the absence of centrifugal force. Further development resulted in the full-size engine of 1901, shown in figures 13 and 14, with specifications in Table 1, and in the 1/4-size one of the same year, described in Manly's letter of 27 April 1926 (fig. 9).

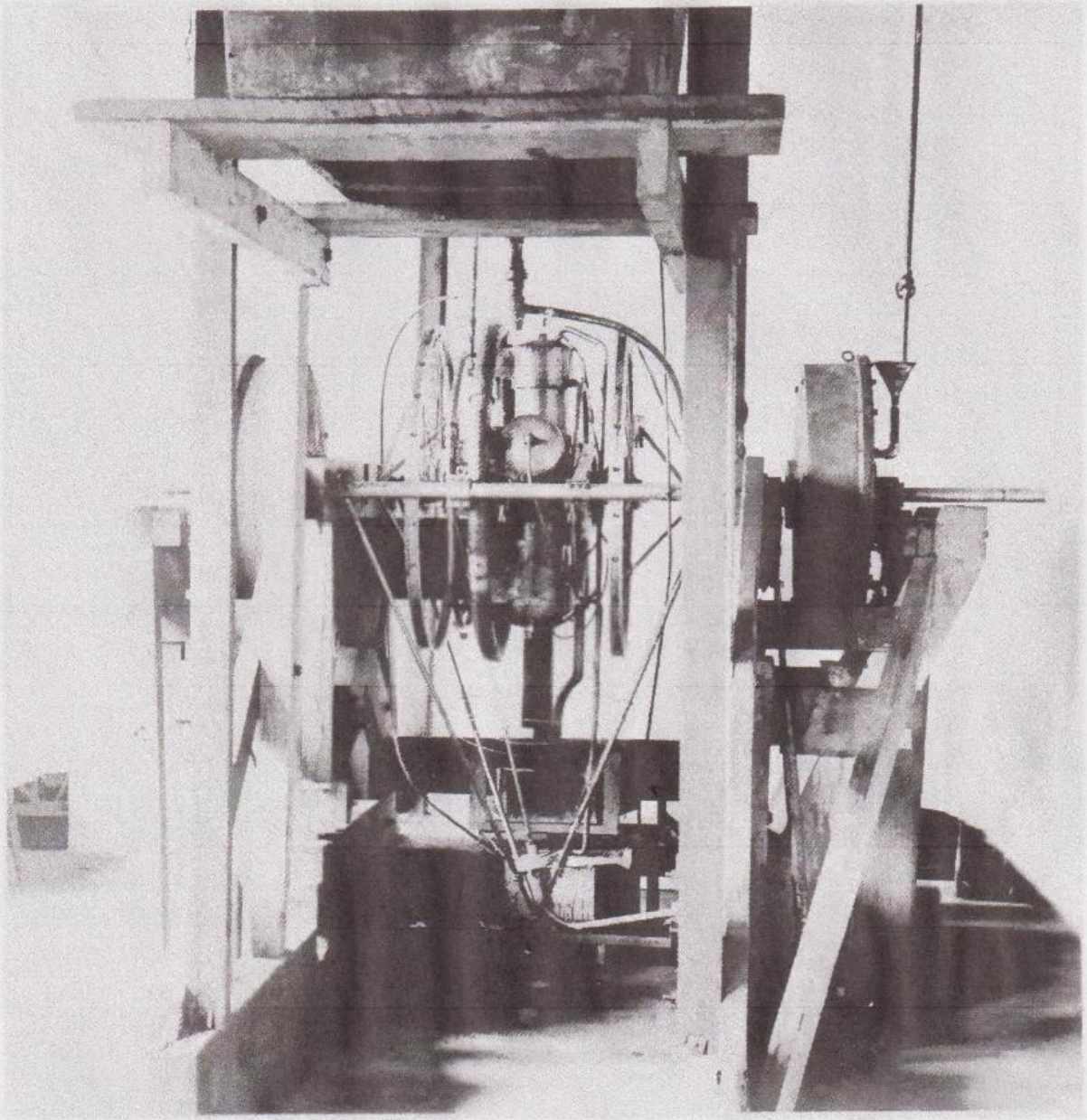


Figure 13.—Langley Aerodrome A engine (NASM 1918–1), 1903, in test stand; 52 hp at 950 rpm, 135 lb. A description of this engine appears in "Langley's Aero Engine of 1903," by R. B. Meyer (*Smithsonian Annals of Flight*, no. 6, 1971). (*Photo A–15864*)

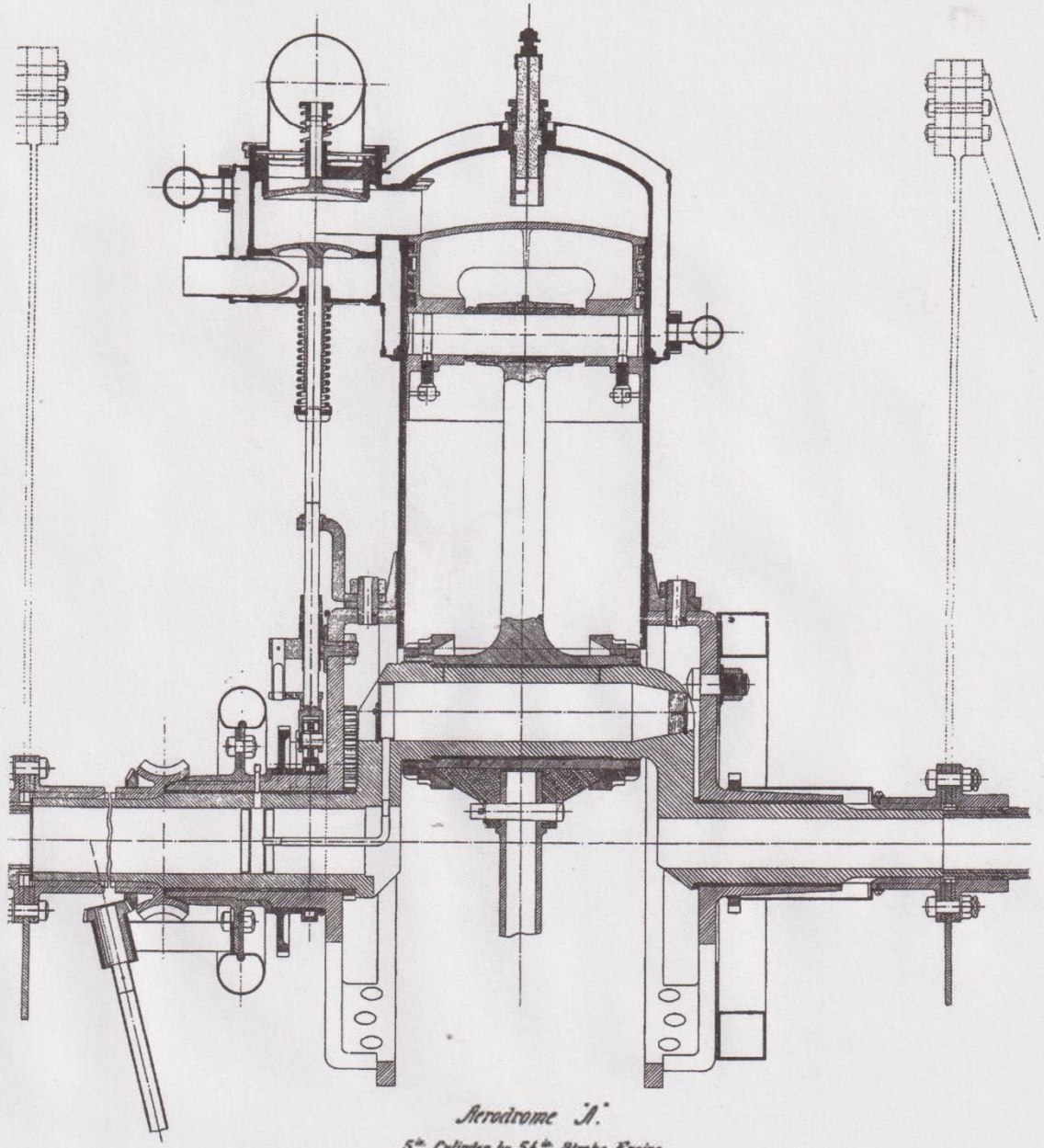


Figure 14.—Section through cylinder and crankcase of Langley Aerodrome A engine, 1903. (From *Langley Memoir*, pl. 78)

Both engines, described in detail in the *Langley Memoir,* are now displayed in the Smithsonian, removed from their Aerodromes. Power of the large engine was carefully measured on a dynamometer and, most remarkably, sustained for three consecutive 10-hr tests. The specific weight, 2.58 lbs./hp, remained as a low record until the Liberty engine of 1918. The figure 0.196-lbs./cu in. displacement has never been closely approached.

The 5-in. bore cylinders, assembled by Manly himself, were built-up of steel 1/16 in. thick, lined with 1/16 in. of cast-iron. The water jackets, of steel 0.020 in. thick, were brazed onto the cylinder as were the cylinder heads and valve ports. The difficulty of this operation is mentioned by Manly and can well be imagined.

This engine somewhat anticipated modern large aircraft engines in its use of the radial arrangement with a master connecting rod, its cam and valve-gear arrangement and its use of crankcase, cylinders and other parts machined all over to carefully controlled dimensions.

Manly's skill as an Engineer and Machinist was matched by his courage in making two (unsuccessful) take-offs from the top of a houseboat; without previous instruction or experience as a pilot and in an airplane without landing gear. His survival of two crashes into the icy waters of the Potomac River testifies to his quick thinking and skill as a swimmer. In contrast to the poor preparation for the Manly attempts the Wright brothers, before making their first powered flights, flew several hundred times in gliders of a size and type quite similar to that of their first powered airplane. All early Wright machines were equipped with landing skids.

Nowadays, it is hard to appreciate the difficulties of these early aircraft engine builders. Although successful automobiles were in operation both in Europe and in the United States, most of them were equipped with engines far too heavy and too low in power for airplane use. Accessory equipment such as spark plugs, carburetors and magnetos was not available on the open market and had to be obtained from reluctant automobile builders or else built by hand.

Worst of all, there was no established body of good practice and details of existing practice were either very difficult to find or else held as closely guarded secrets. In view of these difficulties, the accomplishments of the Wrights and the Langley group are all the more remarkable.

Engines 1903-1909

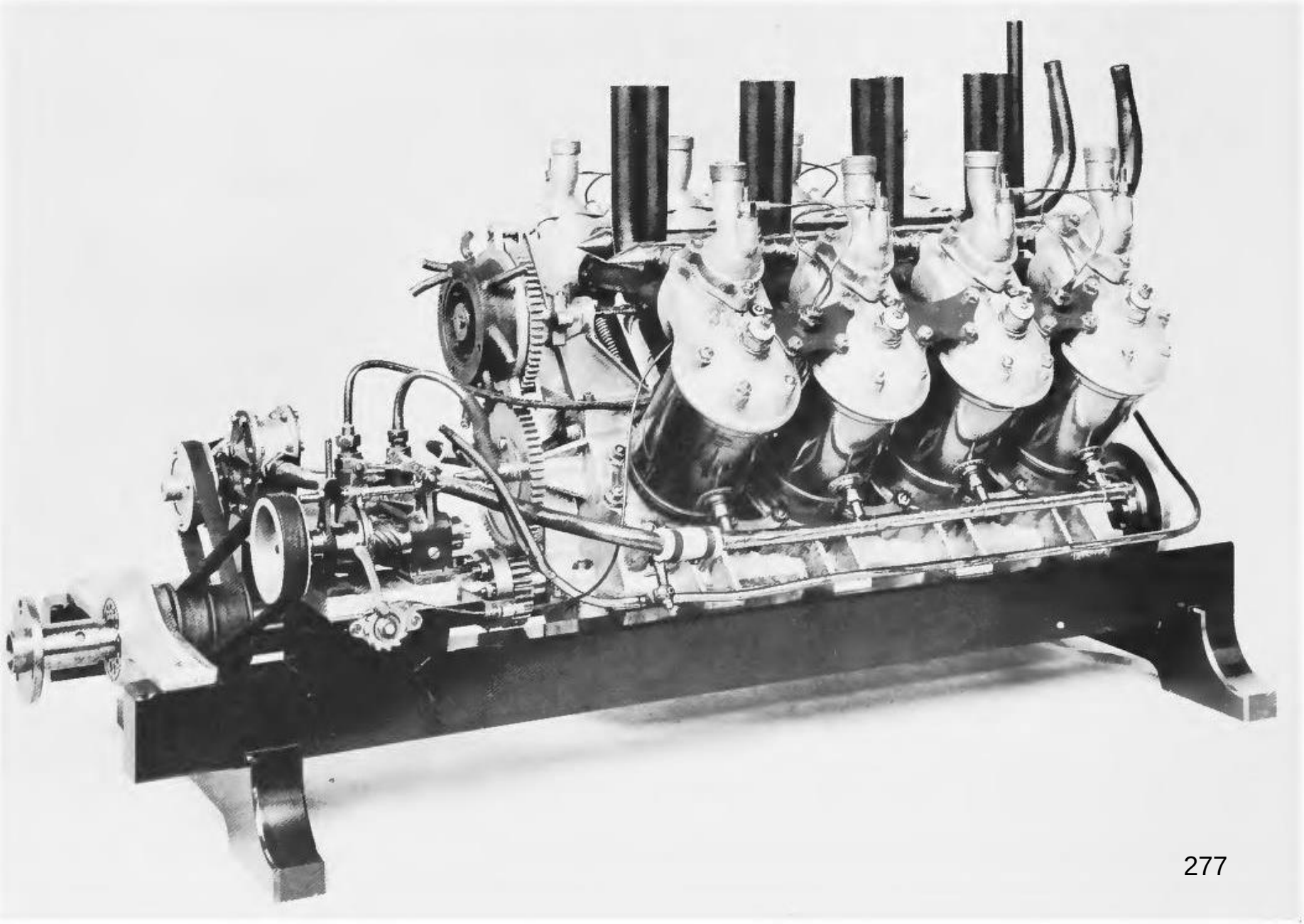
After the Wrights had demonstrated the actuality of airplane flight, a period of nearly three years elapsed before anyone else flew in a heavier-than-air craft. Meanwhile the Wrights increased their duration of flight to more than half-an-hour and their distance to nearly 25 miles; both records accomplished in their flight of 5 October 1905. In 1906 the Hungarian Trajan Vuia, the Dane J.C.H. Ellehammer and the Brazilian Alberto Santos-Dumont accomplished flights, hardly more than short “hops,” in airplanes with unconvincing control systems. Not until 9 November 1907, did anyone but the Wright brothers stay in the air for as long as a minute or fly a distance of over a thousand feet. On that date Henri Farman, in a Voisin biplane, flew 3,368 ft. in 1-min 14-sec, with a 50-hp Antoinette engine, apparently under good control.

Antoinette engines (figs. 15 and 16) were built in Paris by Levavasseur as early as 1905 and were to become very important power-plants for European aviation in the next few years.



Figure 15.—Antoinette monoplane with Levavasseur Antoinette engine, 1909. (*Photo A-3099*)

Figure 16.—Levavasseur Antoinette 8-cylinder engine, 1905–1907; 32 hp at 1400 rpm, 93 lb.
(*Photo courtesy Science Museum, London*)



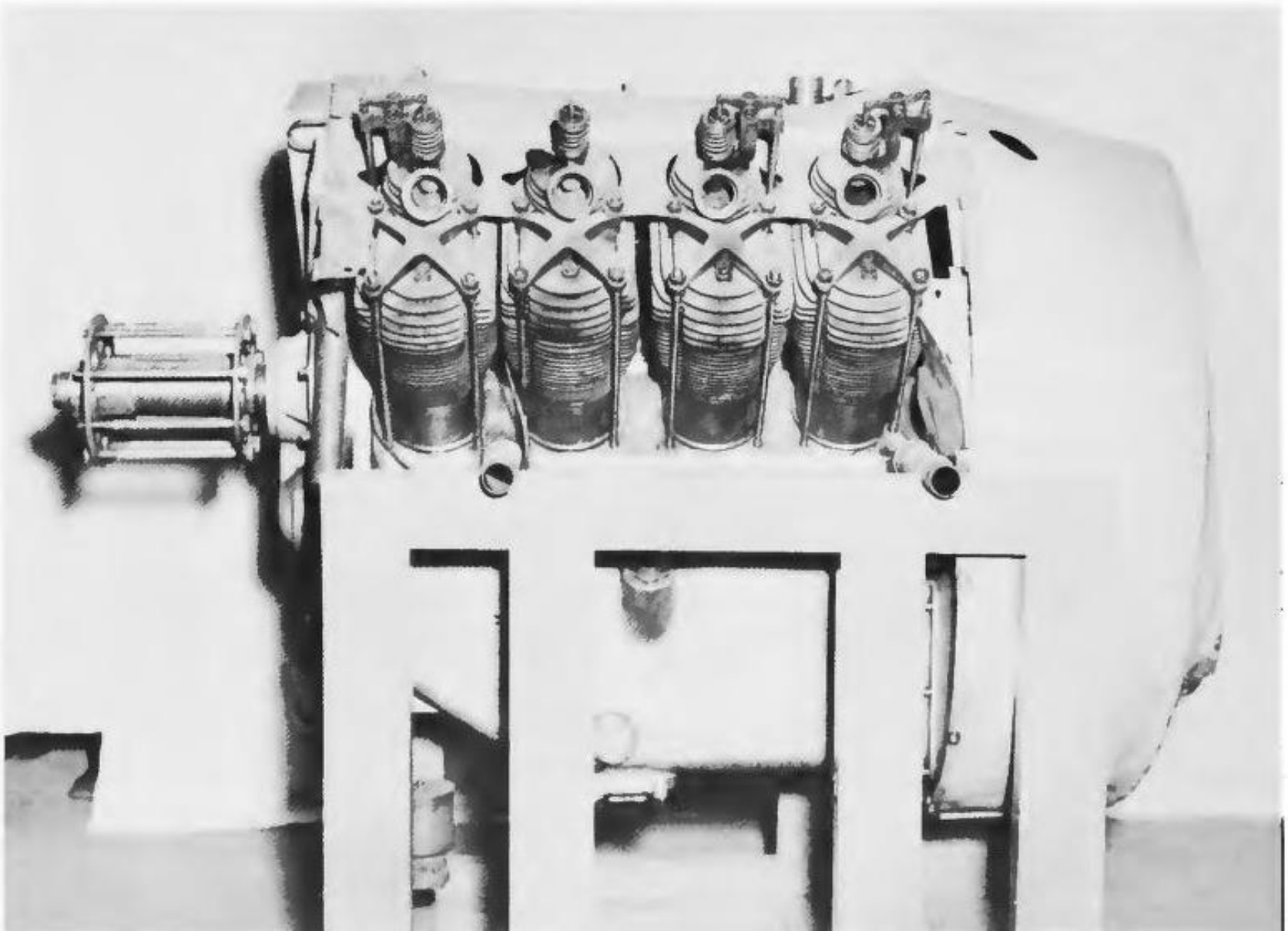
Santos-Dumont used one rated at 24-hp for his “hop” of 772 ft. in November 1906. The engines of Farman and Santos-Dumont were 8-cylinder V-types rated at 50- and 24-hp, respectively. Farman’s engine weighed 3 lbs./hp, a remarkable figure at that time (see Table 1).

Antoinette engines had machined-steel cylinders with brass water jackets. All were water-cooled V-types and were later built in 16- and 32-cylinder models. Together with the engines of Glenn Curtiss and the French ENV (fr., *en V*) of 1909, they pioneered the use of the water-cooled V-type engine in aeronautics. Other noteworthy details of the Antoinette included inlet port fuel-injection and evaporative cooling.

Louis Bleriot also used the 50-hp Antoinette engine in his first tractor monoplane, *No. VII,* which flew in December 1907. The first helicopter to lift a man off the ground (Paul Cornu, 13 November 1907) was also powered with an Antoinette engine. Cody made the first airplane flight in England on 16 October 1908 with an airplane somewhat resembling the Wright in design, powered by the 50-hp Antoinette.

The year 1908 was memorable for the rapid development of increasingly successful airplanes and engines. Two important new engines appeared - the 35-hp Renault 8-cylinder air-cooled V-type (an 80-hp example is shown in fig. 17) and the Curtiss air-cooled V-type 8-cylinder (fig. 18) which powered a flight of 1-min 43-sec. in the *June Bug* on 4 July. And, except for Wright airplanes (which had flown for over an hour), the longest flight had been by Farman in a Voisin, 44 min, on 2 October, until that day in 1908 that Wilbur Wright flew for 2-hr. 20-min. and 23-sec at Auvours, France. It was, according to a French commentator, *“un des plus passionants spectacles qu'ait presents Vhistoire des sciences appliques.”*

Figure 17.—Renault 80-hp V-8 engine (NASM 1932–125), about 1916, with geared propeller drive (rating of the 1908 version was 35 hp at 1400 rpm, 242 lb). One of the earliest geared engines, it used long hold-down studs on the cylinders, a practice widely followed in later aircraft engines. (*Photo A–42316–B*)



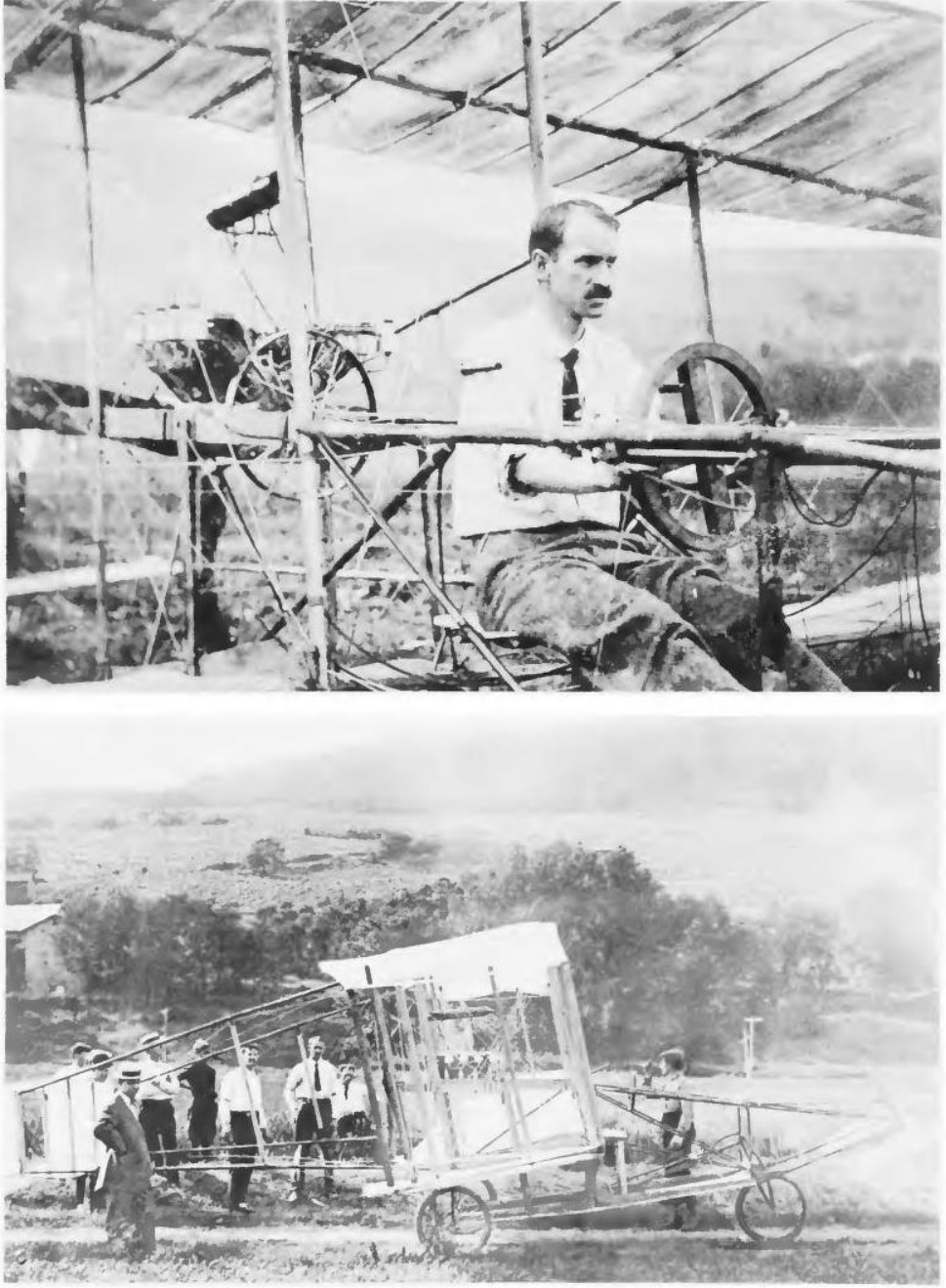


Figure 18.—(*Above*) Glenn H. Curtiss in his airplane *June Bug*, showing its 8-cylinder air-cooled engine installed, 1908. (*Below*) The *June Bug* at Hammondsport, New York. (*Photos A–3100, A–3101*)

Glenn Curtiss was building and racing motorcycle engines soon after 1900. In 1902 Thomas Baldwin engaged him to supply an engine for Baldwin's dirigible airship, which flew successfully in 1904. In 1907 Curtiss joined the Aerial Experiment Association headed by Alexander Graham Bell and thus began his distinguished career as designer and builder of both airplanes and engines and as an airplane pilot.

Curtiss' earliest engines were air-cooled, including the V-8 engine used in the famous *June Bug*, Late in 1908, however, he settled on a water-cooled V-8 engine similar to the Antoinette of Lavavasseur except that the cylinders were of cast-iron, with monel-metal water jackets.

Next to the Wright brothers, Glenn Curtiss was certainly the most important figure in early American aviation, both in engine and in airplane design. The most noteworthy engine which developed from his early work was the famous OX-5, to be described later. Engines bearing his name have an important place in aviation to this day.

The year 1909 has been called the "year of practical powered flying" because in that year flight began to be convincingly demonstrated by others than the Wright brothers. Four types of airplane - Wright, Antoinette, Farman and Bleriot - had made flights of more than an hour's duration.

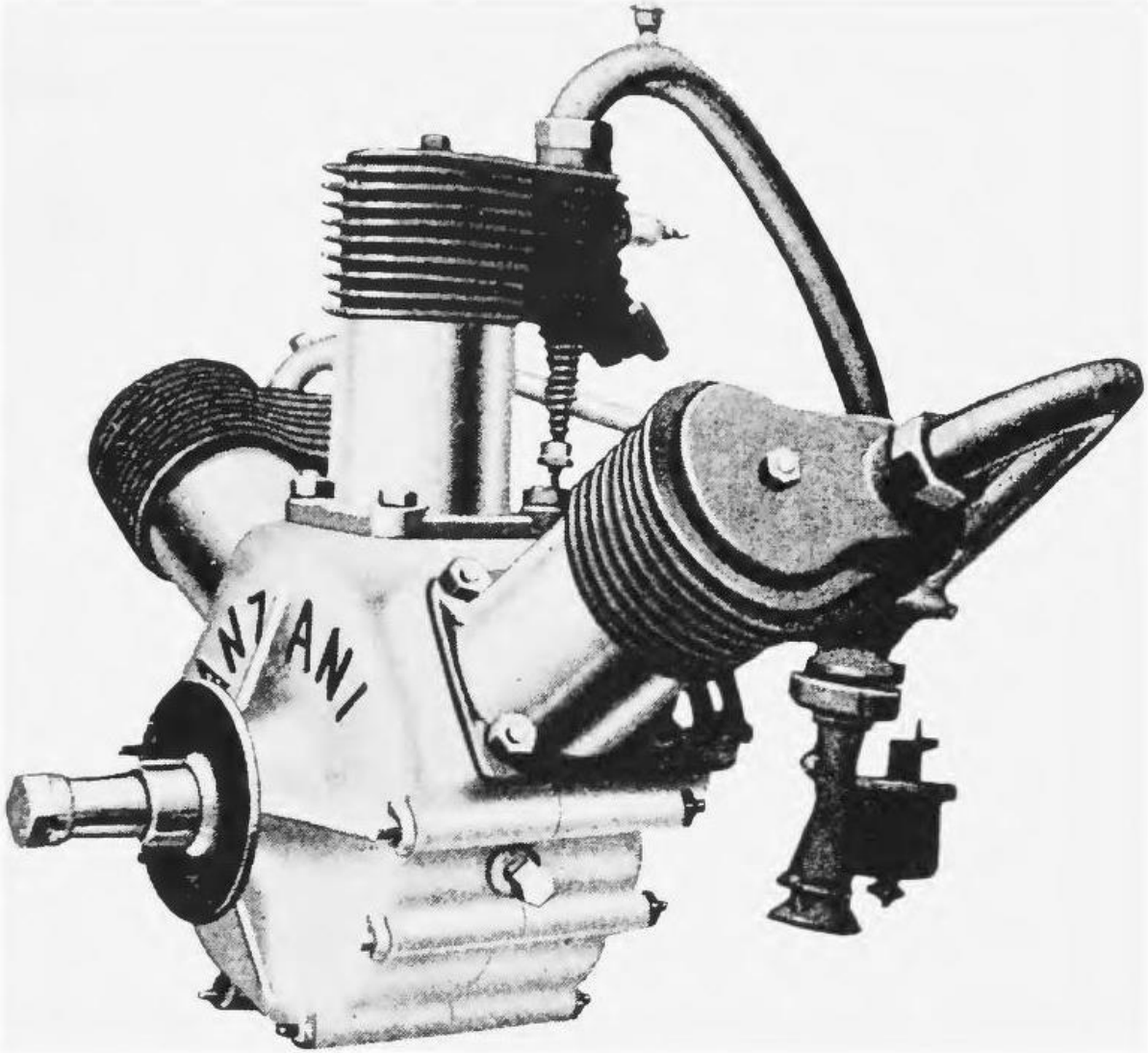


Figure 19.—Anzani 3-cylinder fan-type engine, 1909. The type used in Bleriot's crossing of the English Channel, its rating was 24.5 hp at 1600 rpm, 145 lb. (*Photo A-49846-E*)

Bleriot made his famous cross-channel flight (37-min, 23.5-miles) on 25 July 1909. His tractor monoplane was equipped with a 24.5-hp, 3-cylinder Anzani fan-type air-cooled engine (fig. 19).

Later Anzani built 1- and 2-row radial air-cooled engines that were used in a number of airplanes prior to and soon after World War I. Another fan-type engine of this period was the REP of Robert Esnault-Pelterie, installed in an unsuccessful airplane in 1907. His subsequent REP fan-type engines were used in several successful airplanes.

An outstanding engine to appear in 1909 was the 50-hp 7-cylinder Gnome rotary-radial, first flown in Henri Farman's *No. III* biplane. Rotary types had been built for automobiles by Stephen Balzer and Adams-Farwell in the United States before the turn of the century and this type had been originally planned and built for the Langley Aerodrome, but it was first adapted to flying in the Gnome. This engine (figs. 20 and 21, table 2) was a masterpiece for its time and deserves special attention here.

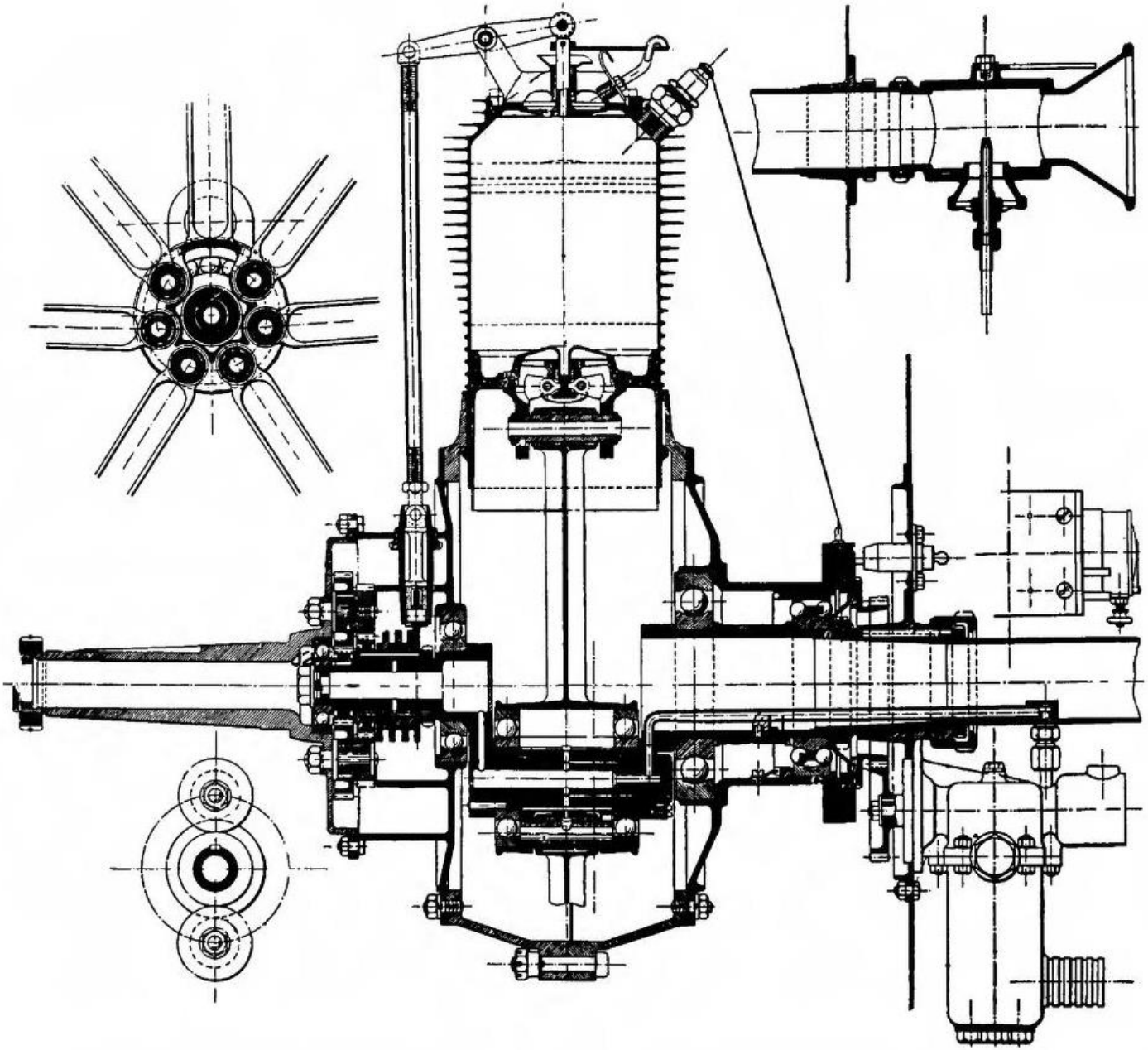


Figure 20.—Gnome 7-cylinder Monosoupape rotary-radial engine, 1910; 50 hp at 1150 rpm, 165 lb. In this longitudinal section note inlet valve in piston to admit fuel-air mixture from crankcase. (From *Aerosphere 1939*, p. 341)

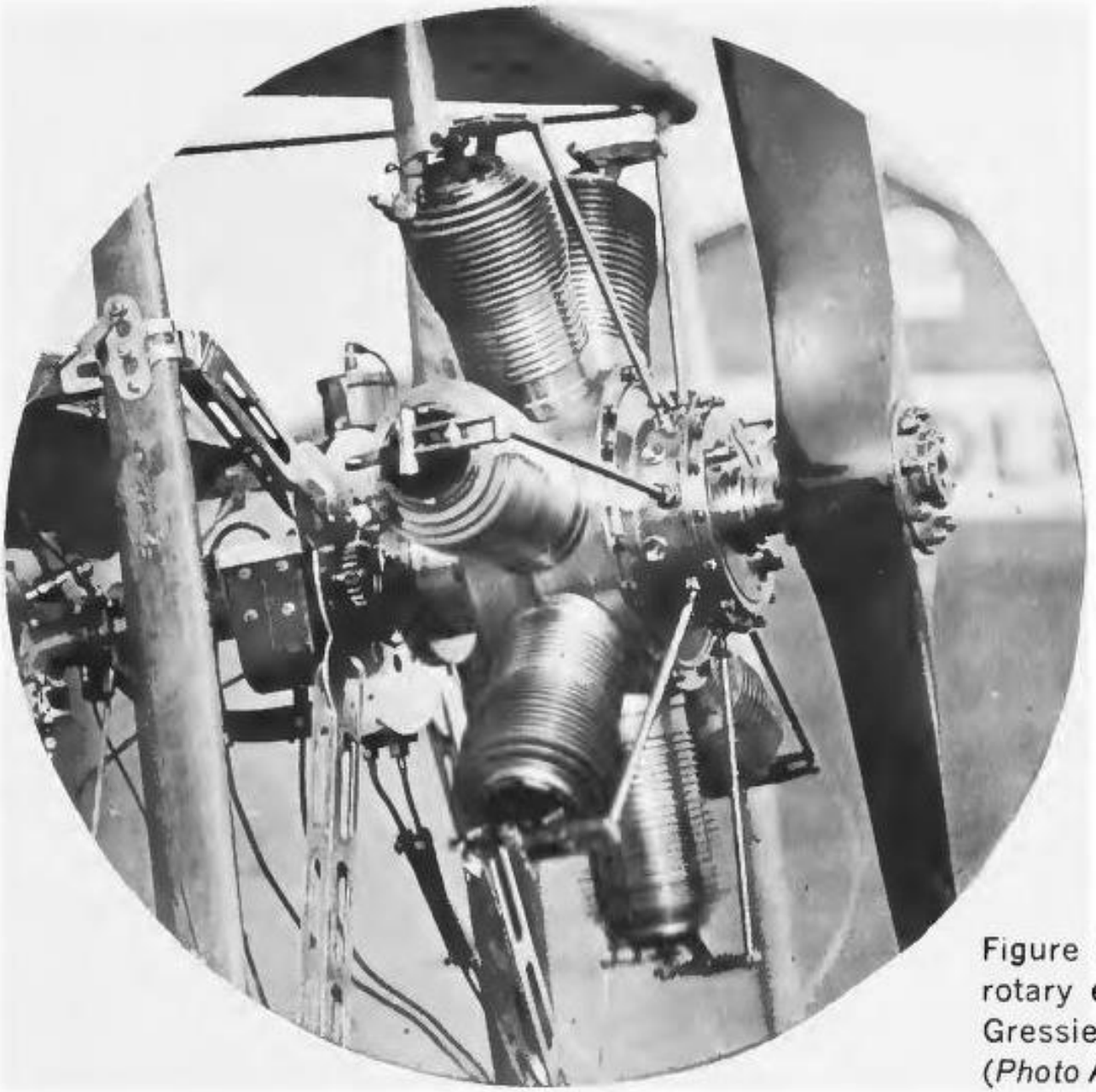


Figure 21.—Gnome 50-hp 7-cylinder rotary engine, 1910, as installed in Gressier Canard pusher biplane. (*Photo A-50895*)

TABLE 2.—Credits, by Country, for Engine Developments

First manned flight	*Engine*	*Aircraft*	*Year*
	AUSTRIA		
Internal combustion engine	Lenoir gas engine	Haenlein (dirigible)	1872
	DENMARK		
Fixed radial engine air-cooled	Ellehammer	Ellehammer	1906
	ENGLAND		
With gear-driven centrifugal supercharger	Armstrong Siddeley	Armstrong Siddeley	1917
Transatlantic nonstop	Rolls-Royce Eagle	Vickers Vimy	1919
Automatic constant-speed propeller	Bristol Jupiter	Gloster Grebe	1928
Turbo-propeller engine	Rolls-Royce Trent	Meteor	1945
	FRANCE		
Steam engine	Steam	Giffard (dirigible)	1852
Electric motor	Electric motor	Tissandier (dirigible)	1883
Air-cooled Otto-cycle engine	Tricycle engine	Santos-Dumont (dirigible)	1898
Helicopter	Antoinette V–8	Cornu helicopter	1907
Rotary radial engine	Seguin Gnome	Voisin	1909
More than 8 cylinders	Levavasseur Antoinette 16-cylinder	Antoinette	1910
Propeller reduction gear	Renault V–8	Farman	1910
Inlet-port fuel injection	Antoinette	Antoinette	1906
Seaplane (floats)	Gnome	Heurig Fabre	1910
Turbosupercharger	Rateau	R.A.F. 4D	1918
	GERMANY		
Rocket engine	von Opel	Opel–Sander Rak–1	1929
Diesel engine in commercial transport	Junkers 2-cycle opposed piston	Junkers G–38	ca. 1936
Jet engine	von Ohain	Heinkel He–178	1939
Axial flow jet engine	Junkers Ju–004	Messerschmitt 262	1944
Rocket engine in military service	Walter	Messerschmitt 163	1944
	SPAIN-SWITZERLAND		
Aluminum cylinder structure	Hispano-Suiza	Spad 7	1914

The design of the Gnome was by Laurent Seguin. Made entirely from steel forgings machined all over, with integrally machined cooling fins and a modern master-rod system, it anticipated many features of the latest large air-cooled radials. The rotary feature was used in order to eliminate the flywheel, which had been previously thought essential, and also to assist in cooling. It frequently used a cowling with central air intake, something like that later developed for static radials by the National Advisory Committee for Aeronautics (see Table 2). Unlike the NACA cowling, however, the cowling used here had its opening for outlet air at the bottom, rather than around the rear edge. Its primary purpose was, probably, to encourage discharge of exhaust gases and oil under the airplane, away from the pilot. The fact that it also greatly reduced engine “drag” as compared with un-cowled engines, may not have been understood at that time. This seven-cylinder model, and subsequent larger and more powerful versions, became perhaps the most popular aircraft engines up to World War I and were used widely by both sides through that war.

I had the pleasure of flying with a Gnome engine in 1920 and found it exceptionally free of vibration and also relatively quiet. The only disagreeable feature was the castor-oil fumes discharged from the exhaust. Lubrication was achieved by pumping castor oil into the crankshaft at a fixed rate and oil which was not burned eventually found its way out of the exhaust ports and, despite the cowling, much of it settled on the airplane (and on the pilot!).

One of my first assignments in aviation (1917) was to make tests to show that mineral oil could be used in aero-engines. Previous to that time castor oil had been considered as indispensable for aero-engines as it was for young children.

Another interesting feature of the Gnome engine was its method of control. No carburetor was used; the fuel and air were introduced through the hollow crankshaft, by means of separate valves controlled by the pilot. Because of the great inertia of the rotating engine, it was possible to adjust to the appropriate mixture by trial, without danger of stalling the engine. With a known setting of the valves for idling, after the engine had been started the air throttle was opened wide, at which time firing ceased but rotation continued. The fuel valve was then opened until firing restarted and maximum propeller speed was attained. Because the reverse process was difficult, throttling-down was accomplished by temporarily cutting the ignition and the engine was kept going by short bursts of power. Oddly enough this technique was easy to learn and pilots seemed to like it.

Important engines of 1909 included the following (see also Table 1):

Wright	4- and 6-cylinder vertical, water cooled
Curtiss	8-cylinder V-type, water cooled
Antoinette	8- and 16-cylinder V-type, water cooled
ENV	8-cylinder V-type, water cooled
Darracq	2-cylinder opposed, water cooled
Gnome	7-cylinder rotary, air cooled
Renault	8-cylinder V-type, air cooled
REP	7-cylinder fan, air cooled
Anzani	3-cylinder fan, air cooled

These engines accounted for nearly all important flights in 1909, including the winners of the first official aviation contests at Rheims.

The Darracq engine, used by Santos-Dumont, was important for being one of the first aircraft engines to use mechanically operated inlet valves. The JAP (J. A. Prestwich Co.) motorcycle engine used by A.V. Roe in his early airplane appears to have been the only other one using such valves. All other aircraft of the period used automatic inlet valves, opened by suction. Since automobile engines had been using mechanically operated valves for many years before 1909, it is hard to understand why this important feature was so late in coming into use for aircraft engines.

Engines 1910-1918

The period 1910-1918, which included World War I, saw such rapid developments of aircraft engines that only the important ones can be described here. By “important” I mean those which pioneered successful new design features or which were particularly notable in service.

Early in this period the Gnome air-cooled rotary engine was dominant and was built in many countries and in several modified designs, including models by LeRhone and Clerget (French) the Bentley BR-1 and BR-2 (British) and the Oberiirsel and Siemens (German). It reached its maximum development early in the war and was definitely obsolescent by 1918. Reasons for its demise were chiefly a limitation on speed due to centrifugal stress, the considerable windage losses, design limitations imposed by rotation of all parts but the crankshaft, and a rather strong gyroscopic effect on the airplane during turns. It set a pattern, however, for the later development of the modern air-cooled radial engine. It was a forged-and-machined-all-over engine and it was radial and air-cooled, features which are now characteristic of most large aircraft piston engines. Other rotary engines were built at this time, but none achieved the importance or success of the Gnome and its descendants.

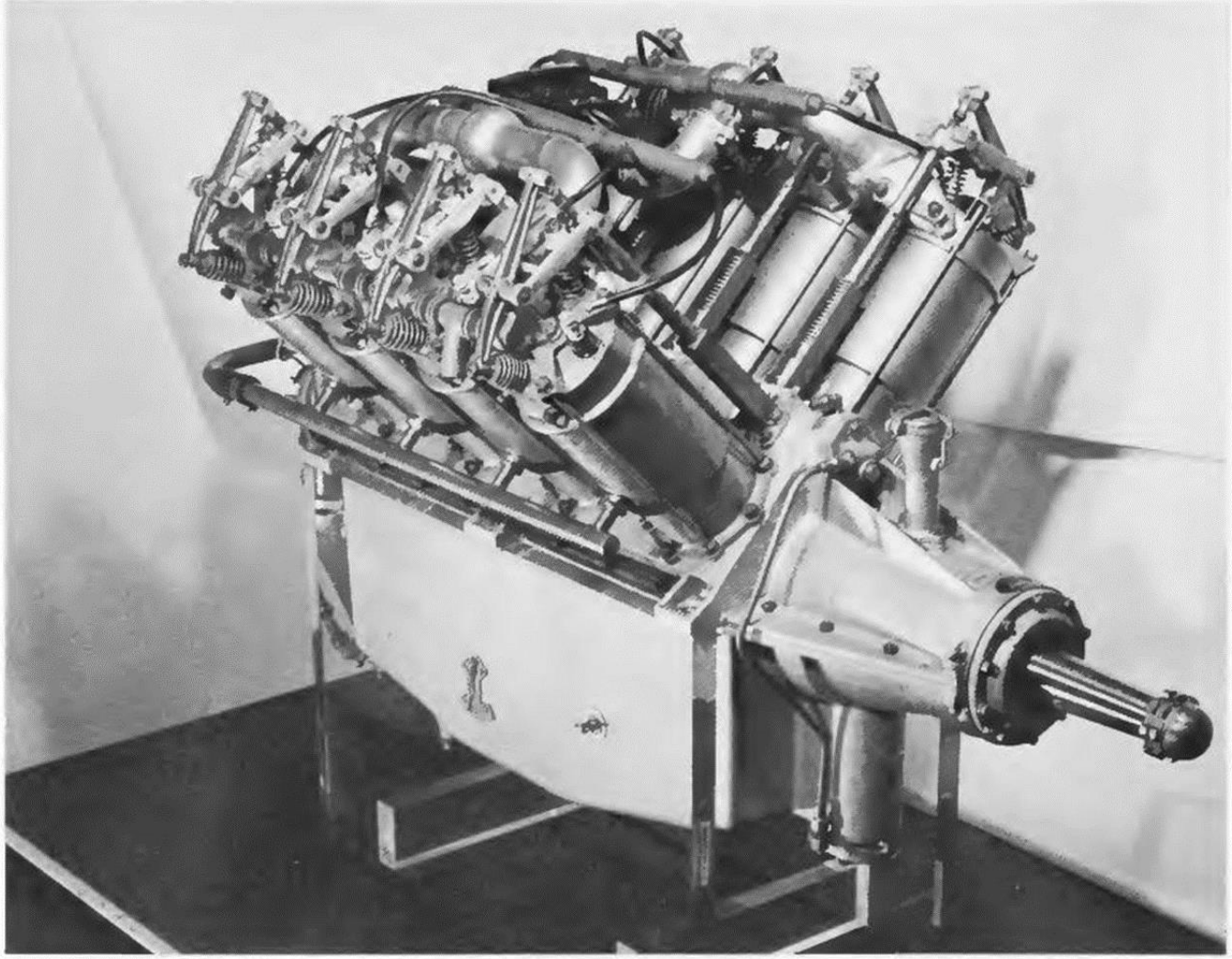
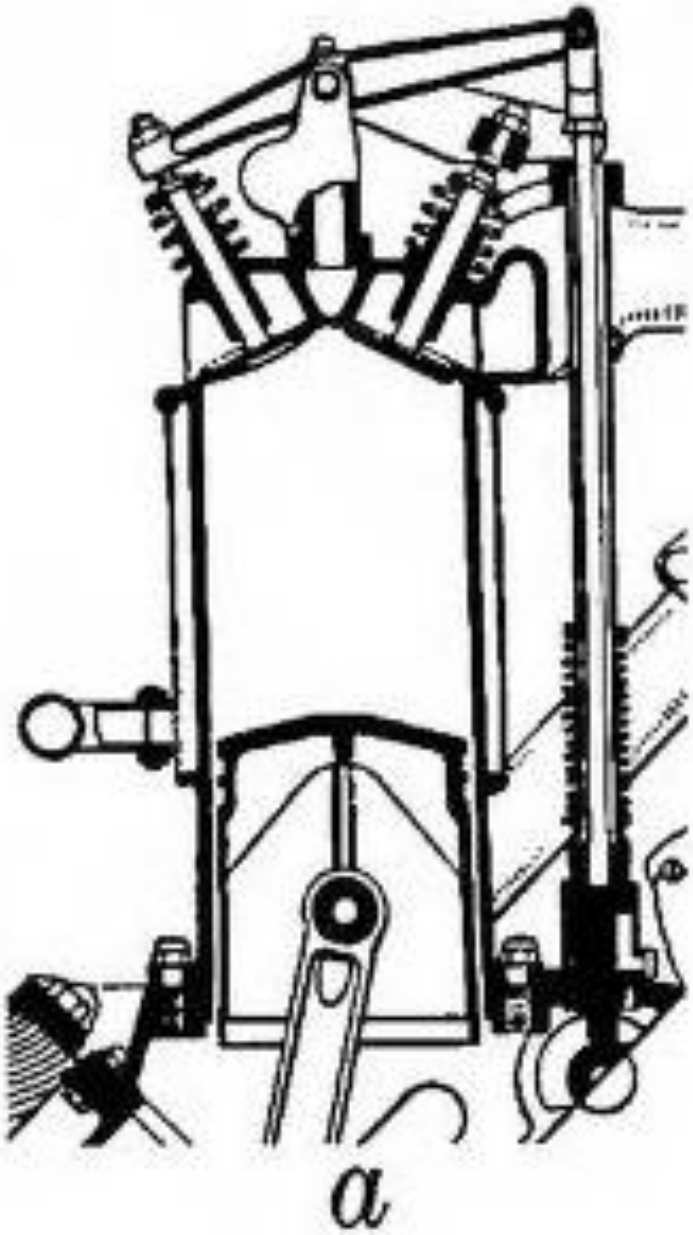


Figure 22.—Curtiss OX–5 water-cooled V–8 engine (NASM 1920–8), 1917; 90 hp at 1400 rpm, 320 lb (see also fig. 34a). (*Photo A–1832*)

As the rotary engines became obsolete, the water-cooled V-type engine became dominant. In the United States the Curtiss OX-5 engine (fig. 22 and Table 1) led the field until 1917, when the Liberty and Hispano-Suiza engines were introduced.



a

The OX-5, a water-cooled V-8, had an aluminum crankcase, cast-iron cylinders (see fig. 34a, left) with sheet monel-metal water jackets brazed onto the barrels and overhead valves, push-rod operated. Used by both Army and Navy, it powered practically all United States and Canadian training airplanes and was probably responsible for training more pilots for World War I than any other engine.

Figure 23.—Curtiss JN-4 Jenny airplane with OX-5 engine, 1915. (*Photo courtesy Harrah's Automotive Museum, Reno, Nevada*)



The best-known trainer, the Curtiss JN-4, affectionately known as the *Jenny,* is shown in figure 23. My first airplane ride (1917) was in a single-float seaplane with the OXX-2, the Navy version of this engine.

The OX-5 engine was considered very reliable for its day, but few pilots completed the training course (very short) without at least one forced landing. Its weaknesses included single ignition, a rather flimsy valve-operating gear including “pull-rods” for the inlet valves and a tendency to leak water from the water pump down onto the low-slung carburetor. In freezing weather the latter defect accounted for many forced landings.

A very important new style in liquid-cooled cylinder design appeared in 1915 on the German 6-cylinder 180-hp Mercedes engine (fig. 24 and Table 1). This was the built-up welded-steel cylinder construction widely used for a long time thereafter in most water-cooled engines. It was copied by such famous makes as the Rolls-Royce Eagle (fig. 25), Liberty, FIAT (Fabrica Italiana Automobili Torino), Renault, Salmson and BMW (Bayerische Motoren Werke), but finally gave way to the cast-aluminum en bloc construction, to be discussed later.

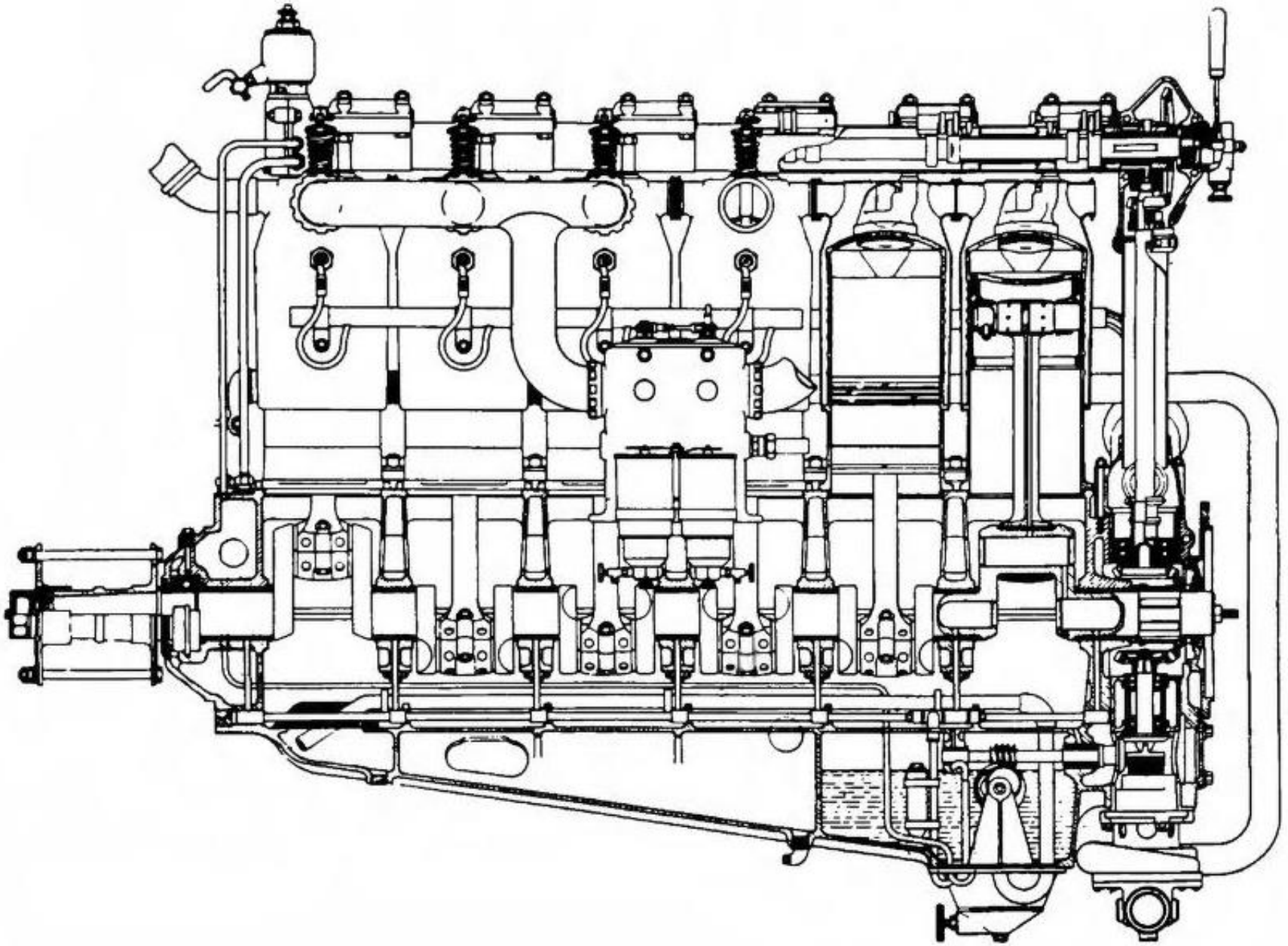
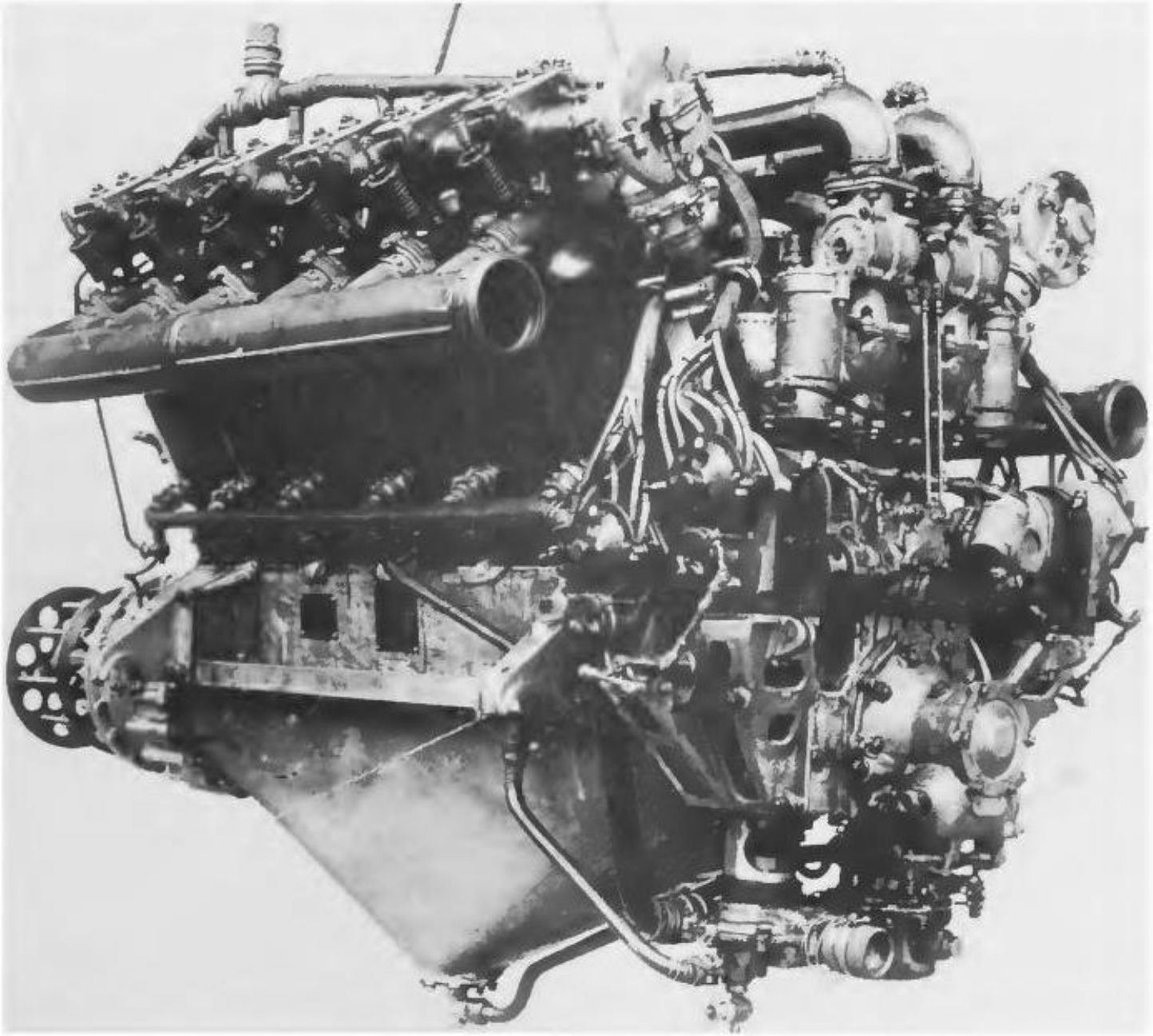
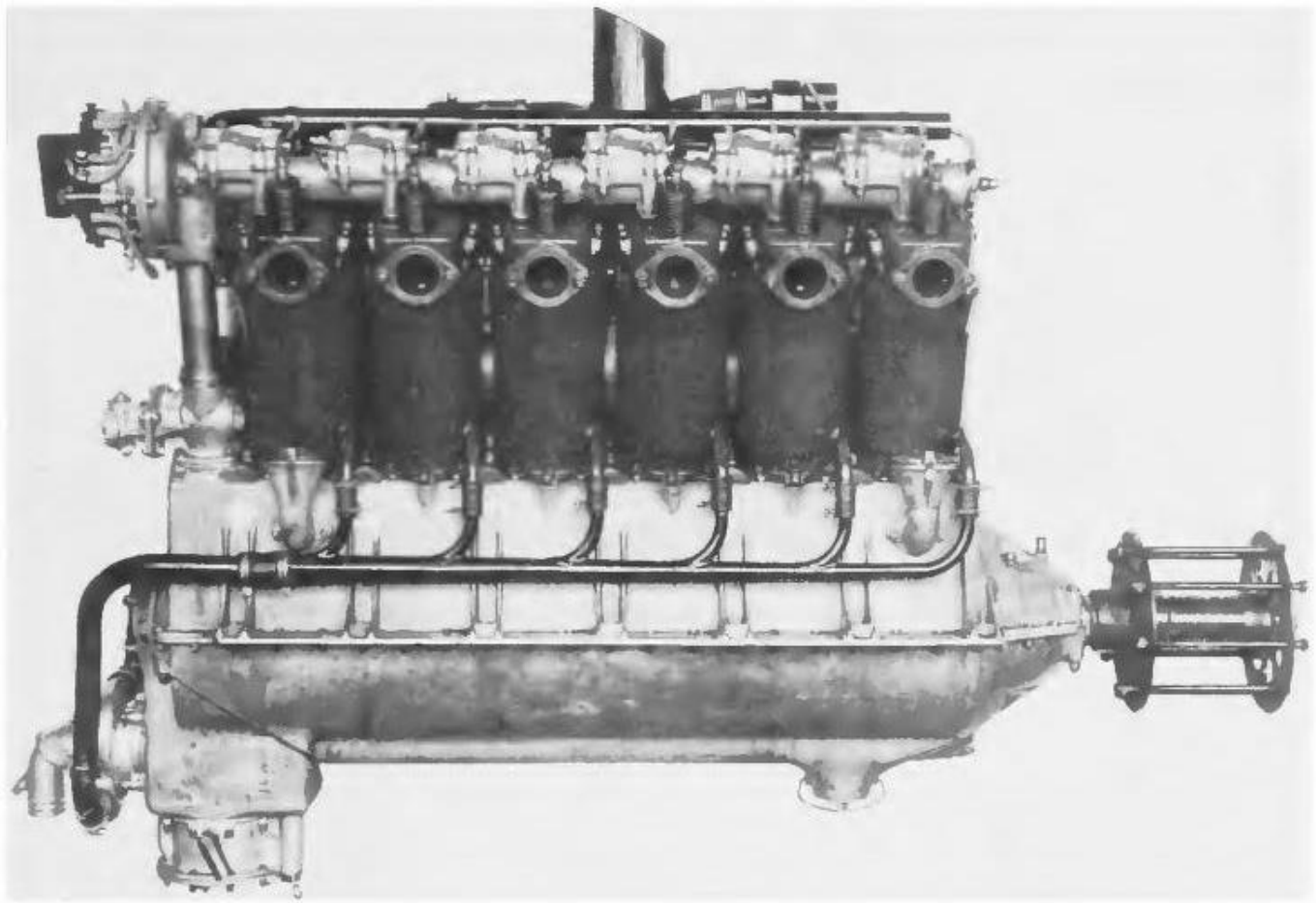


Figure 24.—Mercedes 6-cylinder engine, 1915; 180 hp at 1500 rpm, 618 lb. This engine pioneered welded-steel cylinder construction. (From [British] Ministry of Munitions, *Report on the 180-H.P. Mercedes Engine*, March 1918)

Figure 25.—Rolls-Royce Eagle V-12 engine, 1917; 360 hp at 1800 rpm, 900 lb. Its cylinder construction is similar to that of the Mercedes in figure 24. (*Photo A-487*)





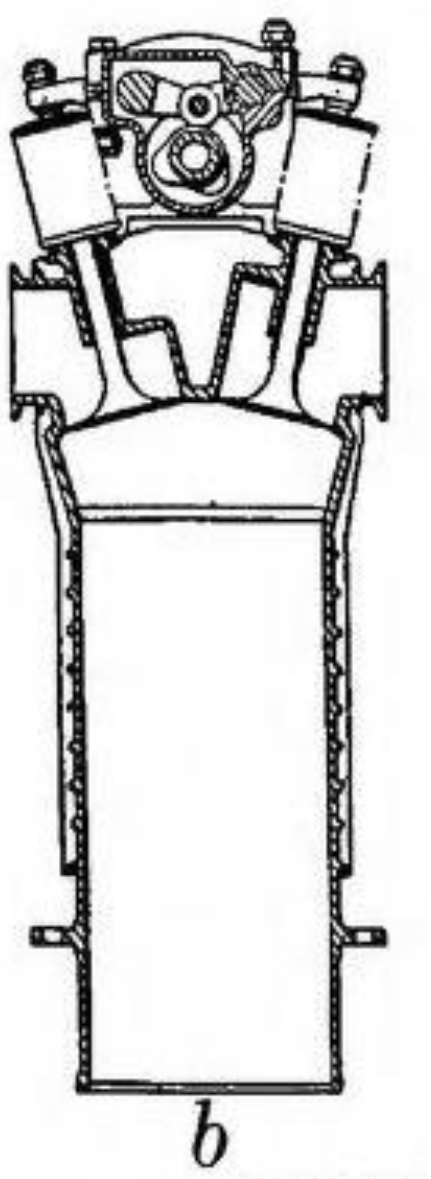


Figure 26.—Liberty V-12 engine, 1918; 420 hp at 1700 rpm, 856 lb. It has Mercedes-type cylinder construction (see also fig. 34b). (*Photo A-691*)

Among the engines built in this style, an important one was the United States Liberty (figs. 26, 27 and 34b), which was developed under extraordinary circumstances.

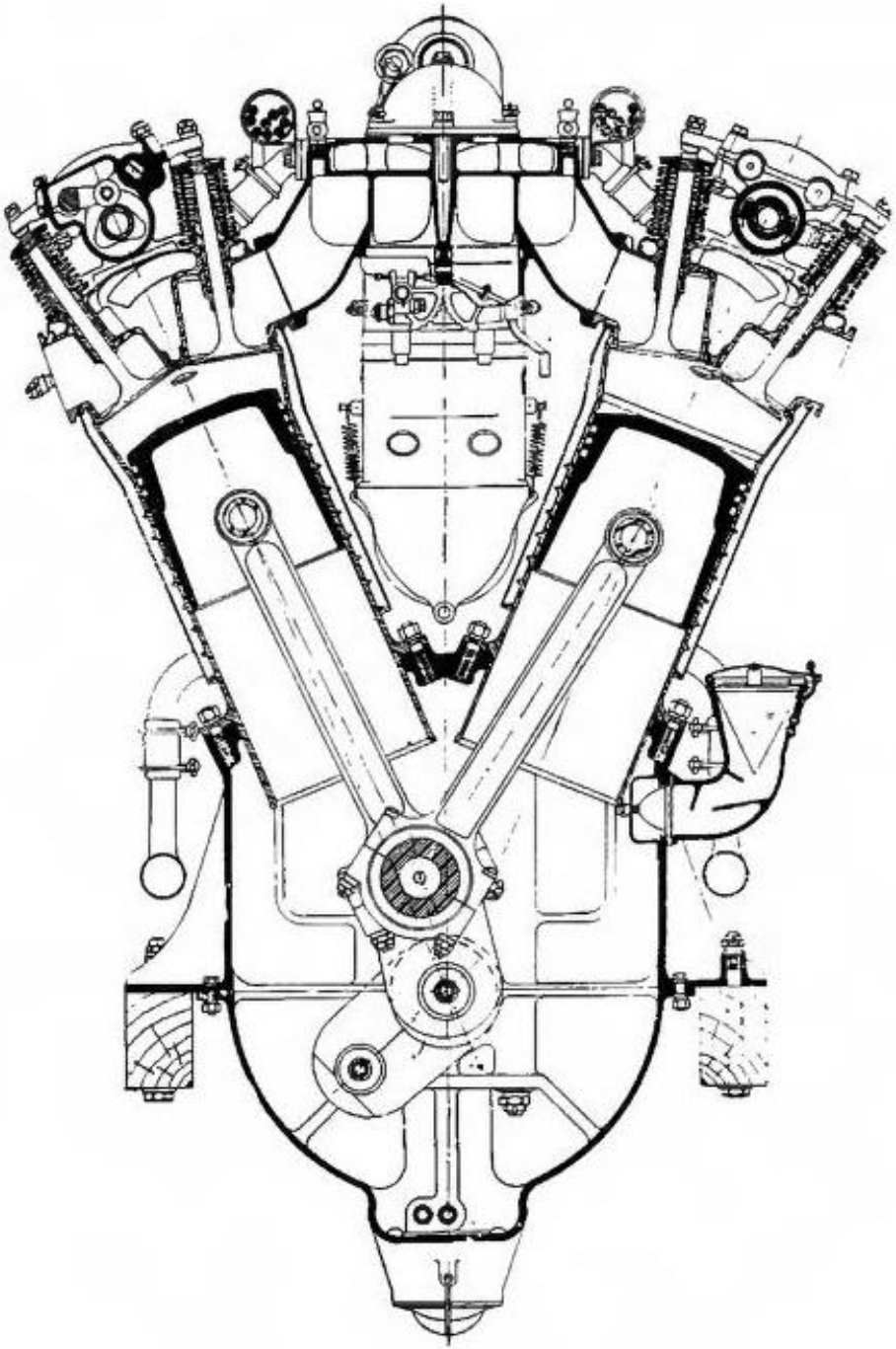


Figure 27.—Liberty 12A, V-12 engine, transverse section viewed from rear, 1918. (From *Aerosphere 1939*, p. 467)

After a decision on 29 May 1917 (only 7 weeks after the United States entered the war), by the War Production Board to build an airplane engine more powerful than any in use up to that time, J.G. Vincent, Chief Engineer of Packard and Elbert J. Hall, of the Hall-Scott Motor Co., started to design such an engine in the Willard Hotel, Washington, D.C. On 31 May preliminary layouts were approved by the WPB and some extra help was called in. Complete layouts were approved 4 June, all drafting was completed by 15 June, the first 8-cylinder engine was delivered to the Bureau of Standards for test 3 July and the first 12-cylinder engine completed the official 50-hr test 25 August 1917. The first "production" engine was delivered to the Army Air Service in Dayton on Thanksgiving Day 1917; just 6 months after Vincent and Hall had started their layout. I believe this record has never been equaled, before or since, except perhaps by the first Pratt & Whitney Wasp, described later.

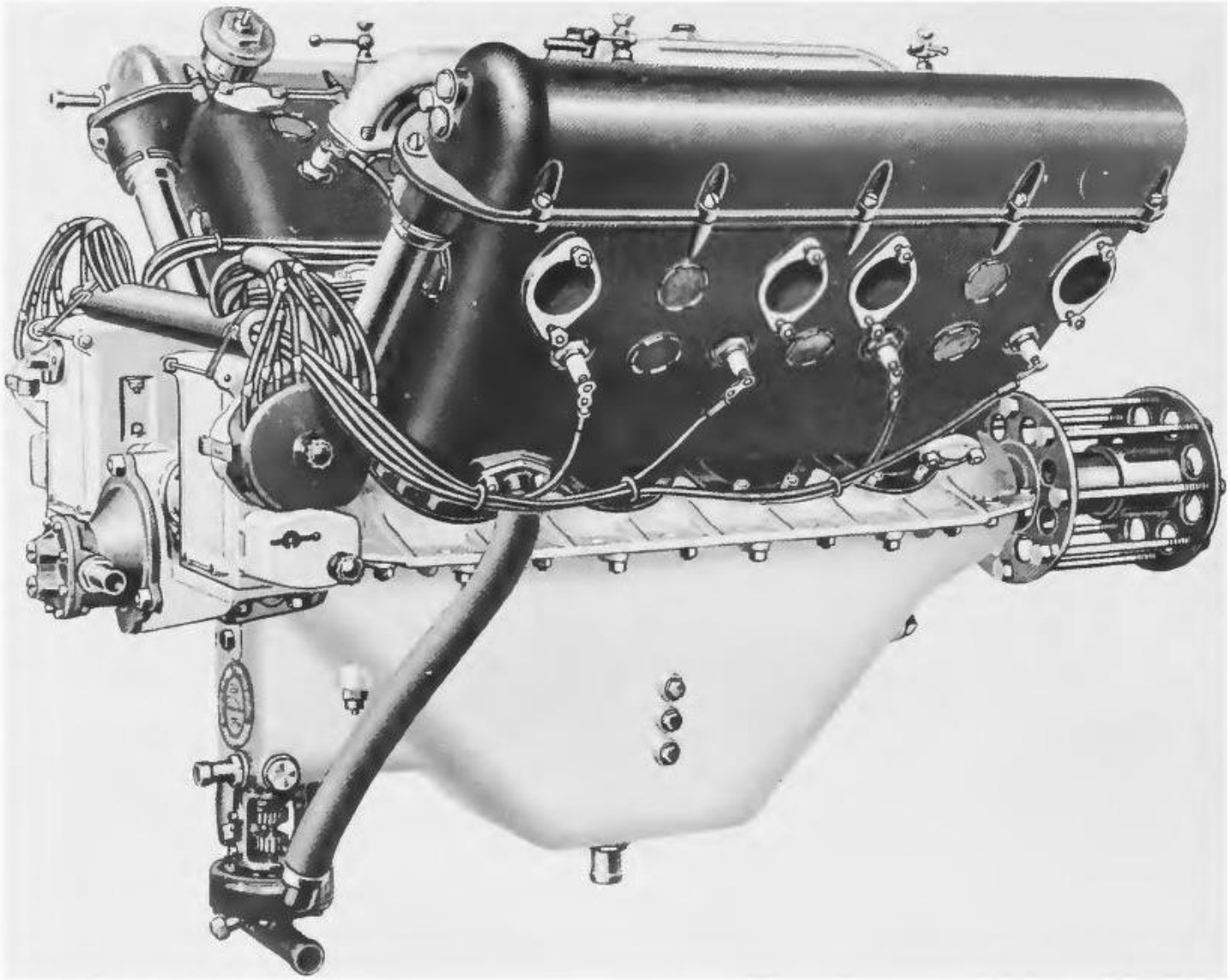
The design was based on the welded-cylinder construction pioneered by Mercedes. It had no radical features, but was an excellent synthesis of the state-of-the-art of its time. Its principal weaknesses were cracking of the cylinder-head water jackets, burning of exhaust valves and breaking of accessory gears. These faults were gradually reduced as time went on and it came to be considered a reliable engine.

Early production engines had a 50-percent chance of passing the government 50-hr endurance test. In a later modification, a bar was welded between the ports to reduce cylinder distortion and jacket cracking and heavier teeth were used in the gears. The only major weakness remaining was in the exhaust valves, which served well most of the time.

Large quantities of the Liberty-12 engine were produced by the automobile companies, including Packard, Ford, Lincoln and some General Motors divisions. It was used by the British in military airplanes as well as by the United States Army Air Service and Naval Flying Corps. Liberty engine production was far ahead of airplane production in this country and at the end of the war many thousands of these engines were on-hand. Many were sold at low prices to “rum-runners” and were very successfully used in running liquor through the Coast Guard blockade along the Atlantic and Pacific coasts during the Prohibition Era. During these years the Coast Guard had no “requirements” for a light and powerful marine engine and their motor boats were far outclassed by the Liberty-equipped bootleggers’ craft.

The Liberty engine remained important in United States Army and Navy aviation well into the 1930s. This engine was used in the NC flying boats with a special economical carburetor setting developed at the Washington Navy Yard. The NC-4 was, of course, the first aircraft to cross the Atlantic, 16-27 May 1919. The Liberty was also the first engine to fly nonstop across the American Continent (in the Fokker T-2, 2-3 May 1923, piloted by Kelly and McCready). Also, in a turbo-supercharged version, it held the world's altitude records in 1920, 1921 and 1922 and, in 1924, it powered the flight of several Army airplanes around the world.

From a technical viewpoint, the outstanding airplane engine during World War I was undoubtedly the Hispano-Suiza V-8 (figs. 28, 29 and 34c and Table 1), built first in Barcelona by a Swiss Engineer, Marc Birkigt. It was adopted for French fighters in 1915 and used in the Spad (Societe pour Aviation et ses Derives) 7 and 13, perhaps the best fighters of World War I (see fig. 30).



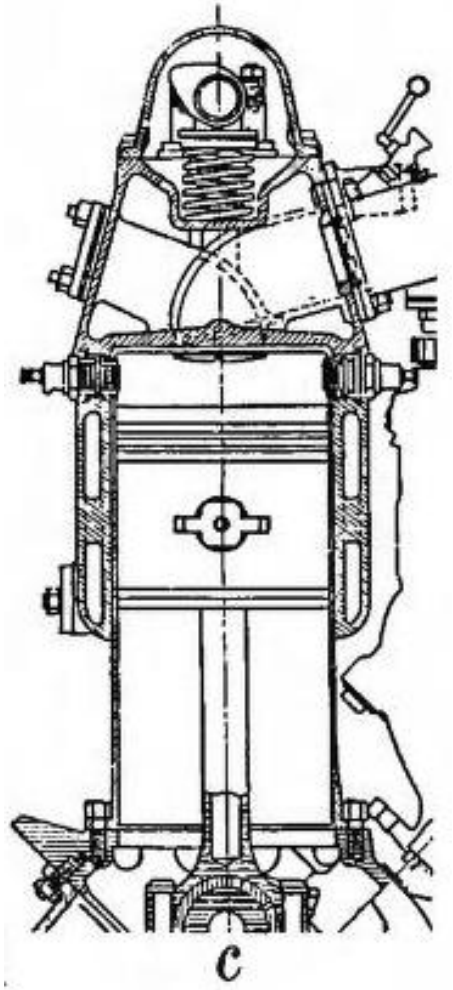


Figure 28.—Wright Aeronautical Corp. Hispano-Suiza Model E V-8 engine, magneto end, 1920; 180 hp at 1700 rpm, 470 lb. The French-built model was rated at 150 hp (see also fig. 34c). (*Photo A-51011*)

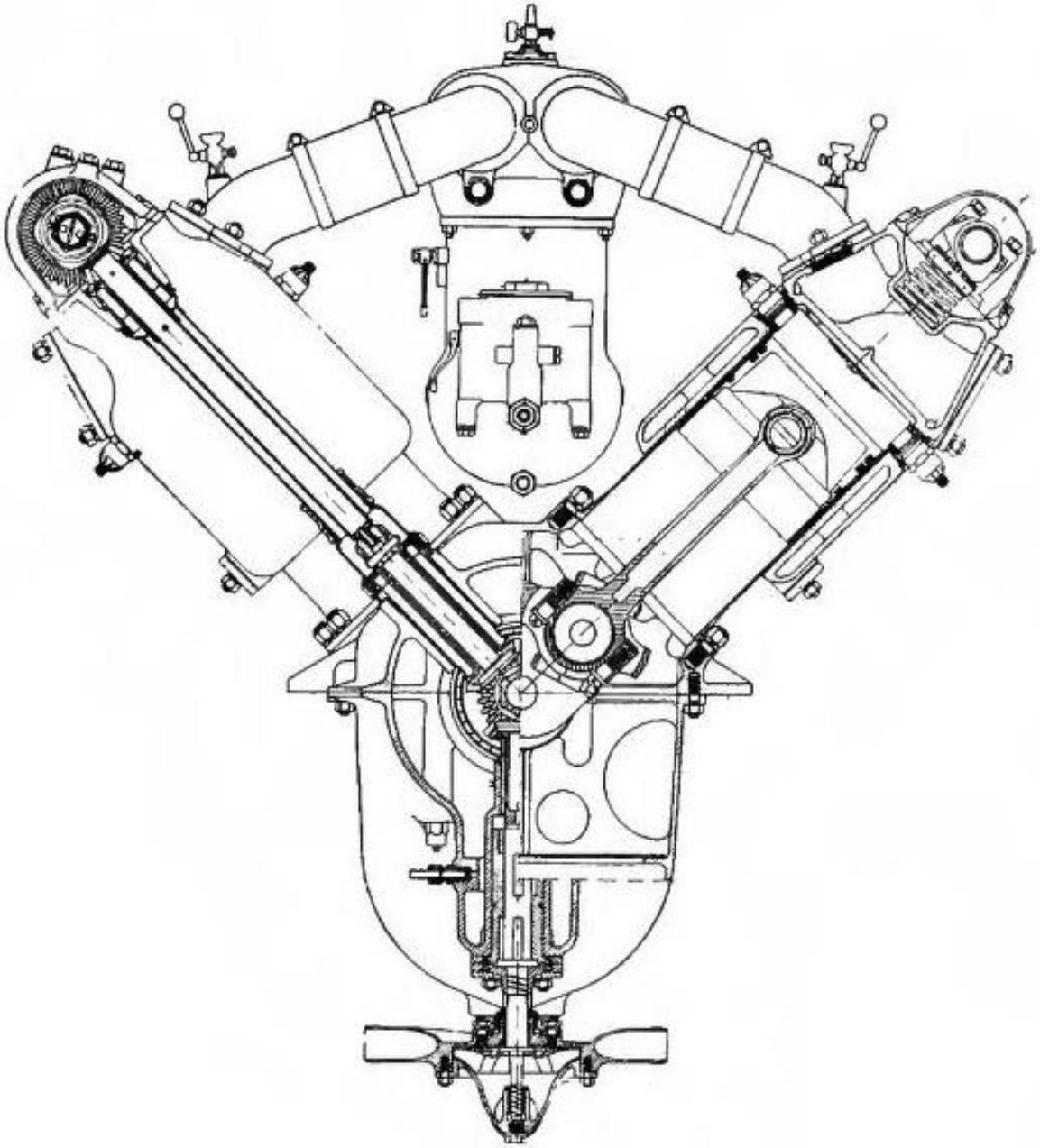


Figure 29.—Hispano-Suiza V-8 engine, transverse section, viewed from rear. (From *The French Hispano-Suiza Aero Engine, Instruction Book*, p. 25)



Figure 30.—An Hispano-Suiza V-8 powered this Spad 7 airplane, used by 27th Squadron, AEF, World War I, 1917–1918, (*Photo A-44832-C*)

The basic contribution of Birkigt to engine design was the en bloc cylinder construction with a cast-aluminum water jacket containing steel cylinder barrels and with enclosed and lubricated valves and valve gear. The success of this engine started a revolution in liquid-cooled engine design which culminated in the Rolls-Royce Kestrel and Merlin, via the Curtiss K-12, C-12 and D-12 engines. It was also the prototype for the Mercedes and Junkers engines which were the backbone of the 1940-45 German Luftwaffe, together with en bloc Russian, Japanes, and Italian designs. By 1917, Hispano-Suiza engines were being built in England and the United States as well as in France.

The only weakness in the early Hispano-Suiza engines, by standards of the time, was a tendency toward exhaust-valve burning. This was due to the fact that the steel cylinder heads were “dry,” that is, they did not come directly into contact with the cooling water (see figs. 29 and 34c). The flat steel head had a tendency to warp and lose contact with the aluminum jacket, which reduced valve cooling and also distorted the valve seats, causing exhaust valves to leak and burn under conditions of severe operation.

The development of this engine was continued in the United States after World War I by the Wright-Martin Company which, in 1919, became the Wright Aeronautical Corporation. One of the most important changes made was to eliminate the steel cylinder head and to seat the valves in bronze inserts pressed into the aluminum heads. This basic improvement set a pattern for the most successful subsequent liquid-cooled engines. In contrast to the all-forged construction of the Gnome and the modern large radial engines, the Hispano-Suiza engine and its descendants were essentially cast-aluminum engines except for the moving parts and the cylinder barrels.

Piston Engines After 1918

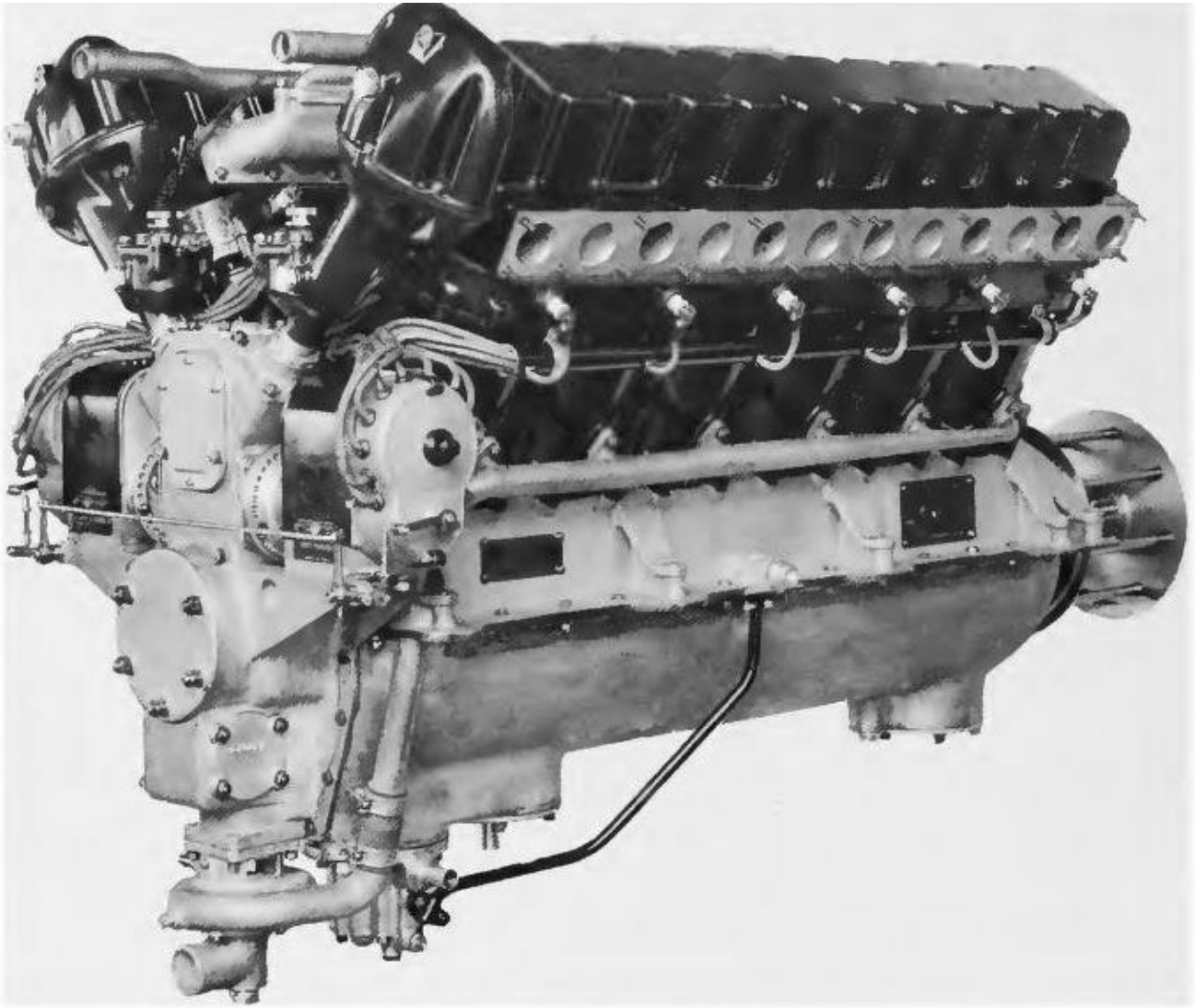
In the period after 1918 hundreds of new engine types appeared. From the technical point-of-view, the period is marked by the following significant developments:

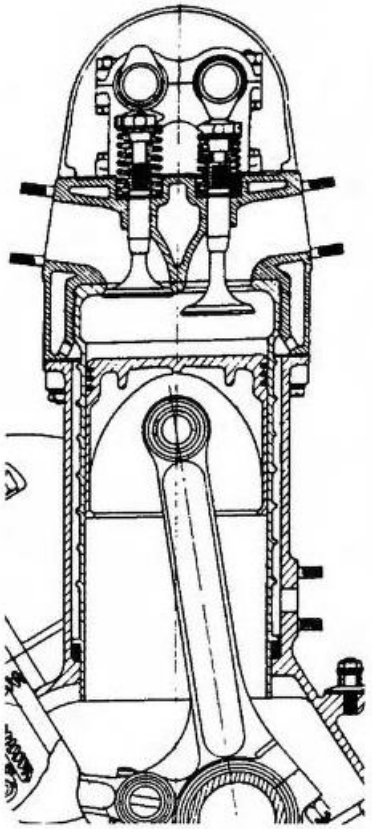
• Further development of the liquid-cooled engine of the all-cast type, chiefly for military purposes
• The development of the air-cooled radial engine to a place of dominance in all but fighter-type military and small civilian aircraft
• The advent of 4-cylinder vertical in-line and later, opposed-cylinder, horizontal, air-cooled engines for light aircraft

Liquid-Cooled Engines

By 1920, the success of the Hispano-Suiza engines; then built in both the original and a larger (300-hp) size, had convinced most designers that the welded-cylinder construction was obsolescent.

The Curtiss Company in the United States took-up the cast-aluminum engine, generally based on the Hispano-Suiza, with successive 12-cylinder designs known as the K-12, 13 C-12, D-12 (fig. 31), and V-1400 models. These were all of the 12-cylinder V-type; with 4 valves-per-cylinder instead of 2, as in the Hispano-Suiza. The two early models had steel cylinder heads like that of the original Hispano-Suiza, but cooling was greatly assisted by an integral stud, in the center between the valves, by means of which the head was held tightly against the water-jacket casting (fig. 34d). In the D-12 the steel head was abandoned and the valve seats were bedded directly in the aluminum head, as in the Wright version of the Hispano-Suiza.



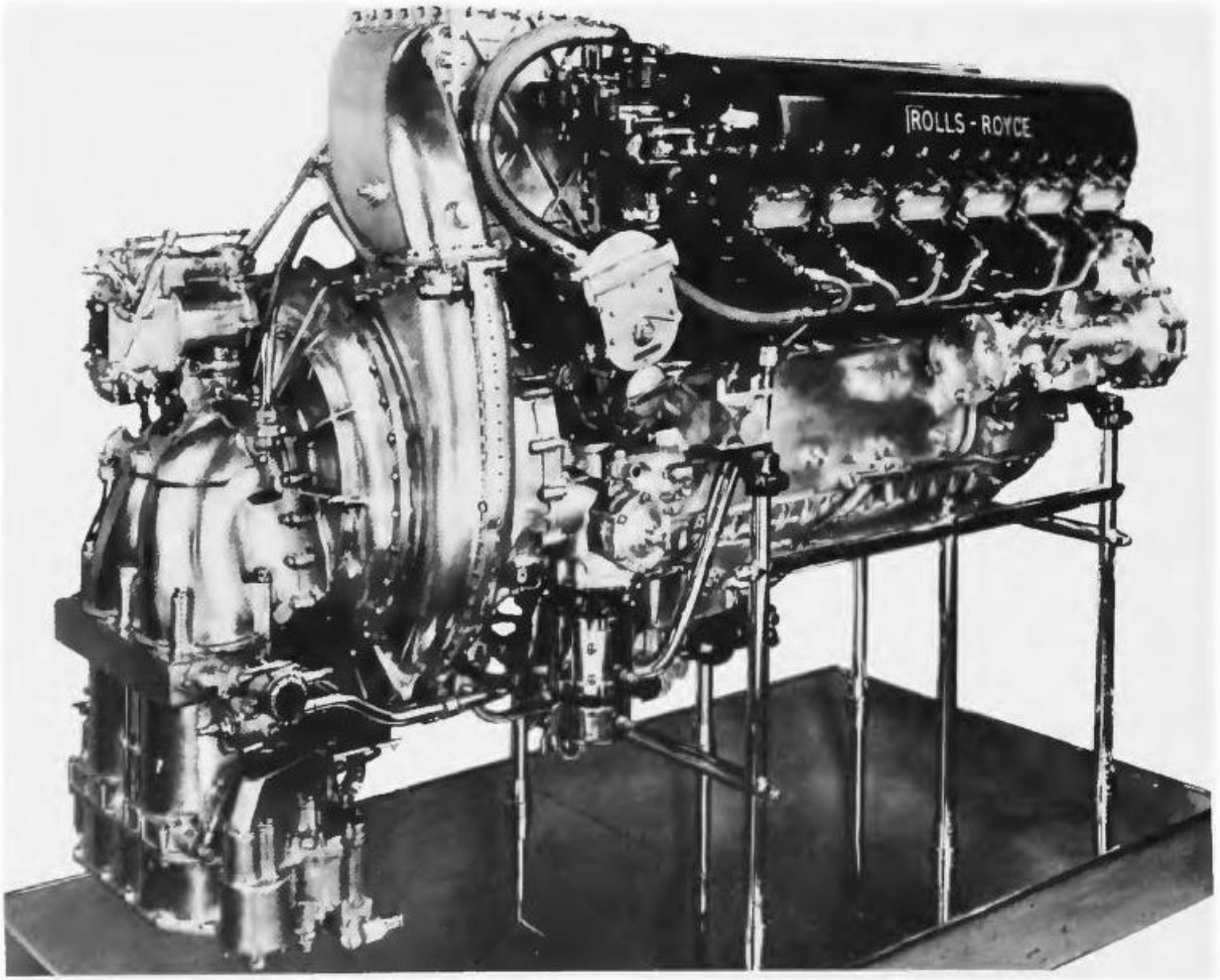


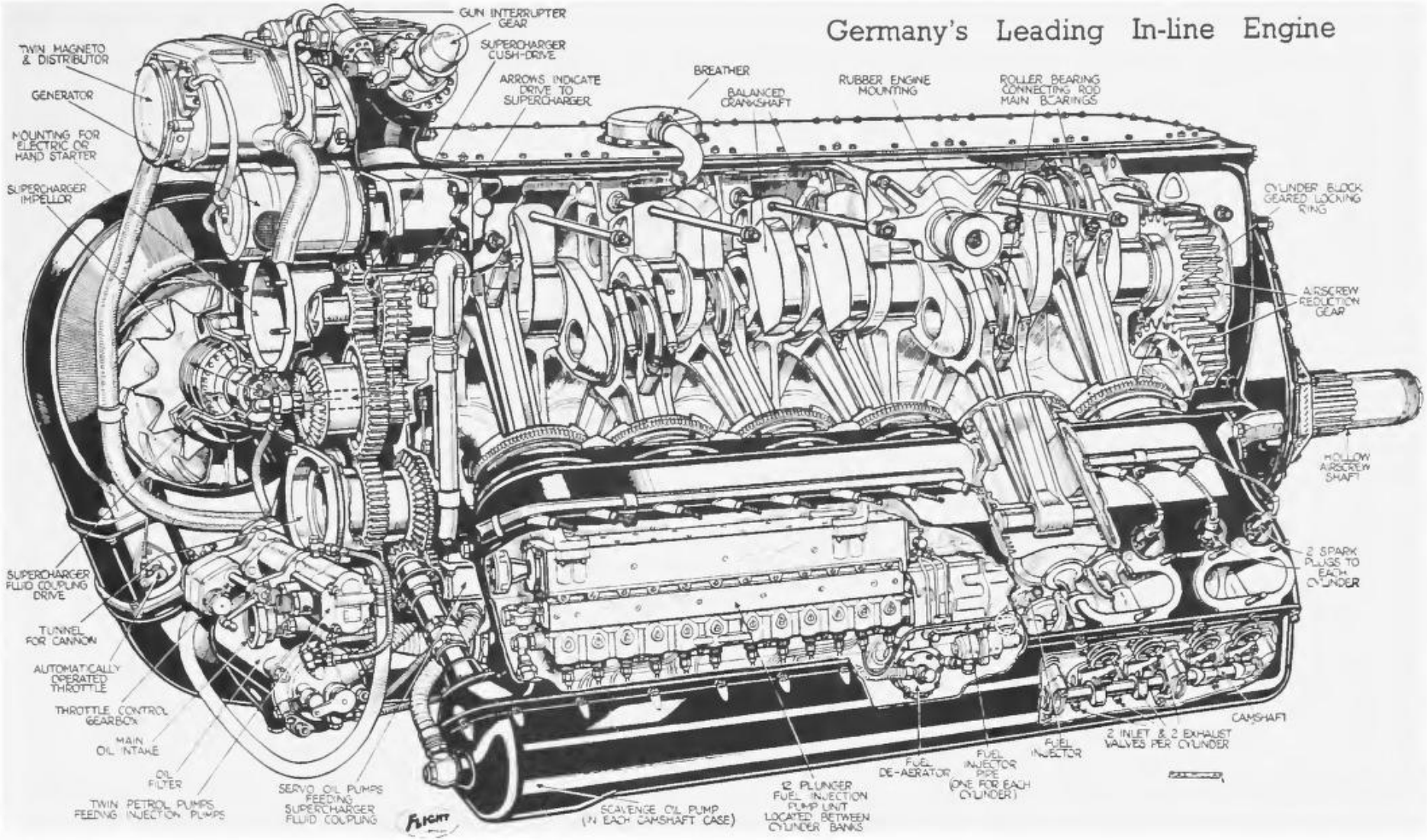
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Figure 31.—Curtiss D-12 V-12 engine; 325 hp at 1800 rpm, 704 lb. This engine was the first to fly more than 200 mph, in the Mitchell Trophy race, Detroit, 1922; and for the race, engine speed was increased so that it probably developed about 400 hp. (*Photo A-3109*)

The great success of the Curtiss engines in racing (first to exceed 200 mph in the Mitchell 14 Trophy race, Detroit, 1922, and winner of the Schneider trophy in 1923 and 1925) led the Rolls-Royce company to develop aluminum V-12 engines of similar type. The first was the Kestrel of 1927 soon followed by the racing, or R-type which attained theretofore unheard of power output in proportion to its size and weight and won the Schneider trophy in 1929 and 1931. The Kestrel was followed by the Rolls-Royce Merlin (fig. 32), winner of the Battle of Britain and also by the Allison V-1710 (a fairly faithful copy of the Merlin) and the German Daimler-Benz (fig. 33) and Junkers V-12 liquid-cooled engines, all descendants of the Hispano-Suiza and Curtiss.

Figure 32.—Rolls-Royce Merlin 61 V-12 engine with 2-stage supercharger, about 1944; 2000 hp at 3000 rpm, about 1700 lb. (*Photo A-3110*)





Part-sectional drawing of the liquid-cooled D.B.601N of 33.9 litres, bore and stroke 150 × 160 mm. Features of the engine are the twelve plunger in-line direct injection pump, and the fluid coupling which provides an infinitely variable gear for the supercharger drive. B.H.P. at 2,600 r.p.m. is 1,270, which for a weight of 1,540 lb. = 1.20 lb./h.p.

Figure 33.—Daimler-Benz, DB-601-N V-12, Germany's leading World War II engine (see also fig. 34h). Roller bearings are used on the crankpins. (From *Flight*, vol. 41, p. 367, April 16, 1942.)

In all these engines the valves were seated in inserts embedded in the aluminum head and thus had better valve cooling than the original Hispano-Suiza design. In every case the basic structure consisted of cast-aluminum crankcase with en bloc water jackets and cylinder heads, also of cast-aluminum. Cylinder barrels were uniformly of steel. Design details varied, especially in the method of taking the cylinder-head-to-crankcase load. This was successfully done as follows (fig. 34 illustrates the evolution of liquid-cooled cylinder construction):

Figure 34.—Liquid-cooled cylinder development:

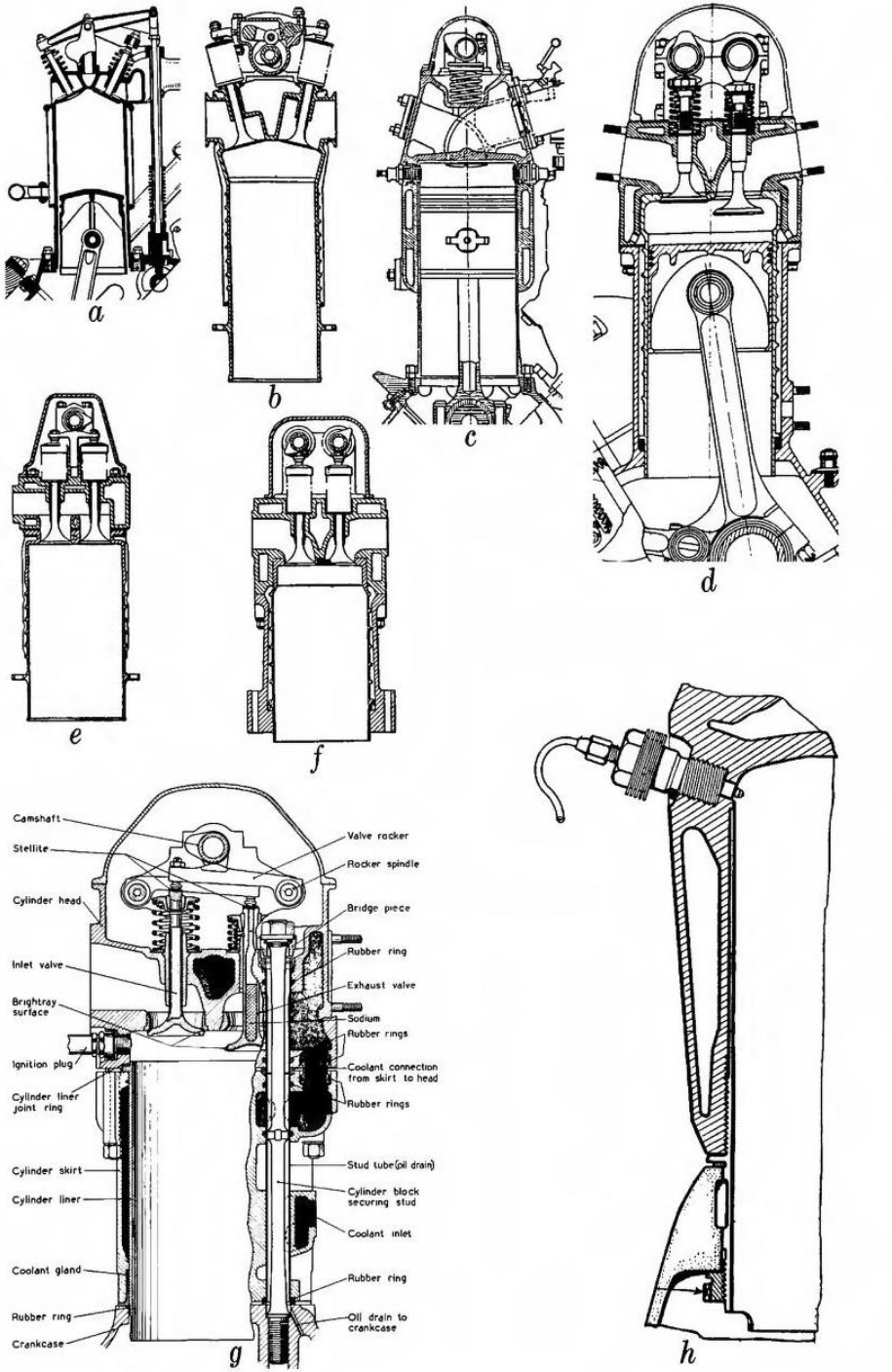
	Year	*Name*	*Barrel*	*Jacket*	*Load by*
a	1914	Curtiss OX-5	Cast iron	Monel sheet	Studs
b	1917	Liberty	Steel	Steel, welded	Barrel
c	1915	Hispano-Suiza	"	Cast aluminum	"
d	1921	Curtiss K-12 [1]	"	" "	Jacket
e	1922	Packard V-12 [2]	"	Steel, welded	Barrel
f	1923	Curtiss C-12 [3]	"	Cast aluminum	Jacket
g	1934	Rolls-Royce Merlin	"	" "	Studs
h	1935	Daimler-Benz [4]	"	" "	Barrel

[1] Water jacket is cast integral with crankcase.

[2] Aluminum casting containing valve ports and camshaft was continuous over 6 separate steel cylinders.

[3] Improvement on K-12 by bolting separate water-jacket casting to crankcase for easier assembly and disassembly.

[4] Unique fastening of cylinder barrels to crankcase by means of a ring nut.



- Through the cylinder barrels – Liberty (fig. 34b), Hispano-Suiza (fig.-34c), Packard (fig. 34e) and Daimler-Benz (fig. 34h)
- Through the aluminum water-jacket structure - Curtiss (fig. 34d and f) and Junkers V-12 gasoline engine
- By long bolts from cylinder heads to crankcase - Curtis OX-5 (fig. 34a), Rolls-Royce (fig. 34g) and Allison

The improvement in performance of liquid-cooled engines since 1918 has been astonishing. The following figures for two engines of nearly the same piston displacement and representing design ideas 30 years apart illustrate this development:

	1918	*1948*
Engine	Liberty	Packard Merlin
Number of cylinders	12	12
Bore and stroke, in.	5x7	5. 4x6
Maximum hp	420	2, 250
Rpm	1, 700	3, 000
Brake mean effective pressure, psi	118	360
Mean piston speed, ft-min	1, 985	3, 000
Hp per sq in. piston area	1. 78	8. 2
Weight, lb, per hp, dry (without water, oil, radiators)	2. 04	0. 78

These improvements are attributable not only to improved detail design, but also to important developments in fuel, supercharging and cooling fluid, which will be discussed later.

Air-Cooled Engines

The Gnome and its rotary descendants (LeRhone, Clerget, Bentley B.R., Oberiirsel and others) were obsolescent by 1918. Also obsolescent were air-cooled engines using cast-iron cylinders with integral heads and fins. These included the radial Anzani and the Renault V-type with its descendants, the RAF (Royal Aircraft Factory) and FIAT.

During the First World War it had become evident that the simple cast-iron cylinder had reached its limit and the Royal Aircraft Factory of Great Britain had employed Prof. A.H. Gibson, assisted by Samuel D. Heron, to develop more effective air-cooled cylinders. By 1918, they had constructed and tested steel cylinders with cast-aluminum heads screwed onto them that were capable of higher specific outputs than any cast-iron cylinder (fig. 35, right).

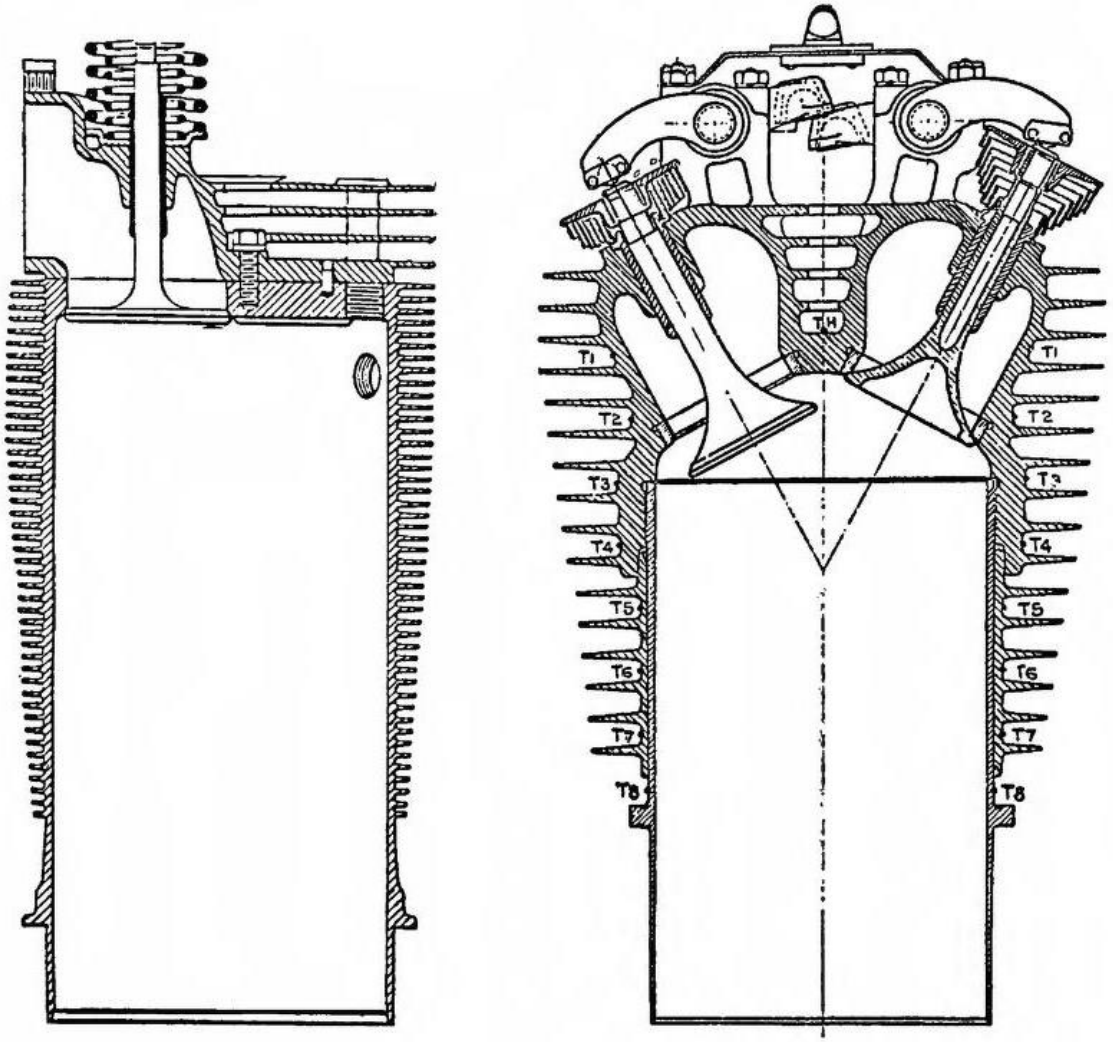


Figure 35.—British air-cooled cylinder development: *Left*, ABC steel cylinder with finned aluminum cap, 1917; this cylinder had poor head and valve cooling (from *Journal of the American Society of Naval Engineers*, vol. 38, no. 4, p. 872, 1926). *Right*, Cylinder developed by Dr. A. H. Gibson at Royal Aircraft Establishment, 1918, anticipated the essential features of modern air-cooled aircraft-engine cylinders—that is, aluminum head, with hard valve-seat inserts, screwed over steel barrel; applied finning on barrel is typical of many modern engines (from [British] Advisory Committee for Aeronautics *Report I.E.C. 260*, p. 268, fig. 11, January 1919).

However, the practical use of the aluminum-head cylinder in England was seriously delayed by a parallel development, starting in 1917, of air-cooled radials with steel flat-head cylinders capped by a bolted-on valve-port assembly of cast-iron or cast-aluminum (fig. 35, left). This cylinder design suffered from the same trouble as the early Hispano-Suiza engines, namely, poor exhaust-valve cooling because of poor contact between the head and the separate cooling element; however, the first radial engine using this cylinder type, the ABC (All British Engine Company) Wasp of 4-1/2 in. bore, was successful enough to gain the support of the British government for its development in a larger version; the Dragonfly of 5-1/2 in. bore. The fact that cooling problems increase with increased cylinder size evidently was not realized at the time.

This development finally became, through several changes in ownership, the Bristol Jupiter engine (fig. 37), which was built and used in considerable quantities in England and in Europe, chiefly for military purposes. It was never a really satisfactory aircraft engine because of poor exhaust-valve cooling (S.D. Heron said that its consumption should be given in terms of pounds of exhaust valves rather than in pounds of fuel per-horsepower-hour!). Finally realizing this fact, Bristol changed from steel heads to Aluminum heads with the Jupiter F, about 1930.

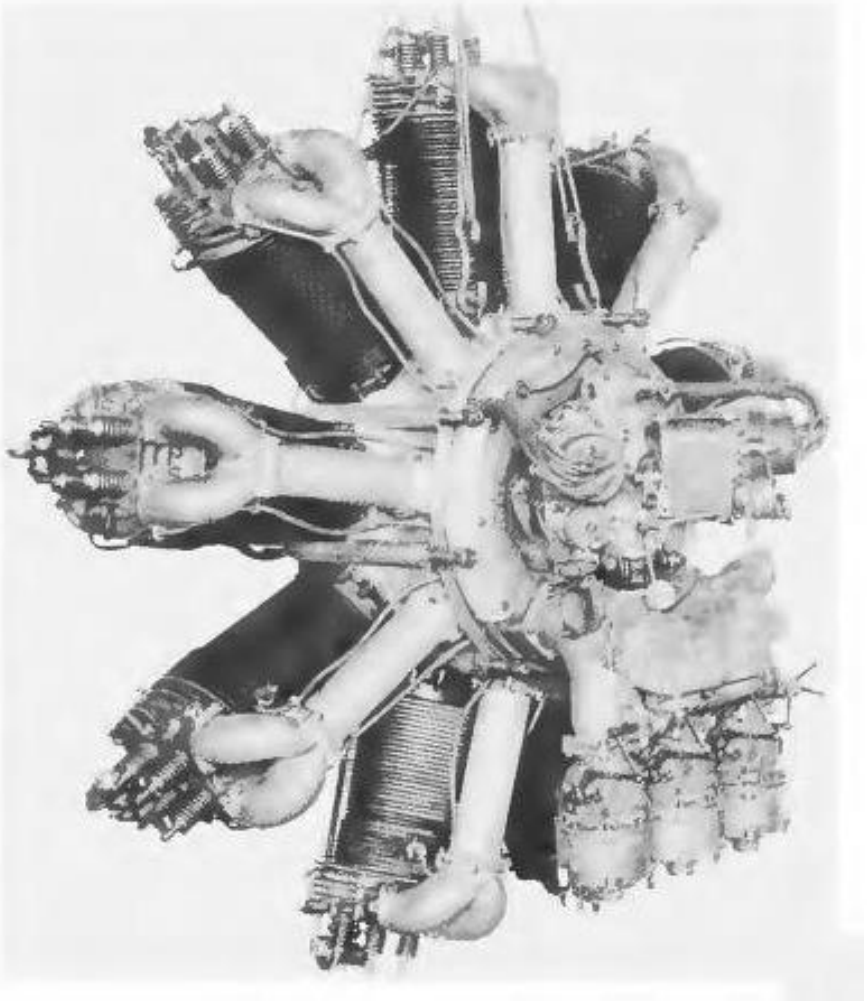


Figure 37.—Bristol Jupiter 9-cylinder engine, 1922; 400 hp at 1650 rpm, 700 lb. This example was built by Cosmos Engineering Co., Ltd. Cylinder design is similar to that of ABC cylinder in figure 35, left. (*Photo A-3104*)

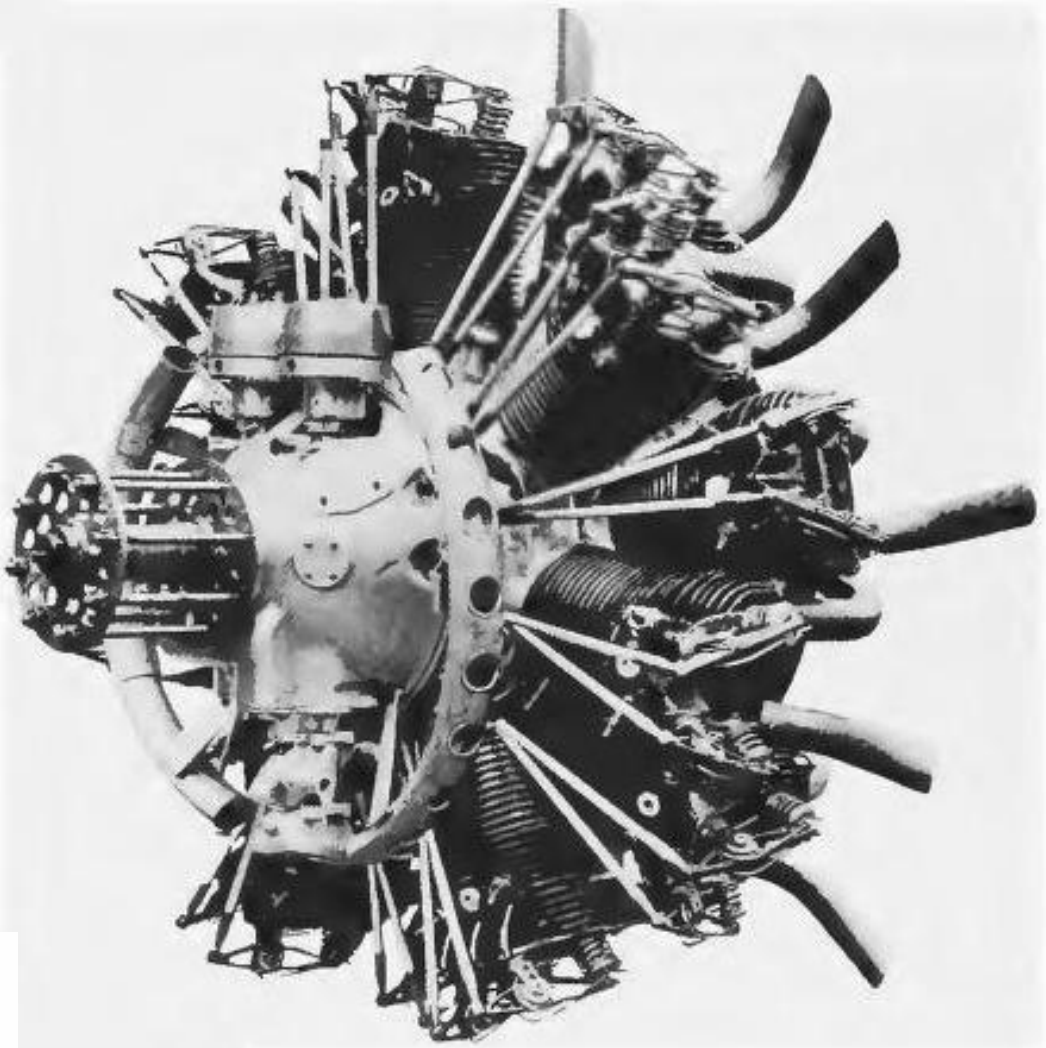


Figure 38.—Armstrong-Siddeley Jaguar 14-cylinder 2-row radial engine, about 1922; 360 hp at 2000 rpm, 910 lb. First successful British radial engine with aluminum-head cylinders and gear-driven supercharger. Cylinder design is similar to that of Gibson cylinder in figure 35, right (*Photo A-3111*)

Meanwhile the Gibson-Heron type cylinders had been further developed by Armstrong-Siddeley and were used on the Jaguar 2-row radial (fig. 38) which passed its type-test in 1922, ten years after Gibson started his work.

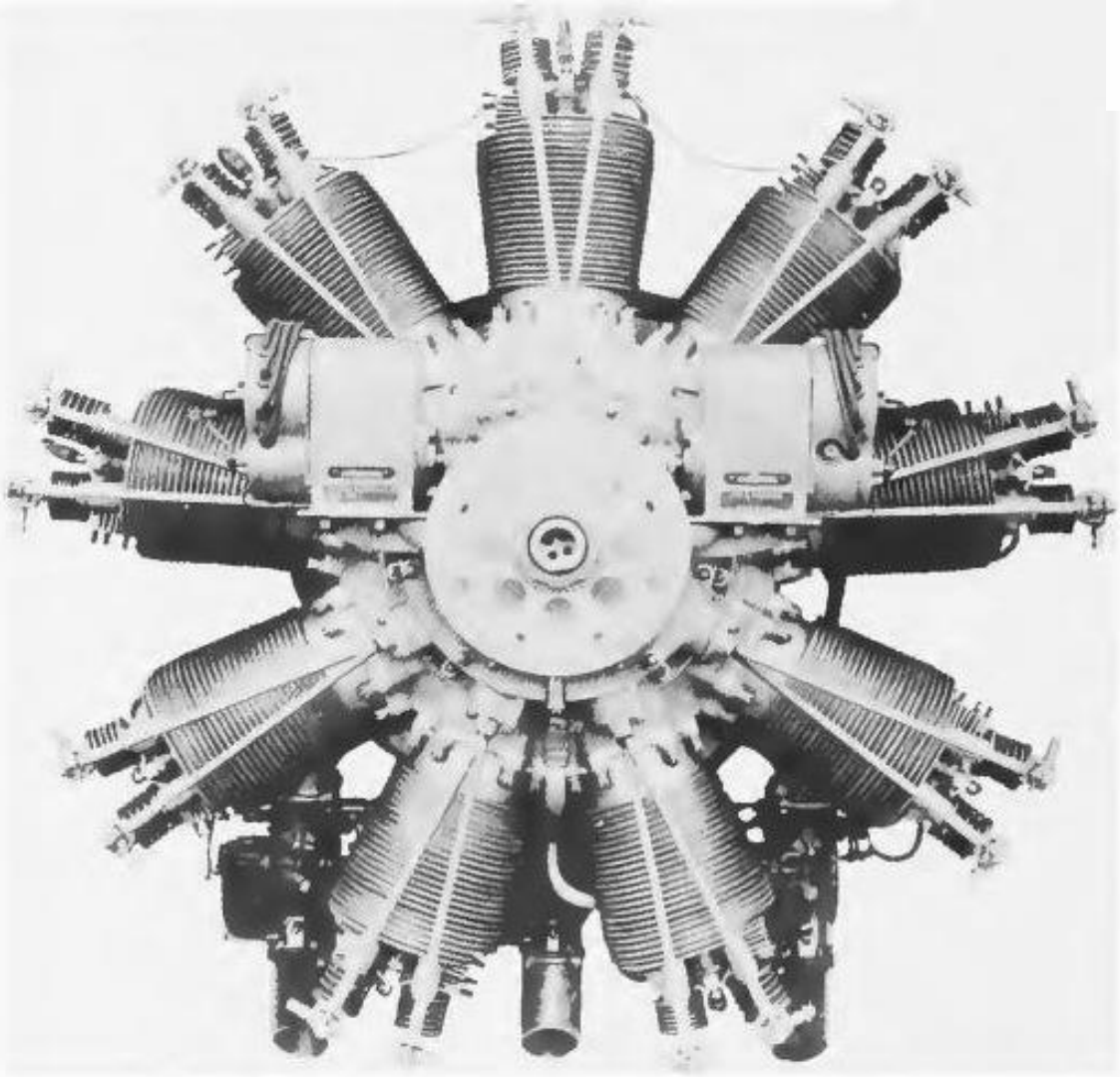
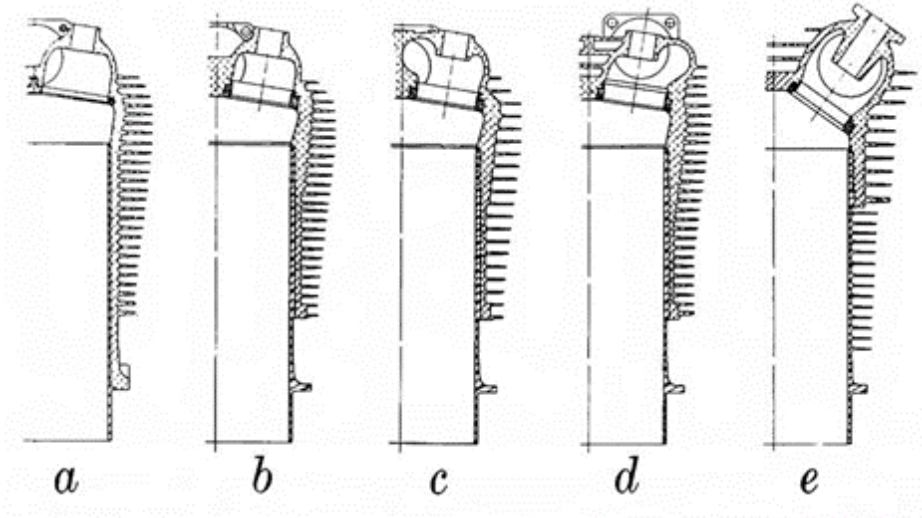
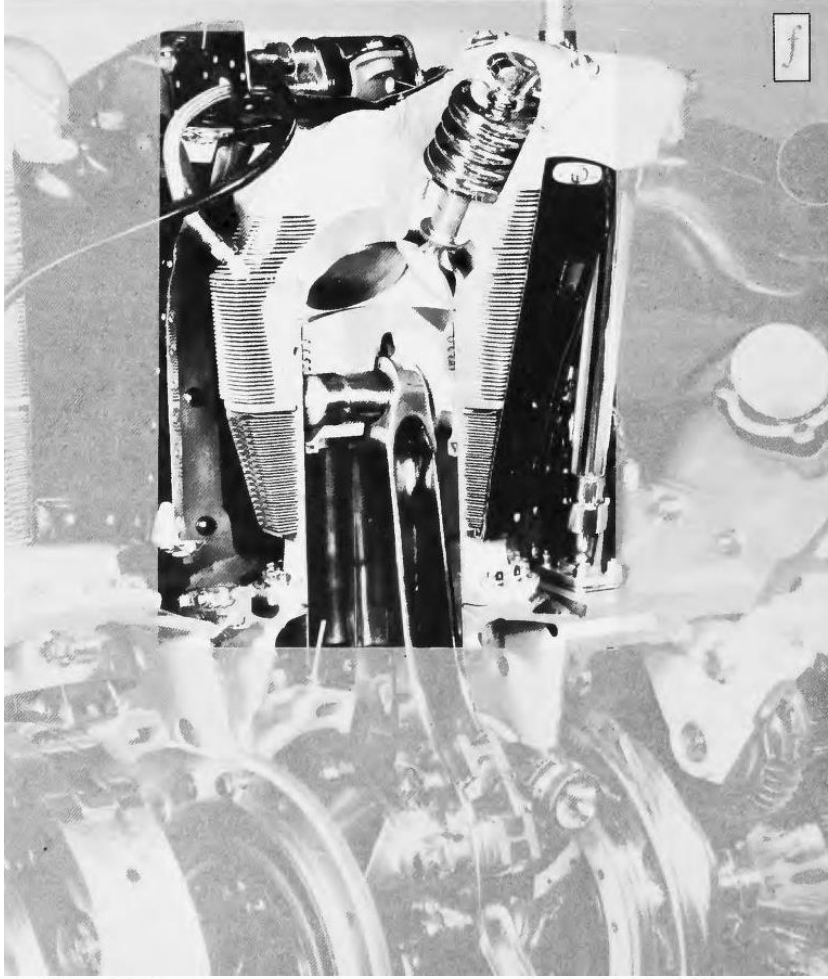


Figure 39.—Lawrance J-1 air-cooled radial engine, 1922. The first American-designed 9-cylinder radial to be put into general use, its rating was 200 hp at 1800 rpm, 476 lb. The cast-aluminum cylinder head and internally cooled exhaust valves have been retained in modern practice. Cylinder section is shown in figure 36a. (*Photo A-3086*)

A parallel development of air-cooled engines with aluminum cylinders having steel liners was begun about 1916 by Charles L. Lawrance. Starting with a 2-cylinder opposed engine, he built a 3-cylinder engine in 1919 and finally a 9-cylinder 200-hp radial in 1921. This was the J-1 (fig. 39), which was supported by an order for 200 engines from the United States Navy.





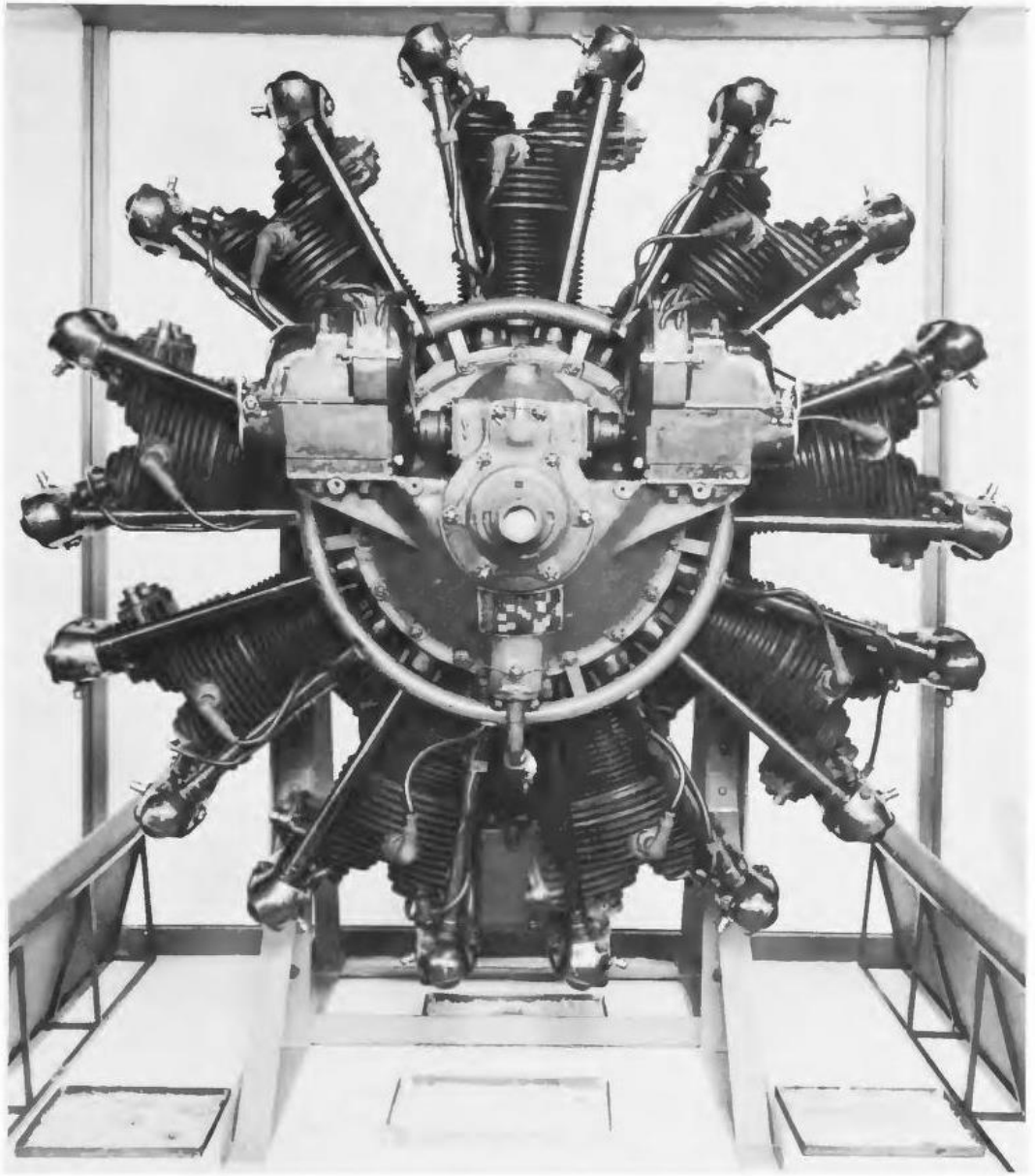
In 1922 Lawrance's company was absorbed by the Wright Aeronautical Corporation and, with Navy support, the 9-cylinder engine was built in improved models known as the Wright J-3, and J-4b, all with essentially the Lawrance cylinder design (see fig. 36a-d).

Figure 36.—Development of air-cooled cylinders in the United States: *a*, Lawrence J–1 (1922) and Wright Aeronautical J–3 (1923) used cast aluminum structure with thin steel liner. *b*, Wright J–4 (1924) used flanged steel barrel with screwed-on head and jacket casting. *c*, Wright J–4A (1924–5) similar to J–4. *d*, Wright J–4B (1925–6) similar to J–4A but with air passage and fins between the ports. *e*, Wright J–5 (1926–7) designed by Heron; barrel carries integral steel fins. *f*, Wright Turbo-Cyclone cylinder of 1948, with forged and machined aluminum head, forged-steel barrel with rolled-on aluminum fins, and sodium-cooled exhaust valves, stellite-faced, has more than 100 square inches of fin area for each square inch of piston area. (*a–e*, from *Transactions of the Society of Automotive Engineers*, vol. 21, pt. 2, p. 872, 1926; *f*, *courtesy Wright Aeronautical Corporation.*)

During the same period; 1918-1926, S.D. Heron had left England and had been employed by the United States Army Air Service at McCook Field, Dayton, Ohio, to assist in the development of large radial engines. Heron was a devoted worker and an able Engineer and by 1921 had developed successful air-cooled cylinders of nearly 6-in. bore, based on his work with Gibson plus his own improvements worked-out at McCook Field.

Against considerable resistance from their Chief Engineers, who at the time were thoroughly committed to water cooling, the Curtiss Aeroplane Company and Wright Aeronautical accepted contracts from the Army Air Corps to build prototype radial engines with Heron-designed cylinders. Some engines were built, but in very small numbers.

The Lawrance and Heron developments were brought together when Heron, in 1926, joined Wright Aeronautical Corporation, of which Lawrance was President. The first result; the Wright J-5, was essentially a Lawrance-type engine with Heron-type cylinders (figs. 36e and 40).



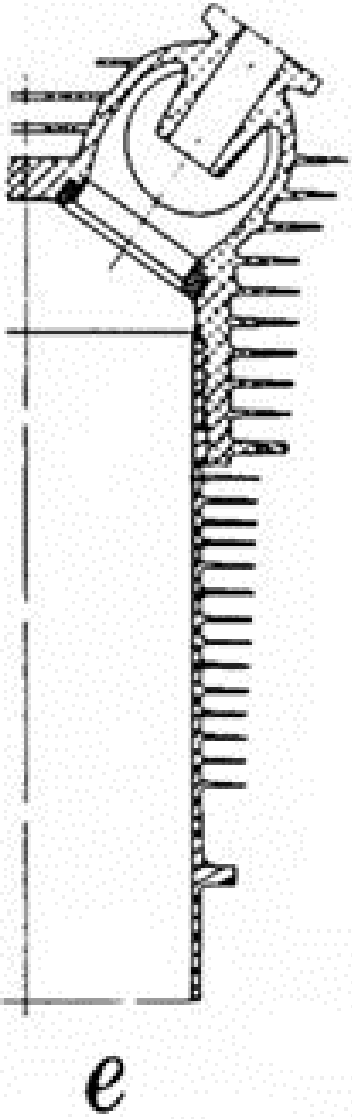


Figure 40.—Wright Whirlwind J-5 engine (NASM 121) of 1927; 220 hp at 1800 rpm, 510 lb. This is the type used in transoceanic flights by Lindbergh, Chamberlin, Byrd, and others. Cylinder section is shown in figure 36e. (*Photo A-44092*)

This was a successful engine of the 200-hp class, as evidenced by its use in Lindbergh's New York-Paris flight, 20-21 May 1927, in many other pioneering flights and in a number of early transport airplanes. It won the Robert J. Collier trophy, this country's most sought after aviation award, in 1927. Wright Aeronautical had also been experimenting with air-cooled radial engines having cylinders larger than those of the J-5, the bore of which was 4.5 in., but the first really successful engine of the larger type was the Pratt and Whitney 425-hp Wasp of 1927.

Subsequent to the merger of Wright and Lawrance, a considerable fraction of the Wright Aeronautical staff, headed by the Chief Engineer George J. Mead, resigned to join Frederick B. Rentschler in forming the Pratt & Whitney Aircraft Company of Hartford, Connecticut. In a time almost as short as that for the Liberty engine, this new group produced the Wasp (shown in fig. 41); the first large radial air-cooled engine of what may be called "modern" design.

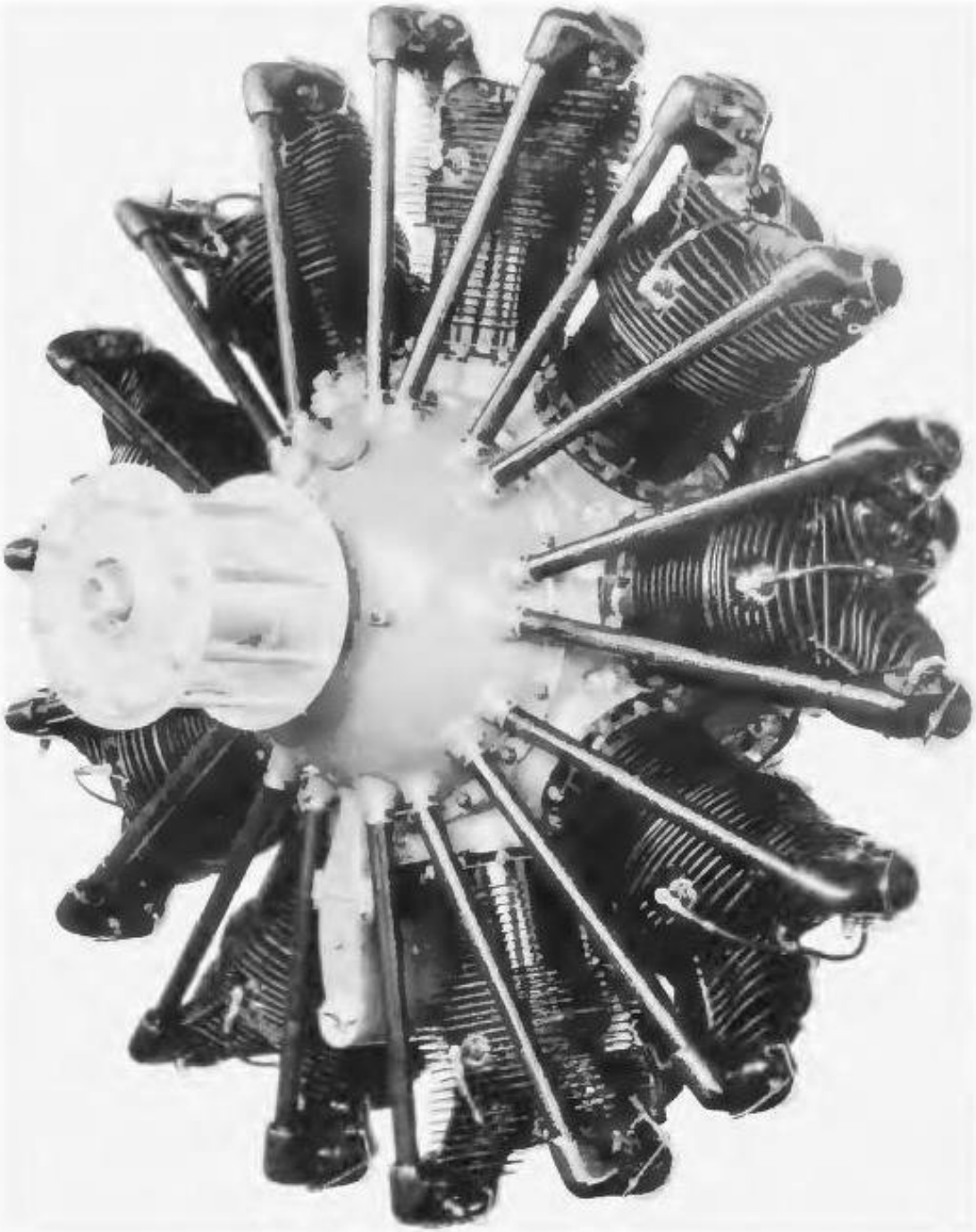


Figure 41.—Pratt & Whitney Wasp air-cooled radial engine, 1926; 425 hp at 1900 rpm, 650 lb. The first such United States engine of over 400 hp to go into general service, it pioneered many technical features which became standard practice for this type. Cylinder design was similar to that of the Wright J-5 (fig. 36e) except that rocker-arm supports and housing were cast integral with the cylinder head—an important innovation. (*Photo A-3087*)

Figure 42.—Forged aluminum crankcase of Pratt & Whitney Wasp engine. Left, complete crankcase. Right, forging of one half before machining. (*Photo A-3105*)

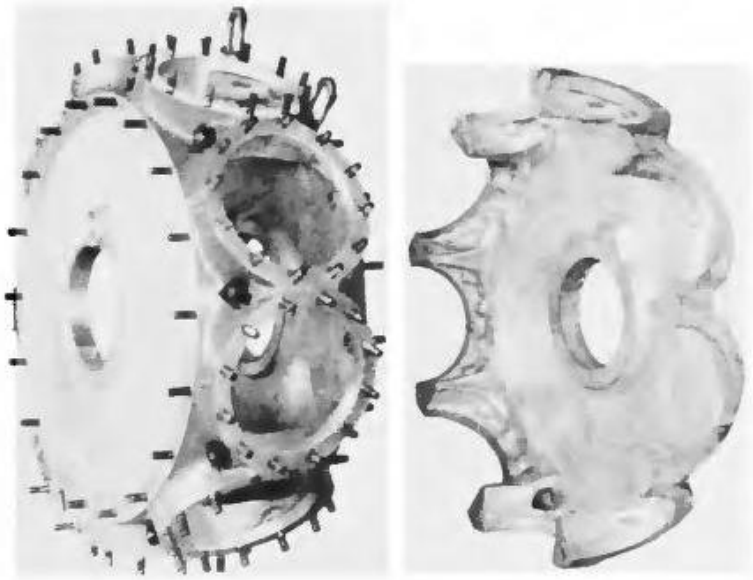
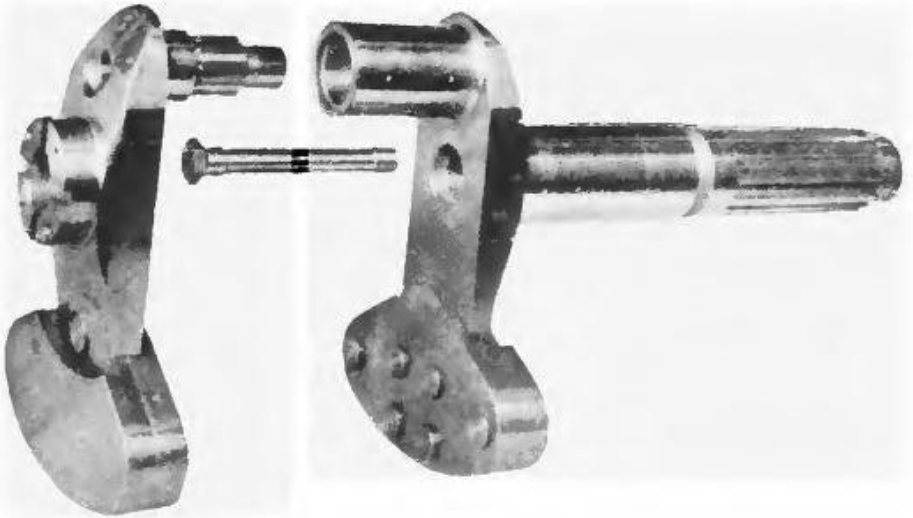


Figure 43.—Divided crankshaft, from Pratt & Whitney Wasp engine. The Gnome (see fig. 20) pioneered this design for radial aircraft engines. (*Photo A-3106*)



The notable features of this engine included:

Rating, 425 hp at 1,800 rpm
9 cylinders, 5.75x5.75 in. bore and stroke
Built-in geared centrifugal supercharger
Fully enclosed valve gear, with rocker boxes integral with cylinder head (fig. 41)
Forged and machined crankcase (fig. 42)
Domed-head, 2-valve cylinders, basically of the Heron design
Divided crankpin (fig. 43) with one-piece master rod

The only important basic improvements to be developed later for radial air-cooled engines were:

The forged and machined aluminum cylinder head, pioneered by Bristol in England and Wright Aeronautical in the United States about 1940 (Gnome had pioneered the forged and machined steel head for air-cooled engines)

The automatically lubricated (by engine oil) valve gear, pioneered by Pratt & Whitney in 1932 (first used in water-cooled aero engines by Hispano-Suiza, ca. 1914)

The vibration-absorbing counterweight, introduced by Wright Aeronautical in 1935, which will be discussed later

Second-order balancing weights, to reduce unbalanced forces

The basic features of the Wasp, with the addition of the above improvements, are used in all modern large air-cooled radial engines. This type, of course, has dominated transport and much of military aviation until the recent advent of the jet and turbine engine.

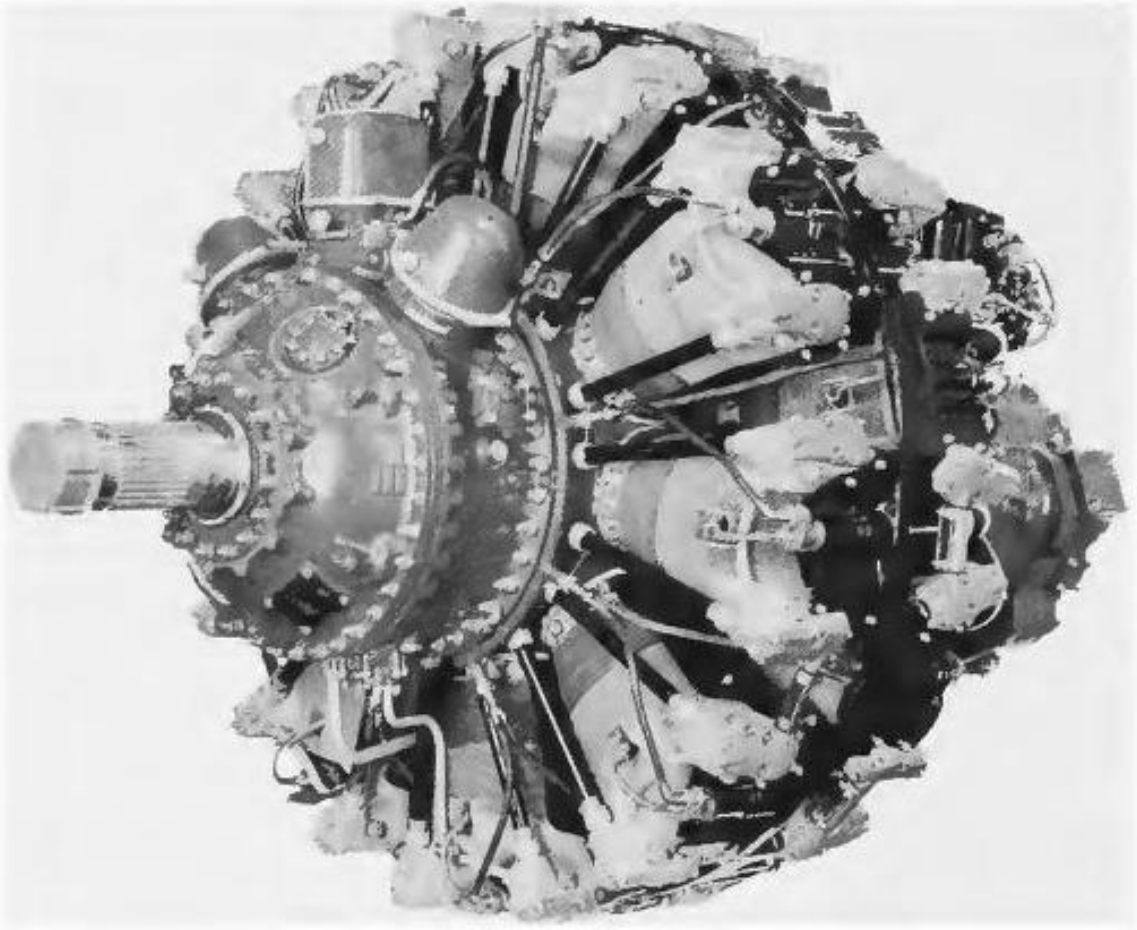
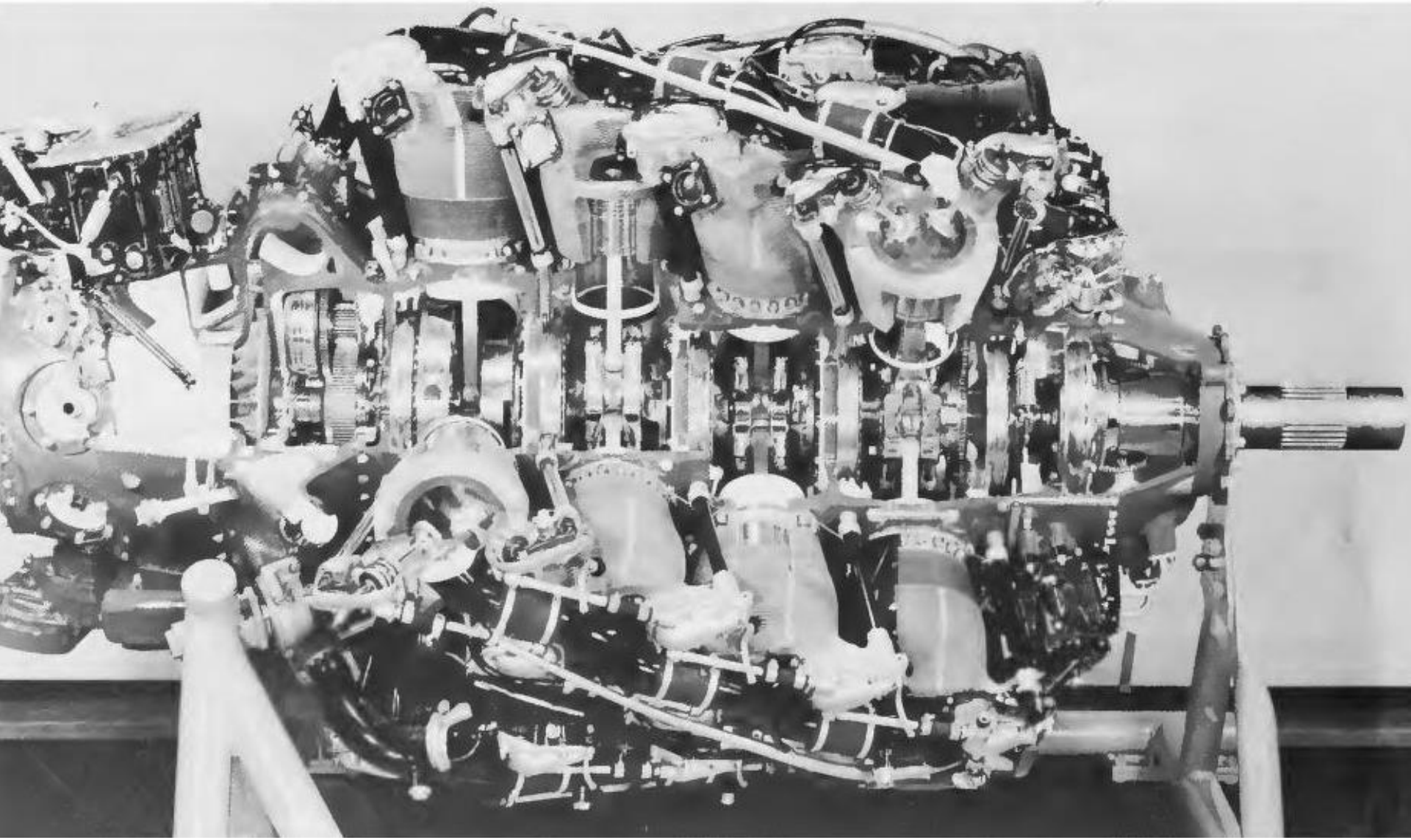


Figure 44.—Pratt & Whtney Double Wasp R-2800-CB-16 18-cylinder air-cooled 2-row radial engine, 1946; 2800 hp at 2800 rpm, 2327 lb. Earlier models were extensively used in World War II, and this model was widely used in commercial and military aircraft. (*Photo A-3103*)

Figures 44-47 show the outstanding modern air-cooled radial engines which are basically descendants of the Gnome, but with greatly improved detail design, including the composite steel and aluminum cylinder construction pioneered by Gibson, Heron, and Lawrance. Figure 36 shows the evolution of Wright cylinders from about 1920 to 1930, in comparison with the cylinder used on the Wright turbo-compound engine, the most highly developed air-cooled radial.

Figure 45.—Pratt & Whitney Wasp Major R-4360 28-cylinder 4-row radial engine, 1948 (cutaway); 3500 hp at 2900 rpm, 3842 lb. A post-World War II military and commercial engine. (*Photo A-4132*)



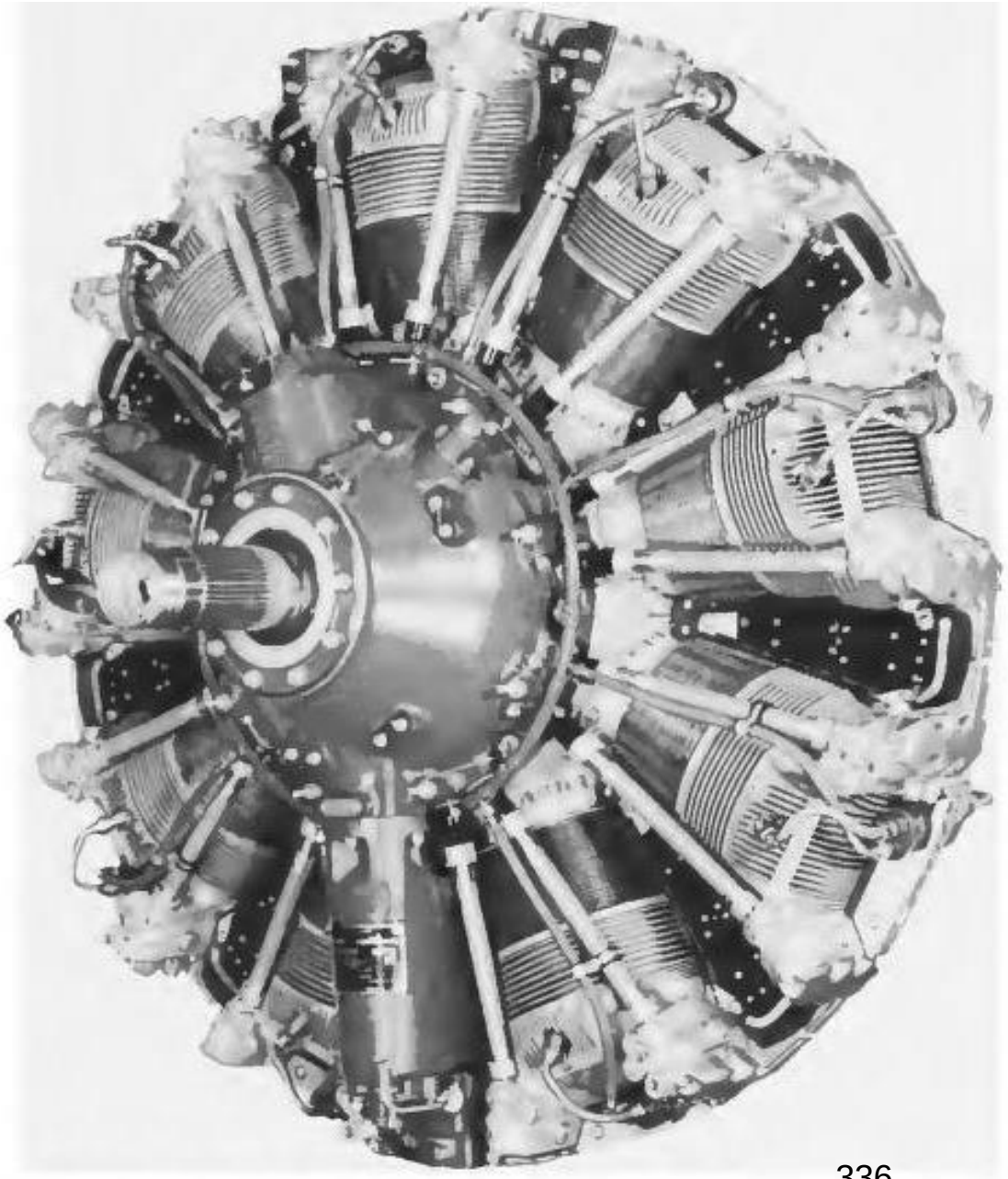
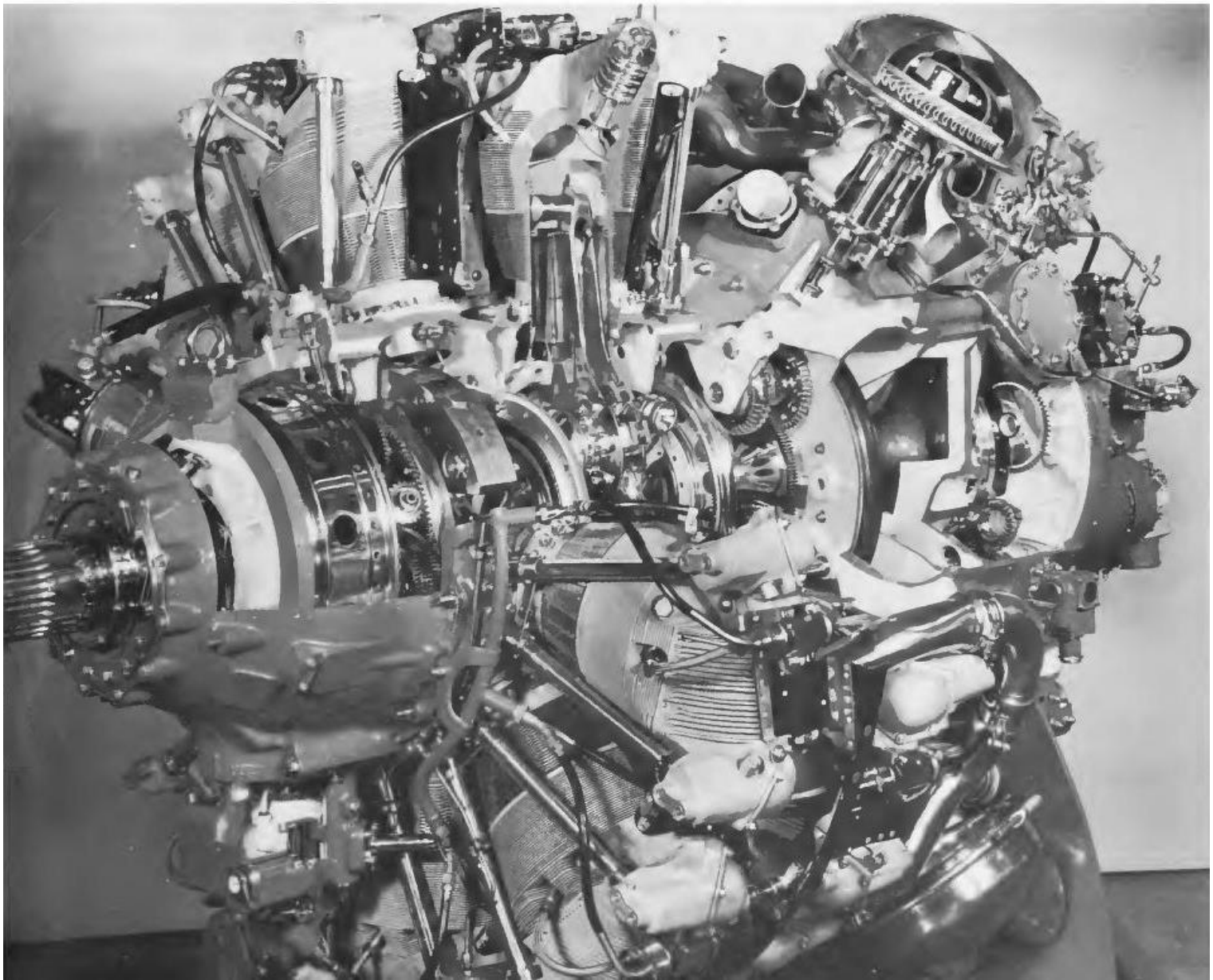


Figure 46.—Wright Cyclone R-1820 1425-hp 9-cylinder engine, 1953. When this engine first came into use in 1933, it was rated at 525 hp at 1900 rpm. It was used in the Douglas DC-3 and Boeing B-17, among others. (*Photo A-3090*)

Figure 47.—Wright Turbo-Cyclone R-3350 18-cylinder 2-row radial engine, 1955 (cutaway); 3700 hp at 2900 rpm, about 3000 lb. This post-war engine had three exhaust-driven turbines geared to the crankshaft, and it was the latest and most highly developed piston type to be widely used in large military and commercial airplanes. (*Photo A-3089*)



The following comparison illustrates the development of air-cooled engines from 1922 to the present time:

	1922	*1955*
Engine	Lawrance J–1	Wright Turbo-Compound
Number of cylinders	9	18
Bore and stroke, in	4.5x5.5	6.125x6.3125
Maximum hp	200	3, 700
Rpm	1, 800	2, 900
Brake mean effective pressure, psi	112	302
Mean piston speed, ft/min	1, 650	3, 070
Hp per sq in. piston area	1. 4	7. 0
Weight, lb, per hp, dry (without oil and oil radiators)	2.38	0.96

As had been true of liquid-cooled engines, improvements in fuels, supercharging, and cooling systems as well as great improvements in detail design, were important factors in this development.

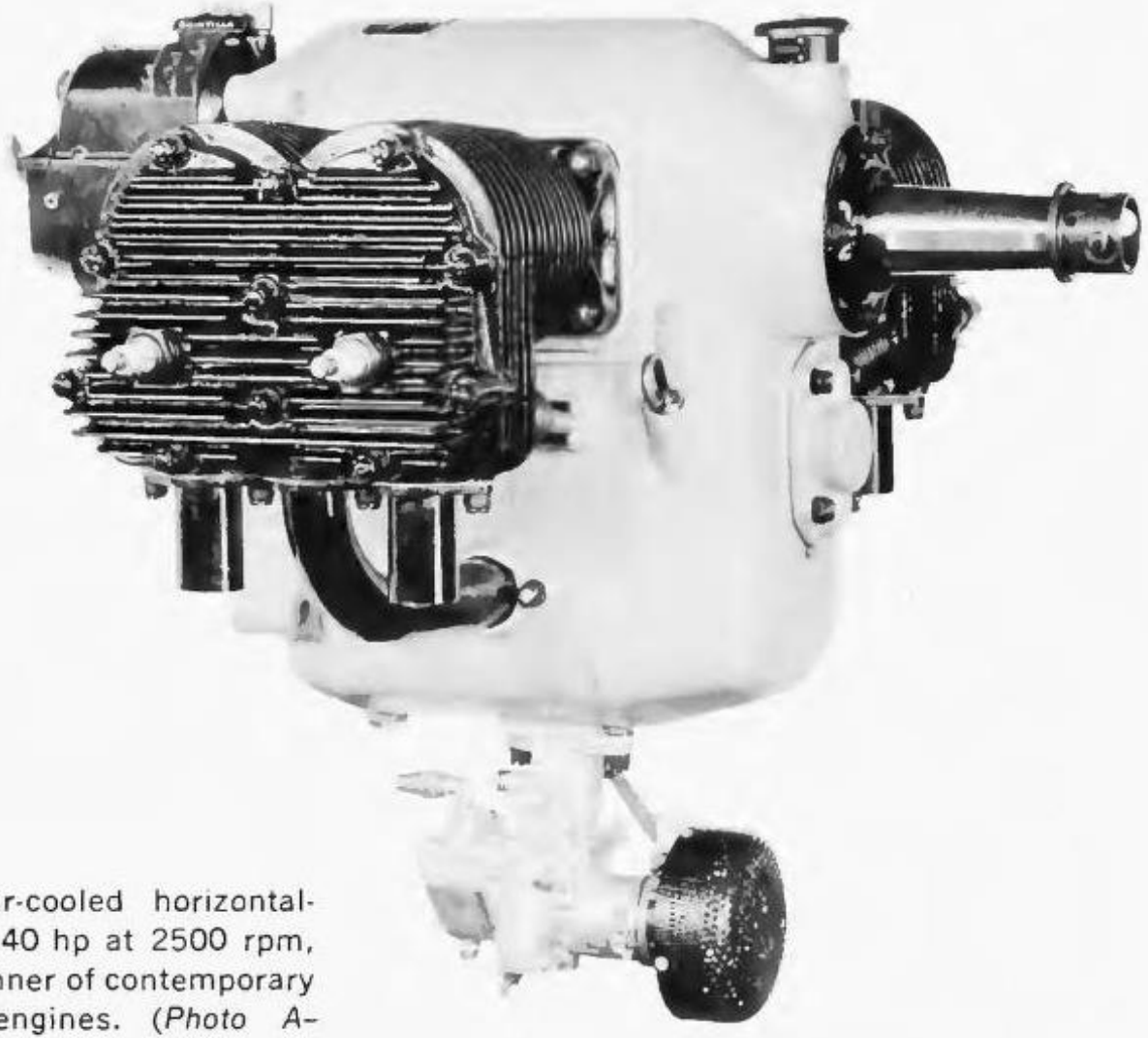


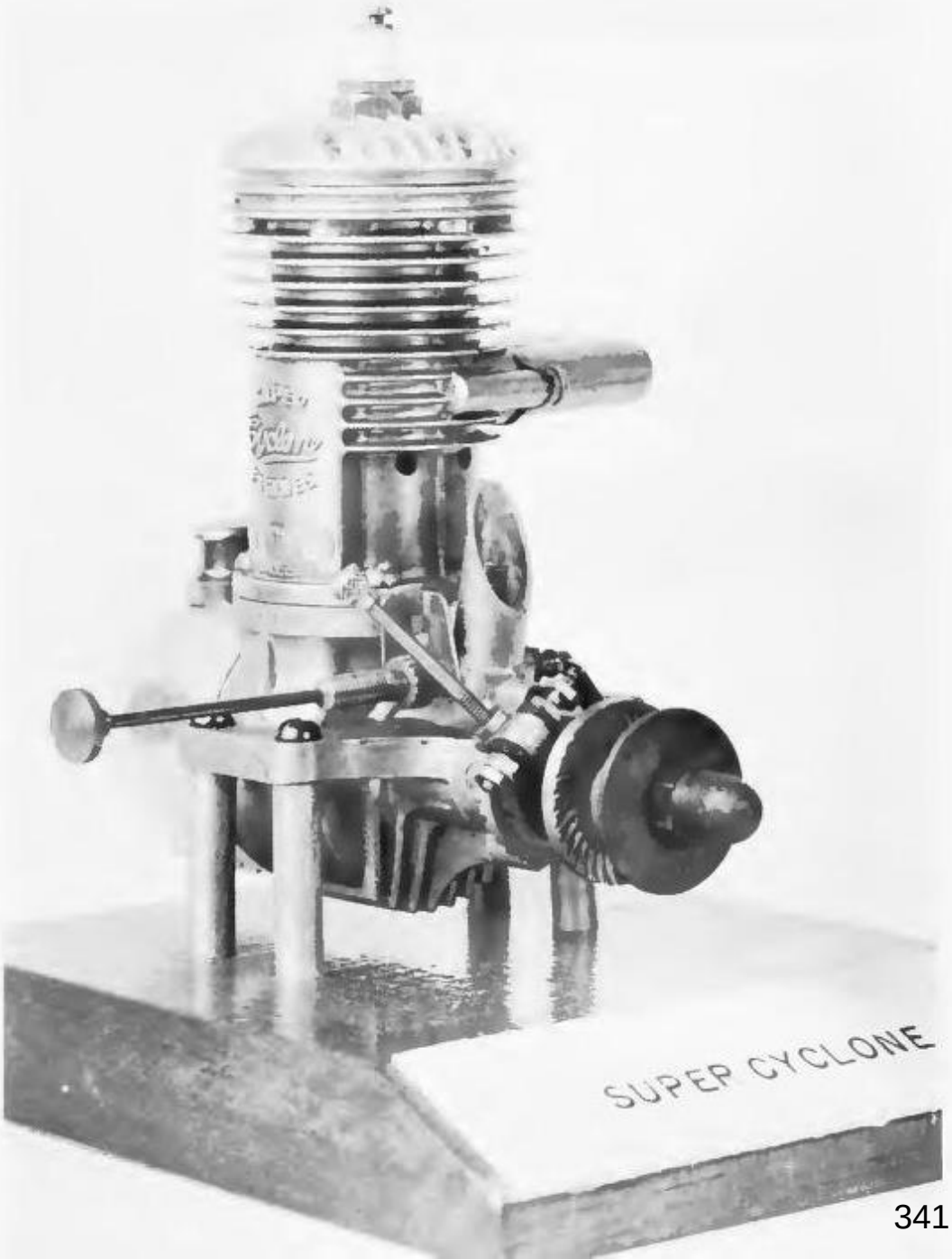
Figure 48.—Continental A-40 air-cooled horizontal-opposed 4-cylinder engine, 1931; 40 hp at 2500 rpm, 145 lb. This engine was the forerunner of contemporary horizontal-opposed light-plane engines. (*Photo A-50897*)

The subject of the air-cooled engine should not be left without mention of the remarkable development of the light-airplane engine, beginning with the small British 4-cylinder vertical Cirrus and DeHavilland Gypsy engines of 1927 and of the 4-cylinder Continental A-40 (fig. 48).

Introduced in 1931, this 38-hp engine used cast-iron L-head cylinders. It was the forerunner of contemporary horizontal-opposed light-plane engines. Later models use composite aluminum and steel cylinders similar to the J-5 cylinder of figure 36e. Engines of this type built by Continental Motors Corporation and by others, including principally the Lycoming Division of Avco Corporation, have developed to a remarkable degree of reliability and performance. In 1961, a license to build Continental engines of this type was acquired by Rolls-Royce, a real compliment to the high quality of these small power-plants.

Another interesting category of air-cooled engines comprises those built for installation in model airplanes. These are usually 1-cylinder 2-cycle engines of less than 1 in. bore and stroke (fig. 49).

Figure 49.—Model airplane engine, Super Cyclone (NASM 1944-20), about 1950; about 1/10 hp at 10,000 rpm, 5 ounces. This typical single-cylinder, 2-cycle, air-cooled model engine uses special fuel with hot-wire ignition. (*Photo A-36625*)



Some are rated up to 1-hp at speeds of 15,000 rpm or more. Originating in the United States about 1930, these engines were produced in very large quantities between 1945 and 1950. It is claimed that there were 180 manufacturers of model engines in the United States during that period and their total production, in number of engines, probably exceeded that of all other aircraft engines combined. The popularity of engine-powered model airplanes fell off about 1950, but has revived during the past decade. During 1966, one manufacturer alone produced a million model aero-engines.

Air vs. Liquid Cooling

The classic and often emotionally charged argument over the relative merits of liquid- and air-cooling started with the early days of flying (Antoinette vs. Gnome, for example) and persisted to the end of World War II, when the advent of jets and turbo props diverted attention elsewhere.

As we have seen, water cooling was dominant through World War I, except for the rotaries, which at its close were obsolescent. European military aviation remained generally committed to water cooling up to and through World War II, although some air-cooled engines were used in bombers and transports, and there was one excellent air-cooled European fighter, the Focke-Wulf with the BMW 2-row radial, developed from a Pratt & Whitney license. Japanese fighter aircraft also used air-cooled radials copied from Wright and Pratt & Whitney designs. Their other military aircraft used these and copies of the German Daimler-Benz liquid-cooled engine (fig. 33).

In the United States, the Navy made a commitment to air cooling in 1921 which has held for reciprocating engines to this day. It was chiefly Navy support that underwrote early Pratt & Whitney and Wright air-cooling developments. The reason for this choice lay in the limitations of the aircraft carrier, which imposed such design criteria as short takeoff, compact size and minimum maintenance. Commander Bruce Leighton was probably the individual most responsible for this well-considered decision.

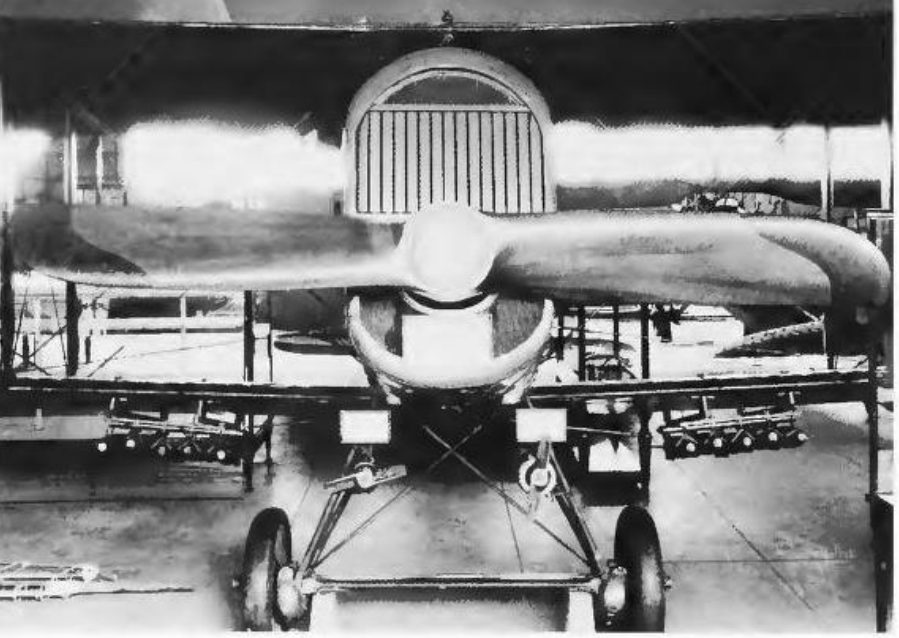


Figure 50.—Frontal coolant radiator for Liberty engine on DeHavilland DH-4 (NASM 1919-51), 1918. This position for the radiator required a large cooling surface and contributed heavily to airplane drag. (*Photo A-9850-D*).

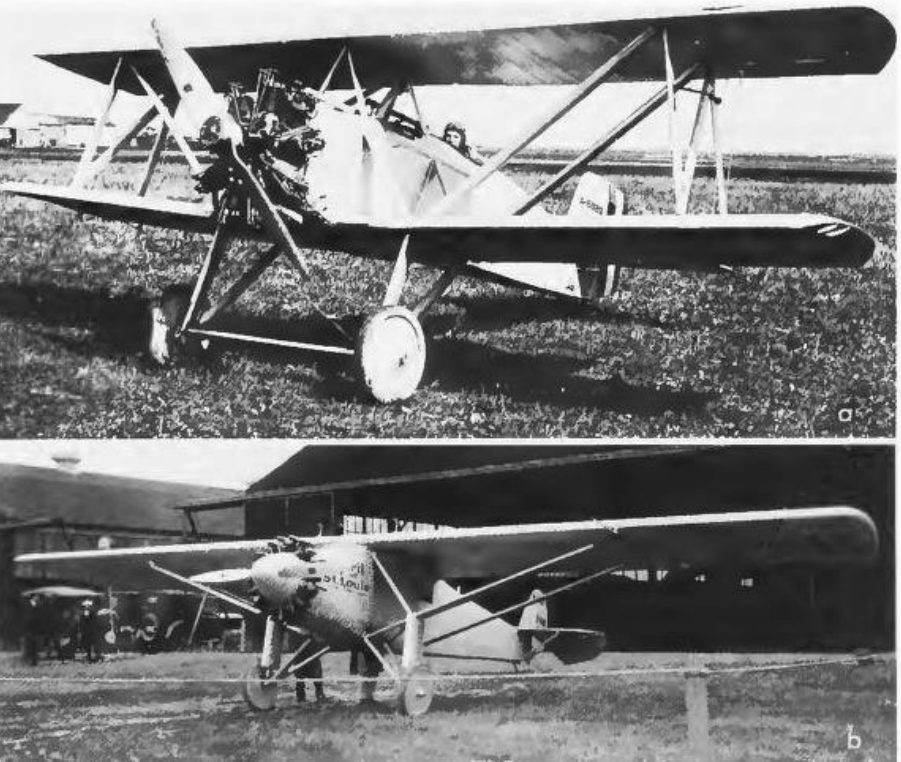


Figure 51.—Completely exposed Lawrance J-1 radial engine on Curtiss F4-C1, about 1924. *Below*, Partially exposed Wright J-5 engine on Ryan NYP airplane *Spirit of St. Louis* (NASM 1928-21), after return from Europe, 1927. (*Photos A-47190, A-1193-B*).

The most intense controversy on this subject took place in the United States Army Air Service, whose support for air-cooled engine development in the 1920s and 1930s was never as enthusiastic as that of the Navy, because of the assumed larger frontal area and greater drag of air-cooled radials, especially for use in fighter airplanes. That cooling drag was a real problem in the early days is illustrated by figures 50 and 51, showing typical installations of the 1920s.

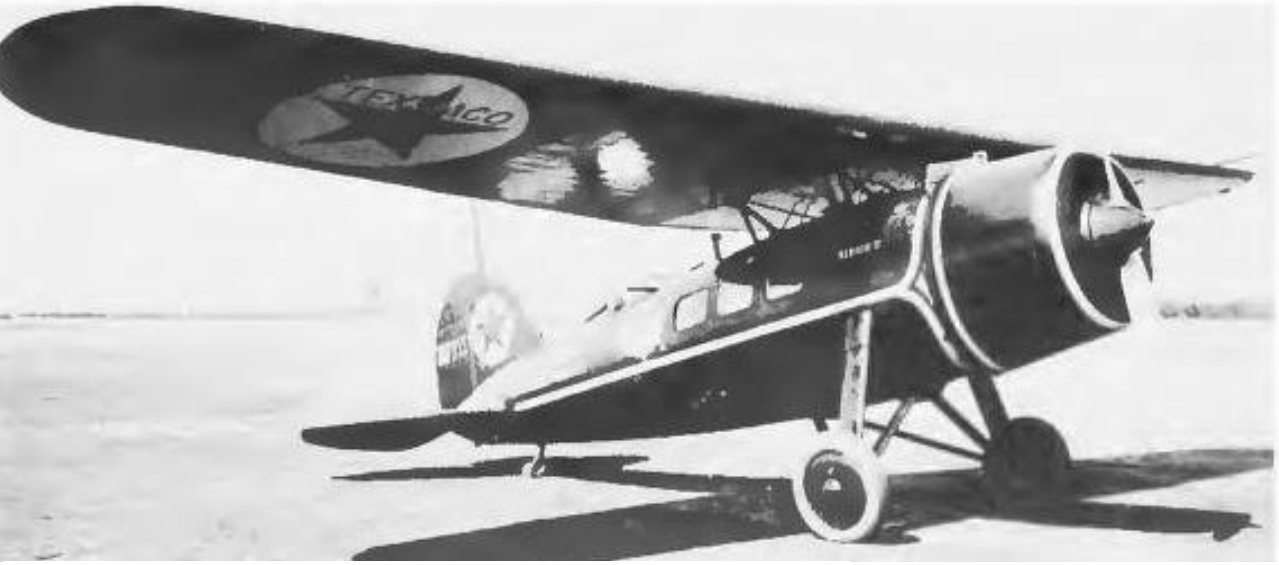


Figure 52.—Radial engine with NACA-type cowling on Frank Hawks' Lockheed Air Express, 1929. (*Photo A-33428-E*)

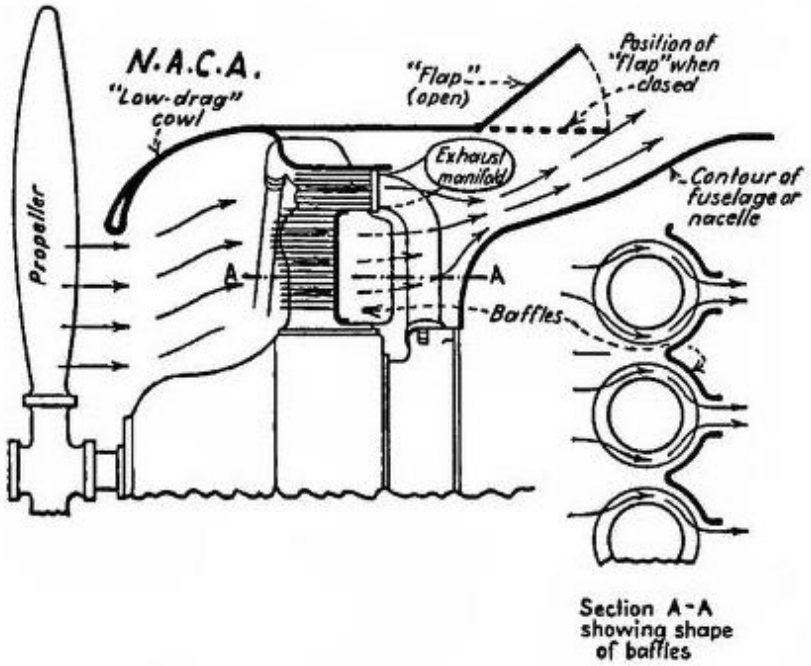


Figure 53.—Cooling-air flow in tractor installation of a cowled radial engine. Only the upper half of the installation is shown.

The drag of air-cooled engines was greatly reduced by the advent of the very effective cowling and cylinder baffing developed at Langley Field by NACA, starting in 1929 (figs. 52 and 53).

Further reductions in cooling drag were achieved by increased cooling-fin area, which reduced the air velocity required for cooling (compare figs. 36a-e and 36f). These developments put the air-cooled radial virtually on a par with the water-cooled engines with regard to cooling drag, until the advent of high-temperature liquid-cooling with glycol-water mixtures. Figure 54 shows modern cowling for the air-cooled radial engines.

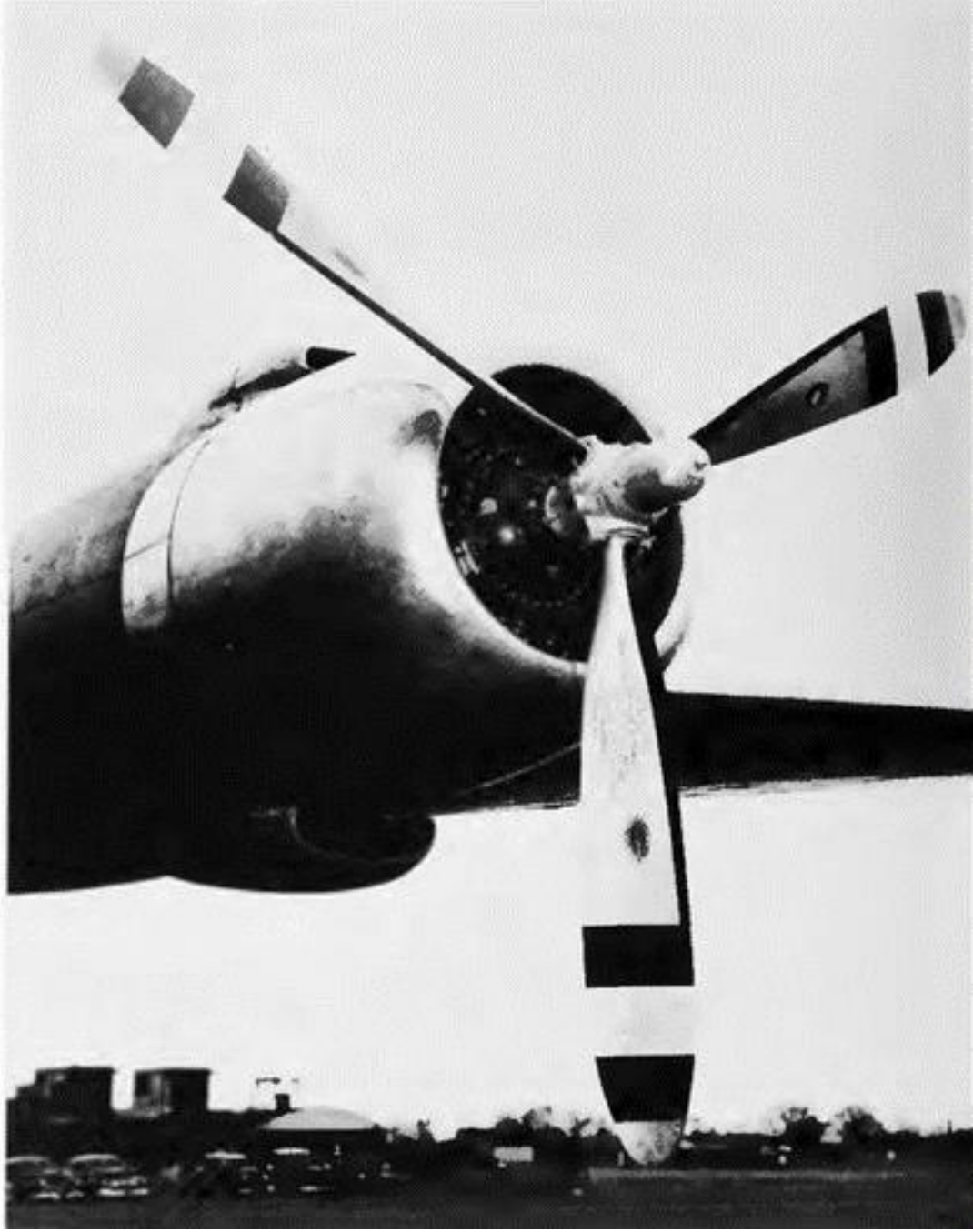
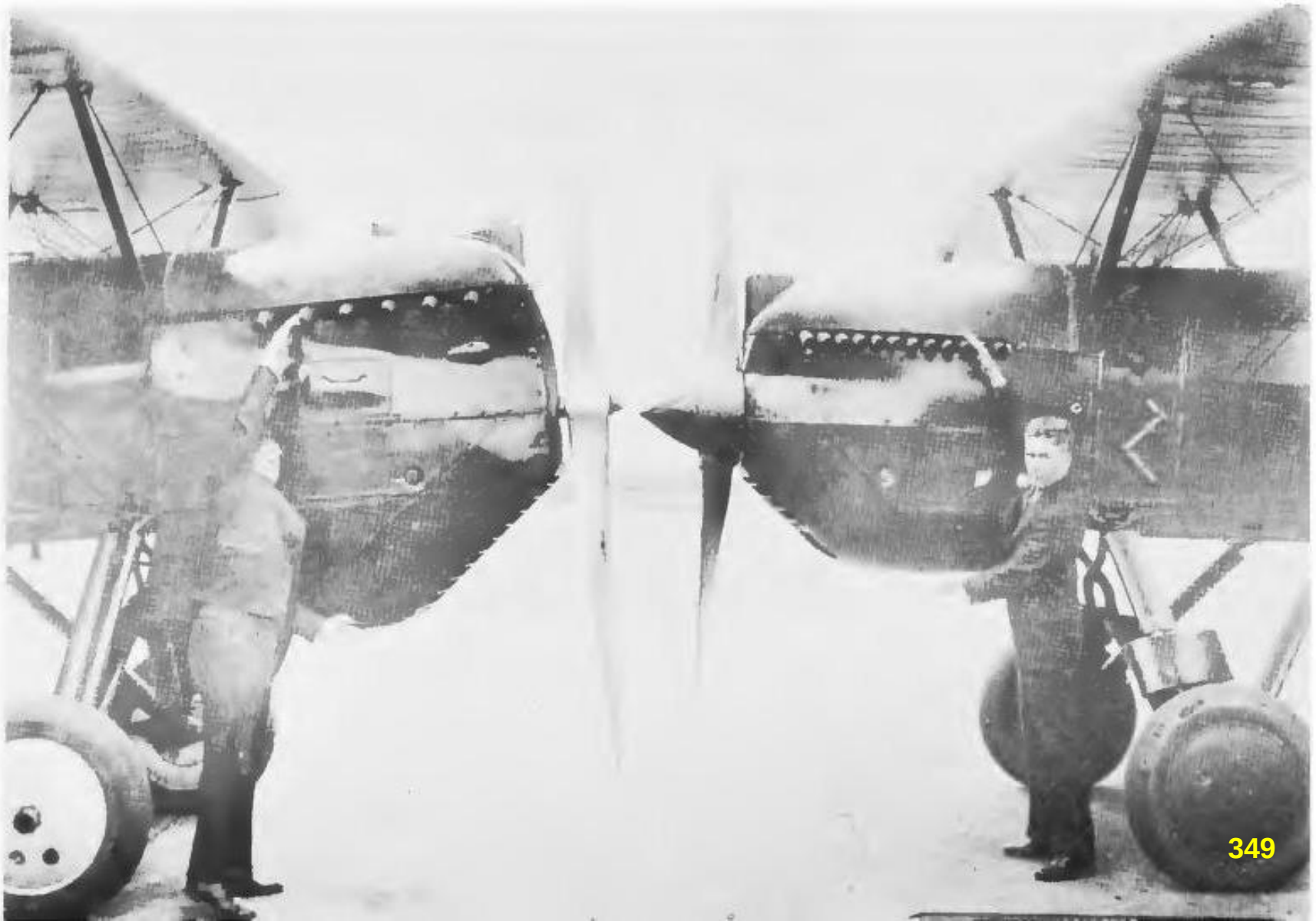


Figure 54.—Installation of radial engine on a Douglas DC-6, 1949, showing modern cowling for radial engine, with controllable outlet flaps. (*Photo A-50822*)

The use of high-boiling liquids (mixtures of water and ethylene glycol) for engines formerly water-cooled was an important forward step in reducing the heat-transfer area, and thereby the drag, of radiators for liquid-cooled engines. At the suggestion of S.D. Heron, a 1-cylinder engine was tested at McCook Field in 1923 with a mixture of water and ethylene glycol at a high coolant temperature, probably near 300-degrees F. During 1928-29, further tests were made at McCook Field with a Curtiss D-12 engine. After considerable development work to avoid leaks and to overcome other troubles encountered, the use of this method of cooling was adopted for Curtiss liquid-cooled engines by 1932 and used soon afterward by Allison and Rolls-Royce. This change, which allowed operation of the coolant at 250-degrees F, reduced the radiator area required by about 50 percent (fig. 55).

Figure 55.—Comparison of radiator installations for water (left) and for ethylene glycol cooling, on Curtiss Falcon airplanes, 1930. (From *The Project Engineer*, vol. 13, no. 10, p. 9, 1954, publ. by the Thermix Corp.)



This improvement, together with better radiator design and radiator cowling (fig. 56) brought the drag of liquid-cooled engines well below that of air-cooled radials of equal power. Their installed weight, which had been greater than that of air-cooled radials, also came down to more comparable figures. Schlaifer gives the weight-per-horsepower of the best liquid-cooled fighter installation in relation to a comparable air-cooled installation as 30 percent more at sea-level and about the same at 25,000 ft.



Figure 56.—Liquid-cooled fighter, North American P-51 Mustang of World War II. Coolant radiator is housed under fuselage, below the star insignia. Inlet and outlet ducts are designed to minimize drag. (*Photo A-45801*)

The fact that the Battle of Britain was won by liquid-cooled engines (the Rolls-Royce Merlin) gave a great impetus to the Army prejudice in favor of water-cooled fighters. Actually, both types were used and it was found that the air-cooled fighter was better at low altitude both because of its lighter specific weight and its lesser vulnerability to small-arms fire.

For commercial uses, however, the elimination of the weight, complication and maintenance requirements that characterize liquid-cooling has been a chief reason for the popularity of air-cooling for air-transport purposes since about 1932; and with few exceptions, commercial air transports all over the world have used air-cooled engines, mostly of American manufacture, from the early beginnings in the late 1920s up to the present. Although today (1969) jet and turbine engines are standard for large military and commercial airplanes, there are still many more planes powered by air-cooled piston engines, because of their use in planes of smaller size, than by all other types combined.

Unconventional Engines

Hundreds of unconventional types of aircraft engines have been proposed, built and tested. Among these the following may be mentioned.

Barrel- or Revolver-Type Engines. In this type the cylinders were positioned around the crankshaft with their axes parallel to it. Its advantage was its compactness, which provided a small frontal area and allowed good streamlining. Perhaps the best known was the Almen engine of 1921. None were successful - although during 1929 there were brief demonstrations of the Swiss Statex and British Redrup types and an example of the latter, the Fury, powered a Simmonds Spartan biplane in flight. The methods of linking the pistons to the driveshaft caused lubrication and mechanical problems that were never solved.

Fairchild-Caminez Engine. This was a 4-cylinder radial engine (fig. 57) with rollers in the pistons operating on a 2-lobe cam. Its advantages were its small diameter and a propeller shaft running at half engine speed without the usual reduction gearing. The only crank-less reciprocating engine to reach the stage of official approval, it received in June 1927 United States Department of Commerce Approved-Type Certificate No. 1. During 1926-28 it was flown experimentally, but it proved impractical because of excessive vibration resulting from torque variation.

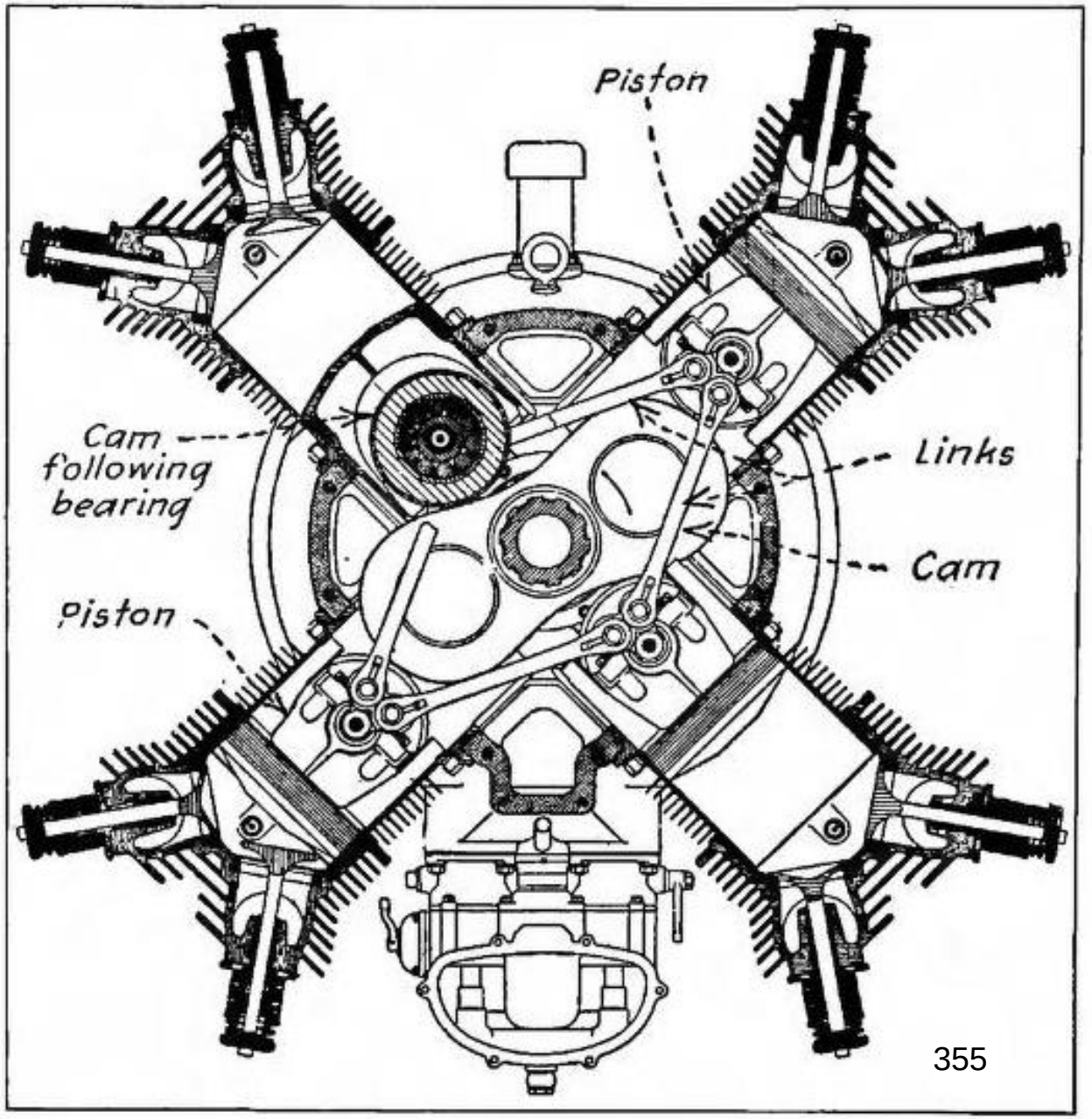


Figure 57.—Fairchild-Caminez engine, transverse section; 135 hp at 1000 rpm, 360 lb. The only crankless reciprocating eingine to reach the stage of official approval, it was later found to be impractical because of severe torque variation. (From Pagé, *Modern Aviation Engines*, 1929, vol. 2, p.1112, fig. 535).

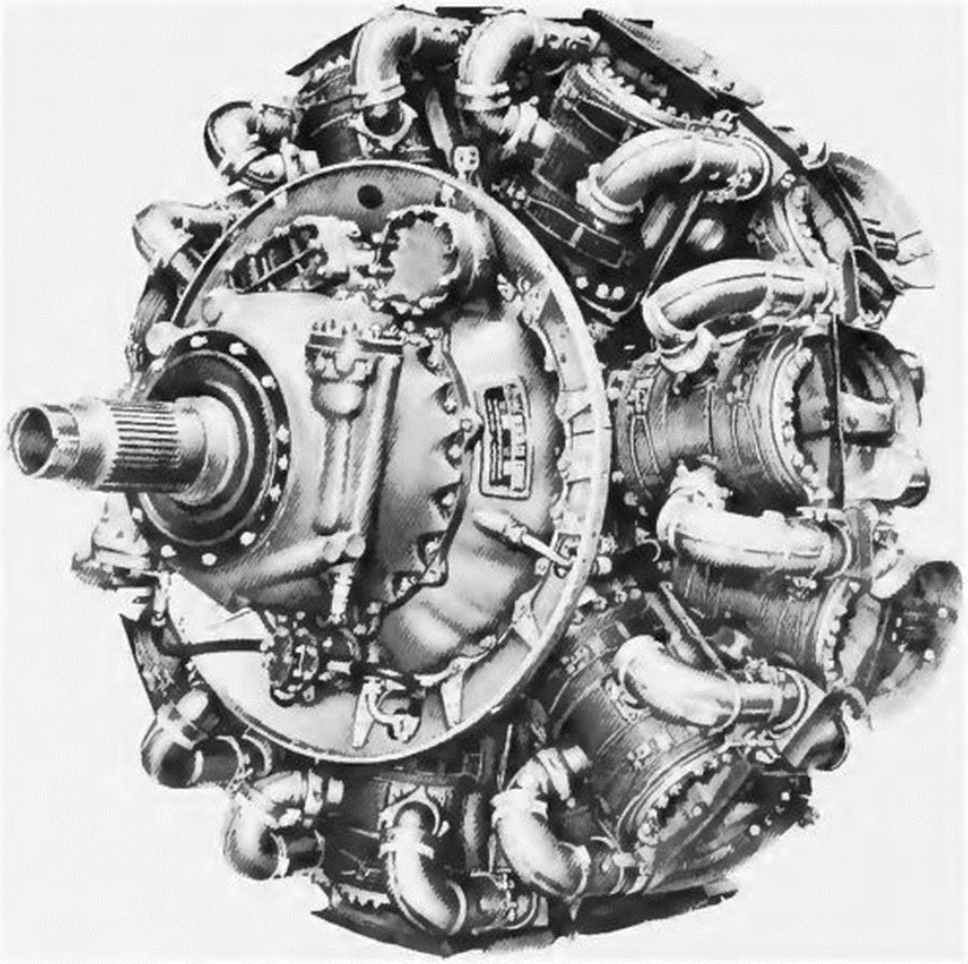


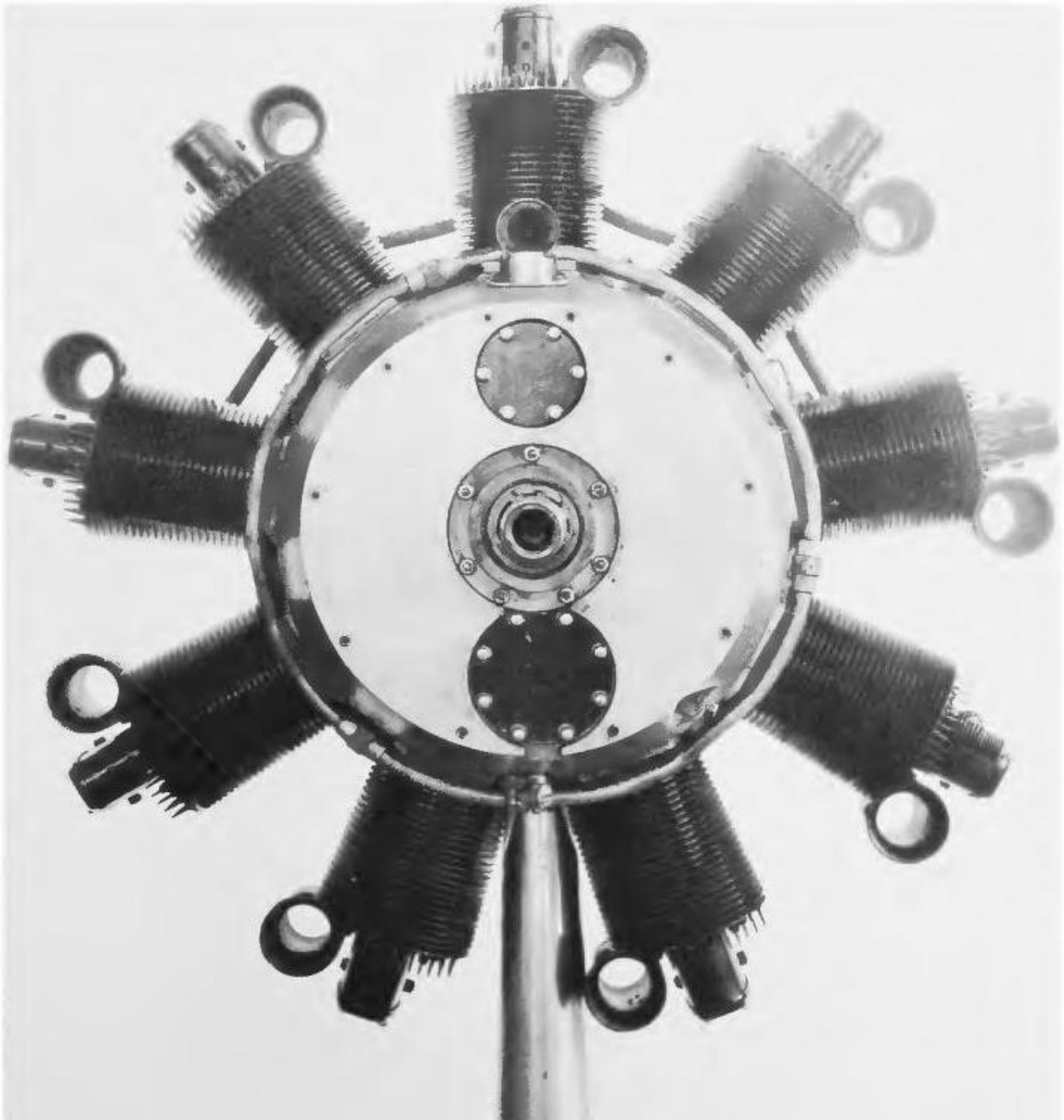
Figure 58.—Bristol Hercules 759 14-cylinder sleeve-valve engine, 1956; 2000 hp at 2800 rpm, 2060 lb. Earlier models were used in British bombers during World War II. (From Wilkinson, *Aircraft Engines of the World*, 1954, p. 244)

Sleeve-Valve Engines. The earliest development of a sleeve-valve aircraft engine that I recall was that of the Belgian Minerva, a Knight-type, or double-sleeve, engine which appeared in the 1920s, but never got beyond the experimental stage. The single-sleeve, or Burt-McCollum, type, was exploited chiefly in England and finally became operational in the Bristol line of aircraft radial engines, including the Hercules (fig. 58), Perseus and Centaurus.

These were used by the Royal Air Force during World War II. The Napier Sabre, also using the single-sleeve valve, was a 24-cylinder, liquid-cooled, 2-crankshaft H-type engine used in British fighters toward the end of World War II. The Rolls-Royce Eagle (not to be confused with the 12-cylinder Eagle of World War I), a 24-cylinder H-type engine with sleeve valves, was very similar to the Napier Sabre. It was developed after the war, too late to compete with the rapidly developing jet and turbine engines.

Diesel Aircraft Engines. Diesel engines built by Beardmore and Maybach were used experimentally in some rigid airships during the 1920s. Those used operationally aboard the Hindenburg and its little-known sister ship, the Graf Zeppelin II, were of Daimler-Benz manufacture. The first diesel engine to power an airplane was a Packard air-cooled radial (fig. 59) designed by L.M. Woolson, who was killed in a crash (due entirely to bad weather) of an airplane powered with one of these engines before the development was completed.

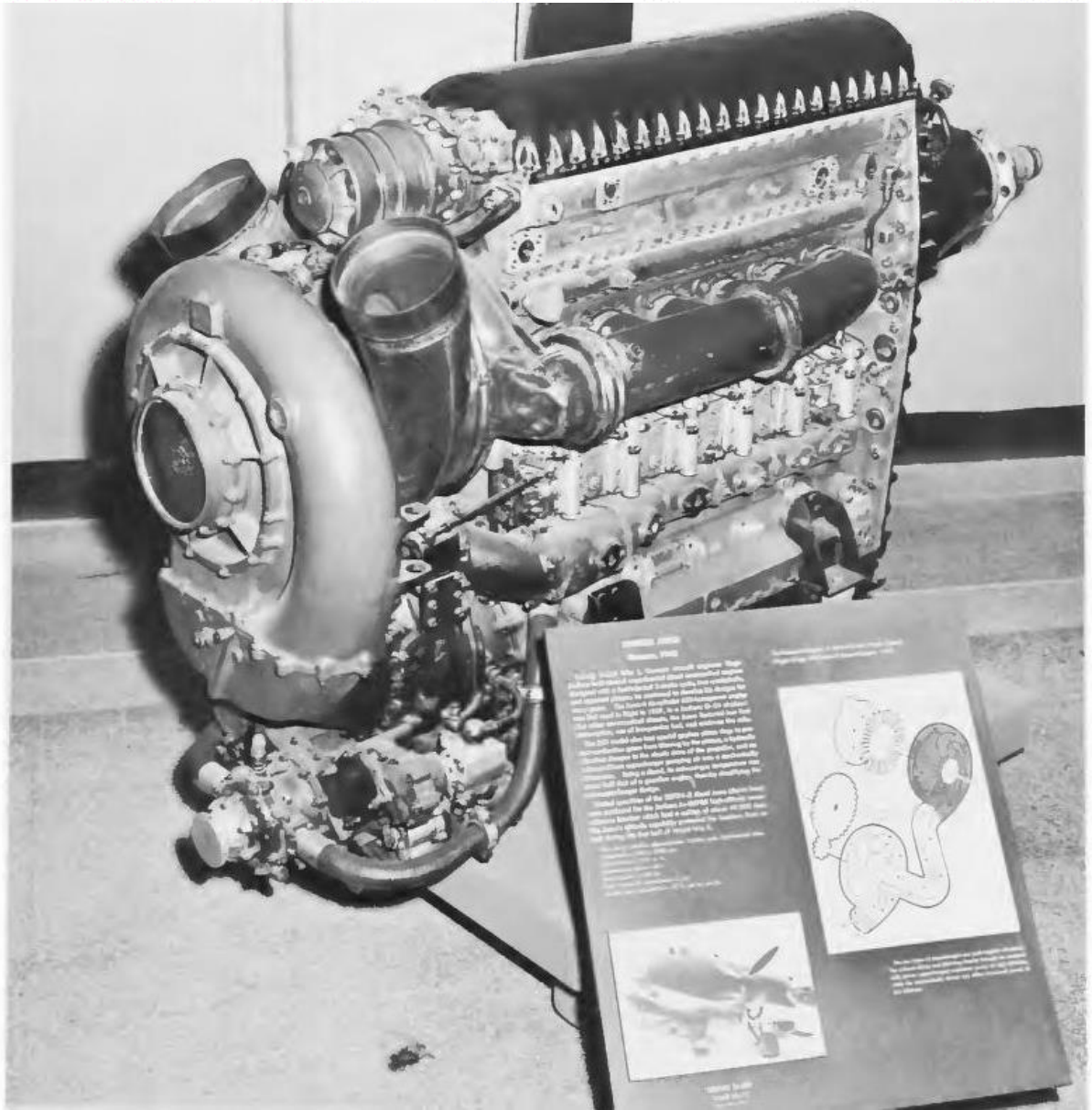
Figure 59.—Packard 4-stroke-cycle 9-cylinder radial air-cooled diesel engine (NASM 1932–7), 1928; 225 hp at 1950 rpm, 510 lb. Although diesel engines had been used earlier in lighter-than-air craft, this was the first to power an airplane. (*Photo A–2388*)



The Packard diesel received from the Civil Aeronautics Administration a CAB Approved-Type Certificate 43 on 6 March 1930. It set the world's non-refueling duration record for heavier-than-air craft 25-28 May 1931, a record that still stands. This engine and its designer and manufacturer were the recipient of the Robert J. Collier trophy for 1931; however, it never became an important airplane power-plant. The Guiberson air-cooled radial diesel engine appeared about three years after the Packard, receiving a CAB Approved-Type Certificate, but was never widely used.

The most successful diesel airplane engine was the Junkers Jumo; a 6-cylinder, opposed-piston, water-cooled engine (fig. 60), the development of which was started about 1920. This engine was used to a limited extent in German military airplanes and in German air transport in the late 1930s. A model fitted with a turbo supercharger powered a high-altitude photographic reconnaissance airplane of World War II; the Junkers Ju86P, but by that time the engine was obsolescent.

Figure 60.—Junkers Jumo 207–D 2-stroke-cycle 6-cylinder opposed-piston diesel engine (NASM 1966–13); 1200 hp at 3000 rpm, 1430 lb. Photograph shows engine equipped with exhaust-driven turbo-supercharger as used in high-altitude German reconnaissance airplane in World War II. Earlier unsupercharged versions (rated 750 hp at 1800 rpm, 1650 lb) were used in pre-war commercial airplanes. (*Photo A–3112*)



NACA (National Advisory Committee for Aeronautics, later the National Aeronautics and Space Agency, NASA, Washington, D.C.) conducted exhaustive research directed toward the development of aircraft Diesel engines during the decade 1930-1940. This work was centered on injection-system development and combustion-chamber design. No multi-cylinder engines were built.

The Napier Nomad engine, a 2-cycle diesel compound power-plant was designed after World War II for exceptionally high specific output, but it was made obsolete by the gas turbines before full development.

Numerous other aircraft diesels were built and test flown, mostly in Europe, but by the beginning of World War II and with the general use of high octane fuels, it became evident that the diesel engine could not compete with the conventional spark-ignition type and its development terminated. The research work of the NACA on diesel engines for aircraft during the late 1920s and early 1930s was extensive and outstanding, but it found no practical application.

Two-Cycle Gasoline Engines. The earliest 2-cycle aircraft engine flown successfully was built in England by the New Engine Company, Ltd. (NEC), in 1909. It was used in a British-Wright airplane of that period. The cylinders were cross-scavenged with a Roots-type scavenging pump. From 1909 to 1912 both air-cooled and water-cooled NEC engines were built having 2 to 6 cylinders and 20- to 90-horsepower.

A great many 2-cycle gasoline aircraft engines have been proposed and many were built experimentally. Most of these were of the crankcase-compressor type, now common in outboard marine engines. The attraction of this type of engine lies in its mechanical simplicity and low cost, but it has serious drawbacks for aircraft use, principal among which are its high fuel consumption when used with a carburetor and its tendency toward misfiring and stalling at light loads. Most of the proposals have been for small, low-cost engines, but so far none has been developed with the characteristics necessary for a truly successful full-scale aircraft engine.

On the other hand, nearly all engines used for model airplanes are 2-cycle and crankcase scavenged, for the sake of mechanical simplicity. In 1966, an engine of this type became available for small target aircraft. The Junkers diesel engine described above stands as the only 2-cycle aircraft engine ever to be used in considerable numbers for military and transport aircraft.

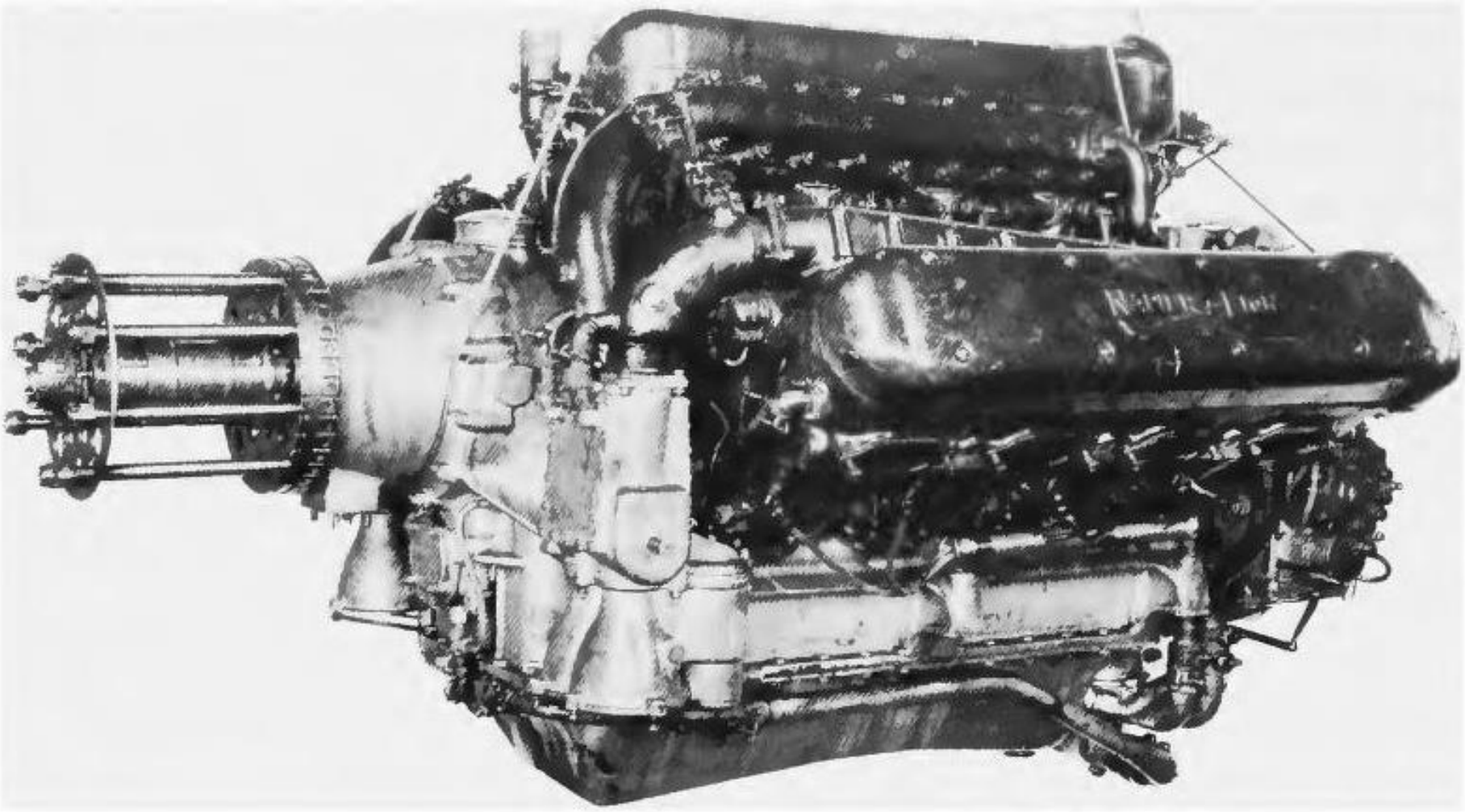


Figure 61.—Napier Lion 12-cylinder W-type liquid-cooled engine, the only W-type ever widely used; 450 hp at 2350 rpm, 985 lb. A racing version, of 800 hp, powered the 1927 winner of the Schneider Trophy, the Supermarine S–5 seaplane, which flew at 281.65 mph. (*Photo A–3098*)

Unconventional Cylinder Arrangements. Finally there should be mentioned some engines with unconventional cylinder arrangements. The first is the Napier Lion (fig. 61), the only W-type engine to see extensive service.

This engine was liquid-cooled with its 12 cylinders arranged in 3 rows of 4 each. Brought out in 1918, it was quite widely used in British military and commercial aircraft and won the Schneider Trophy; a race for seaplanes, in 1927. A second engine in this category is the Pratt & Whitney R-4360, 28-cylinder air-cooled radial with 4 rows of 7 cylinders each (fig. 45). This is the largest (but not the most powerful) successful piston-type aircraft engine ever to reach the service stage. It has been used in many large military aircraft and in the Boeing 377 Stratocruiser. Besides the large number of cylinders and their unusual arrangement in “staggered” radial formation, unusual features include machined-all-over cylinder heads of novel shape and an ingenious arrangement of the pushrod valve gear. This engine would undoubtedly have been more fully developed had it not been for the advent of turbo-jet and turbo-prop engines.

The Rolls-Royce Eagle (the second line with that name) and the Napier Sabre, both using the double-crankshaft H arrangement, have already been mentioned.

Related Technical Developments

Fully as important as the historical development of actual engines, has been progress in engine research, leading to improved understanding of the basic phenomena involved. Especial attention under this heading should be given to the improvement in the structural design of aircraft engines made possible by the development of experimental stress analysis; however, a history of research in the field of internal-combustion engines is beyond the scope of this paper. Various sections of the bibliography contain selected references to some of the important contributions in this area. While this list is by no means complete, it should serve as a convenient introduction to the subject. Most of the items listed contain relevant bibliographies.

Interesting related historical developments have also occurred in fuel systems, exhaust systems, control systems, fire extinguisher systems and many of the other elements comprising the aircraft power-plant. To treat all of these in detail is beyond the scope of this work, but a few are of sufficient importance to deserve mention here.

Valves and Valve Cooling

As previously mentioned, the poppet exhaust valve has always been a critical item because it is subjected to such high gas temperature (up to 3,000-degrees F) and high gas velocity, with small areas available (stem and seat only) for heat dissipation to the coolant. One method of attack on this problem has been through the use of improved materials. By 1918 the ordinary steels used at first had given way to high-speed tool steel which has a high degree of strength at elevated temperatures. Tungsten is the chief alloying element in such steel. Unfortunately, this type of steel burns readily at the seat of a leaking valve. Since about 1920, austenitic (high-chromium) steels have been successfully used in various forms, with several other alloying elements, including principally silicon, nickel, and cobalt. A further important improvement, about 1934, was the use of Stellite facing on both valve seats and seat inserts. This development occurred jointly in the United States and abroad (chiefly in Britain) with the manufacturers of poppet valves playing an important part.

Another, and very important, contribution to exhaust-valve life and reliability has been the use of a hollow valve partially filled with liquid for the purpose of improving the conductivity of heat from head to stem. Heron and Gibson tried water in 1913, but the high steam pressure exploded the valve stem. Mercury was next tried, with more success, since its vapor pressure is lower.
But mercury will not wet steel.

When S.D. Heron came to McCook Field in 1919, he continued his work on valve coolants and soon used successfully the mixture of sodium and potassium nitrate previously used for heat treating of steel. This material has the necessary low vapor pressure, but its density is low. Continuing his work, Heron by 1928 had adopted liquid sodium as the internal coolant, now used in large aircraft exhaust valves and in many non-aircraft engines.

Figure 62 shows a sequence of development in exhaust-valve design. Much ingenuity has been displayed by valve manufacturers in fabricating the modern hollow-head with hollow-stem valve and filling it (partially) with metallic sodium.

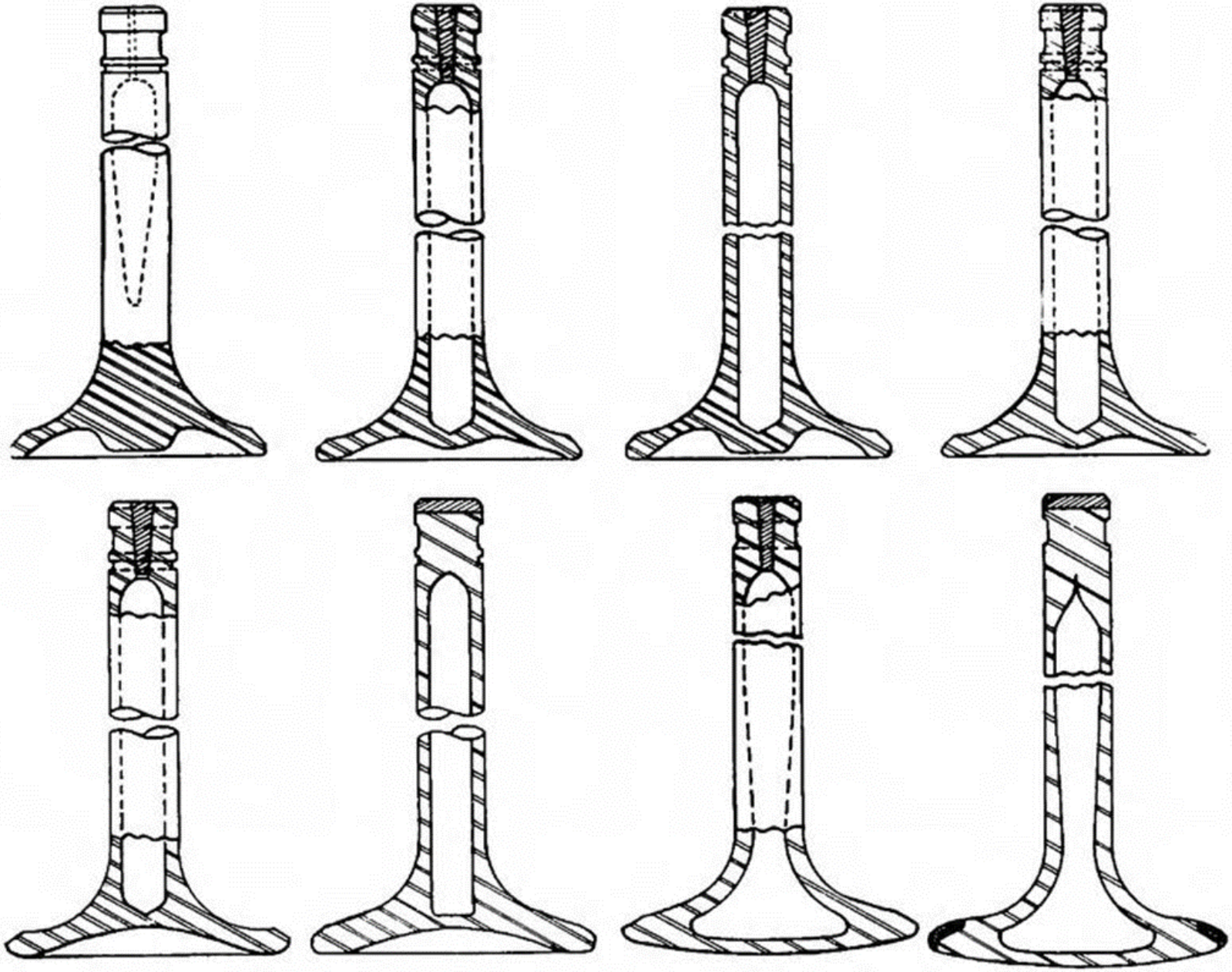


Figure 62.—Evolution of exhaust valves used in Wright radial engines. In all but the first (upper left) the interior space was half filled with sodium to promote heat flow from head to stem and thus to assist in cooling the valve. (From *S.A.E. Journal*, vol. 46, no. 4, p. 150, fig. 9, 1940)

The automatic lubrication of valves by engine oil, introduced to liquid-cooled engines by Hispano-Suiza (1914) and to air-cooled engines by Pratt & Whitney (1932), has also been an important contribution to the present long-life and reliability of aircraft-engine valves.

Another method of attack on the valve-cooling problems was to eliminate the poppet valve in favor of some form of sliding valve. As already mentioned, the Bristol Aeroplane Company developed its single-sleeve-valve air-cooled radial in the 1930s to the point where it was used in World War II and the Napier Sabre and the second Rolls-Royce Eagle also had sleeve valves.

Fuels and Combustion

One of the most important developments in aircraft propulsion has been the improvement in, and control of, aviation gasoline. This development is a long and complex story and only a bare outline can be given here.

For successful use in spark-ignition engines, gasoline must have the proper volatility range and the highest possible resistance to “knock” or detonation. Control of volatility seems never to have been a serious problem and development work in aircraft fuels has centered around increasing their anti-knock value. Earliest work on the relation of detonation to fuel composition seems to have been by Harry R. Ricardo in England and by Charles F. Kettering in the United States. Intensive work, under Kettering’s direction, was started by Thomas Midgeley and Thomas A. Boyd in Dayton, Ohio, in 1917. During the course of this work it was discovered that some substances, notably iodine, had a strong anti-knock effect even in very small concentrations. This discovery led to an intensive search for powerful anti-knock agents.

Midgeley’s work was done on a small 1-cylinder engine in an old Dayton kitchen and when a promising substance was found there, he would bring it to the McCook Field engine laboratory for test in an aircraft engine. I was closely associated with his work during my administration of that laboratory, 1919-1923.

By 1920 toluene and its related compounds appeared promising as an additive and were used in flight tests, notably by Schroeder for the 1920 altitude record with a turbo-supercharged Liberty engine. By 1921 the extreme antiknock effects of metallo-organic compounds was evident and in 1922, Midgeley brought the first samples of tetraethyl lead, $Pb(C_2H_5)_4$, to McCook Field for tests in 1-cylinder and full-scale aircraft engines. Experimental work with leaded fuel continued thereafter at a rapid pace. It was officially adopted for use in aviation gasoline by the United States Navy in 1926 and by the Army in 1933 and has since become universally accepted as an additive for gasoline.

Another important contribution was Graham Edgar's work, about 1926, in determining the effect of fuel structure on anti-knock quality and, specifically, discovering the high anti-knock properties of the branched chain parafins such as iso-octane.

Specifications and laboratory tests for antiknock quality of aviation fuels were sponsored by the Cooperative Fuel Research Committee in 1933 and led to good control of this quality in United States aviation fuels soon after. S.D. Heron was also an important contributor to this result. The "performance number" of a fuel, used from about 1942, is the ratio of knock-limited indicated mean effective pressure (klimep) with that fuel, to the klimep in the same engine using iso-octane.

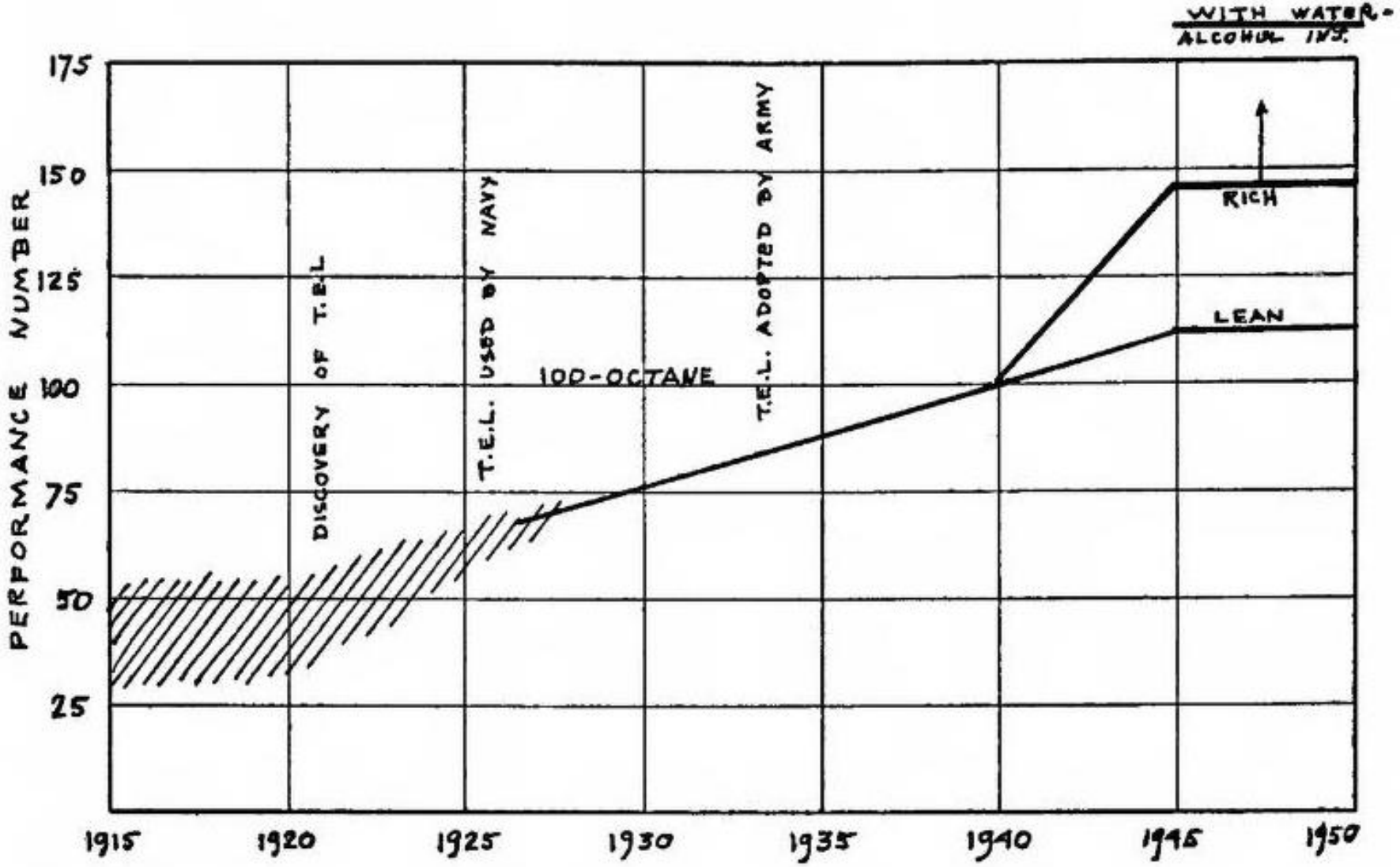


Figure 63.—Increase in aviation fuel performance number with respect to time. The improvement was due both to additions of tetraethyl lead (T.E.L.) and to improved refining methods. Performance number is ratio of knock-limited power to that with pure iso-octane (x100).

Figure 63 shows the improvement in the performance number achieved both by the use of tetraethyl lead and the control of fuel composition.

The powerful effect of water or water-alcohol injection is also illustrated in figure 63. This development seems to have been started at Pratt & Whitney about 1940 and was continued by them, by the Army Air Corps at Wright Field and by the NACA laboratories. By 1946, water-alcohol injection was generally used for take-off by both military and transport airplanes. The high consumption of the auxiliary fluid (about 50 percent of the fuel flow) limits its use to short periods and to engines with sufficient supercharging to take advantage of the increased knock limit.

Altitude Performance and Superchargers

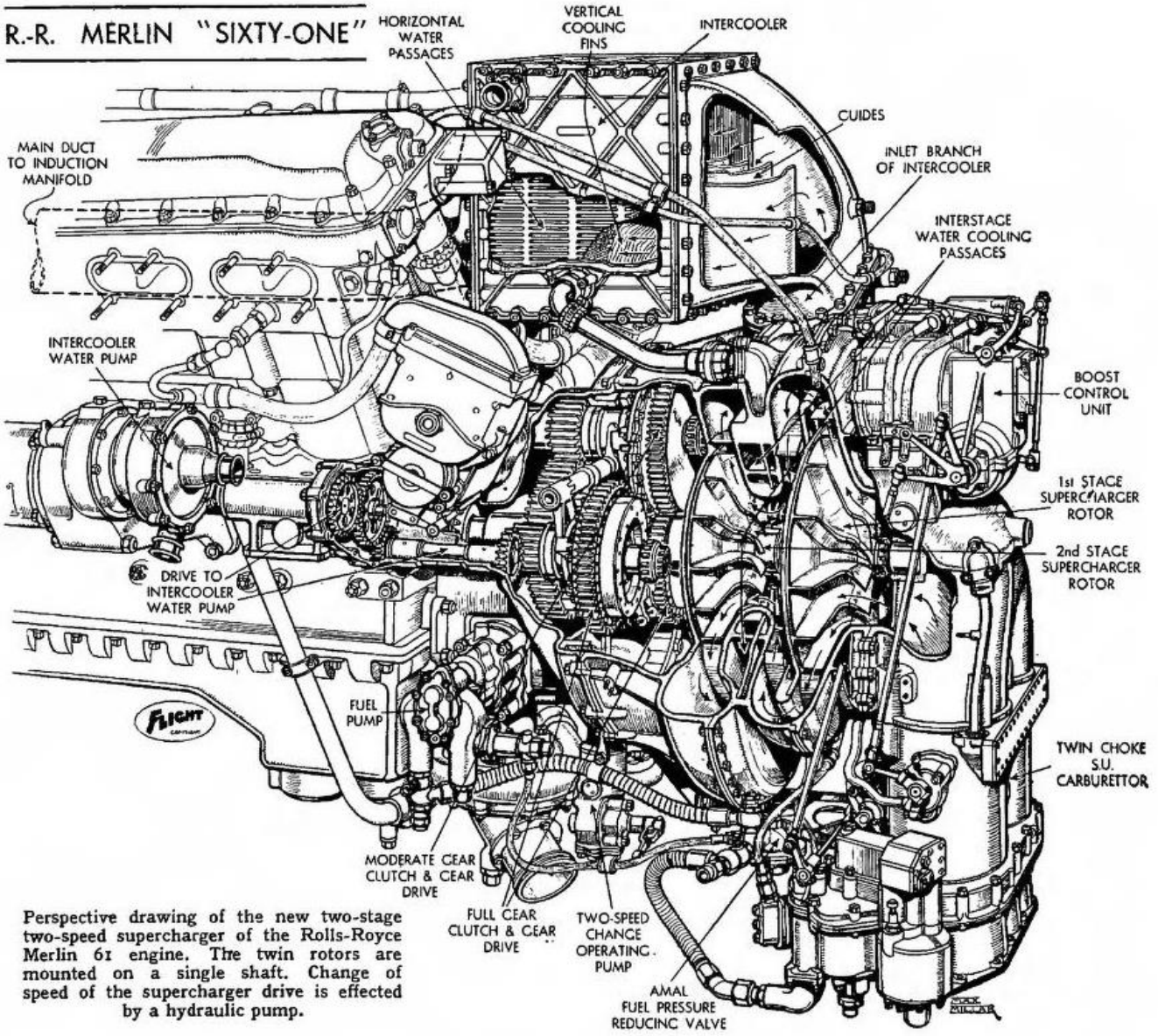
The fact that, as altitude increases, reduced air density reduces engine power must have been realized before it became obvious in 1909, when airplanes began to try for high-altitude flight. The advantage of altitude in military work became very apparent in World War I, but the only attempt at improved altitude performance used in World War I was embodied in the German BMW and Maybach engines, which were designed to be partly throttled near sea-level, the throttle to be fully opened only above about 5,000-feet. Both engines were designed to be lighter in weight than would have been required for full-throttle operation at sea-level and the BMW also had higher compression ratios than could be used with full throttle at sea-level without detonation. The advantage in altitude performance over an engine capable of full-throttle operation at sea-level, however, was quite small.

Measurement of engine performance at altitude was first seriously undertaken when the United States Bureau of Standards completed its altitude test chamber in 1918. Subsequently, a considerable literature on this subject developed.

The Swiss Engineer A.J. Buchi suggested the turbo-supercharger for aircraft in 1914. This type was then developed in France by Rateau and experimental models were tested during the war, but none was put into service use. Laboratory work on gear-driven superchargers was conducted during the war by the RAF at Farnborough, England. Intensive development of supercharging equipment began both in England and the United States in 1918.

Many types of compressors have been considered, but only one, the centrifugal type, ever got beyond the experimental stage. The Royal Aircraft Factory had Armstrong-Siddeley construct a radial engine with a built-in geared centrifugal supercharger in 1916, but the design was unsuccessful, probably because of torsional vibration in the drive system. Siddeley did not produce a successful geared supercharger until that used in 1926 in the Jaguar (see fig. 38).

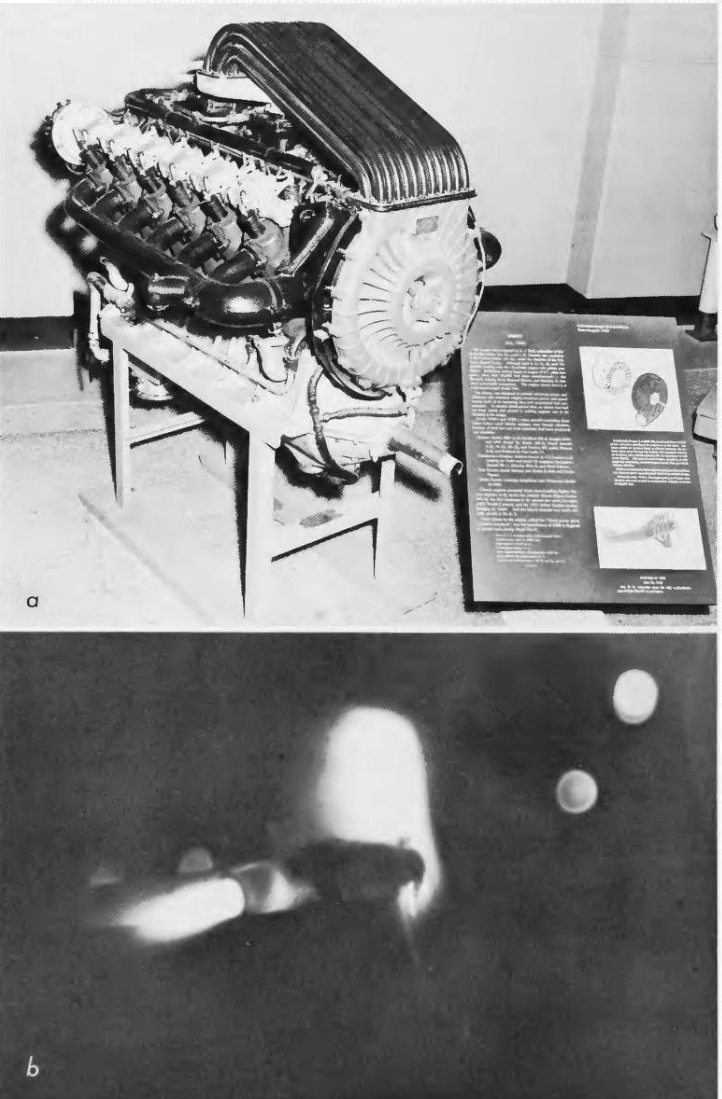
Geared superchargers were built experimentally by Curtiss and by Wright Aeronautical Corporation in 1925, but the first United States production engine to be so equipped was the Pratt & Whitney Wasp of 1927; a year later than the Jaguar. After 1930 all military and transport engines were equipped with geared centrifugal superchargers and in all cases, some kind of flexible coupling was introduced in the gear train to prevent critical torsional vibration. The culmination of the geared centrifugal type is represented by the 2-stage, 2-speed supercharger of the Rolls-Royce Merlin (fig. 64).



Perspective drawing of the new two-stage two-speed supercharger of the Rolls-Royce Merlin 61 engine. The twin rotors are mounted on a single shaft. Change of speed of the supercharger drive is effected by a hydraulic pump.

Figure 64.—A two-stage two-speed geared supercharger with intercooler and aftercooler, as installed on the Rolls-Royce Merlin 61 engine of 1942, the first of its kind to be used in service. (From *Flight*, vol. 42, p. 656, Dec. 17, 1942)

Figure 65.—*a*, General Electric turbo-supercharger installed on Liberty engine (NASM 1966–43) of the type which held the world's altitude record for 1920, 1921, 1922. Tubes conveying air from compressor to carburetor serve as an aftercooler. *b*, Night view of turbo-supercharger in operation. The exhaust manifolds and the nozzle box are white hot (about 1500° F) and the turbine, operating at over 20,000 rpm, is surrounded by hot exhaust gas. (*Photo A–3092, A–3193*)



In 1918, the Engineering Division of the Army Air Service contracted with the General Electric Company to develop turbo-superchargers of the Rateau-type. The man in-charge of this development for GE was Dr. Sanford A. Moss, who remained in this position for over twenty years. Experimental models applied to the Liberty engine were tested at the top of Pikes Peak in 1918 and in flight at McCook Field, in 1919.

Figure 65 shows an installation of this early type of General Electric supercharger on a Liberty engine.

A Le Pere airplane with this equipment held the world's altitude record for the years 1920, 1921 and 1922. Supercharging was hard on an engine not originally designed for it and I remember when Major Schroeder, who made the 1920 record, returned from a flight with the Liberty engine and its nacelle cut in two by a failed connecting rod at the third crank from the front-end. The only elements holding the four forward cylinders and the propeller in place were the crankshaft and the two camshaft housings. In spite of this condition and the loss of all its cooling water, the Liberty engine was still running!

A serious difficulty with the supercharger shown in figure 65 was the failure of turbine blades due to inadequate cooling of the turbine. In 1922, Ernest T. Jones, in-charge of superchargers under Major G.E.A. Hallett, Chief of the Power-plant Section at McCook Field, was asked to redesign the General Electric supercharger to overcome this difficulty. In a conference with Jones over the Design Board, I suggested placement of the turbine wheel on the nacelle surface, using an overhung turbine wheel as in figure 66.

Figure 66.—Side-type turbo-supercharger installed on Curtiss D-12F 460-hp engine in Curtiss P-5 Hawk, 1927. This exposed position of the turbine wheel was effective in reducing the blade temperature as compared to the earlier arrangement shown in figure 65. (*Photos A-3094*)



This suggestion was adopted for the new design. Turbine wheels of this type have been used on all subsequent installations of turbo-superchargers in the United States, including the Martin biplane bombers of the 1920s and the B-17 and B-24 bombers and P-38 and P-47 fighters of World War II. The Boeing Stratocruiser and the B-29 and B-50 bombers used essentially the same system, although in these airplanes the turbine was located inside the nacelle and the overhung wheel was cooled by air piped in from outside. Beginning with the B-17, the engines were also equipped with gear-driven superchargers acting as the second stage.

The only service use of turbo-superchargers on foreign-built airplanes appears to be that of the German Junkers diesel-engine high-altitude photographic plane shown in figure 60. It is remarkable that this very effective device received so little development outside of the United States.

In 1927, the official world's altitude record was taken by Lieutenant C.C. Champion, Jr., USN, with a Pratt & Whitney Wasp equipped with a NACA Roots-type supercharger acting as first stage to the engine's own geared centrifugal equipment (fig. 67). This is the only important use of a non-centrifugal supercharger in aircraft.

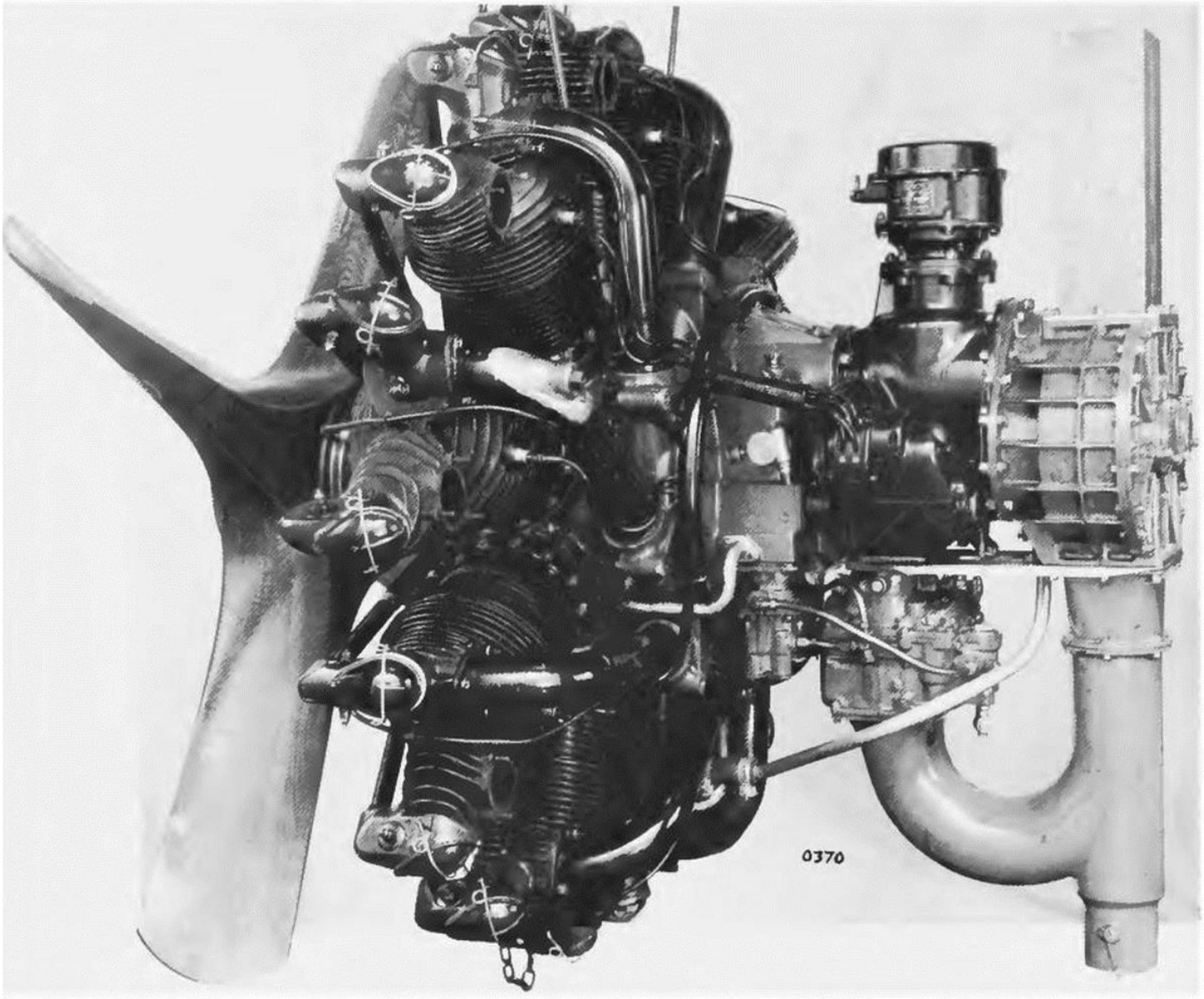


Figure 67.—NACA Roots-type supercharger, coupled to Pratt & Whitney Model A Wasp engine, 1927. Bypass valve, lower right, controls inlet pressure. A world's altitude record was established in 1927 with this installation in a Wright Apache airplane. (Photo courtesy Pratt & Whitney)

Aftercoolers, that is, devices to cool the air after leaving the supercharger, have been generally used with turbo-superchargers and with 2-stage geared types. Such coolers are shown in figures 64 and 65. The Merlin engine (fig. 64) used a water-cooled aftercoolcr with its own separate radiator and circulation system.

The culmination of the supercharger art is represented by the Wright Turbo-cyclone R-3350 engine shown in figure 47. This engine, introduced about 1946, has three exhaust-driven turbines geared into the power system as well as a 2-speed centrifugal geared supercharger. It is standard on the Douglas DC-7 and the Lockheed Super Constellation, the last large piston-engine passenger-transport planes built in the United States.

Vibration Control

Powerplant vibration presents two kinds of problems in aircraft. One is external vibration, or vibration of the power-plant with relation to the airplane itself. The other is internal vibration, that is vibration of parts within the power-plant. Considerable external vibration from engine and propeller was accepted as normal in the early days of aviation. In my experience it became of concern first in 19-20, with the Hispano-Suiza V-8 300-hp engine; a larger version of the original model. This engine, like all V-8s up to that time, had cranks at 180-degrees, which gave a strong second-order horizontal vibration. It also had an unusually large torque variation, due to its large cylinders and high mean effective pressure. Pilots complained of discomfort with this engine.

About 1921, the Wright Aeronautical Corporation, which produced the 300-hp Hispano engine, built one with counterbalanced cranks at 90-degrees, thus eliminating the horizontal shake. Vibration measurement at that time was in a crude state and the improvement obtained was demonstrated on the test stand by the fact that, with the 90-degree shaft, a penny would remain on the crankcase, whereas with the 180-degree shaft the penny would quickly bounce off.

The next test was to mount two engines in similar Thomas-Morse fighters, one with the 180-degree shaft and one with the 90-degree shaft. A number of Engineers ran these engines on the ground and a number of pilots flew them. The consensus was that there was no noticeable difference in vibration of the airplane. Probably, the engine torque variation was so large in both cases as to obscure the improvement in sidewise shake. In any case, the 90-degree shaft was not approved, although it soon became standard on V-8 engines for non-aircraft use. Such was the state of vibration analysis in 1922!

Reduction of engine vibration became essential in the early days of commercial aviation when passenger comfort became important. In this case, radial engines were used. Charles S. Draper and George Bentley made a serious study of the shaking forces and movements of radial engines in 1937-1938. One solution lay in flexible engine mounts to reduce the transmission of vibration to the airplane structure. This involved a problem of “droop” due to gravity when the engine was mounted at its rear, as in the case of radials.

There was also the problem of decoupling the several modes of vibration in order to avoid numerous critical speeds. This problem was solved by the mount patented by Edward S. Taylor and K. Browne, which has been widely used since. The principle employed is an arrangement of links which have the effect of supporting the engine at its center-of-gravity, although the actual flexible mounts are at the rear. Otto C. Koppen has used very flexible decoupled engine mounts in light airplanes with good effect since about 1939. Another contribution to reduction of engine vibration was the adoption by Wright and Pratt & Whitney, in the late 1930s, of second-order rotating weights to balance the second-order shaking component characteristic of the master-rod system in radial engines.

Internal vibration of reciprocating engines has been most serious in the propeller-crankshaft system. This type of vibration originates chiefly from the torque variation inherent in piston engines and may be destructive when resonance is involved. The Liberty engine of 1917 had a torsional resonant speed of 1900 rpm with the usual propeller. Its rating at 1700 rpm was close enough to cause accessory-gear breakage, as previously mentioned. Serious trouble with torsional vibration was experienced in the 1920s in dirigible airships using long shafts between engine and propeller. This type of vibration also held back the development of metal propellers, to be discussed later.

A very critical case of crankshaft-propeller vibration appeared with the introduction of the geared version of the Wright 9-cylinder 1820-cu-in. radial engine in 1935. This problem was quickly and brilliantly solved by E.S. Taylor and R. Chilton, who developed the pendulous counterweight, which effectively counteracted the principal torque components of the engine and prevented breakages in the drive system. The basic concept was that of E.S. Taylor, for which he received the Reed Award in 1936. Chilton contributed the mechanical embodyment. This type of device has been used in large radial aircraft engines ever since and also in many non-aircraft power-plants. After the first engines so equipped had been tested, it was found that these inventions had been anticipated in France, but the credit for practical application should go to Taylor and Chilton. It should also be mentioned that the Packard Diesel engine of 1928 was equipped with spring-loaded pivoted counterweights designed to reduce torsional vibration. These, however, could be effective only at one speed, whereas the Taylor-Chilton design was effective over the entire speed range.

Another important torsional vibration problem was that caused by the gear-driven supercharger rotor. Various types of flexible coupling have been used in the gear train to avoid serious trouble.

Further consideration of vibration problems is included under the heading, *Propellers.*

Propellers

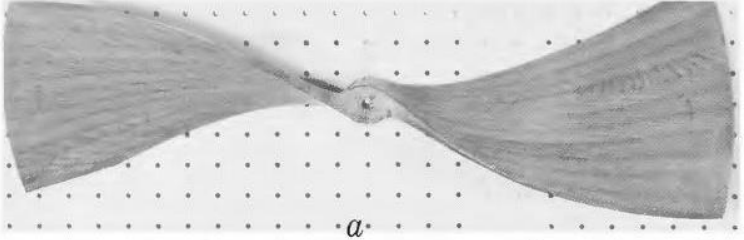








Figure 68.—Propeller development: *a*, Langley wood propeller (NASM 1938-56E) of 1893, used on Aerodrome No. 4. *b*, Curtiss-Reed twisted-duraluminum propeller (D-6), 1925. *c*, Hamilton-Standard 2B20 constant-speed propeller, 1946. *d*, Hamilton-Standard Hydramatic full-feathering propeller of 1947. For typical wooden propeller of the period 1910 to present, see figure 50. (*Photos, respectively, A-287, A-51875, A-3096, A-3097*)

Gibbs-Smith credits the Chinese with first use of the air propeller, on toy helicopters. A helical screw is shown on a Da-Vinci helicopter drawing of about 1500, and screw propellers were used on dirigible balloons as early as 1784. An early Langley propeller is shown in figure 68a.

The success of the Wright brothers was in no small degree due to the excellent performance of their two counter-rotating airfoil-section propellers, chain driven at 8/23 engine speed, or about 380 rpm. They gave serious attention to propeller design. Apparently they could get no useful data from Marine Engineers and had to develop their own theory. In doing so, they often argued each other into a reversal of opinion, but finally arrived at a design which Frank W. Caldwell says ran at near optimum ratio of forward speed to tip speed and had an efficiency of about 0.70.

The Wright propellers were of 3-ply laminated wood, very light in weight. It should, perhaps, have served as a warning to future propeller designers that the first fatal accident - the crash of Orville Wright and Lieutenant Thomas E. Selfridge in 1908, resulting in the death of Selfridge - was caused by a propeller failure. A broken blade set-up sufficient vibration to cause the propeller to cut a rudder-bracing wire, upon which the tail came askew and all control was lost.

Wooden propellers were universally used from the time of the Wrights' first flight until well after World War I. They were very reliable for the needs of that time, and were superseded only when the requirements for power and tip speed exceeded the limits within which a wooden propeller would safely operate.

Materials superior to wood were actively sought after World War I. Frank Caldwell, head of the propeller section at McCook Field (1918-1930) and later Chief Engineer at Hamilton Standard, was a leader in this field and has given excellent accounts of propeller developments. Here there is space for only the briefest review.

Micarta (canvas laminated with bakelite) was successfully used as a wood substitute by 1920. In 1921 Caldwell tested a steel-bladed propeller on his electric whirling machine to twice its rated power. He then, very innocently, presented it to me for a “routine” test on a Hispano-Suiza 300-hp engine. After a few minutes at rated power a blade broke off, came through the control board between the heads of two operators, climbed a wooden staircase and went through the roof. The engine was reduced to junk.

The above incident was an early warning of the importance of vibration and fatigue in propeller operation. At my insistence, further “routine” propeller tests on experimental propellers were made in a specially constructed “bombproof” shelter. All metal propellers of that time (1921-1922) failed, with murderous results to the engine. In one case the whole assembly of crankshaft, rods and pistons was pulled out and thrown 20-feet from what remained of the engine and stand.

Subsequent metal propeller development involved careful attention to vibration problems. The Reed type, using a twisted aluminum plate as a base (fig. 68b), was one of the early successful designs. Later, the manufacturers of metal propellers developed elaborate equipment and procedures for the measurement and suppression of blade vibration.

An excellent historical record of the development of variable-pitch propellers is given by K.M. Molson. The idea started with marine propellers as early as 1816. The need for pitch control in airplane propellers was realized as early as 1912. Various designs of controllable-pitch propellers were tested, usually with disastrous results because of mechanical weaknesses. Variable pitch became essential with the advent of the high-performance airplane; the Boeing 247 and the Douglas DC-3 being early examples. Important propeller developments, with approximate dates are:

1921	Aluminum blades, fixed pitch (Reed)
1923	Aluminum blades, adjustable pitch
1931	Hollow steel blades
1929	Controllable pitch, 2-position
1935	Automatic, constant speed
1938	Feathering
1945	Reversible and feathering

The above dates indicate general use in at least some airplanes. Among the first flights with controllable pitch were those at McCook Field with the Heath propeller about 1921. The first application of the constantspeed variable-pitch propeller was by Hele-Shaw and Beacham for a test flight in England in 1928. Both hydraulic and electric pitch control were used until after World War II. Now hydraulic control and aluminum blades are standard on piston engines, with a few exceptions. Figure 68 shows examples.

Reduction Gears

The Wrights, with their chain drive, were evidently aware that the optimum speed for engines is not usually that for propellers. Even before the Wrights, most experimental airplanes (Stringfellow, Maxim, Langley and others) had belt- or gear-driven propellers, although the drive ratio for steam engines was usually up rather than down.

Direct propeller drive, with the propeller mounted on the crankshaft, is attractive for its simplicity and reliability, and was used by most of the early fliers after The Wright's and up to the start of World War I. An exception was the early Renault air-cooled V-8 (fig. 17), the propeller shaft of which was an extension of the camshaft (or vice-versa) and ran at half crankshaft speed - a ratio which has been widely used since.

Other geared engines which appeared for use in World War I included the RAF (a copy of the Renault), the 8-cylinder-in-line Mercedes and the 220-hp Hispano-Suiza. These were soon followed by the Rolls-Royce Eagle, with planetary gears.

The need for propeller gearing results from the fact that the propeller speed for optimum propeller efficiency is usually lower than the speed at which the engine gives its best performance. Without gearing, the speed for the engine-propeller combination is chosen as a compromise - too high for best propeller efficiency and too low for maximum engine power. As improved engine design called for higher engine speeds this compromise became more unsatisfactory. By 1920, most large European engines were geared. In the United States, however, the general use of reduction gears came much later. For that matter, in 1924 gearing was actually eliminated from the Curtiss D-12 engine in order to save 25 pounds of weight! Nevertheless, by 1930 it was evident that large engines should be geared to allow of optimum performance. Pratt & Whitney used an internal gear in 1931 and both Wright Aeronautical and Pratt & Whitney adopted the Farman planetary gear for use in the DC-3 in 1933 (fig. 69).

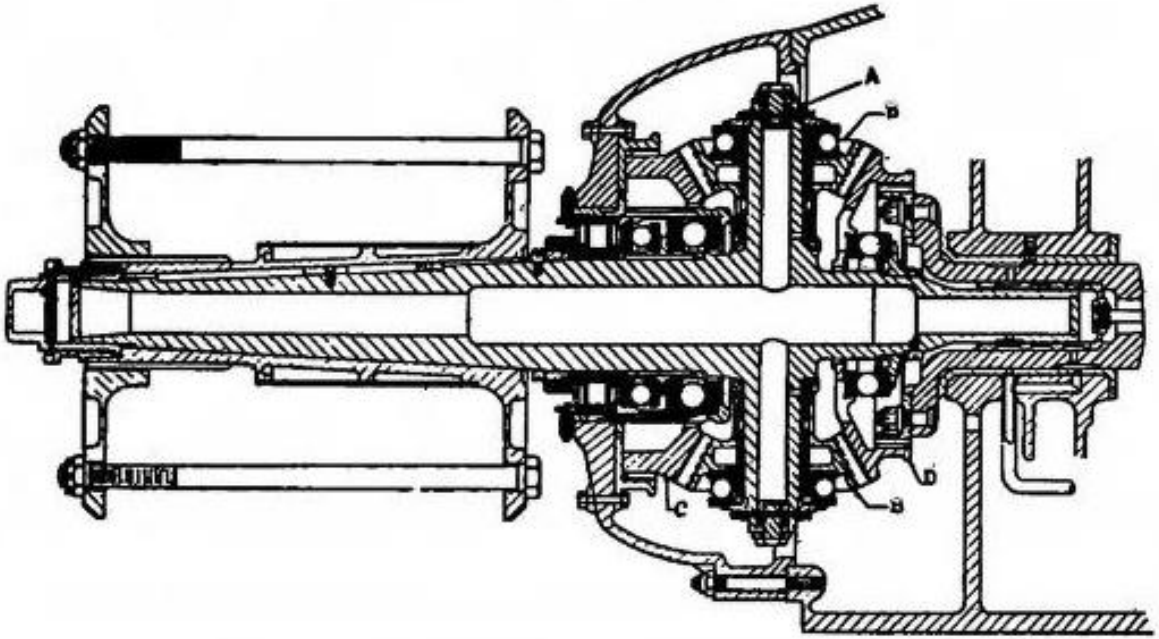
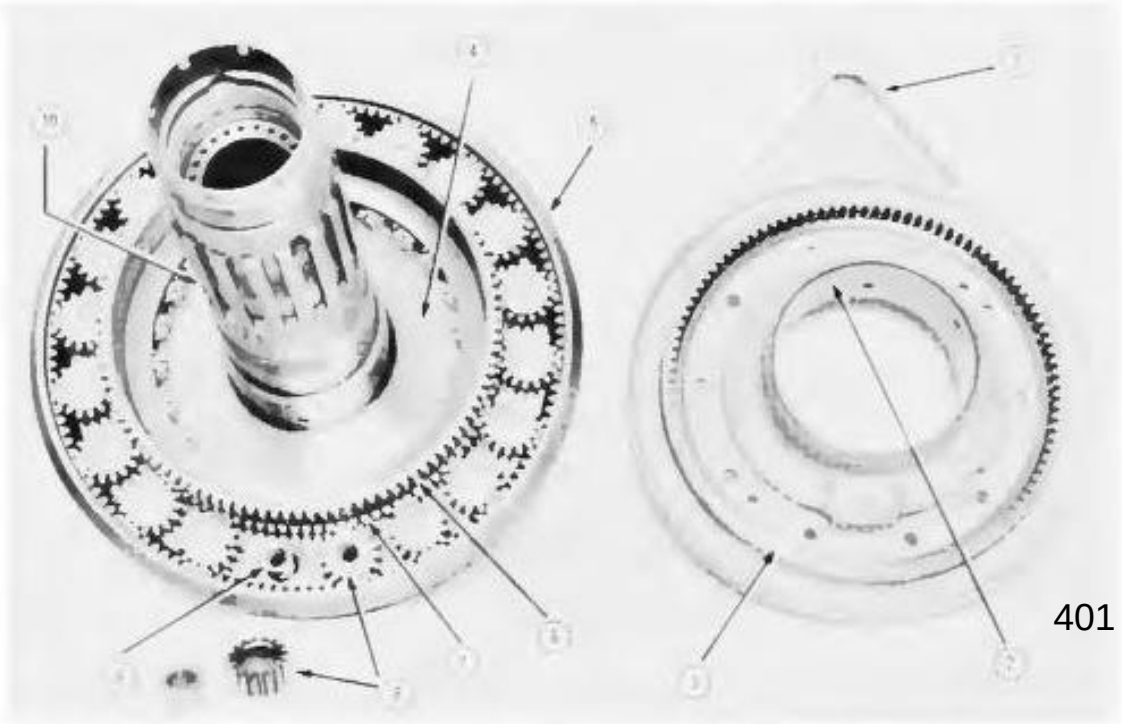


Figure 69.—Bevel planetary reduction gear system as used on Farman engines, after World War I. This type was also used by some American engine builders under license from Farman. *Below,* Spur-type planetary reduction gear system which superseded the bevel type.



From that time on, propeller reduction gears became an integral part of all large airplane engines; spur-type planetary gears being standard for most radials and plain 2-element spur gears for V-type engines (fig. 70). The plain spur gears used by the Rolls-Royce Merlin of 1945 carried 2,200 take-off horsepower satisfactorily on a face 2 in. wide; a remarkable achievement in gear design.

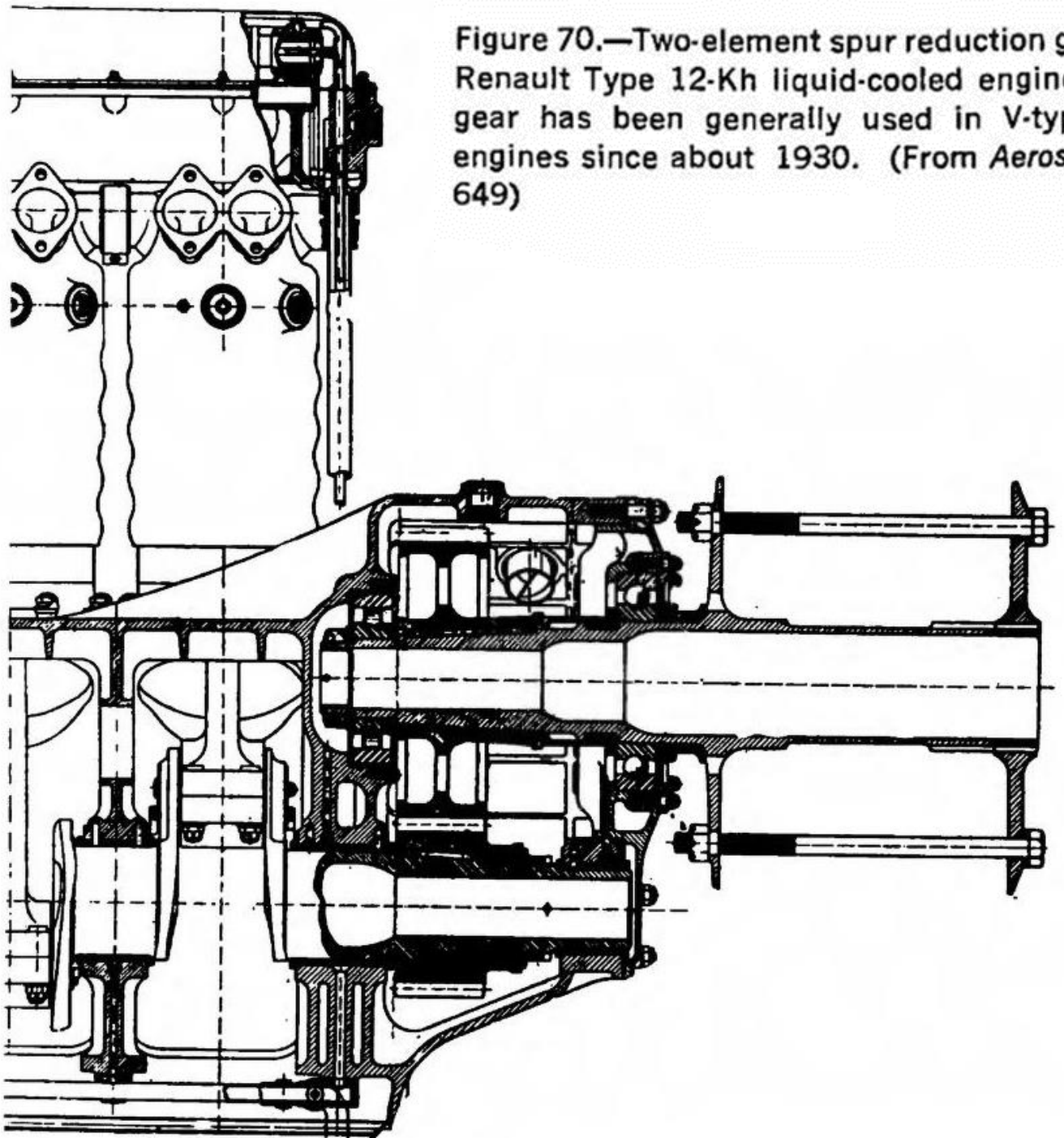


Figure 70.—Two-element spur reduction gear as used on Renault Type 12-Kh liquid-cooled engine. This type of gear has been generally used in V-type and in-line engines since about 1930. (From *Aerosphere 1939*, p. 649)

Other Developments

Only brief mention can be made here of the numerous secondary, though often very important, problems encountered and solved in the development of reciprocating aircraft engines. Among these, however, should be mentioned the following:

Ignition Systems. As mentioned previously, the Wright Brothers' engine of 1903 used "make-and-break" ignition. This system involved a pair of contacts within the cylinder; one insulated and connected to a battery and coil system and one operated by a shaft protruding through the cylinder wall. This shaft was operated from the camshaft so as to "break" the contact points apart at the moment of ignition. The low voltage arc so formed was an effective igniter. However, the mechanical complication involved and the difficulty of cooling the contact levers within the cylinder made it impractical for any but very low-output engines. This system was soon displaced by the "high-tension" system with spark plugs which was used in all other successful airplane engines and, in its essentials, is accepted practice to date for all spark-ignition engines.

Ceramic-insulated spark plugs were generally used in the United States before 1921. Both mica and ceramic plugs were used in Europe. From about 1921 to 1940, mica plugs were generally used. The development of new ceramic materials about 1940 caused a universal change to this material.

Carburetion. At the time of the Wright brothers' first flight, little was known about carburetion and various devices were used to introduce fuel to air. As mentioned earlier, the Wright brothers used gravity fuel feed from a small can to a heated surface in the inlet pipe. Manly used a large sheet-metal box filled with porous wooden blocks; a scheme originally conceived by Balzer. These blocks were saturated with fuel and the engine air was drawn past them in the hope that a combustible mixture would result. The Antoinette engine and all of the Wright brothers' engines produced during 1907-1912 used a small pump to inject fuel into the inlet ports. The carburetion system used for the Gnome rotary engine has already been described. All these systems required experimental adjustment, good for only one engine speed.

Meanwhile, float-type carburetors were being developed for automobile use, and these were used by most aircraft engines after the Gnome and Antoinette. Float-type carburetors were used by the Wright brothers on their later engines and were generally used for aircraft engines up to about 1935. A floatless carburetor was introduced by the Chandler-Groves Corporation in 1935 and the Stromberg floatless injection-type carburetor became operational about 1938. Since that time, most military and transport engines have used floatless-type carburetors, many of the injection type. Light-plane engines have, generally, continued to use float-type carburetors, although injection systems are available for this type.

Fu**el Injection.** Direct injection into the individual cylinders was used in gasoline engines for a short time on some Pratt & Whitney Wasps in 1931-1932. This method was developed to service use in World War II in German military engines. It was adopted by Wright Aeronautical Corporation for their R-3350 engine in 1944.

Injection through nozzles located at each inlet port, first used on the Antoinette engine of 1906, has been used to a limited extent in light-aircraft engines since about 1946.

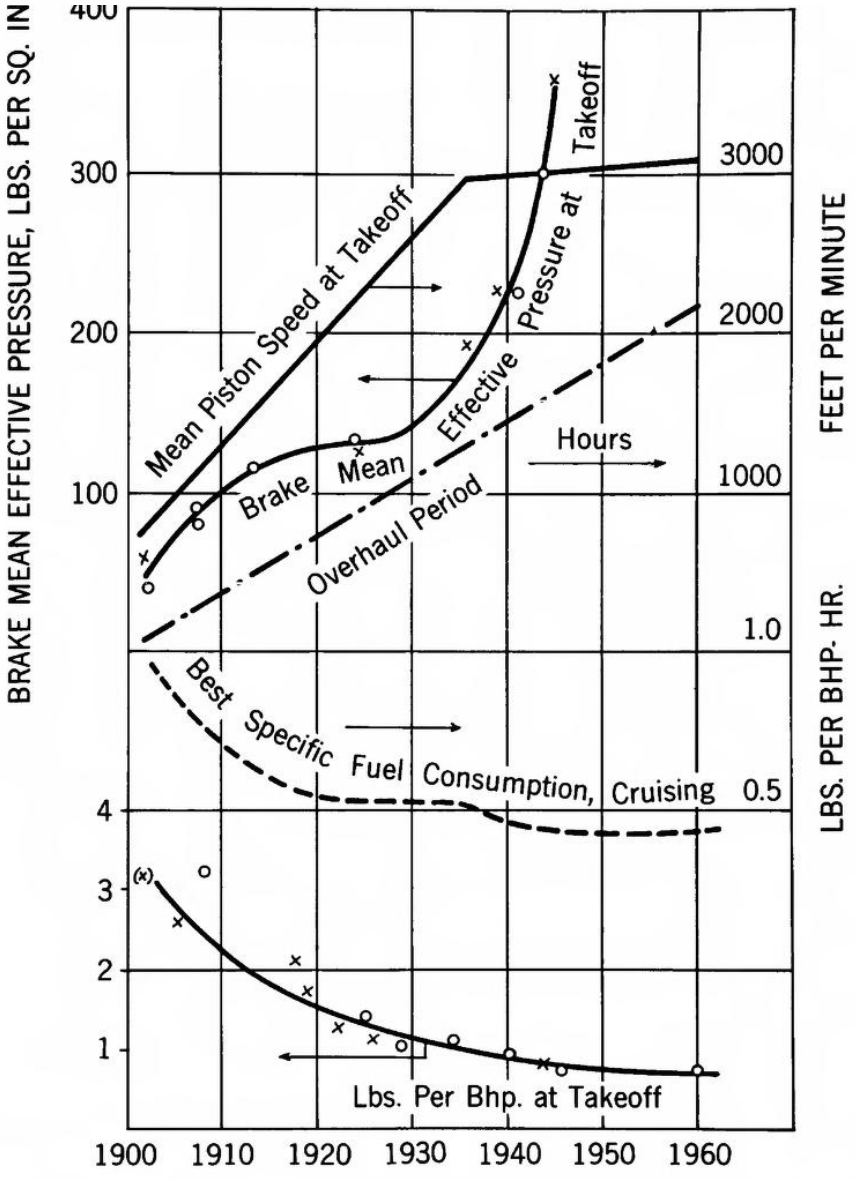
Starting. Hand starting by the propeller was standard before 1920. Subsequent development included simple hand cranks, hand cranks with inertia flywheel, cartridge starters, air starters and finally the present electric starter with storage battery.

Bearings and Lubrication. Most radial engines, even as early as the Gnome (fig. 20), used ball or roller bearings for the crankshaft. This practice has been continued with few exceptions of which figures 44 and 45 show examples. Ball or roller bearings occasionally have been used for crankpins (see figs. 20 and 33). Thrust bearings generally have been of the ball type.

Most aircraft engines have used plain journal bearings for the crankpin and, with the exceptions noted above, for the main crankshaft bearings. Before about 1930, such bearings were made of the lead-tin-antimony alloy babbit. This material is excellent for bearings in all respects except in structural strength, which is low.

After about 1930 the increases in power and speed, resulting in increased bearing loads, began to cause serious fatigue failure of plain babbit bearings. Meanwhile, a subsidiary of the General Motors Corporation had developed a bearing material consisting of a copper matrix filled in with lead. These “copper-lead” bearings were found to have excellent load-carrying ability as compared to babbit and were soon adopted as standard for all high-output aircraft engines.

Figure 71.—Engine development curves. Typical performance characteristics of military and large commercial airplane piston engines, 1903–1960. From 1930 on these curves apply to supercharged engines; unsupercharged engines, except as regards overhaul period, remain at approximately the 1930 levels.



During World War II, U.S. radial engines started to have crankpin-bearing failures when over-speeded in combat dives. A bearing consisting of a steel shell lined with a thin layer of cadmium, with a very thin overlay of silver was developed to solve this problem. Variations on this bearing have been used in large radial-engines crankpins since that time. Copper-lead bearings, when improved with a very thin overlay of tin, have generally been found adequate for V-type engine crankshafts and crankpins. These bearing developments have been an important factor in the up-rating of airplane engines illustrated by fig. 71.

Improvements in lubrication systems have included the use of full pressure feed to bearings, rather than gravity or splash feed, or such “total loss” systems as that already described for the Gnome engine. Another important improvement has been the installation of adequate oil filtering elements within the engine’s oil-circulation system. As size and power of engines has increased, it has become necessary to limit oil temperature by circulating the lubricant through oil radiators, usually air-cooled.

The use of castor oil as a lubricant for most, if not all, aircraft, engines previous to 1918, has already been mentioned. When fresh, this type of oil is an excellent lubricant, but has the disadvantages of rapid breakdown to gummy deposits in the engine and a very limited supply base. Work to explore the possibilities of petroleum oils for aircraft-engine lubrication was started at the United States Navy Aero-Engine Laboratory at Washington, D.C., in 1917, and within a few months a number of proprietary mineral oils were found satisfactory and approved for use in all except rotary engines. Since that time, development of mineral oils suitable for aircraft engines has been energetically carried on by the oil industry. The resulting improved quality of lubricants has been an important factor in increasing the reliability, and the running-time between overhauls, of aircraft piston engines.

Engine Instruments. The development of engine instruments has been concurrent with that of the engines themselves. The earliest flights were made without any engine instruments at all. Early instruments were chiefly for the purpose of indicating whether or not the engine was performing satisfactorily (in fact, this is still the purpose of most engine instruments carried in aircraft). First to come into use was some sort of tachometer for observing engine speed. It was followed, in the approximate order of use, by sight glasses or gauges to indicate oil flow or oil pressure, remote-reading temperature gauges for oil and coolant, and thermocouples for indicating the temperature of air-cooled cylinders at some critical point. As flight duration increased, fuel-supply indicators, usually showing fuel-level in tanks, were found important. The introduction of supercharging required manifold-pressure indicators. A late development in engine instruments is the engine "analyzer;" an electronic system which observes the ignition-voltage versus time curve of any cylinder on a cathode-ray screen and which requires the services of a Flight Engineer. Used in most large multi-engine airplanes, it enables a trained observer to detect and anticipate many forms of engine trouble or incipient failure by observing these curves for each cylinder in turn.

A detailed account of instrument history and technology is beyond the scope of this volume. Chatfield, Taylor, and Ober in the various editions of *The Airplane and its Engine* (1928-1948) give descriptions of instruments as they appeared at the time of publication.

Summary of Piston-Engine Development

Figure 71 shows performance parameters for piston aircraft engines since 1903.

Brake mean effective pressure (bmep) is a measure of an engines' ability to withstand high cylinder pressures and to produce power with a given speed and size. Starting at 62 psi (Langley, 1902), it rose to 130 by 1925, which is near maximum for un-supercharged engines. With the introduction of supercharging and improved fuels in the 1930s, bmep was increased to take-off values up to 360 psi (Rolls-Royce Merlin) and 300 psi (large radial engines in the United States) where it has remained since the advent of jets and turbines.

Mean piston speed (mps) at take-off rose steadily from 750 ft./min. in 1903 to a maximum of 3,000 ft./min. in 1935, where it has remained.

Specific fuel consumption has been reduced from nearly 1 lb./hp-hr. to current minimum values of less than 0.40. This improvement has been achieved partly through improved design and partly because improved fuels have allowed higher compression ratios (from about 4.0 in 1903 to present values, up to 8.0).

Best weight-per-horsepower in 1903 was that of the Manly engine, at 2.6 lbs./hp. This figure was reduced to 1 in 1935 and has gone slightly below that since (see Table 1).

TABLE 1.—Engines of Historical Importance

Engine	Year [a]	Type	No. cyl.	Bore (in.)	Stroke (in.)	Displ. (cu. in.)	Horsepower [b]	Rpm	Weight [c] lb	Weight [c] lb/hp	Bmep (psi)	Piston speed (ft/min)
Water-cooled												
Langley	1901	radial	5	5	5.5	687	52	950	135	2.6	63	870
Wright	1903	horizontal	4	4	4	200	[d] 16	1,090	179	11.2	58	725
Antoinette	1906	V	8	3.15	3.15	196	32	1,400	93	2.9	91	735
Darracq	1909	opposed	2	5.2	4.72	194	24	1,500	121	5.04	65	1,180
Curtiss OX–5	1910	V	8	4	5	503	90	1,400	320	3.55	101	1,170
Mercedes	1915	vertical	6	5.51	6.3	901	160	1,400	618	3.86	100	1,470
Hispano-Suiza	1915	V	8	4.72	5.11	718	150	1,450	467	3.1	114	1,235
Liberty	1917	V	12	5	7	1,650	420	1,700	856	2.04	118	1,985
Curtiss D–12	1922	V	12	4.5	6	1,145	325	1,800	704	2.16	125	1,800
Rolls Royce Kestrel VI.	1930	V	12	5	5.5	1,296	560	2,500	992	1.77	137	2,290
Rolls Royce Merlin I	1936	V	12	5.4	6	1,650	1,030	3,000	1,320	1.28	165	3,000
Packard-Merlin	1945	V	12	5.4	6	1,650	2,250	3,000	1,740	.78	360	3,000
Air-cooled												
Langley (model)	1901	radial	5	2.06	2.75	46.5	3.2	1,800	7	2.2	30	825
Anzani	1909	fan	3	4.13	5.12	206	24.5	1,600	145	5.9	59	1,360
Renault	1908	V	8	2.76	4.72	226	35	1,400	242	6.9	88	1,100
Gnome	1909	rotary	7	3.93	3.93	335	50	1,150	165	3.3	103	753
Jupiter	1920	radial	9	5.75	7.5	1,753	400	1,650	700	1.75	109	2,060
Jaguar	1922	2-row-radial	14	5	5.5	1,512	360	2,000	910	2.53	94	1,830
Lawrance J–1	1922	radial	9	4.5	5.5	787	200	1,800	476	2.38	112	1,650
Pratt & Whitney Wasp.	1926	radial	9	5.75	5.75	1,344	425	1,900	650	1.53	132	1,820
Wright 1820	1930	radial	9	6.13	6.88	1,823	575	1,900	940	1.64	.....	2,180
	1945	radial	9	6.13	6.88	1,823	1,525	2,750	1,376	.90	245	3,150
Continental A–65	1938	opposed	4	3.88	3.63	171	65	2,350	155	2.38	128	1,420
Pratt & Whitney 2800.	1940	2-row-radial	18	5.75	6.0	2,804	2,000	2,700	2,300	1.15	209	2,700
	1945	2-row-radial	18	5.75	6.0	2,804	2,800	2,800	2,327	.83	305	2,800
Pratt & Whitney 4360.	1948	4-row-radial	28	5.75	6.0	4,363	3,500	2,700	3,470	.99	235	2,700
Wright 3350	1941	2-row-radial	18	6.13	6.31	3,347	2,000	2,400	2,848	1.43	197	2,550
	1955	2-row-radial	18	6.13	6.31	3,347	3,700	2,900	3,560	.96	302	3,070

[a] Refers to year of first general use (except for Langley engine). Where two dates are given, they refer to typical early and late models of the same basic engine.

[b] Maximum rated, or takeoff power.

[c] Radiator, cowling, and coolant are not included in the weight of liquid-cooled engines Cowling is not included for air-cooled engines.

[d] Dropped to 12 hp after 1 min.

All liquid-cooled engines later than Curtiss D–12 are supercharged.

All air-cooled engines later than Lawrence J–1, except Continental, are supercharged.

One of the most remarkable improvements has been in reliability and reduced maintenance. The very early aircraft engines were overhauled after every flight. The approved overhaul period for the best modern transport piston engines is now as high as 2,600 hours.

Further improvements in piston engines would have been made had it not been for the introduction of turboprop and turbojet engines, which virtually put an end to intensive development of the large piston engine. Jet engines are also used for certain categories of small aircraft.

Figure 72 shows the piston-engine family as it has developed, finally culminating in the V-12 liquid-cooled engines as represented by the Rolls-Royce and Packard Merlin and the 18-cylinder air-cooled radials; by the Pratt & Whitney R-2800 and the Wright 3350, of which the latter two remain in air-transport service, as do also the Pratt & Whitney R-1830 and Wright R-1820 (in the DC-3 airplane). There are also some Pratt & Whitney 9-cylinder Wasp and Wasp Jr. engines in service in medium-powered airplanes, especially in Canada, and a few remain in service in the old Ford trimotors dating from about 1930.
A few Pratt & Whitney R-4360 28-cylinder engines also remain
In-service.

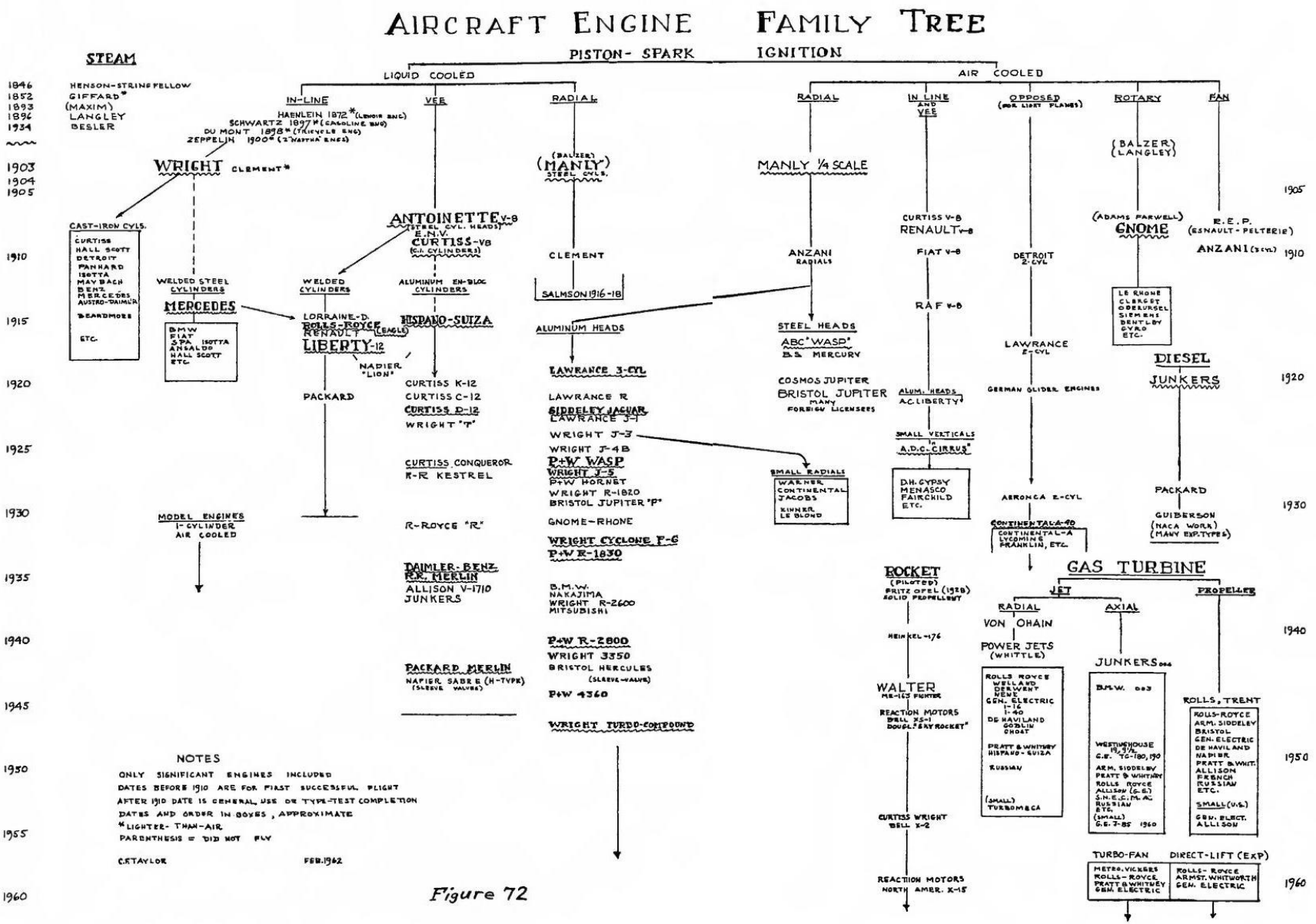

AIRCRAFT ENGINE FAMILY TREE
STEAM
PISTON- SPARK IGNITION
LIQUID COOLED
AIR COOLED
IN-LINE
VEE
RADIAL
RADIAL
IN LINE AND VEE
OPPOSED (MOR LIGHT PLANES)
ROTARY
FAN
1846
1852
1893
1896
1934
1903
1904
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
HENSON-STRINGFELLOW
GIFFARD*
(MAXIM)
LANGLEY
BESLER
HAENLEIN 1872* (LENOIR ENG)
SCHWARTZ 1897* (CAROLINE ENG)
DU MONT 1898* (TRICYCLE ENG)
ZEPPELIN 1900* (2 DAIMLER ENGS)
WRIGHT
CLEMENT*
ANTOINETTE V-8
(STEEL CYL. HEADS)
E.N.V.
CURTISS-V8
(CI. CYLINDERS)
(BALZER)
(MANLY)
STEEL CYLS.
MANLY 1/4 SCALE
CURTISS V-8
RENAULT V-8
(BALZER)
(LANGLEY)
(ADAMS FARWELL)
ENOME
E.E.P.
(ESNAULT-PELTERIE)
ANZANI (3 CYL.)
CAST-IRON CYLS.
CURTISS
HALL SCOTT
DETROIT
PANHARD
MAYBACH
BENZ
MERCEDES
AUSTRO-DAIMLER
BEARDMORE
ETC.
WELDED STEEL CYLINDERS
MERCEDES
BMW
FIAT
SPA
ISOTTA
ANSALDO
HALL SCOTT
ETC.
WELDED CYLINDERS
ALUMINUM EN-BLOC CYLINDERS
LORRAINE-D.
ROLLS-ROYCE (EAGLE)
RENAULT
LIBERTY-12
NAPIER "LION"
HISPANO-SUIZA
PACKARD
CURTISS K-12
CURTISS C-12
CURTISS D-12
WRIGHT "T"
CURTISS CONQUEROR
R-R KESTREL
R-ROYCE "R"
DAIMLER-BENZ
RR. MERLIN
ALLISON V-1710
JUNKERS
PACKARD MERLIN
NAPIER SABRE (H-TYPE)
(SLEEVE VALVES)
MODEL ENGINES
1-CYLINDER
AIR COOLED
CLEMENT
SALMSON 1916-18
ALUMINUM HEADS
LAWRANCE 3-CYL
LAWRANCE R
SIDDELEY JAGUAR
LAWRANCE J-1
WRIGHT J-3
WRIGHT J-4B
P+W WASP
WRIGHT J-5
P+W HORNET
WRIGHT R-1820
BRISTOL JUPITER "P"
GNOME-RHONE
WRIGHT CYCLONE F-G
P+W R-1830
B.M.W.
NAKAJIMA
WRIGHT R-2600
MITSUBISHI
P+W R-2800
WRIGHT 3350
BRISTOL HERCULES
(SLEEVE-VALVE)
P+W 4360
WRIGHT TURBO-COMPOUND
ANZANI
RADIALS
STEEL HEADS
ABC "WASP"
B.S. MERCURY
COSMOS JUPITER
BRISTOL JUPITER
MANY FOREIGN LICENSEES
SMALL RADIALS
WARNER
CONTINENTAL
JACOBS
KINNER
LE BLOND
FIAT V-8
RAF V-8
ALUM. HEADS
A.C. LIBERTY
SMALL VERTICALS
A.D.C. CIRRUS
D.H. GYPSY
MENASCO
FAIRCHILD
ETC.
DETROIT
2-CYL
LAWRANCE
2-CYL
GERMAN GLIDER ENGINES
AERONCA 2-CYL
CONTINENTAL-A
LYCOMING
FRANKLIN, ETC.
LE RHONE
CLERGET
OBERURSEL
SIEMENS
DENTLEY
GYRO
ETC.
DIESEL
JUNKERS
PACKARD
GUIBERSON
(NACA WORK)
(MANY EXP. TYPES)
ROCKET
(PILOTED)
FRITZ OPEL (1928)
SOLID PROPELLENT
HEINKEL-176
WALTER
ME-163 FIGHTER
REACTION MOTORS
BELL XS-1
DOUGLAS "RAY ROCKET"
CURTISS WRIGHT
BELL X-2
REACTION MOTORS
NORTH AMER. X-15
GAS TURBINE
JET
PROPELLER
RADIAL
AXIAL
VON OHAIN
POWER JETS
(WHITTLE)
ROLLS ROYCE
WELLAND
DERWENT
NENE
GEN. ELECTRIC
I-16
I-40
DE HAVILAND
GOBLIN
GHOST
PRATT & WHITNEY
HISPANO-SUIZA
RUSSIAN
(SMALL)
TURBOMECA
JUNKERS 004
B.M.W. 003
WESTINGHOUSE
19, 24
G.E. TG-180, 190
ARM. SIDDELEY
PRATT & WHITNEY
ROLLS ROYCE
ALLISON (G.E.)
S.N.E.C.M.A.
RUSSIAN
ETC.
(SMALL)
G.E. J-85 1960
ROLLS, TRENT
ROLLS-ROYCE
ARM. SIDDELEY
BRISTOL
GEN. ELECTRIC
DE HAVILAND
NAPIER
PRATT & WHIT.
ALLISON
FRENCH
RUSSIAN
ETC.
SMALL (U.S.)
GEN. ELECT.
ALLISON
TURBO-FAN
METRO. VICKERS
ROLLS-ROYCE
PRATT & WHITNEY
GEN. ELECTRIC
DIRECT-LIFT (EXP)
ROLLS-ROYCE
ARMST. WHITWORTH
GEN. ELECTRIC
NOTES
ONLY SIGNIFICANT ENGINES INCLUDED
DATES BEFORE 1910 ARE FOR FIRST SUCCESSFUL FLIGHT
AFTER 1910 DATE IS GENERAL USE OR TYPE-TEST COMPLETION
DATES AND ORDER IN BOXES, APPROXIMATE
*LIGHTER-THAN-AIR
PARENTHESIS = DID NOT FLY
C.F. TAYLOR
FEB. 1962

Figure 72

Where the piston engine continues to reign supreme is with the popular light plane. Literally tens of thousands of air-cooled, horizontally opposed piston engines manufactured by Continental, Lycoming and Franklin power American light planes; and they have their counterparts in lesser quantities in Europe. Although by no means as dramatic as the power-plants that count their horse-power in four digits, these modest prime movers have enjoyed greater quantity production than any other type of aero-engine except those for model airplanes.

Figure 72 also includes a family tree for rocket, turbo-jet and turboprop engines. The history of these developments is so recent and so well covered in the literature (particularly by Schlaifer and Gibbs-Smith) that no attempt will be made to cover it here. There could well be a paper as long as this one, or even a whole volume, devoted to this important and revolutionary development in aircraft propulsion.

It is interesting to review the contributions of the various nations in the field of aircraft propulsion. Table 2 summarizes this subject. It is evident that the United States and France have been the principal contributors to early engine development, while England has made significant contributions in late piston and early turbine engines and Germany was the first to fly rocket and jet engines, although German and British turbojet development was concurrent.

TABLE 2.—Credits, by Country, for Engine Developments

First manned flight	*Engine*	*Aircraft*	*Year*
	AUSTRIA		
Internal combustion engine	Lenoir gas engine	Haenlein (dirigible)	1872
	DENMARK		
Fixed radial engine air-cooled	Ellehammer	Ellehammer	1906
	ENGLAND		
With gear-driven centrifugal supercharger	Armstrong Siddeley	Armstrong Siddeley	1917
Transatlantic nonstop	Rolls-Royce Eagle	Vickers Vimy	1919
Automatic constant-speed propeller	Bristol Jupiter	Gloster Grebe	1928
Turbo-propeller engine	Rolls-Royce Trent	Meteor	1945

France

Steam engine	Steam	Giffard (dirigible)	1852
Electric motor	Electric motor	Tissandier (dirigible)	1883
Air-cooled Otto-cycle engine	Tricycle engine	Santos-Dumont (dirigible)	1898
Helicopter	Antoinette V–8	Cornu helicopter	1907
Rotary radial engine	Seguin Gnome	Voisin	1909
More than 8 cylinders	Levavasseur Antoinette 16-cylinder	Antoinette	1910
Propeller reduction gear	Renault V–8	Farman	1910
Inlet-port fuel injection	Antoinette	Antoinette	1906
Seaplane (floats)	Gnome	Heurig Fabre	1910
Turbosupercharger	Rateau	R.A.F. 4D	1918

Germany

Rocket engine	von Opel	Opel–Sander Rak–1	1929
Diesel engine in commercial transport	Junkers 2-cycle opposed piston	Junkers G–38	ca. 1936
Jet engine	von Ohain	Heinkel He–178	1939
Axial flow jet engine	Junkers Ju–004	Messerschmitt 262	1944
Rocket engine in military service	Walter	Messerschmitt 163	1944

Spain-Switzerland

Aluminum cylinder structure	Hispano-Suiza	Spad 7	1914

United States

First manned flight	*Engine*	*Aircraft*	*Year*
Airplane	Wright	Wright	1903
Seaplane (flying boat)	Curtiss	Curtiss	1912
Over 400 hp	Liberty	DeHavilland–4	1918
Transatlantic with 2 stops	4 Liberties	Navy-Curtiss NC–4	1919
With fuel antiknock	Liberty	DH–4 (McCook Field)	1921
Metal propeller	Reed	Standard J–1	1921
Controllable-pitch propeller	Hispano-Suiza	Curtiss JN–4 (McCook Field)	ca. 1921
Over 200 mph	Curtiss D–12	Curtiss racer (Detroit)	1922
Crankless engine	Caminez	Fairchild	1926
Roots supercharger*	Liberty	DH–4 (NACA)	1927
Diesel engine	Packard	Stinson Detroiter Monoplane	1928
Cylinder fuel injection with spark ignition	Pratt and Whitney	Ford or Fokker	1931
With pendulum-type vibration absorber	Wright 1820	Wright Experimental	1935

*As stated (p. 60), the British two-cycle NEC engine used a Roots-type scavenger blower, but this was not a supercharger in the sense that it was used for altitude compensation

If the art and science of aircraft propulsion develop as fast in the next 50 years as they have since the Wright brothers' initial flight, the following prophecy of Lester D. Gardner in *Aviation* (vol 1, no. 1, August 1916), will be as meaningful today as it was then:

> Now many of the most distinguished scientists in all countries are giving aeronautics close and careful study. From the work of these men aeronautics will derive the information upon which progress, such as has never been thought possible, will be achieved.

Appendix

The Rotary Radial Engine

The radial engine has been built in two essentially different configurations: the static radial, which still enjoys widespread use; and the rotary (rotating) radial, which passed out of use soon after 1918. The former may be considered a “conventional” engine, in which the pistons, reciprocate inside the cylinders of an engine firmly attached to the airframe.

In the rotary radial, however, the anti-propeller end of the crankshaft is attached to the airframe, and the cylinders and crankcase, to which of necessity the propeller is fixed, rotate around the crankshaft (see figs. 20 and 21). The rotary engine functions internally in exactly the same manner as the conventional radial engine, but because of this arrangement the pistons do not reciprocate relative to the mounting structure, and therefore no unbalanced forces result. Thus, in operation, the rotary engine is exceptionally free from vibration. As mentioned in the text, the large flywheel effect of the rotating cylinders was important in relation to the type of control system used at the time.

The rotary radial engine shares with the conventional radial the advantages of compactness, short crankshaft and adaptability to air-cooling. On the other hand it has the following inherent disadvantages:

1. Severe limitations on rpm, resulting from high centrifugal forces created within the revolving engine and wind drag caused by the rotating cylinders.
2. Design limitations imposed by the rotation of all parts except the crankshaft.
3. An undesirable gyroscopic effect on the airplane during turns.
4. Limitations on the lubrication system, which, owing to the design of the engine, resulted in high oil consumption and the throwing out of excess oil with the exhaust, as mentioned in the text.
5. Difficulty of providing a closed exhaust system.

In spite of these disadvantages, however, the rotary engine was an excellent design for the state-of-the-art during the two decades after 1900. It was produced in large quantities during 1914-1918 and powered many successful fighter planes.

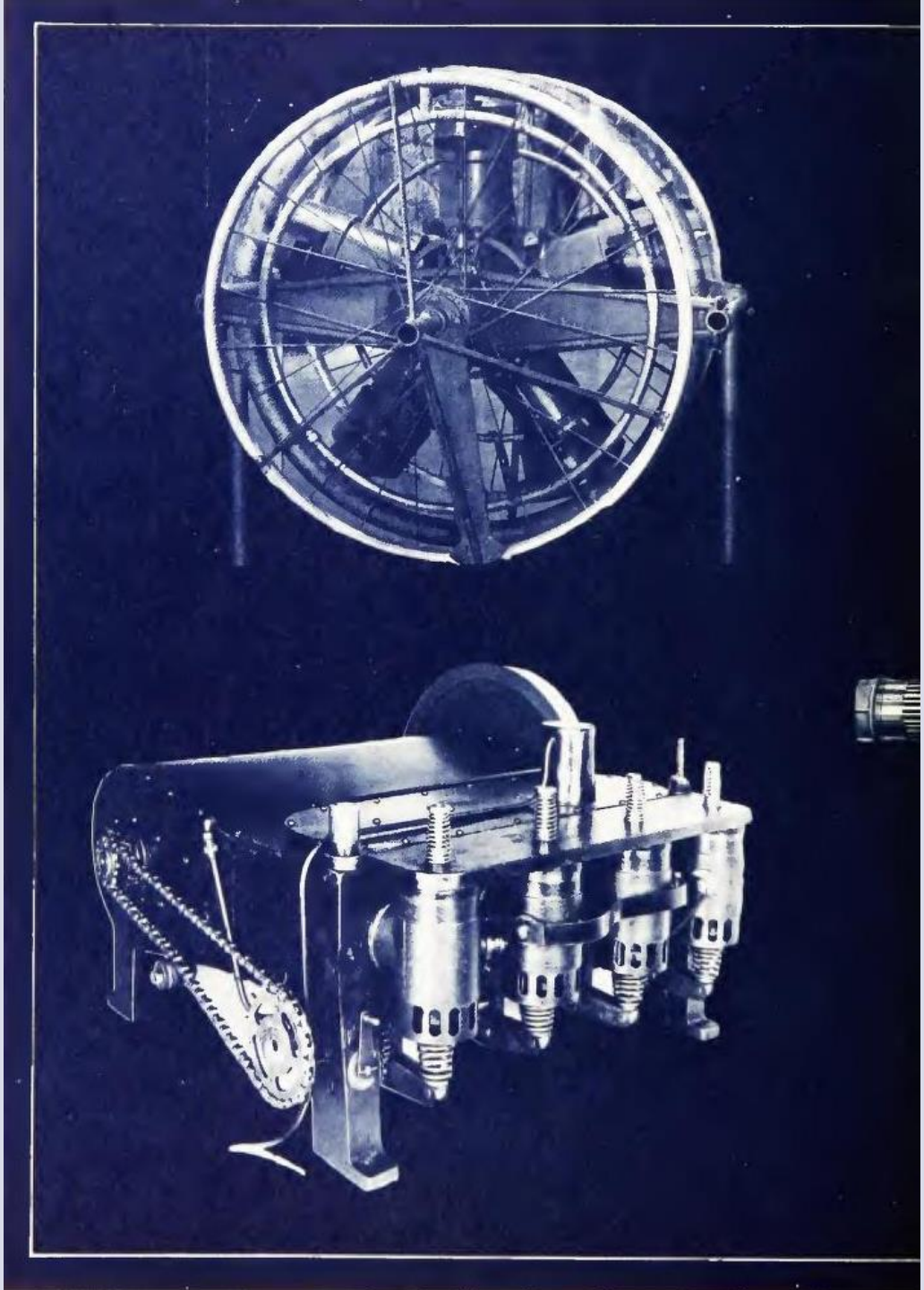
Bibliography

Expanded and Arranged by Dr. Richard K. Smith
from Material Furnished by C. Fayette Taylor

The bibliography is limited to material, mostly in the English language, which the author considers important in connection with the history of aircraft propulsion, and with which he is familiar. An exhaustive bibliography including all important foreign references would be a desirable project for some future Historian.

The first section of the bibliography contains books and periodical articles in which the emphasis is on the historical aspects of engine development. The second and third sections, comprised mainly of references to topical articles in the periodical literature, is arranged chronologically by date of publication. This was done on the assumption that anyone using this bibliography is more likely to be familiar with the time period in which a development has occurred that with an author's name.

NACA (National Advisory Committee for Aeronautics - later the National Aeronautics and Space Administration, NASA, Washington, D.C.) carried out, and also sponsored, exhaustive and important research in airplane engine technology.



Part 3

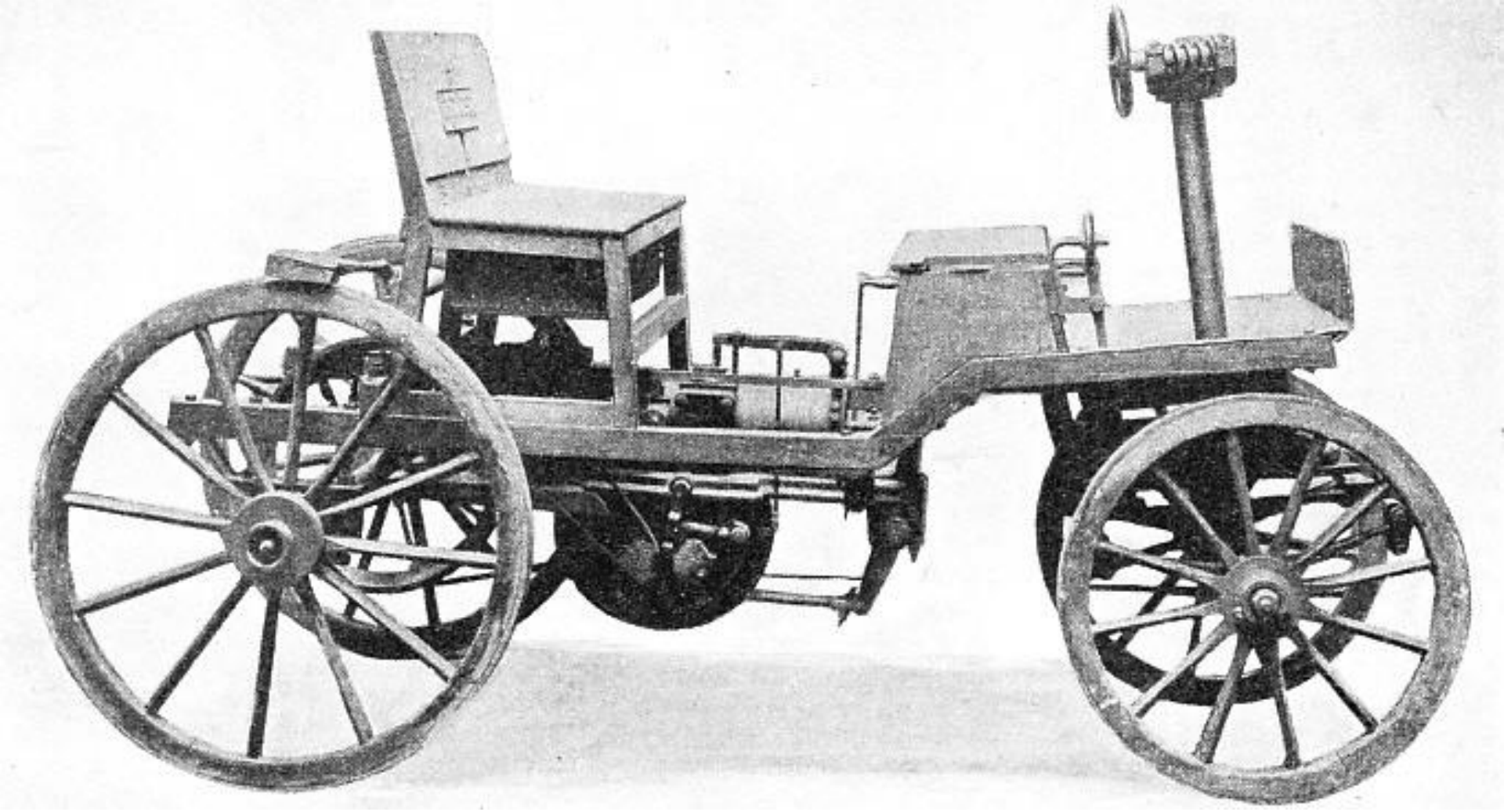
Aero-Engine

The Quest

The quest for efficiency with lightness and reliability
***Wonders of World Aviation*, ca. 1938**
RE: introduction to an article entitled: “Evolution of the Aero-Engine”

Troika

"THE majority of the aircraft engines in use today fall into one of three categories - the vertical engine, the V-type and the radial engine. These three main types have established themselves after nearly forty years of research and experiment and they all have a common origin, which is the light internal combustion engine, as used in the earliest motor cars…"
***Wonders of World Aviation*, ca. 1938**



Caption: "ONE OF THE FIRST PETROL-DRIVEN CARS. It is said to have been built by Siegfried Markus, of Vienna, in the eighteen-seventies, but no precise details of its performance are available. Credit for the motor car, as we know it today, is generally given to Benz and Daimler, whose first vehicles, built in the eighties, were the forerunners of the modern car."

The Otto Cycle

"…When Dr. Otto introduced the light internal combustion engine in the seventies, he laid the foundations of aircraft propulsion. His invention made controlled flight - as opposed to mere ascent in the air - a possibility…"

***Wonders of World Aviation,* ca. 1938**

RE: *Nicolaus August Otto* (1832–1891) was a German Engineer who successfully developed the compressed charge internal combustion engine which ran on petroleum gas and led to the modern *Internal Combustion Engine* (ICE). The *Association of German Engineers* (VDI) created DIN standard 1940 which states: "Otto Engine: internal combustion engine in which the ignition of the compressed fuel-air mixture is initiated by a timed spark," which has been applied to all engines of this type ever since.

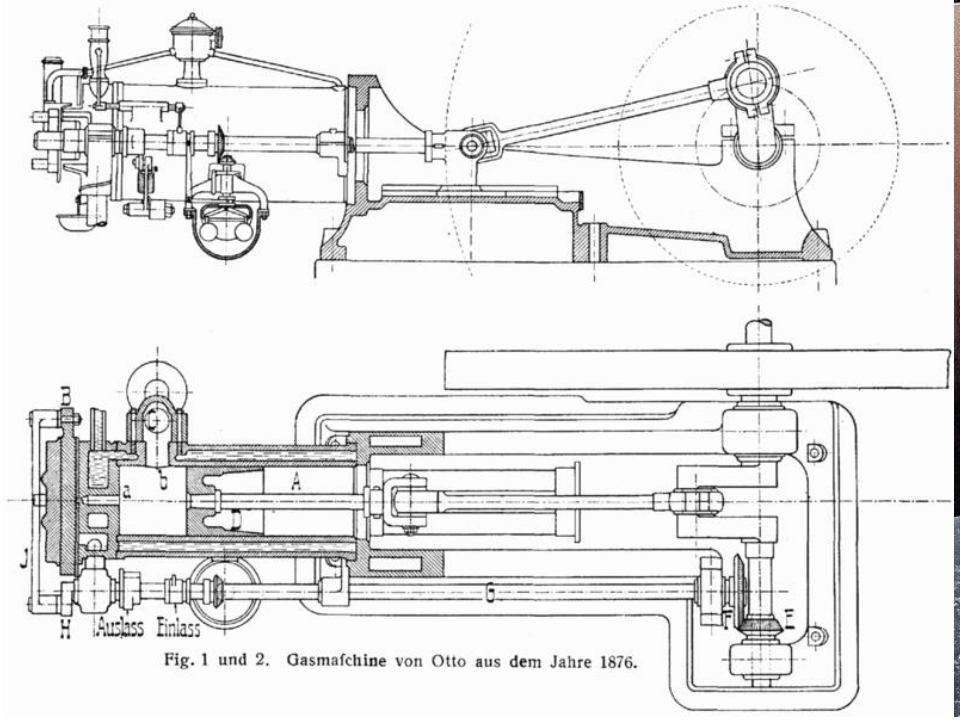
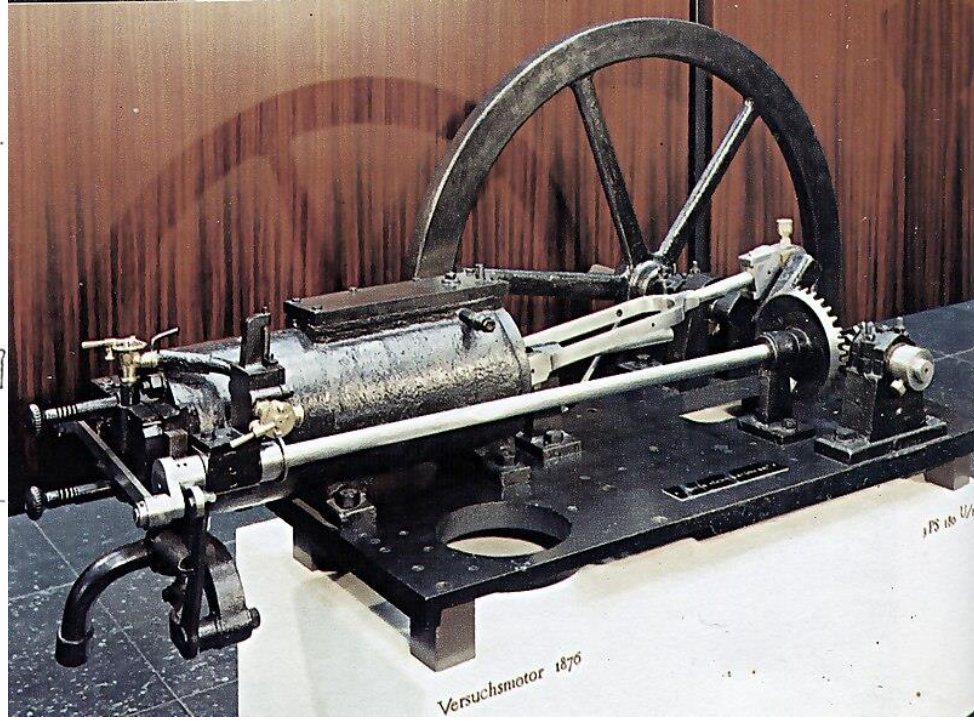


Fig. 1 und 2. Gasmafchine von Otto aus dem Jahre 1876.



The Otto engine (which is the predecessor of the modern engine), as specified by the VDI was Otto's fourth design:

- **1861: a copy of Lenoir's atmospheric engine;**
- **1862: a four-cycle compressed-charge engine (which failed);**
- **1864: the first successful atmospheric engine, and;**
- **1876: the four-stroke compressed charge engine which is acknowledged as the "Otto" cycle engine. The term "Otto Cycle" is applied to all compressed-charge, four-cycle engines.**

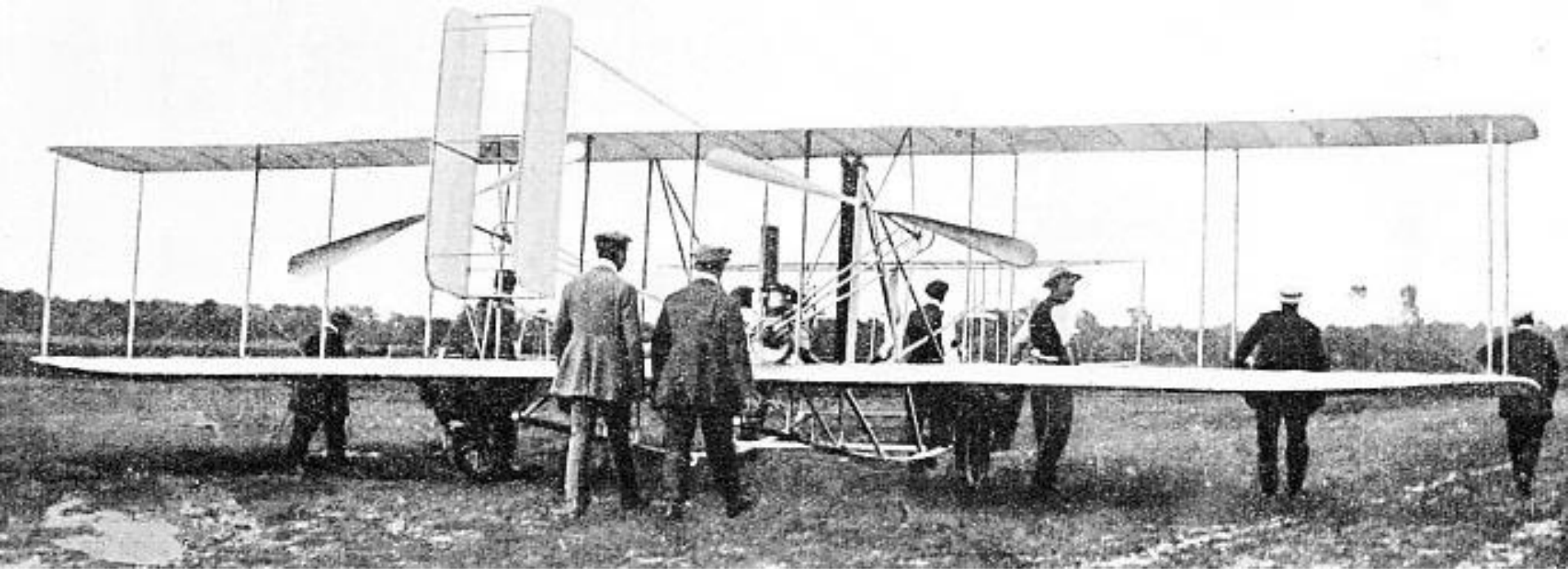
In the action of the Otto engine, the stroke is an upward or downward movement of a piston in a cylinder. Four strokes are involved.

<u>Left</u>: caption: "Diagram of Otto's 1876 four-cycle engine"

<u>Right</u>: caption: "Otto's 1876 four-cycle engine"


75 JAHRE
OTTO-
MOTOR
30
DEUTSCHE BUNDESPOST
L. SCHNELL

The P-W Ratio



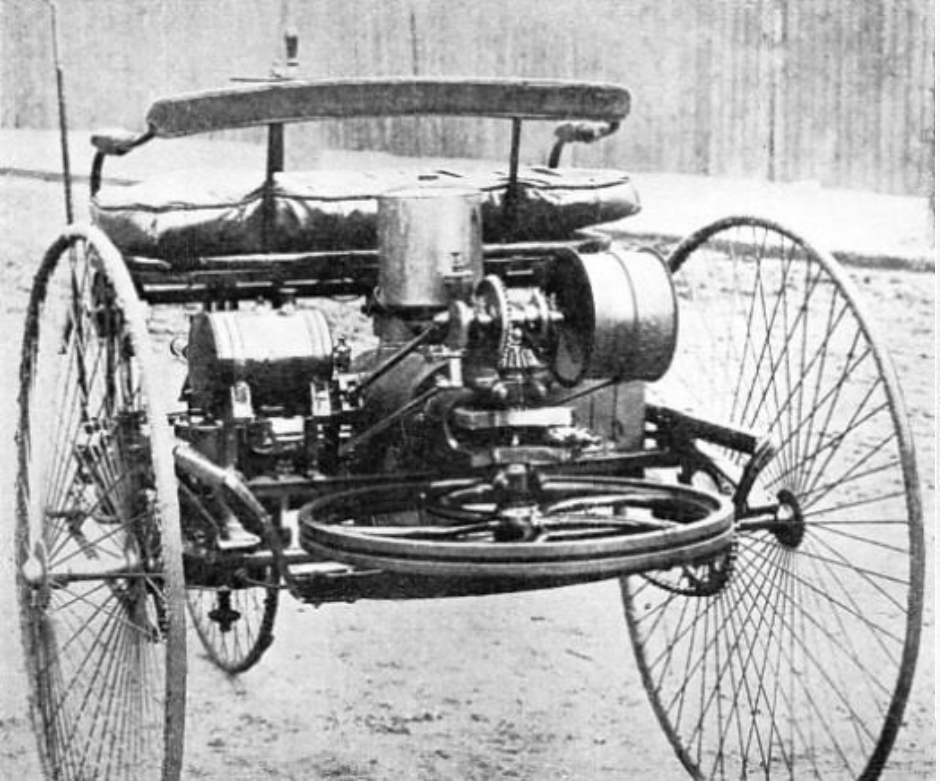
"…Even the earliest internal combustion engines had a power-weight ratio which was much higher than that obtained from other forms of prime mover. It was this relatively high ratio that enabled the Wright brothers to make the first aeroplane flight in 1903…"

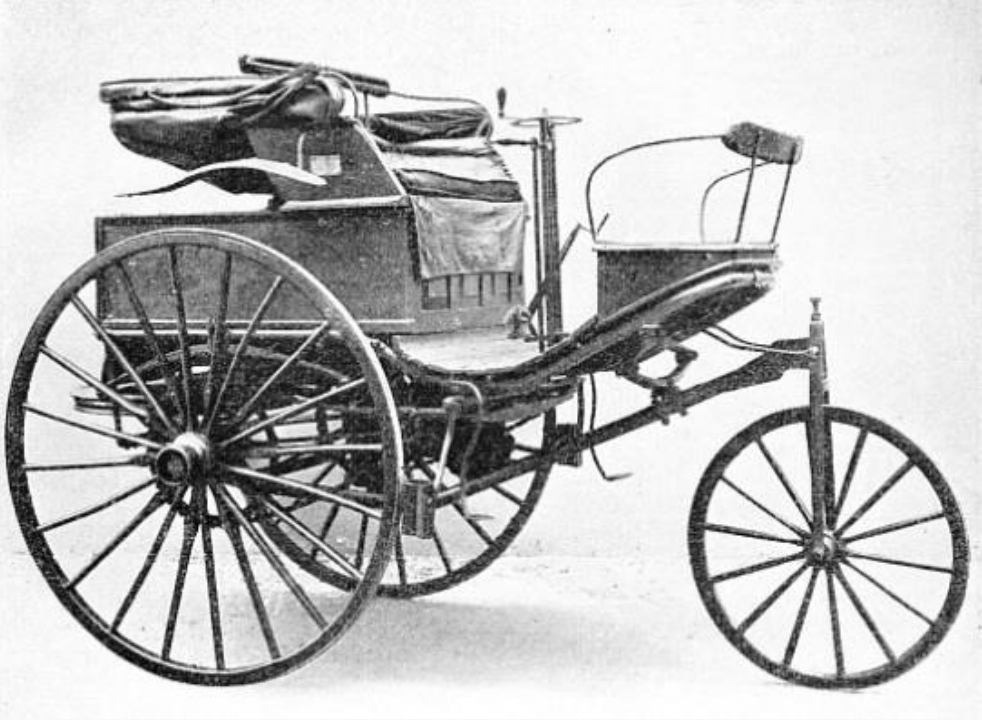
***Wonders of World Aviation,* ca. 1938**

<u>Caption</u>: "THE WRIGHT AEROPLANE IN FRANCE. Wilbur Wright made a number of flights in France in 1908 and convinced the sceptics in Europe of the achievements he and his brother had claimed. His first flight in France was on August 8, 1908, on the Hunaudieres racecourse near Le mans. The general design of this machine was the same as that of its predecessors, but the pilot and passenger were in a sitting instead of a prone position and a more powerful engine was used."

"…The early motor cars played an important part in the development of the modern aircraft engine, although they were designed and used many years before the first aeroplane flight was made…"

***Wonders of World Aviation*, ca. 1938**





Left: caption: "THE FIRST BENZ MOTOR TRICYCLE, built in 1885. The engine was mounted over the rear axle and had a single horizontal cylinder, with a vertical crankshaft which drove a large flywheel. The engine was rated at 3/4-horsepower and ran at a maximum speed of 250 revolutions-a-minute. The driving shaft was divided and fitted with a differential gear. Final drive was by chains."

Right: caption: "A BENZ CAR OF MORE ADVANCED DESIGN, built in 1888. It is a four-seater, with wooden wheels and iron tires. The engine, mounted horizontally above the rear axle, developed some 1-1/2-horsepower at 300 revolutions-a-minute. A surface carburetor was used, ignition being by battery, coil and sparking plug. The single cylinder of the engine was water-cooled, the radiator being replenished with cold water from a tank under the rear seat."

"…It was the use of the internal combustion engine in these early cars that first led designers to attempt to decrease the weight of their engines and to increase the power output. The later history of the aircraft engine is an account of constant efforts to improve the power-weight ratio by every means within the designer's reach…"

***Wonders of World Aviation*, ca. 1938**

"…All the early attempts to fly heavier-than-air machines, however, were carried out with aeroplanes equipped with adapted car engines and no particular attempts were made to lighten them. Their power-weight ratio was generally approximately 8 lbs. per-horsepower…"

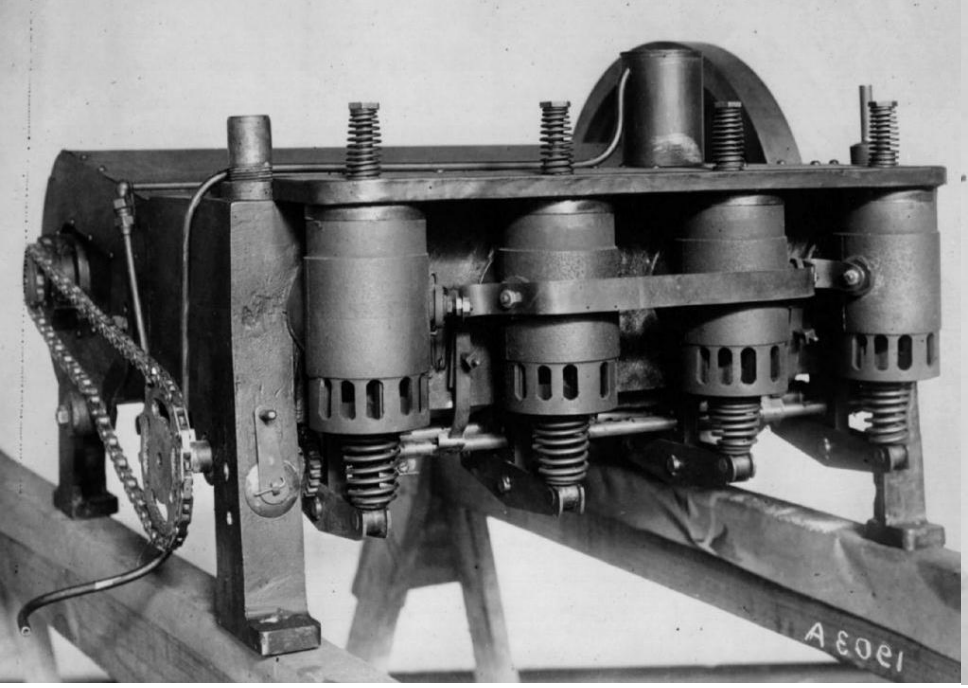
***Wonders of World Aviation,* ca. 1938**

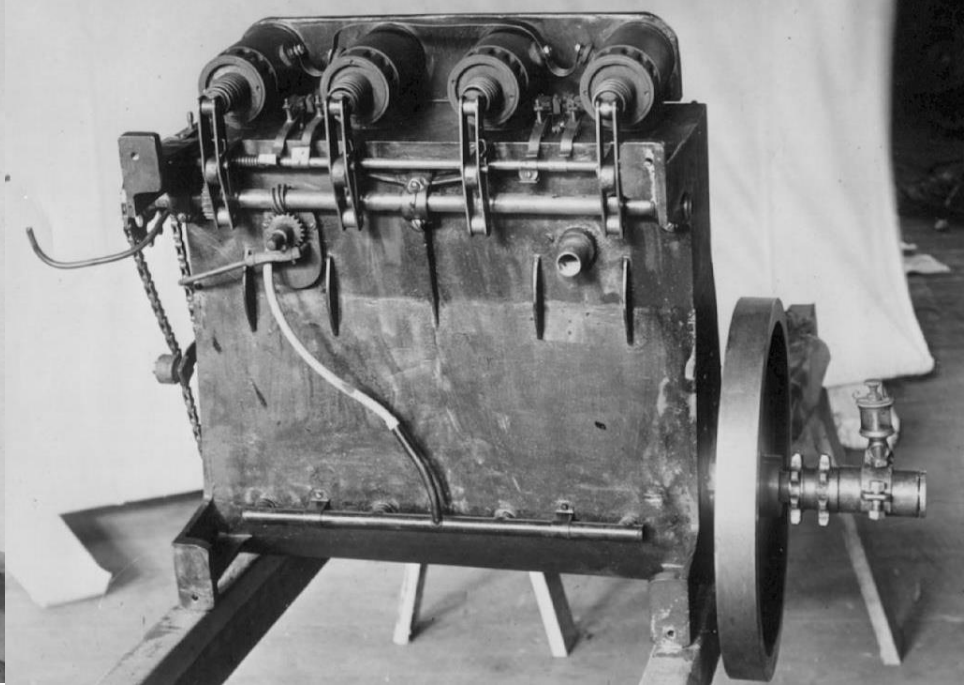
RE: once they had decided to attempt powered flight, the Wright Bros. calculated they needed an engine that produced at least 8-horsepower and weighed no more than 200 pounds. A survey of the automotive market, at the time, demonstrated that there was no such engine available and they would have to make their own.

"…The engine used for the first aeroplane flight was even less efficient; its weight was some 240 lbs. and it developed roughly 15 horsepower. It was a water-cooled four-cylinder engine mounted in the machine in such a way that its cylinders were horizontal…"

***Wonders of World Aviation,* ca. 1938**

RE: an acquaintance at the nearby *Buckeye Irons and Brass Works* advised the Wright Bros. that they could save weight if they cast the engine block from aluminum. Although it was a soft metal, alloys had recently been developed that were much stronger; both Benz and Daimler in Germany were successfully making engines with aluminum blocks. The Wrights decided to cast the block from an alloy of 92% aluminum and 8% copper. After the castings had been made, the Wrights "mechanician," Charlie Taylor, machined the parts and assembled the engine.



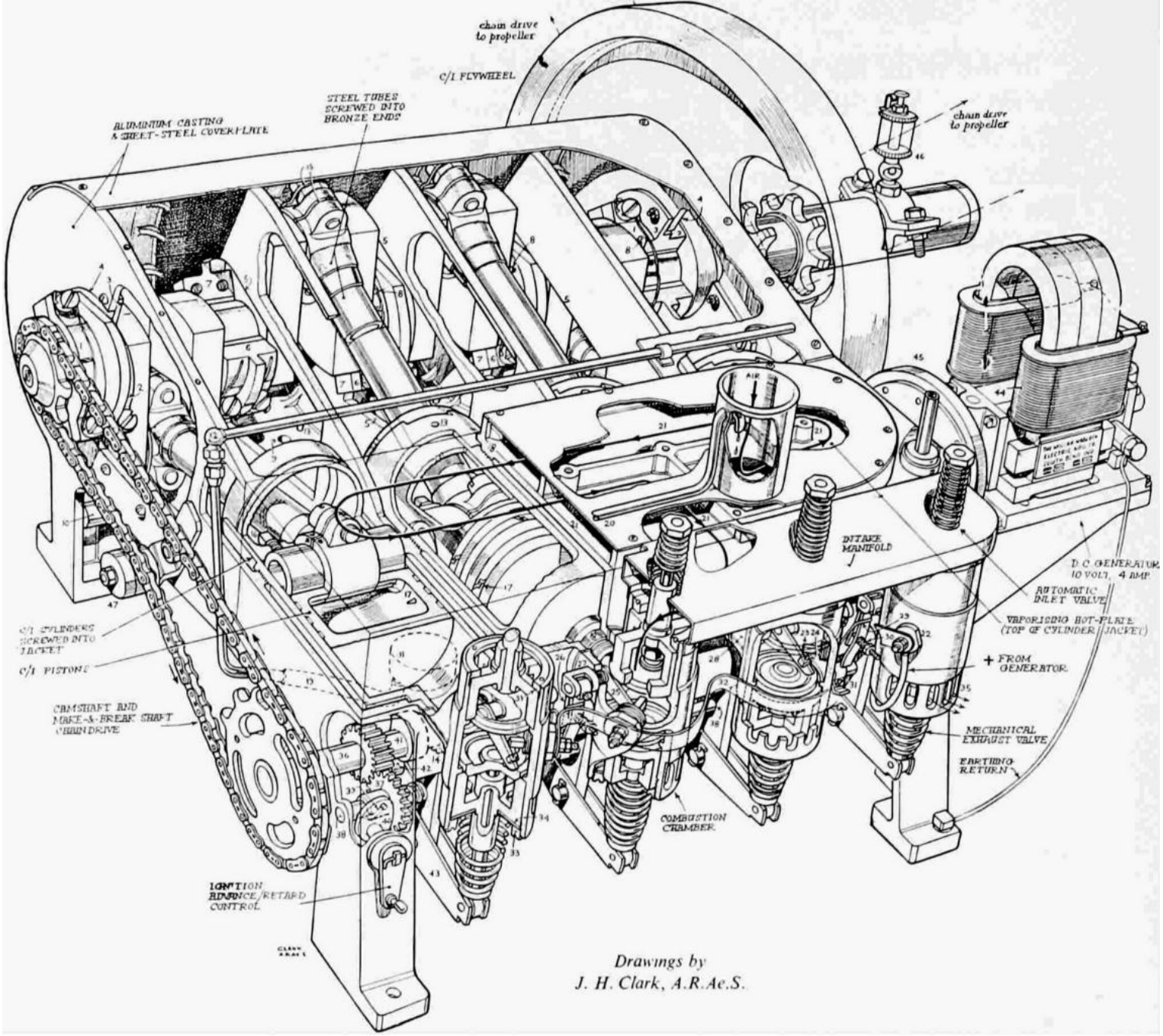


"We didn't make any drawings. One of us would sketch-out the part we were talking about on a piece of scratch paper and I'd spike the sketch over my bench. It took me six weeks to make that engine. The only metal-working machines we had were a lathe and a drill press, run by belts from the stationary gas engine . . . The completed engine weighed 180 pounds and developed 12-horsepower at 1,025 revolutions-per-minute…"

***Charlie Taylor,* Mechanician**

<u>Left</u>: caption: "The 1903 Wright engine on a test bench after it was restored in 1916"

<u>Right</u>: caption: "The underside of the 1903 Wright engine, showing the oil pump as well as the cam shaft and rocker arms that operate the exhaust valves"



A cut-away drawing of the 1903 engine, showing the assembled parts

Do’s and Don’ts

"…The aircraft engine designer has, from the first, been faced with problems quite different from those of the automobile designer…"

***Wonders of World Aviation*, ca. 1938**

"…In the motor car, a heavy flywheel plays a most important part in the achievement of steady running, but a component as heavy as a flywheel cannot be used in an aero-engine. The propeller has a flywheel action, but its effect at low speeds is not great and the pioneers were dealing with speeds which are considered low today…"

***Wonders of World Aviation*, ca. 1938**

"…In their efforts to obtain smoother running without the use of a flywheel, the early designers increased the number of cylinders in their engines, thus securing a more even torque with an increased number of impulses for each revolution…"
***Wonders of World Aviation*, ca. 1938**

"…The importance of producing an engine of light-weight was apparent from the first and this was achieved by shortening the length of the engine; by directly reducing the weight of the crankcase and by using shorter and lighter crankshafts, fewer bearings, lighter bolts, liners and the like…"
***Wonders of World Aviation*, ca. 1938**

Bearing Fruit

"…By energetic application of such methods, designers had succeeded, as early as 1909, in producing engines in which the power-weight ratio was far more favorable than that of motor car engines of the same period…"

***Wonders of World Aviation,* ca. 1938**



"…For example, Green developed a six-cylinder vertical engine of 120 horsepower weighing only 3.66 lbs. per-horsepower. It was in an aero-plane fitted with one of these engines that J.T.C. Moore-Brabazon won, in 1909, a prize of £1,000 offered by a London newspaper…"

***Wonders of World Aviation,* ca. 1938**

RE: on October 30, 1909, flying the Short Biplane No. 2, *John Moore-Brabazon* flew a circular mile and won a £1K prize offered by the *Daily Mail* newspaper

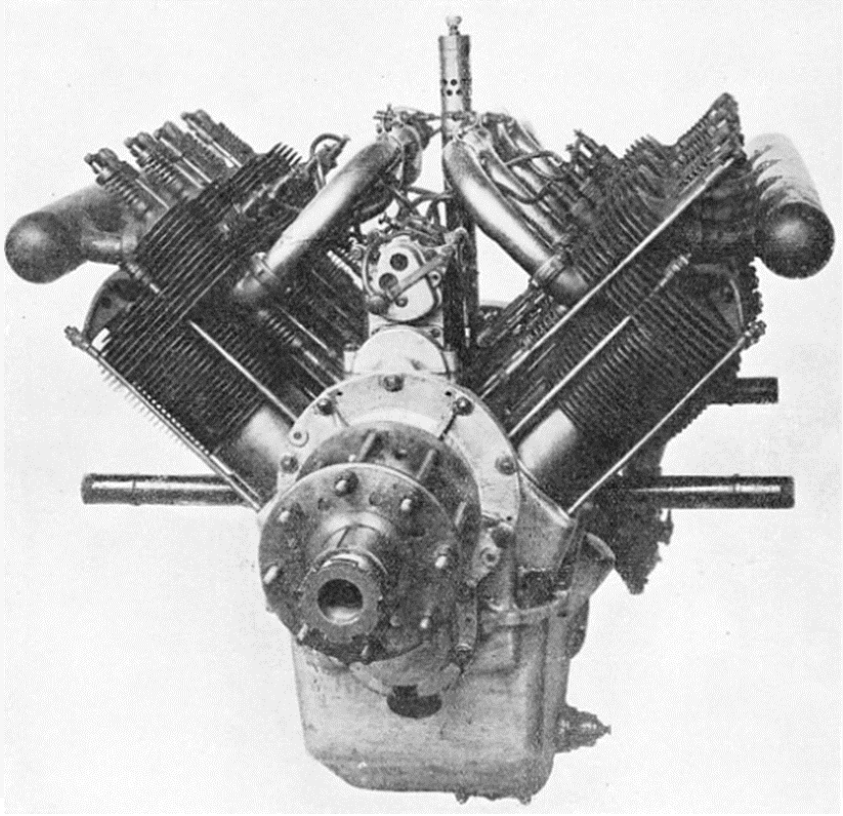
<u>Caption</u>: "J.T.C. Moore-Brabazon winning the Daily Mail £1,000 prize for the first flight of one mile in a closed circuit by a British pilot in an all-British aero-plane in the Short Biplane No. 2 at Leysdown in September 1909"

Limitations

"…It was soon realized, however, that there was a limit to the number of cylinders that could be used with efficiency in the vertical type of engine with cylinders in-line. The power-weight ratio increased rapidly after the first cylinder, but by the time four cylinders had been installed it was impossible to improve conditions greatly by adding more…"

***Wonders of World Aviation*, ca. 1938**

The Letter “V”



"…This limitation led designers to break away from convention and to group their cylinders in two banks arranged in the form of a V. Such an arrangement, with banks of four or six cylinders each, is extensively used today for high-powered engines…"

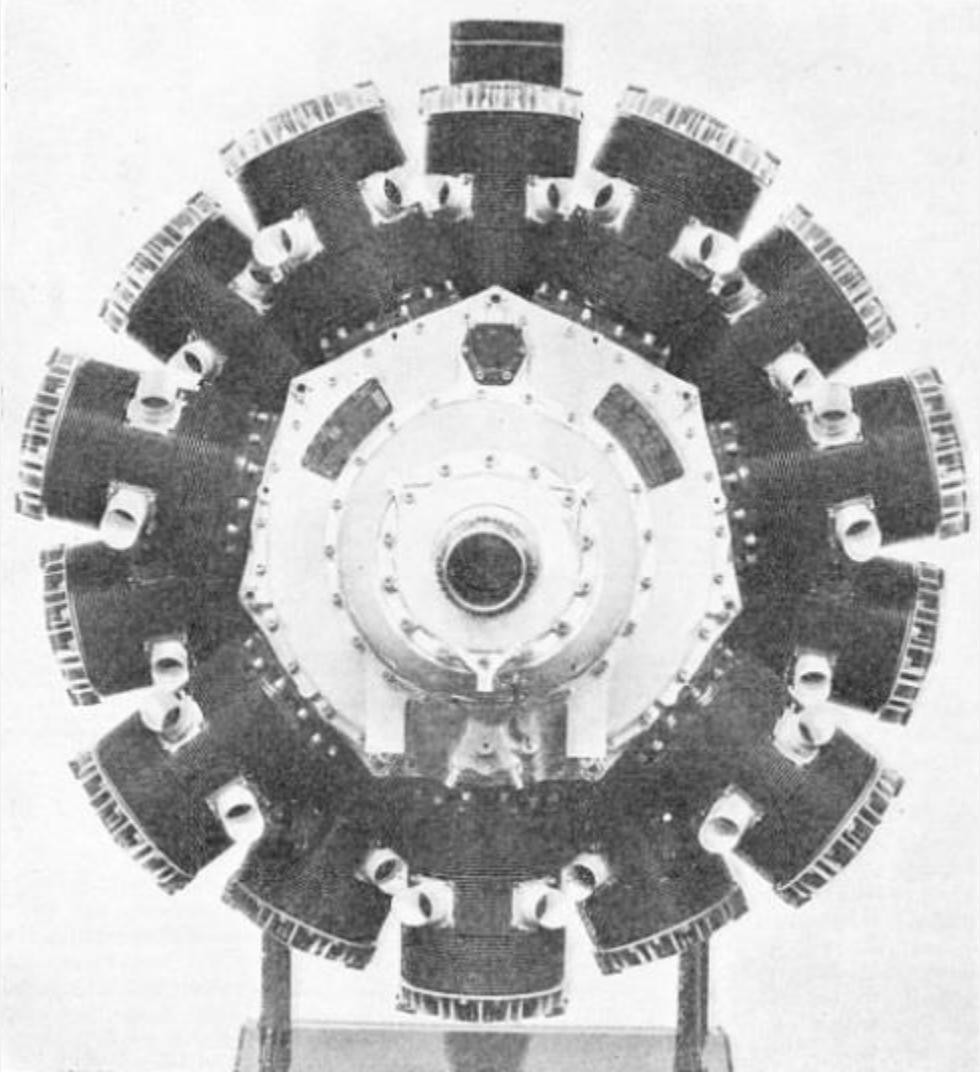
***Wonders of World Aviation,* ca. 1938**

<u>Caption</u>: "V-TYPE RENAULT OF 1913, developing 80-horsepower. This French engine had eight air-cooled cylinders, arranged in two banks of four. The earliest V-type engines used in aircraft were small two-cylinder and four-cylinder motor car engines. Today the V-type is considered one of the best layouts for liquid-cooled engines, whereas air-cooling finds favor in vertical or radial designs."

Reduced to a Minimum

"…Pioneer designers were attracted also by the possibilities of mounting the cylinders radially round the crankshaft; this scheme reduced to a minimum the length of the crankshaft and crankcase and made possible further reductions in weight…"

***Wonders of World Aviation*, ca. 1938**

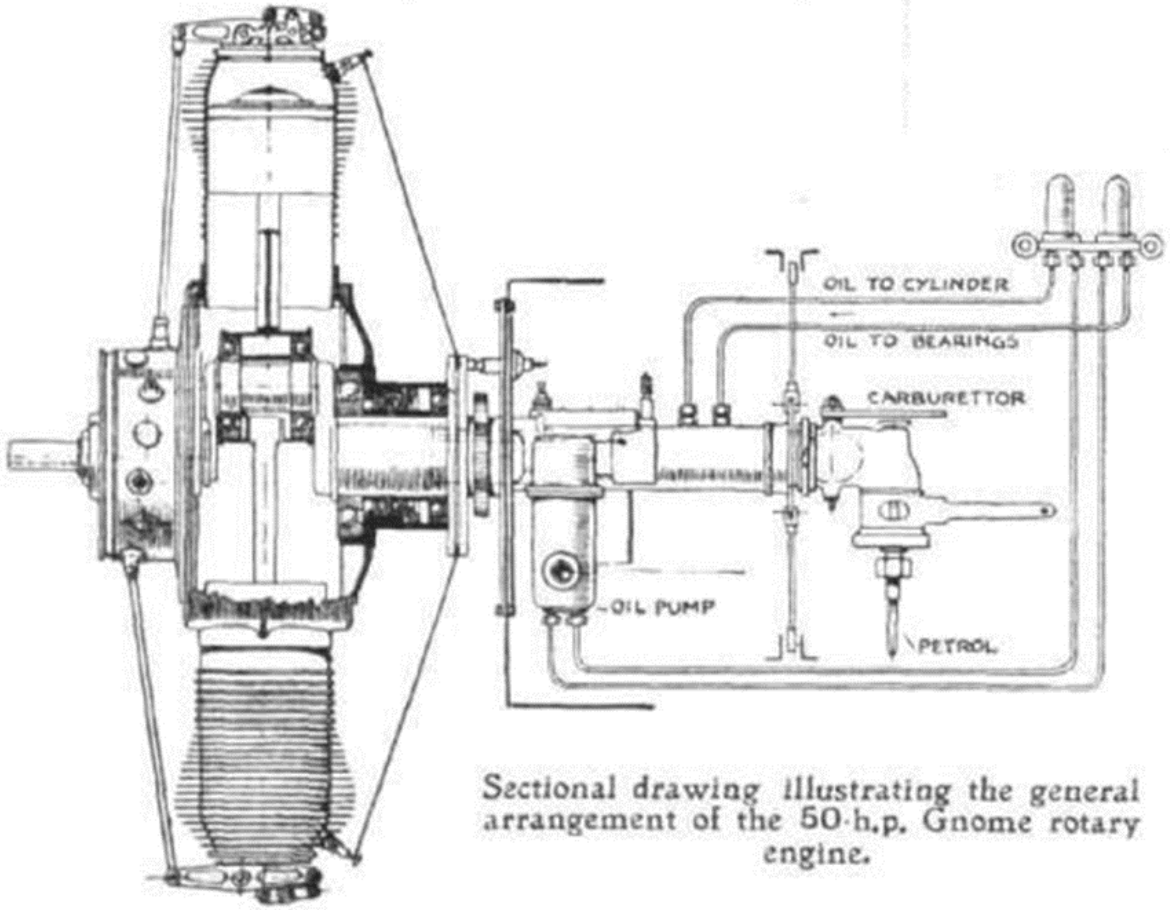


<u>Caption</u>: "WITH FOURTEEN CYLINDERS, the Bristol Hercules is one of the most powerful of British aero-engines. Air-cooled, radial and provided with sleeve valves, the Hercules was first tested early in 1936. The total cylinder capacity of the engine is 38.7 litres. In medium supercharged form it has a maximum take-off power of 1,240-1,290 bhp at 2,650 revolutions and an international rating of 1,100-1,150 bhp at 2,400 revolutions at 5,000 feet."

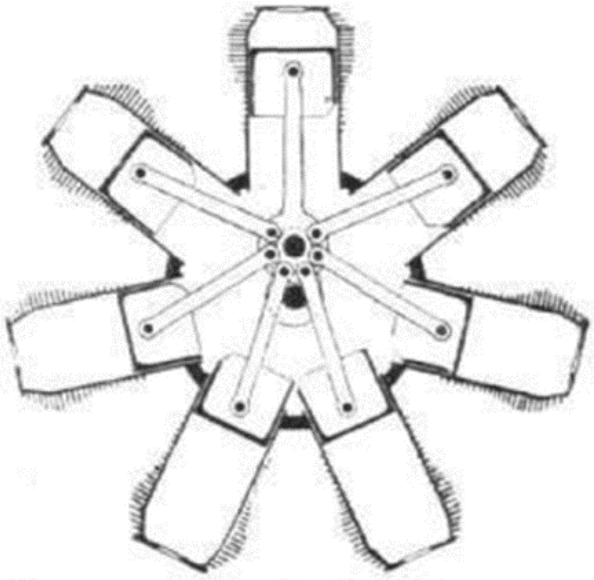
Off-shoot

"…A logical development of the radial engine was the rotary engine, in which the crankshaft remained stationary, the cylinders and crankcase revolving about it. This type was largely developed in France and the first Gnome rotary engines, exhibited at the Paris Salon in 1908, attracted much interest and promised to revolutionize the design of the aero-engine…"

***Wonders of World Aviation,* ca. 1938**



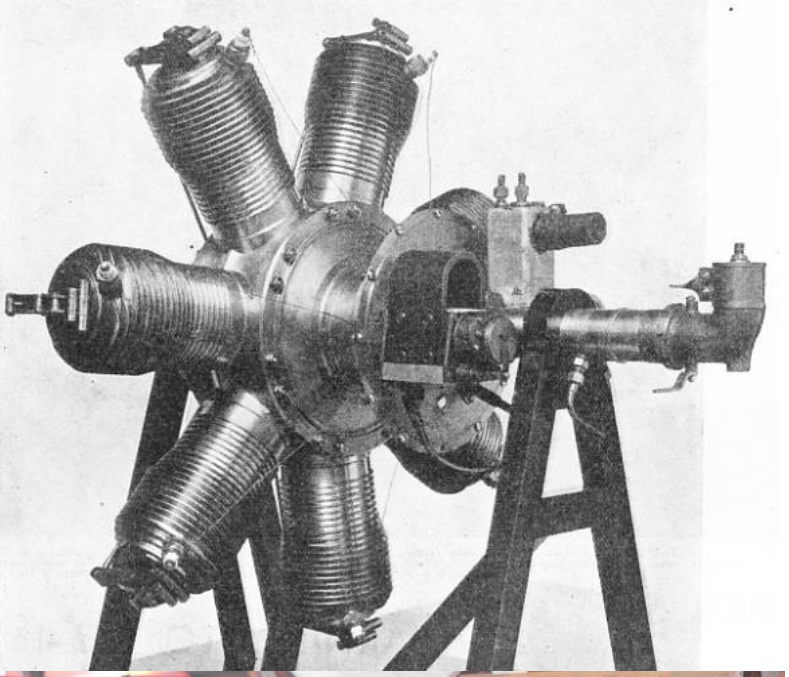
Sectional drawing illustrating the general arrangement of the 50-h.p. Gnome rotary engine.



Diagrammatic sketch illustrating the connections between the pistons and the crank-shaft of the Gnome rotary engine.

<u>Above</u>: the Gnome 7 Omega (a/k/a "Gnome 50-hp") was a French seven-cylinder, air-cooled aero-engine produced by Gnome et Rhône. It was shown at the Paris Aero Salon held in Dec. 1908 and was first flown in 1909. It was the world's first aviation rotary engine produced in quantity. Its introduction revolutionized the aviation industry and it was used by many early aircraft. It produced 50-hp from its 490 cu. in. engine.

<u>Caption</u>: "Sectional views of the Gnome Omega"





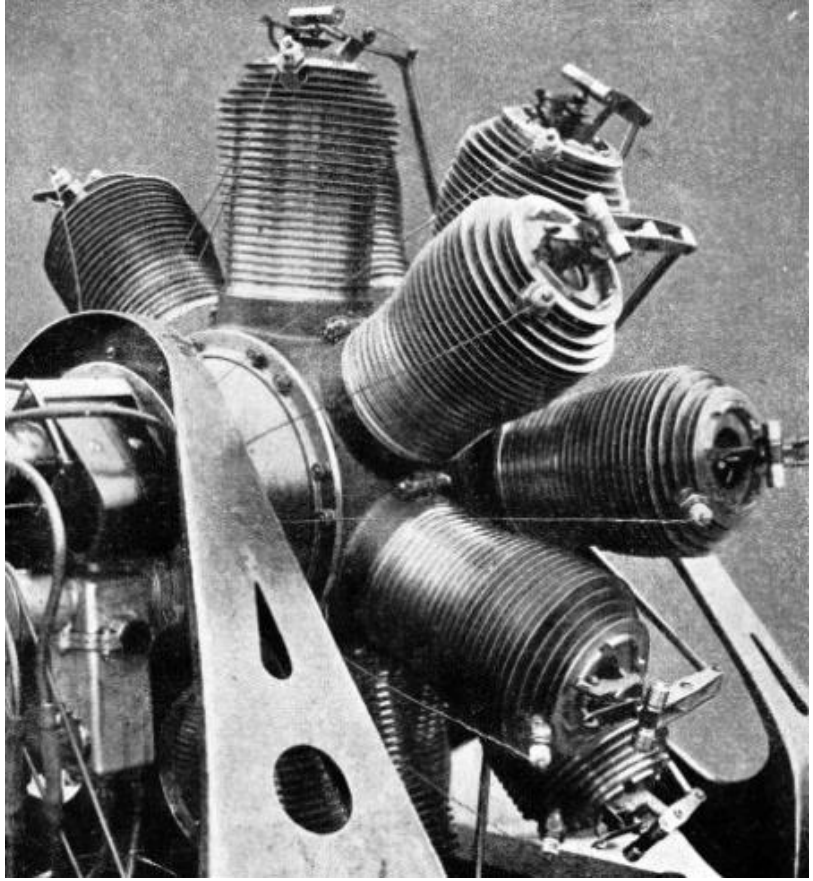
"…The early Gnome engines weighed little more than 3 lbs. per-horsepower, which, at that time, represented an extraordinarily high degree of efficiency…"

***Wonders of World Aviation,* ca. 1938**

Upper: caption: "ROTARY ENGINE OF 1908. This seven-cylinder Gnome, of French design, developed 50 horsepower and revolved round a stationary crankshaft. The engine weighed little more than 3 lbs. per-horsepower - a remarkable ratio for the period. The early Gnomes were followed by larger rotary engines having nine cylinders and developing 80 and 100-horsepower. The rotary engine is now obsolete."

Lower: "Gnome Omega rotary aircraft engine on display at the Newark Air Museum"

Reality Check



"…When the Gnome engines were introduced they were regarded as a permanent solution to many problems. When, however, they had been in practical use for some time their inherent disadvantages were realized…"

***Wonders of World Aviation,* ca. 1938**

<u>Caption</u>: "IN THE EARLY DAYS of aircraft, the 'Gnome' rotary engine was famous. The air-cooled cylinders were arranged round a crankcase and the whole engine, with the propeller, rotated about the axis of the fixed crankshaft. The rotary action was caused by the side pressure of the pistons on the cylinder barrels. The example shown has fourteen cylinders."

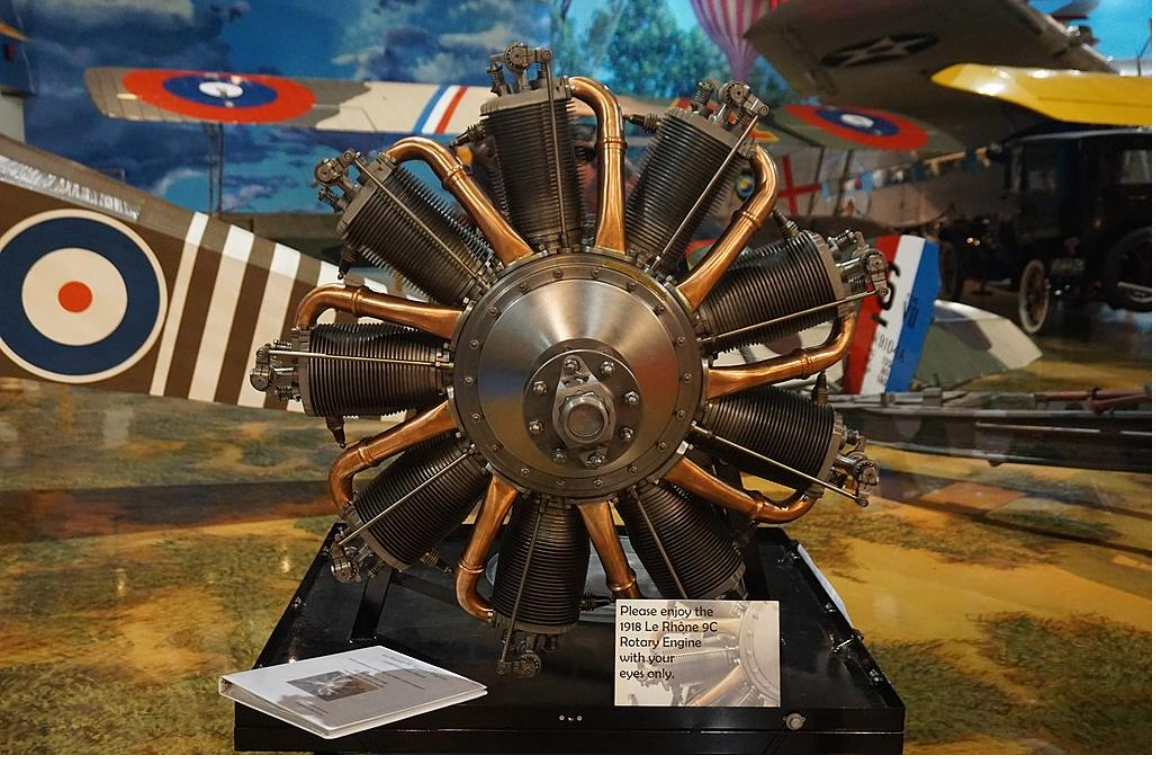
"…A large amount of power was wasted in rotating the cylinders and various cooling problems arose. The gyroscopic effect of the heavy rotating parts had to be compensated for in the design of the aircraft in which rotary engines were used and high fuel and oil consumption also began to worry the designers…"

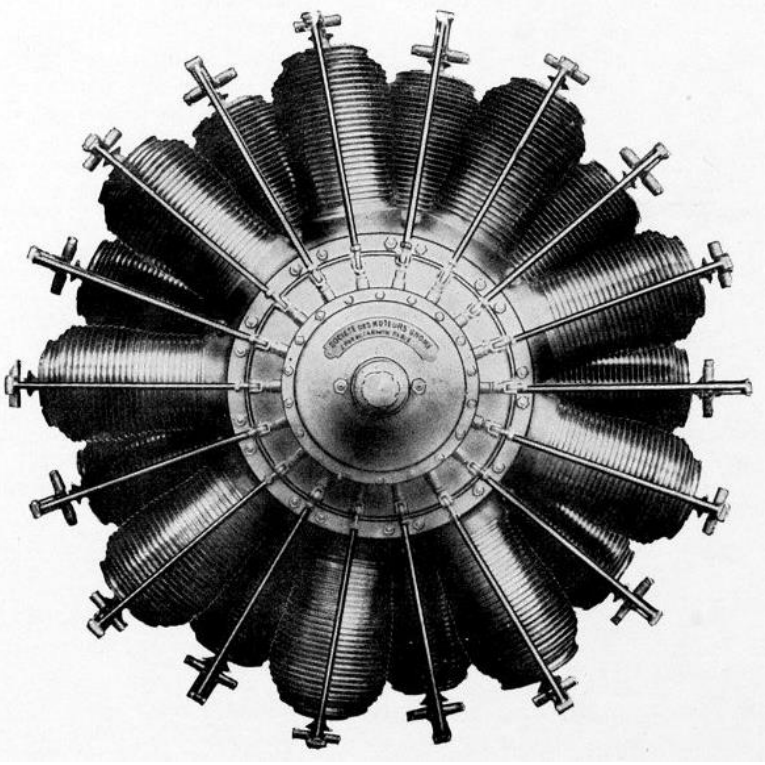
***Wonders of World Aviation,* ca. 1938**

RE: like all early Gnome et Rhône engines, the Omega 7 featured a single pushrod driven exhaust valve on the cylinder head; the intake valve was located in the piston crown, opening by inertia on the down-stroke and feeding the intake charge from the crankcase into the upper part of the cylinder. No throttle was provided; the pilot controlled the aircraft's speed by switching-off the ignition when necessary. A two-row version of the Omega 7 engine was also produced; known as the "Gnome 14 Omega-Omega" or "Gnome 100-hp."

An “Ideal” Specification

"…Despite all these disadvantages the Gnome engine was extensively used during the war of 1914-18, but it was finally superseded by improved forms of the older types of engine, with cylinders in-line or with the radial arrangement…"
***Wonders of World Aviation*, ca. 1938**





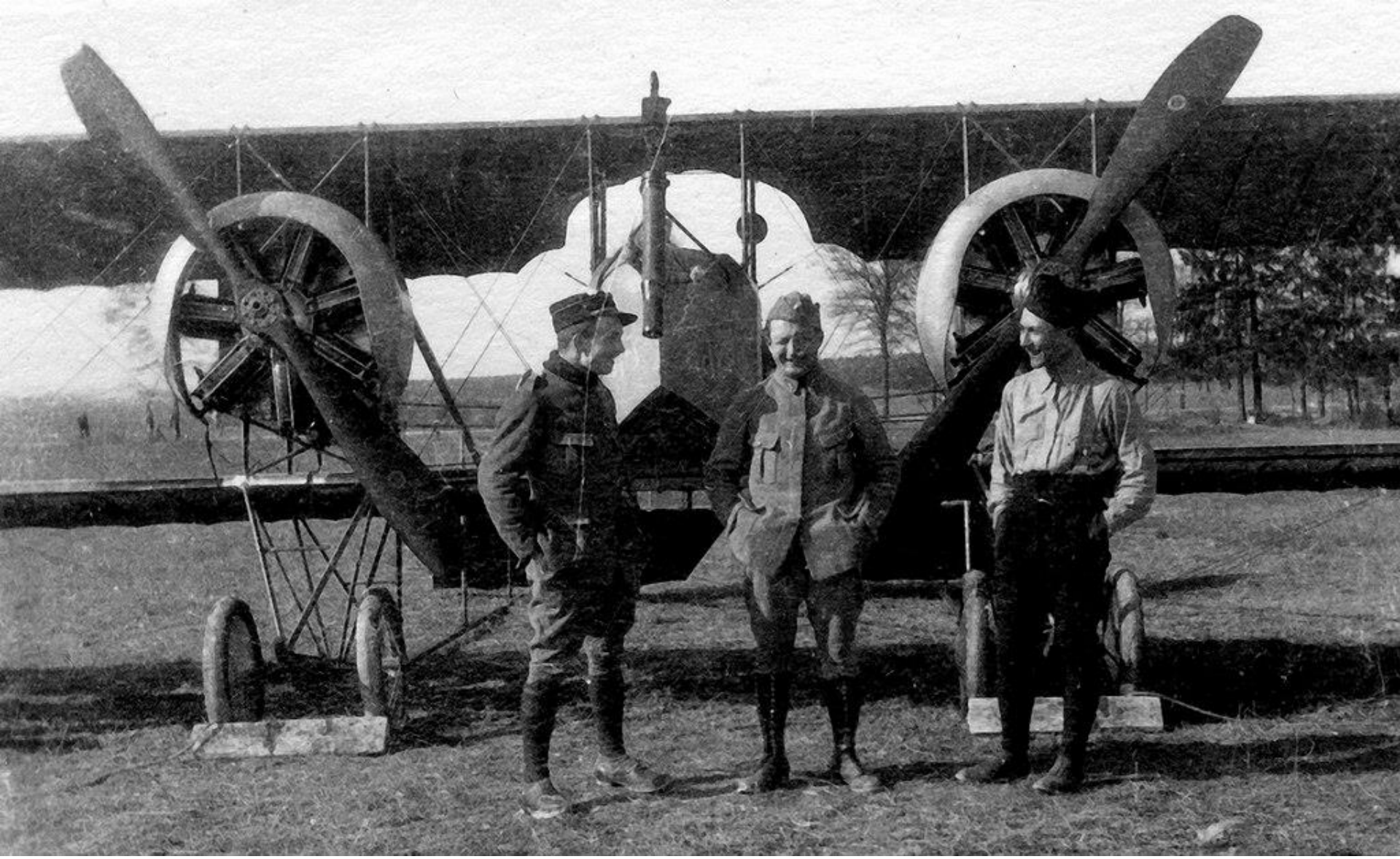
"…The Gnome engines of 1908 used seven cylinders and developed 50 horsepower. They were followed by an 80-horsepower Le Rhone engine and by a 100-horsepower Gnome, these engines being of the nine-cylinder type…"

***Wonders of World Aviation,* ca. 1938**

RE: the Le Rhône 9C (a/k/a "Le Rhône 80-hp) was a nine-cylinder rotary aircraft engine produced in France. The engine was fitted to many military aircraft types during WWI. The Gnome 9 Delta was a French-designed, nine-cylinder, air-cooled rotary aero-engine produced under license in Great Britain.

<u>Left</u>: caption: "Le Rhône 9C on display at the Air Zoo"

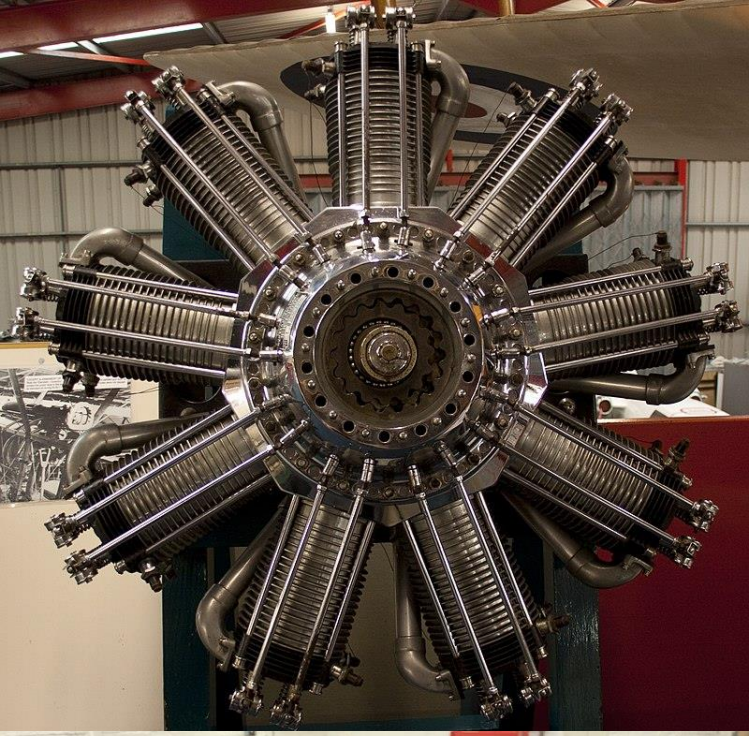
<u>Right</u>: caption: "Gnome 18 Delta-Delta from the 1913 Gnome catalog"



"…A Clerget engine, also with nine cylinders, developed 80-horsepower and the three types were all in use during the war period…"

***Wonders of World Aviation,* ca. 1938**

<u>Caption</u>: "A French twin engine Caudron G4 fitted with Clerget rotary engine"





"…In Great Britain Captain W.O. Bentley designed two rotary engines, the BR.1 and BR.2. These were the last types produced before the design became obsolete…"

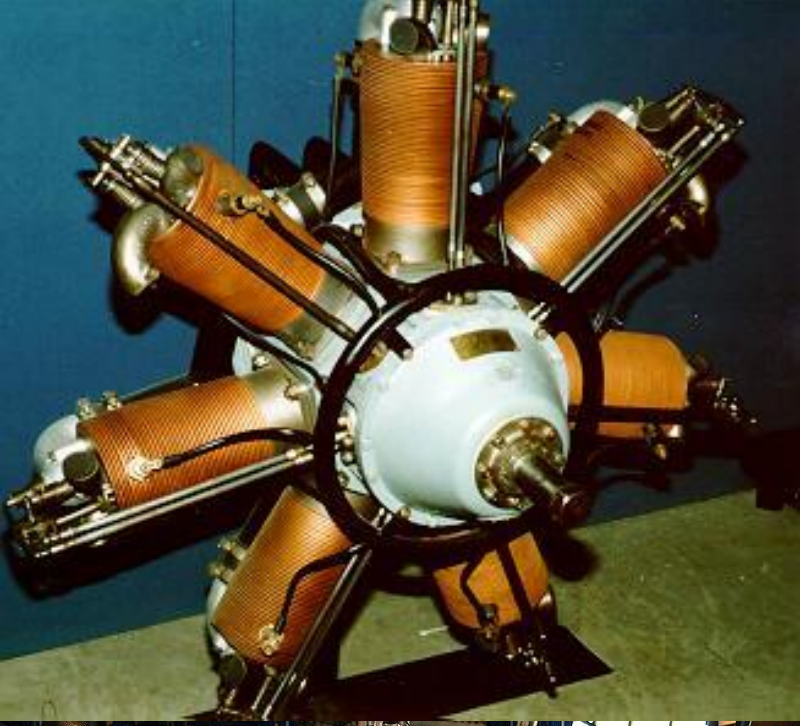
***Wonders of World Aviation,* ca. 1938**

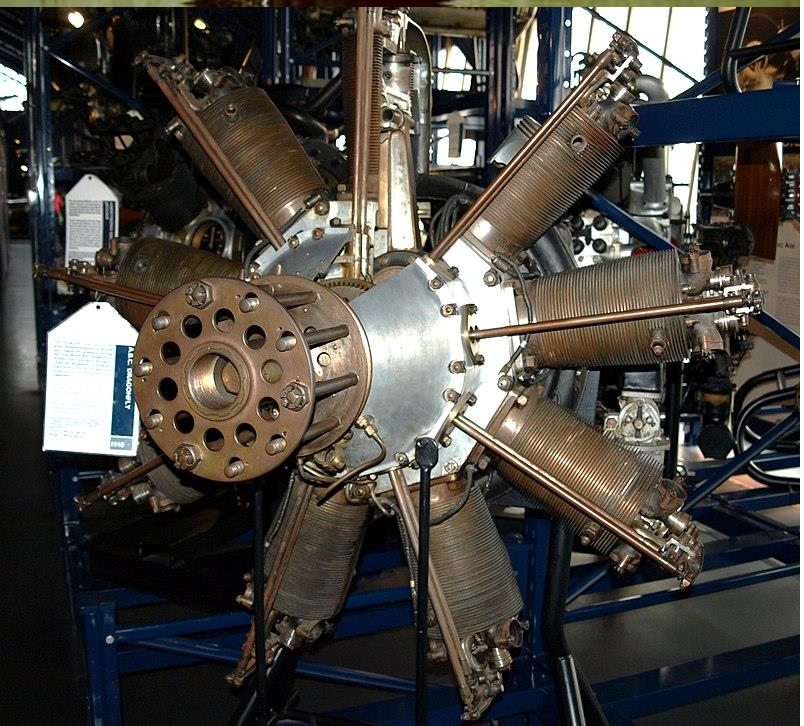
RE: *Walter Owen Bentley*, MBE (1888-1971) was a British Engineer who founded Bentley in London. He built the firm into one of the world's premier luxury and performance automobile manufacturers. In 1931, he sold the company to R-R. During WWI, the Royal Navy gave Bentley a team to design his own aero-engine at the Humber factory in Coventry. Designated the BR.1 (Bentley Rotary 1), the engine was fundamentally different from the Clerget except in the design of the cam mechanism, which was retained to facilitate production. A prototype was running by the early summer of 1916. The bigger BR.2 followed in early 1918. In recognition, Bentley was awarded the MBE (Member of the British Empire).

Upper: caption: "Preserved Bentley BR.1 at the Midland Air Museum"

Lower: caption: "Bentley BR.2 aircraft engine on display at the Shuttleworth Collection"

"…Meanwhile, the radial-type of engine was undergoing development, and French designers were among its champions. This type, however, declined in popularity from 1915 onwards, until fresh impetus was given to its development by the appearance of new engines of high-efficiency…"
***Wonders of World Aviation,* ca. 1938**





"…Two such engines were the A.B.C. Wasp and Dragonfly, both of which had the remarkable power-weight ratio of 1.75 lbs. per-horsepower. The Dragonfly engine was adopted by the Air Ministry for many types of service machines…"

***Wonders of World Aviation,* ca. 1938**

RE: the ABC Wasp was an experimental 170-hp 7-cylinder radial engine designed by noted British Engineer *Granville Bradshaw* and built, primarily, by A.B.C. Motors Ltd. The A.B.C. Wasp was one of the first large, non-rotary, air-cooled radial engines. In 1917, after initial promising tests of the A.B.C. Wasp air-cooled radial, Bradshaw produced a design for a larger and more powerful engine; the 9-cylinder Dragonfly. The engine was simple and easy to produce and was predicted to give 340-hp for a weight of 600 lbs. It proved, however, to be extremely unreliable and was abandoned.

<u>Upper</u>: caption: "British ABC WASP"

<u>Lower</u>: caption: "ABC Dragonfly aircraft radial engine at the Science Museum, London"

"…The Dragonfly was a nine-cylinder air-cooled engine with a bore of 5.5-in. and a stroke of 6.5-in. and it developed 340 horsepower at 1,650 revolutions-a-minute. The cylinders were machined from steel forgings and had radiating fins over most of their length, the outer surface being coated with copper to assist radiation. The pistons were of the aluminum alloy 'slipper' type, with two piston rings above the gudgeon pins…"

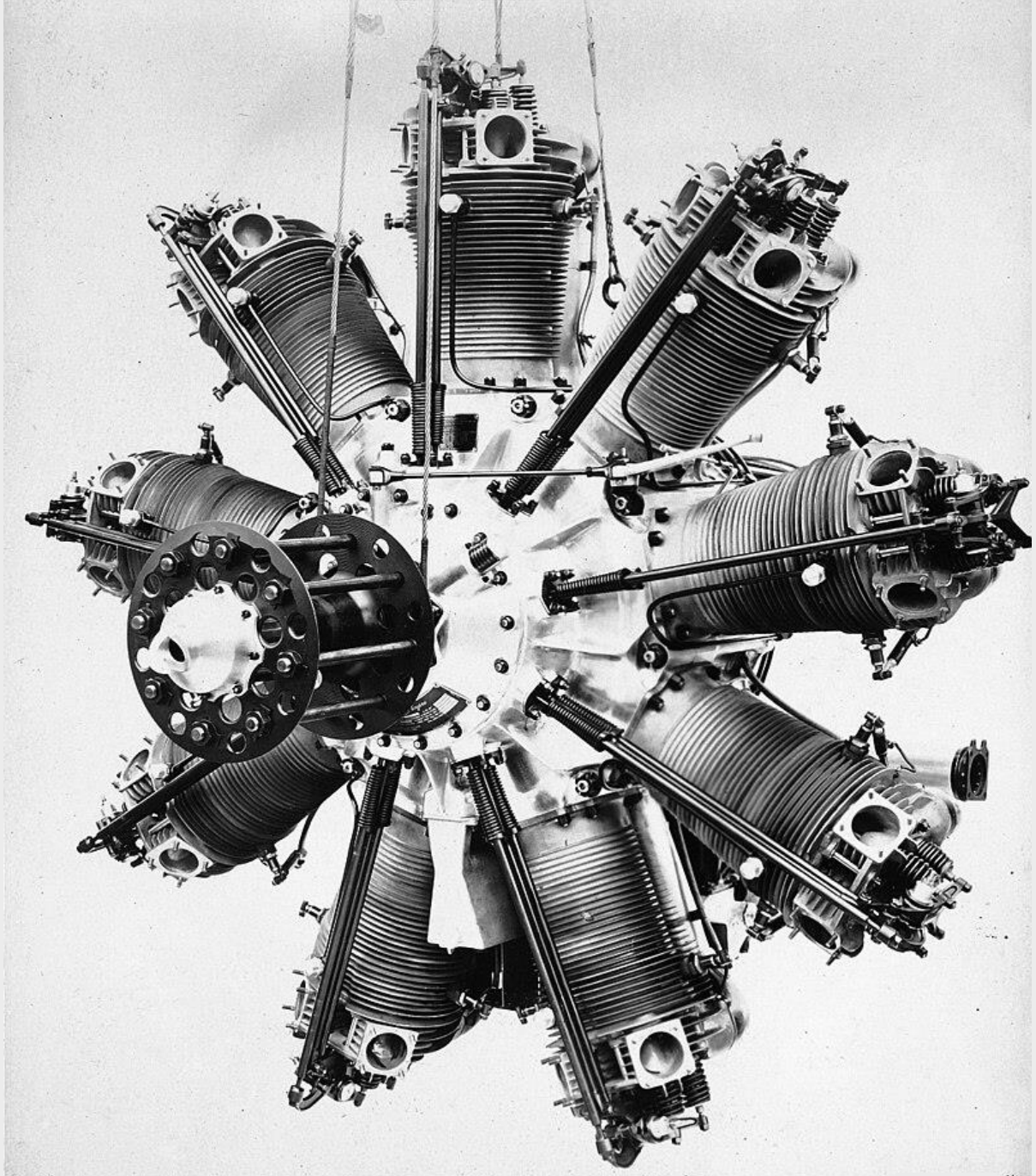
***Wonders of World Aviation,* ca. 1938**

RE: a distinct feature of the Dragonfly was the use of copper-plated cooling fins, which *Granville Bradshaw* claimed to be so effective that water would not boil on the surface of the radiators. 30 kg over its design weight as-built, the Dragonfly was subject to severe overheating. The copper-plated cooling fins proved useless; the cylinder heads tended to glow a dull red at operational speeds and, in extreme cases, caused heat damage and even charring to the propeller. Aviation Journalist *Bill Gunston* referred to it as the worst-cooled aero-engine ever produced. Attempts to improve cooling with cylinder redesign were marginally successful. However, the engine was designed to run at the torsional resonance frequency of its own crankshaft, causing severe vibration.

"…The next radial engine to be developed was the Bristol Jupiter, which appeared in 1921. This also was a nine-cylinder engine of somewhat greater capacity than the A.B.C. Dragonfly. Its bore was 5.75-in., its stroke 7.5-in. and it developed 400-horsepower at 1,550 revolutions-a-minute…"

***Wonders of World Aviation,* ca. 1938**

RE: the Bristol Jupiter was a British 9-cylinder single-row piston radial engine built by the Bristol Aeroplane Company. Designed late in WWI and known as the "Cosmos Jupiter," a lengthy series of upgrades and developments turned it into one of the finest engines of its era. The first Jupiter was completed in 1918 and featured three carburetors, each one feeding three of the engine's nine cylinders via a spiral deflector housed inside the induction chamber. Fairly standard in design, the Jupiter featured four valves per-cylinder which was uncommon, at the time. The cylinders were machined from steel forgings and the cast cylinder heads were later replaced with aluminum alloy following studies by the RAE. In 1927, a change was made to move to a forged head design due to the rejection rate of the castings. The Jupiter VII introduced a mechanically-driven supercharger to the design and the Jupiter VIII was the first to be fitted with reduction gears. The engine matured into one of the most reliable on the market.

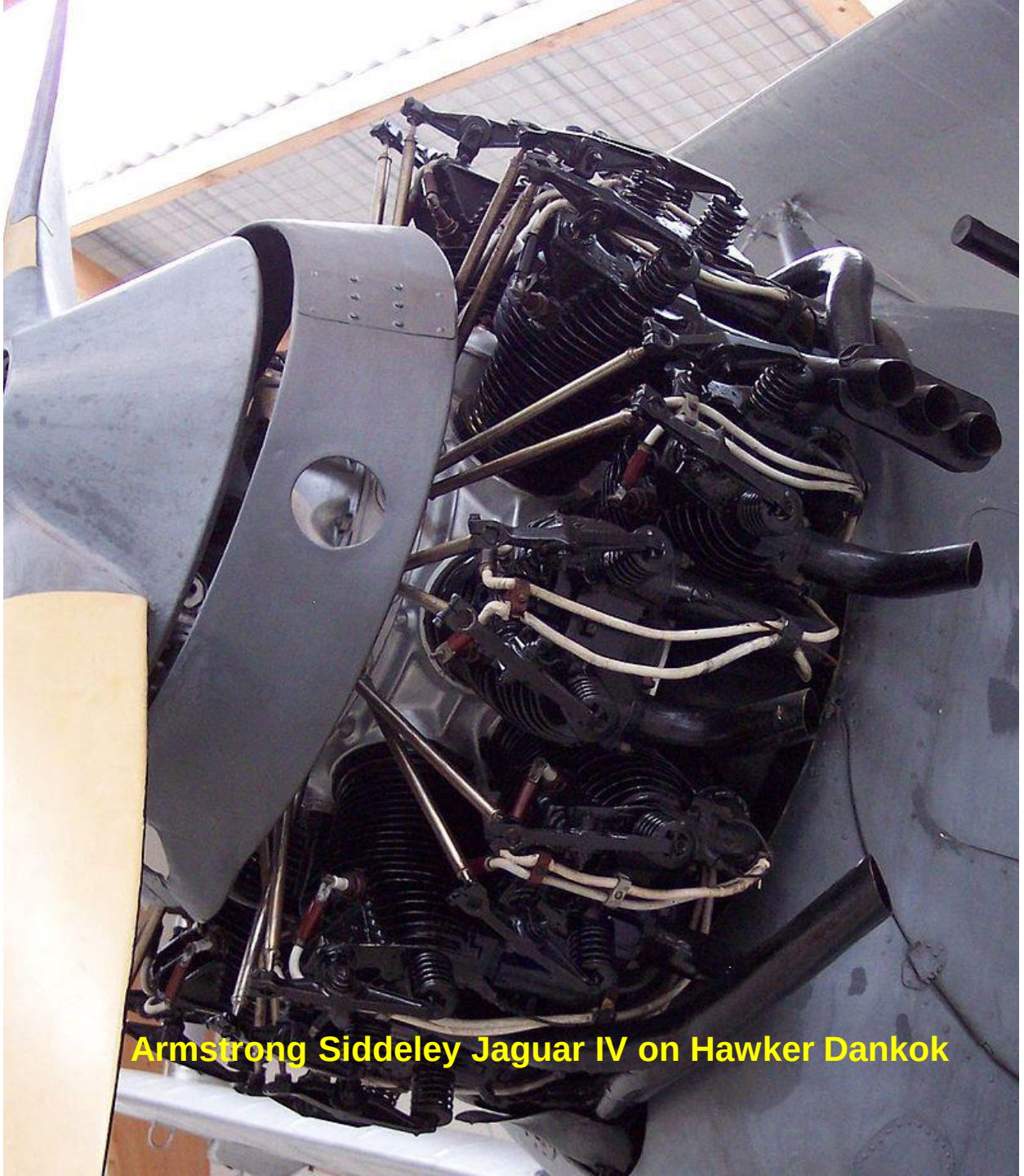


Jupiter IX

"…In 1917, the British Air Ministry issued an 'ideal' specification to encourage research. This led to the designing of another radial engine; the Armstrong Siddeley Jaguar of 19-24…"

***Wonders of World Aviation,* ca. 1938**

RE: the Armstrong Siddeley Jaguar was developed from the Royal Aircraft Factory RAF.8 design proposal of 1916. It incorporated the findings of research into aluminum air-cooled cylinders. Work on the RAF.8 was suspended when the design team took positions with the Siddeley-Deasy Co. There, the focus was to get the unreliable Siddeley Puma; an engine that had been ordered in large numbers despite a lack of testing, into service. As a result, the RAF.8 design, then known as the *Jaguar,* was not run until June 21, 1922.

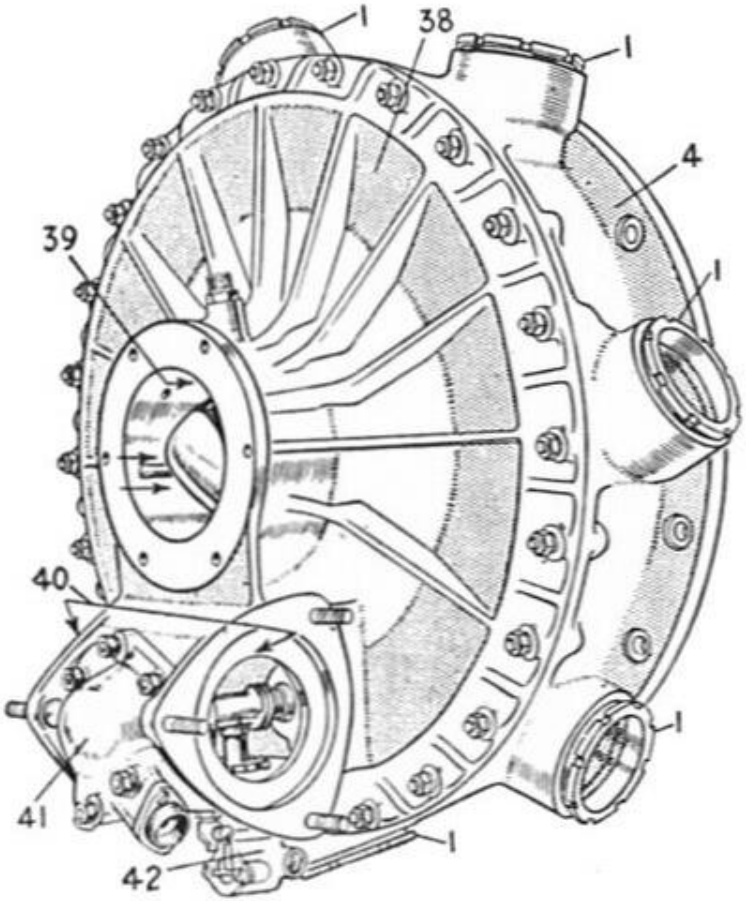


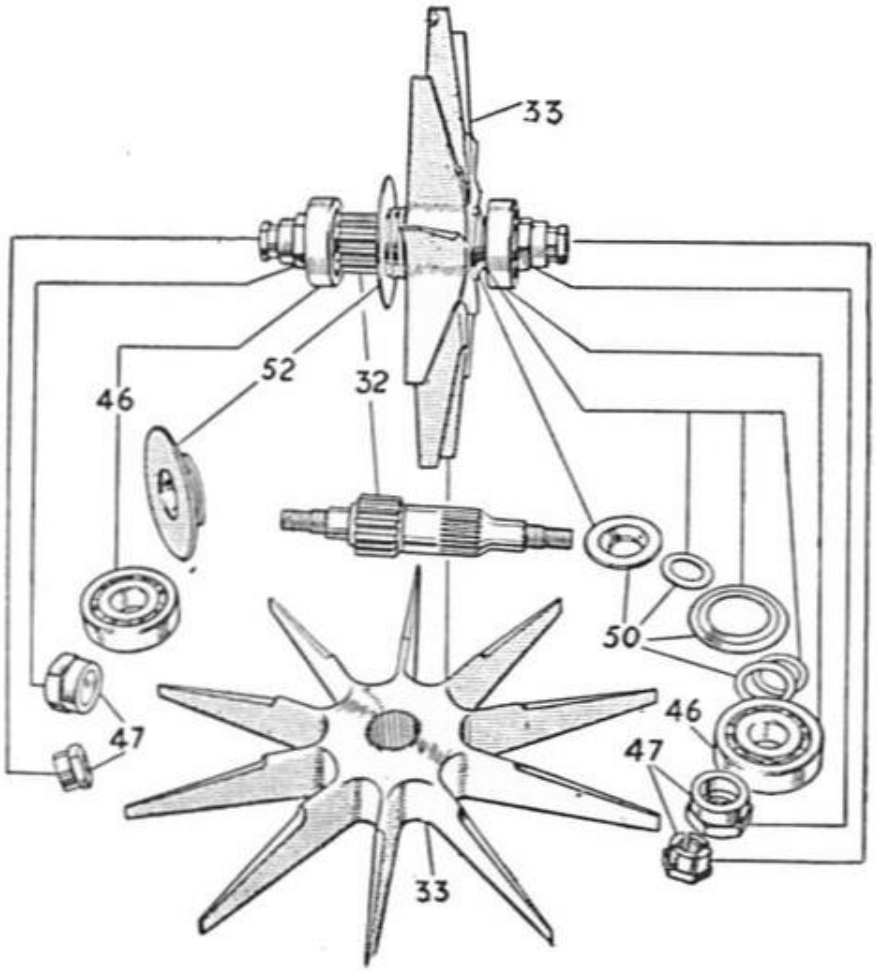
Armstrong Siddeley Jaguar IV on Hawker Dankok

"…This fourteen-cylinder engine developed 385-horsepower at 1,700 revolutions and incorporated several features of design that were before their time. Power-weight ratios were not being improved solely by the reduction of weight; by this time carburation and ignition systems had been greatly improved. Oil and fuel consumption and general reliability were considerably improved also…"

***Wonders of World Aviation,* ca. 1938**

RE: throughout its career, the Jaguar suffered from vibration due to the lack of a crankshaft center bearing. The most powerful version of the engine; the Jaguar VIC, produced a maximum of 490-hp on take-off at 1,950 rpm and weighed 910 lbs.





Because its initial performance was not up to expectations, the stroke was increased to 5.5 in. on all variants after the Jaguar I. By that time, the engine had been fitted with a gear-driven supercharger.

<u>Caption</u>: "The supercharger rotor and its straight blades"

"…Some idea of the enormous technical advances of twenty-one years may be gained from the fact that the Bristol Jupiter engine weighed slightly more than three times as much as the original Wright engine, but developed twenty-six times the power…"

***Wonders of World Aviation*, ca. 1938**

"…The Jupiter and Jaguar engines were extensively used in service aircraft and they reigned supreme among radial engines for some years…"

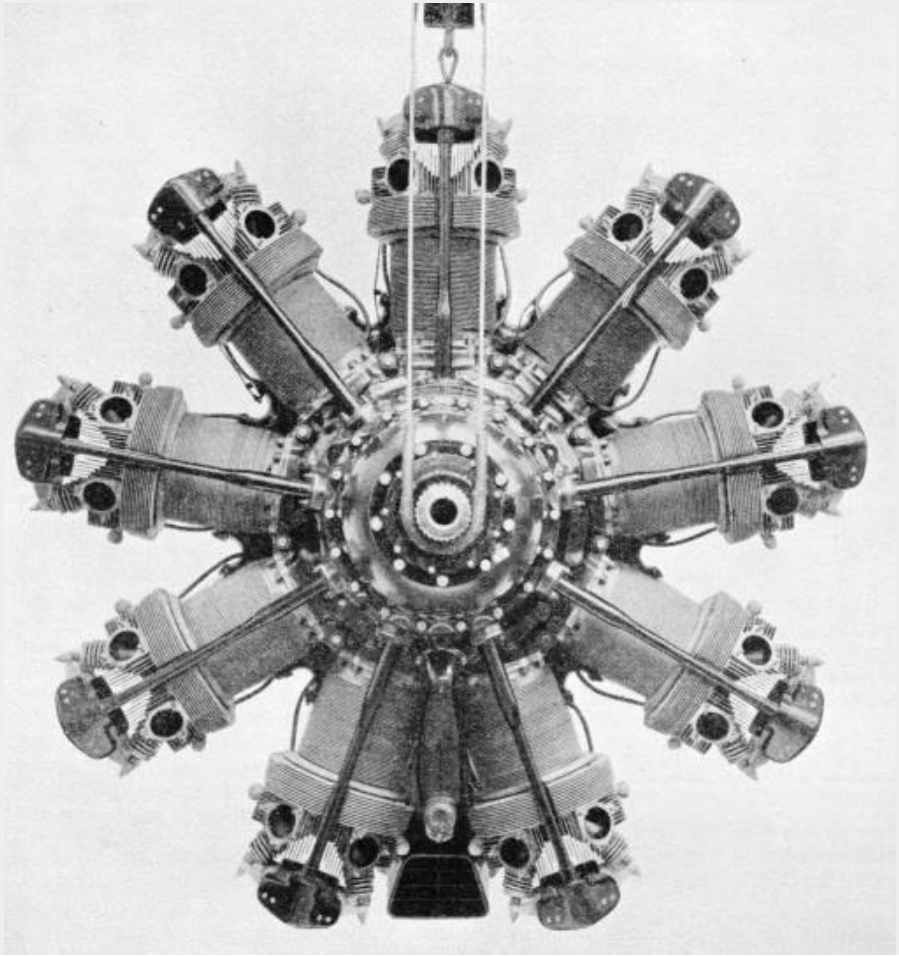
***Wonders of World Aviation*, ca. 1938**

Introduction of Aluminum

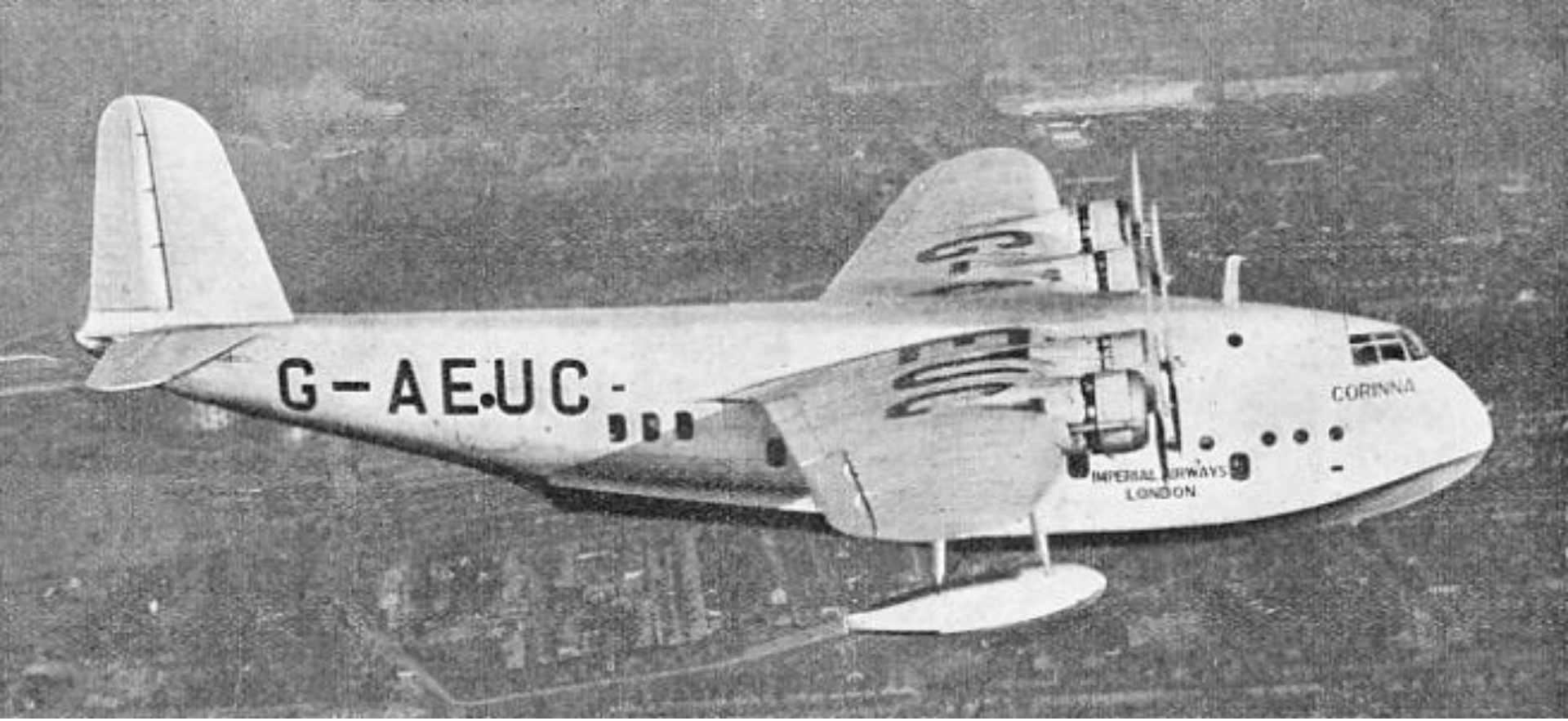
"…Rapid as development seemed to be during the period between 1914 and 1924, it continued apace and to such good effect that the Bristol Pegasus X, produced in 1936, had a power-weight ratio of 1.09 lbs. per-horsepower. This engine was superseded in 1937 by the Pegasus XXII and two entirely new engines; the Pegasus XVII and XVIII, were developed with two-speed superchargers…"

***Wonders of World Aviation,* ca. 1938**

RE: the Pegasus engine had a cubic capacity of 28.7 liters and international rated powers varying between 785 and 855 bhp. Their weights varied between 1,025 and 1,115 lbs. The international rated power of the Pegasus XVII and XVIII, on medium supercharge, was 820-855 bhp at 5K-feet and on full supercharge 765-800 bhp at 15,500-feet, with 980 bhp for take-off.

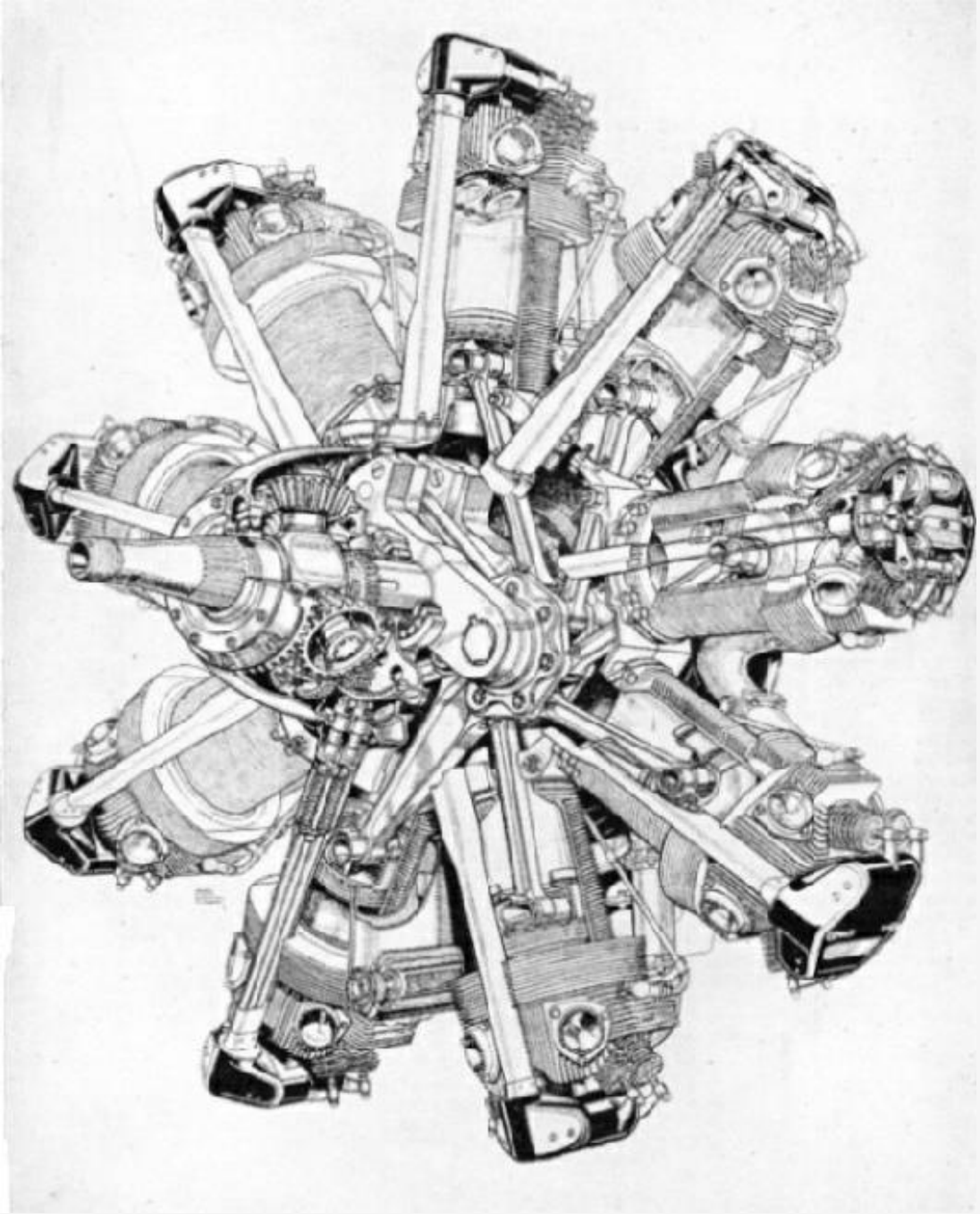


<u>Caption</u>: "A NEW HEIGHT RECORD of 49,944-feet was made on September 28, 1936, by Squadron Leader F.R.D. Swain, flying a monoplane fitted with a Bristol 'Pegasus' engine, of the type illustrated. This is a radial engine with nine air-cooled cylinders having a total capacity of 28.7 litres and weighing 1,010 lbs. The normal rated brake horsepower is 740 at 3,500-feet and the normal speed is 2,475 revolutions-a-minute. A reduction gear is fitted to lower the airscrew speed."



"…The range of Pegasus engines in 1937 included the Pegasus Xc, which was used by Imperial Airways to equip the Empire flying boats…"
***Wonders of World Aviation,* ca. 1938**

RE: the moderately supercharged Pegasus XXII and XXIII replaced the Pegasus X and XI in 1937. The Pegasus XIX and XX were fully supercharged engines; the Pegasus XVII and XVIII were equipped with two-speed superchargers and were introduced in 1937. There was also the civil-rated Pegasus Xc, which was adopted by Imperial Airways for Empire flying boats (above), put into service in 1937.



<u>Caption</u>: “Bristol Pegasus XXII 810-1,010 horsepower aero-engine”

"…The increased power outputs and decreased weights were obtained in several ways. Improved fuels have contributed largely to the achievement of higher power outputs. Higher degrees of supercharging, higher compression ratios and increased crankshaft speeds have also been important lines of development. At the same time, weight has been reduced by refinement in the design of various components and by the introduction of improved steels of greater strength and durability. The judicious use of magnesium castings has made a valuable contribution to development…"

***Wonders of World Aviation,* ca. 1938**

RE: during the period 1920-37, the power output per-liter of cylinder capacity had been increased by 130%; weight reduced by 40%, fuel consumption reduced by 25% and maximum crankshaft speeds increased from 1,625 to 2,925 rpm. The Pegasus series of engines (used for civil and military aircraft) was subdivided into seven types; the differences between them were mainly concerned with airscrew reduction ratios and degrees of supercharging.

"…Vertical engines have reached their present standard of efficiency by a continuous line of development which began with the first aircraft engines…"
***Wonders of World Aviation*, ca. 1938**

"…Early engines always used cast-iron for their cylinder blocks. It was an ideal material in several ways; it had excellent wearing qualities under friction, it was easy to mold, cast and machine. It was, however, a weak material in tension and bending and thick, heavy sections had to be used…"

***Wonders of World Aviation*, ca. 1938**

"…The rotary-type of engine was the first to use steel cylinders, but steel was soon used for vertical engines also. By 1919 cast-iron was obsolete as a material for cylinder walls and bearing surfaces…"

***Wonders of World Aviation*, ca. 1938**

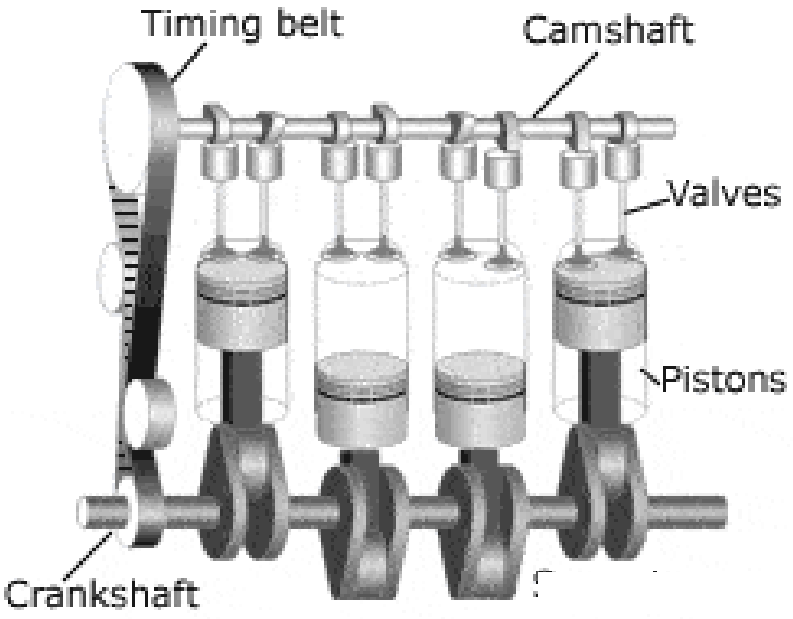
"…Hispano-Suiza engines were the first to use cast-aluminum cylinder blocks with steel liners and aluminum was used in a British engine in 1909. In 1911, this 6-horsepower Green engine won a prize of £1,000, offered by Mr. Patrick Alexander…"

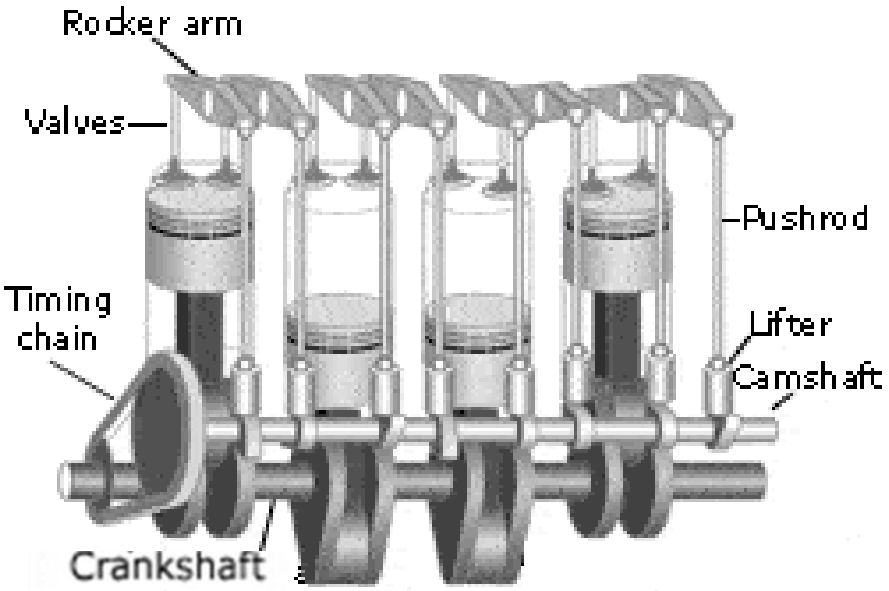
***Wonders of World Aviation,* ca. 1938**

RE: with the start of WWI, Hispano-Suiza turned to the design and production of aircraft engines under the direction of *Marc Birkigt.* Traditionally, aero-engines were manufactured by machining separate steel cylinders and then bolting these assemblies directly to the crankcase. Birkigt's novel solution; the Hispano-Suiza 8, which called for the engine block to be formed from a single piece of cast aluminum and into which thin steel liners were secured. Manufacturing an engine in this way simplified construction and resulted in a lighter, yet stronger more durable engine. Thus, Birkigt's new construction method created the first practical examples of what are commonly known today as "cast-block" engines. His aluminum cast block V-8 design was also noteworthy for incorporating overhead camshafts, propeller reduction gearing and other desirable features that did not appear together on competitors' engines until the late 1920s



A Brussels museum Hispano-Suiza HS.8A SOHC aviation engine from WWI





"…Further saving of weight, as well as improvement in mechanical efficiency, was effected by eliminating the valve tappet rod system and operating the valves directly by overhead camshafts. The overhead camshaft was introduced into automobile engine design, but even at the time of writing its use is far from general…"

***Wonders of World Aviation,* ca. 1938**

RE: an overhead camshaft (OHC) engine is a piston engine in which the camshaft is located in the cylinder head above the combustion chamber (above). The valves are operated directly by the camshaft. This contrasts with earlier overhead valve engines (OHV) where the camshaft was located below the combustion chamber in the engine block (left).

"…The aero-engine and the motor car engine sprang from the same source, but their requirements are so different that each has developed in its own way…"

***Wonders of World Aviation*, ca. 1938**

"…The use of pistons made of aluminum or of one of its light alloys has had an effect far in excess of mere reduction of weight, for such pistons have been responsible for an enormous improvement in mechanical efficiency…"
***Wonders of World Aviation*, ca. 1938**

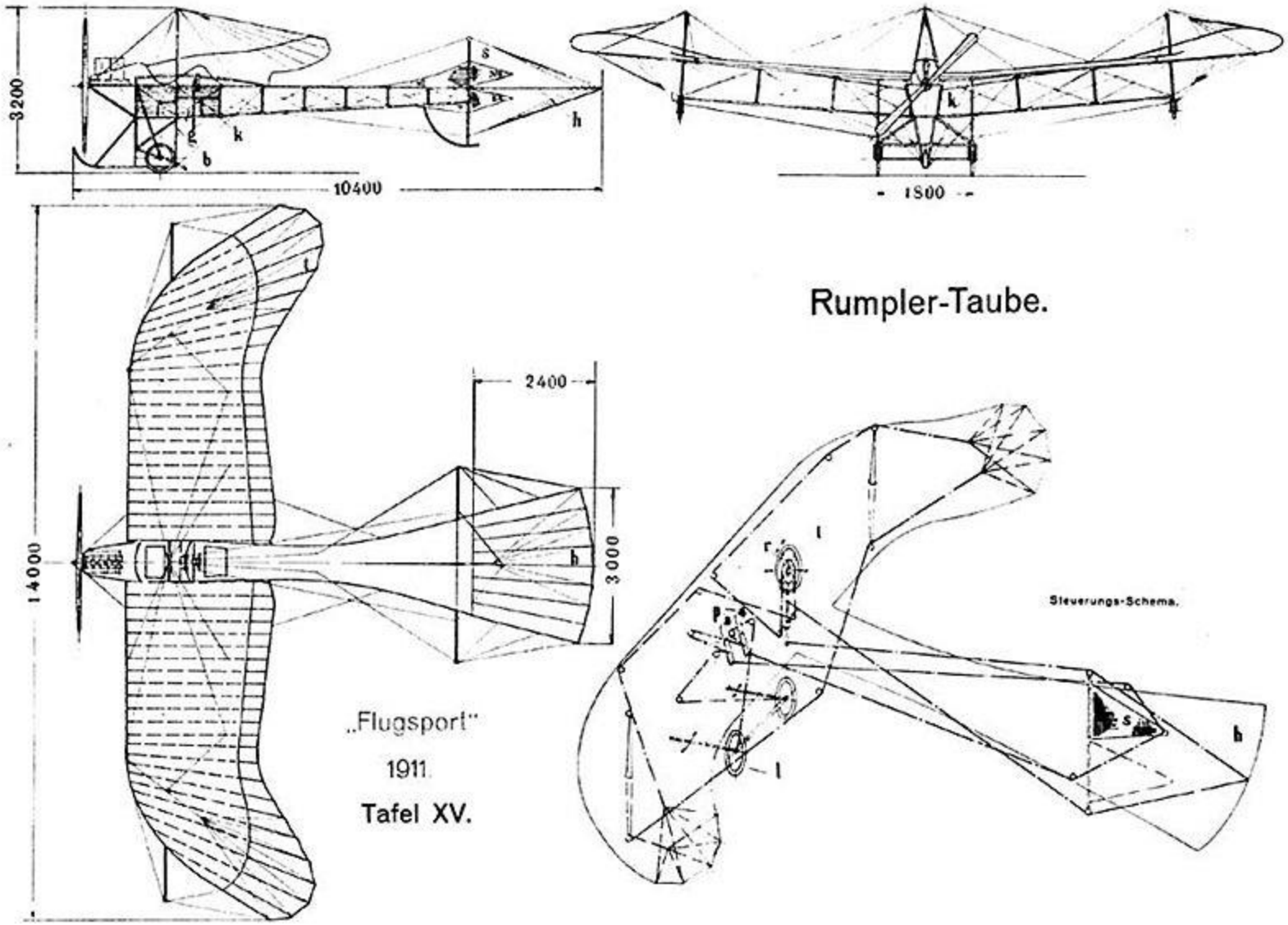
"…During the period 1909-14, at least four types of engine were in regular production - the vertical, the V-type, the radial and the rotary. France and Great Britain favored the eight-cylinder V engine, but Germany was markedly in favor of the four- or six-cylinder vertical-type…"

***Wonders of World Aviation*, ca. 1938**

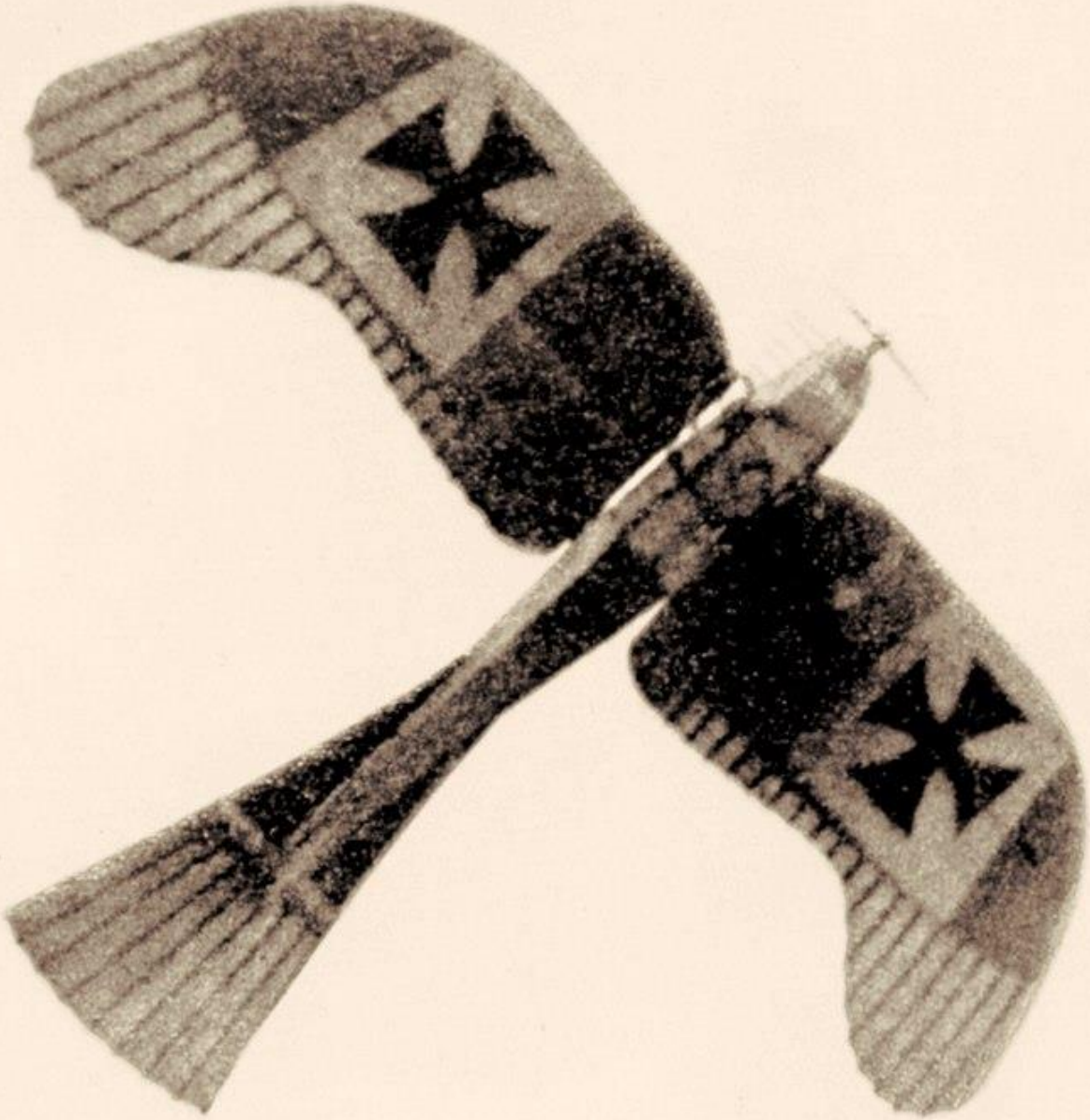
"…A famous German engine was the Mercedes, which superseded the German Argus engine of 1910 and was used in the Taube aircraft during the war of 1914-18…"

***Wonders of World Aviation,* ca. 1938**

RE: the Mercedes D.I (a/k/a Type E6F) was a six-cylinder, water-cooled, SOHC valve-train in-line engine developed in Germany for use in aircraft in 1913. Developing 100-hp, it powered many German military aircraft during the very early part of WWI. Begun in Berlin in 1906 as a subsidiary of Hen-ri Jeannin's automobile business, Argus Motoren company spun-off entirely in November 1906. Their early products were car and boat engines, but later that year they were contracted to produce engines for the French airship; *Ville de Paris*, supplying them with a converted boat motor. They turned increasingly to the aviation market and were widely used by 1910, receiving an order from Sikorsky for one of his large airplanes then under construction in Russia. During WWI, Argus produced engines for the German Army and Air Corps. The Taube (Dove) was designed in 1909 by *Igo Etrich* of Austria-Hungary and first flew in 1910. Despite its name, the Taube's unique wing form was modeled not after any bird but, rather, copied from the seeds of Alsomitra macro-carpa (which glide long distances from their parent tree)



Design drawing of Taube from 1911



"…The Mercedes, with another engine, of Benz design had, by 1912, established itself as the most favored type in Germany…"

***Wonders of World Aviation*, ca. 1938**



"…At the same time the Green engine won favor in Great Britain and in its 35 horsepower size this engine was fitted to the first Avro biplane of 19-11…"

***Wonders of World Aviation,* ca. 1938**

RE: in 1911, A.V. Roe abandoned the triplane configuration and designed a biplane which bore a close resemblance to the Roe IV. Power was supplied by a 35-hp Green engine; the radiator of which was placed vertically behind the engine at right angles to the direction of flight.

<u>Caption</u>: "Avro Type D, 1911"

"…Other vertical engines were developed in Great Britain by the A.B.C. and Beardmore Companies and a 200-horsepower Beardmore-Halford-Pullinger engine was produced by the Siddeley Deasy Motor Company in 1917…"

***Wonders of World Aviation*, ca. 1938**



"…This was a six-cylinder water-cooled engine with two separate cylinder blocks, each comprising the cylinder heads, water jackets, valve passages and inlet manifold of three cylinders. This engine developed 246-horsepower at 1,400 revolutions-a-minute and weighed 625 lbs…"

***Wonders of World Aviation,* ca. 1938**

RE: Beardmore-Halford-Pullinger (BHP) was a series of aircraft engines produced in the UK between 1916 and 1920. The acronym "BHP" came from the surnames of the three key individuals involved in the development and manufacturing of the engines; *William Beardmore, Frank Halford* and *Thomas Pullinger.*

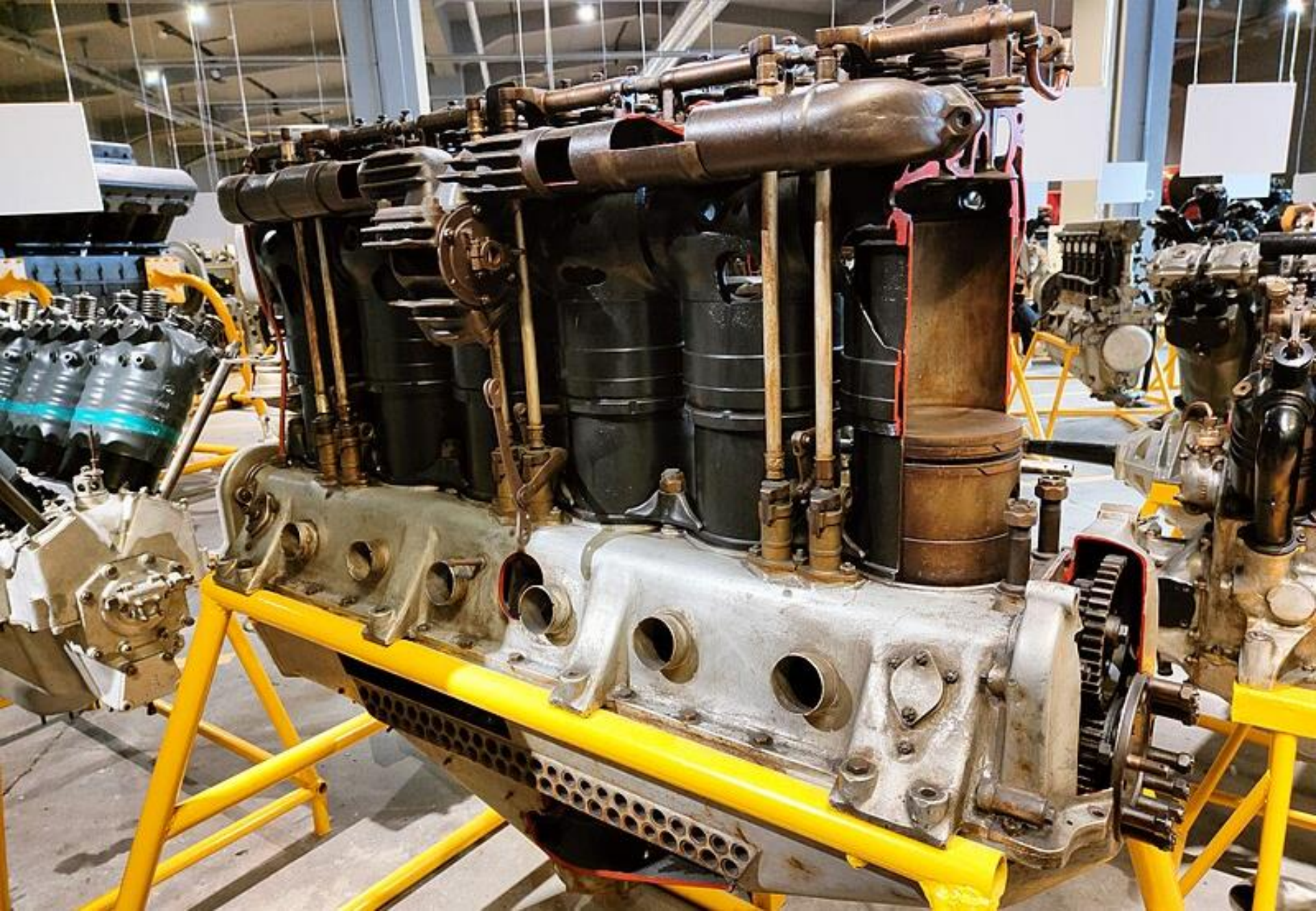
Caption: "Technician boring-out forged con-rods for a 230 hp BHP aircraft engine"

Modified Car Engines

"…The German engine of the 300-horsepower Maybach, which also had six water-cooled cylinders, developed 294-horsepower at 1,400 revolutions-a-minute and weighed 911 lbs. - a less favorable power-weight ratio than that of the British engine…"

***Wonders of World Aviation,* ca. 1938**

RE: the Maybach Mb.IV (originally designated "Maybach HS"), was a straight-six piston engine of 200-240-hp output originally developed for use in airships. It was also used for large aircraft such as the Zeppelin-Lindau Rs.I seaplane. Variants of the original HS engine included the Maybach HS D, Maybach HS K and Maybach HS Lu. The latter engine was used in the Zeppelin-type and Schütte-Lanz Type E airships.



Maybach HS Lu on display at the Polish Aviation Museum

"…Today, the vertical engine is most extensively used in light aircraft. The two great rival designs for high-powered aero-engines are the air-cooled radial-type and the water-cooled V-type…"

***Wonders of World Aviation*, ca. 1938**

"…The Y design, although one of the earliest of all, has now been accepted as one of the best lay-outs for liquid-cooled engines…"

***Wonders of World Aviation*, ca. 1938**



"…The first V engines to be used in aeroplanes were small two- and four-cylinder types built for motor cars. Among the first types with eight cylinders in two banks of four was a 200 horsepower Darracq engine of 1905, built for a racing car. …"

***Wonders of World Aviation,* ca. 1938**

RE: in 1904, Pierre-Alexandre Darracq's Engineer; *Paul Ribeyrolles,* designed a racing car with a large 11.259 liter, four-cylinder engine producing 100-hp. With this car, factory driver *Paul Baras* reclaimed the title of "Fastest on Earth." On a short road in the coastal town of Ostend, Belgium, Baras flew through the kilometer at 104.52 mph. Not content to rest on his laurels, Darracq built an even more powerful car (left), with an all new OHV V-8 engine developing a claimed 200-hp. In late Dec. of 1905, on the Arles-Salon road in Southern France, it set a new Land Speed Record of 108.59 mph.

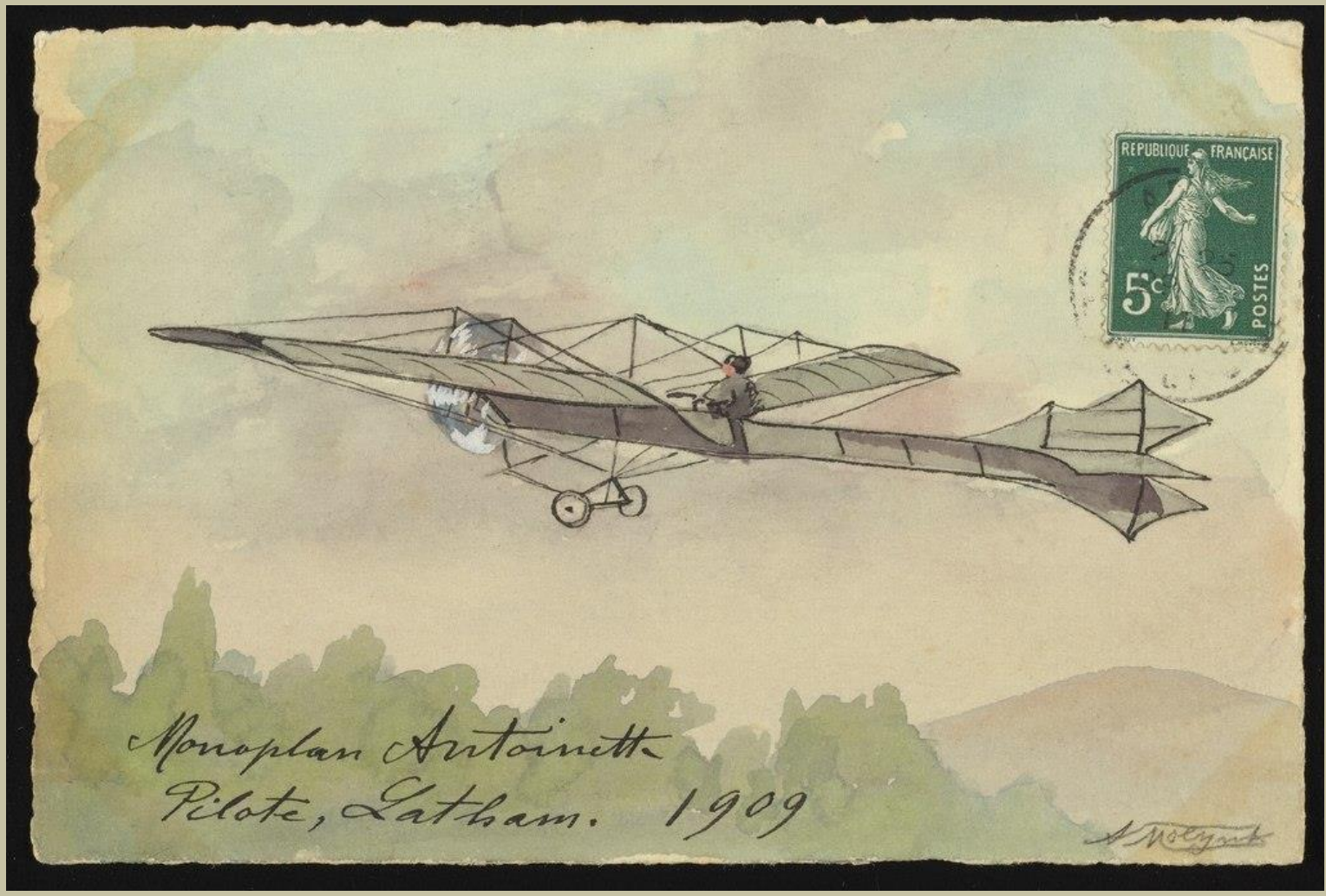


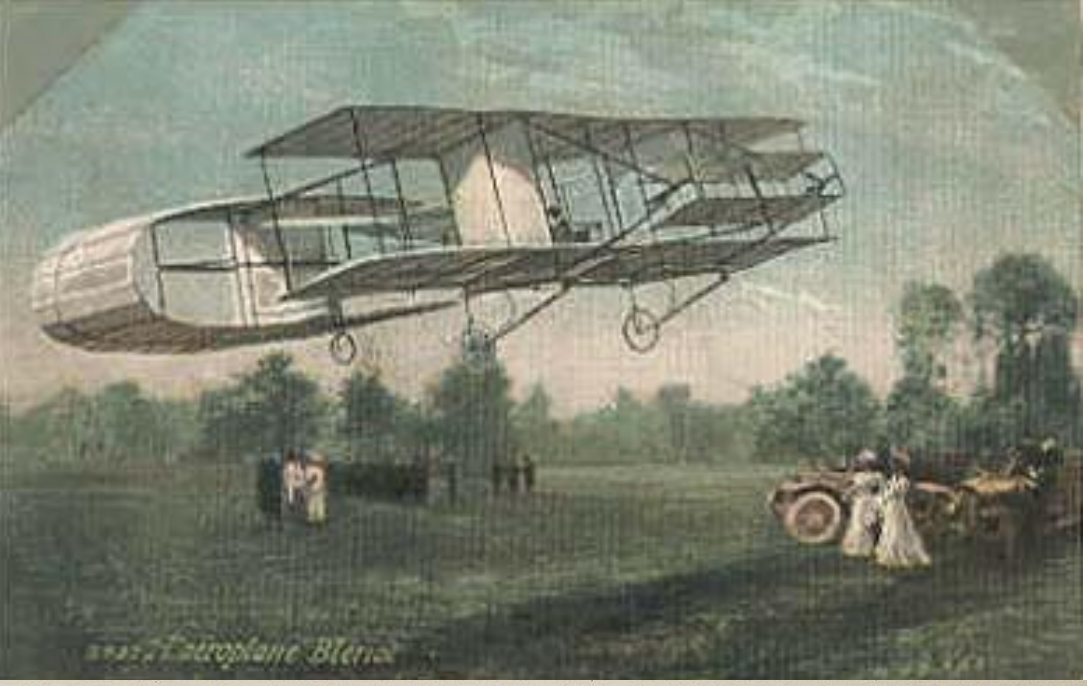
"…The first V engine which had a sufficiently good power-weight ratio for use in an aircraft was the French Antoinette engine of 1905, which had eight cylinders and developed 50 horsepower…"

***Wonders of World Aviation,* ca. 1938**

RE: the Antoinette 8V was an early French eight-cylinder, liquid-cooled, V engine; the first series production gasoline-fueled, spark plug ignition engine of any kind produced with manifold injection. It was typically rated at 50-hp. First produced in 1906, it was used on a number of early French aircraft including Alberto Santos Dumont's 14 Bis and the Antoinette company's own Antoinette VII.

<u>Caption</u>: "Latham's Antoinette VII. This is a 1910 version with 100-hp V-16 engine."


REPUBLIQUE FRANÇAISE
5c
POSTES
Monoplan Antoinette
Pilote, Latham. 1909





"…This engine used steam cooling in conjunction with an air-cooled condenser arranged along the sides of the fuselage. Its first recorded appearance was in a racing launch on the River Seine in April, 1905, and the first aeroplanes to which it was fitted were the Bleriot-Yoisin biplane (1906) and the Santos Dumont 'canard' type…"

Wonders of World Aviation,
ca. 1938

<u>Upper</u>: caption: "The Bleriot IV depicted in a fanciful contemporary postcard. In reality, the aircraft never flew"

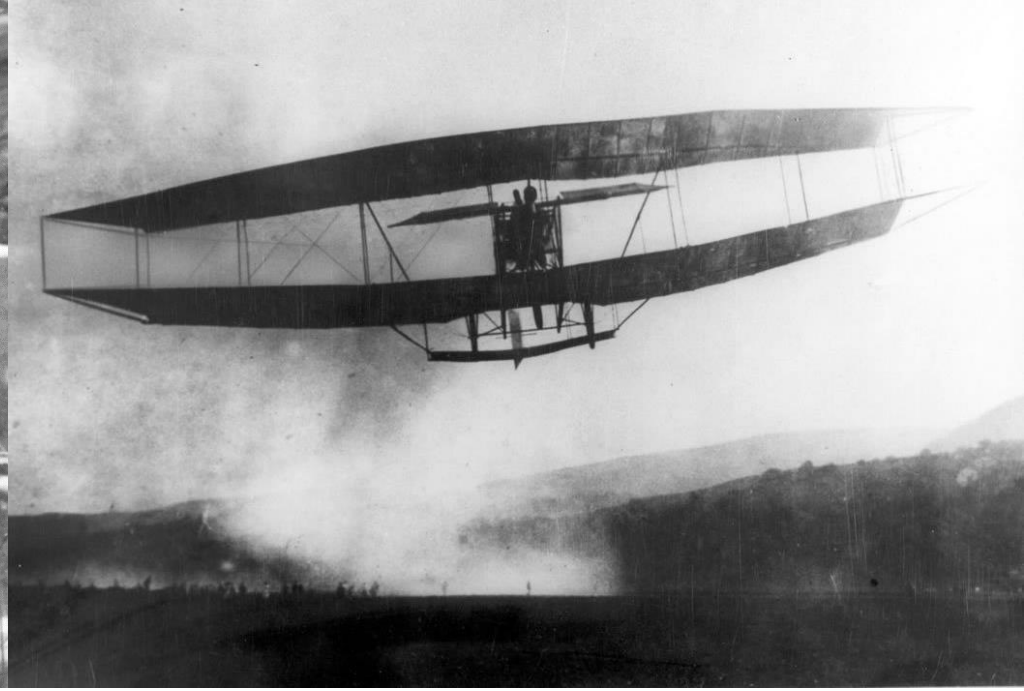
<u>Lower</u>: caption: "The 14-bis was a canard-style biplane designed and built by Brazilian aviation pioneer Alberto Santos-Dumont which made a flight in 1906"

"…The other engines available were mostly modified car engines, but none of them had the weight per-horsepower figure of the Antoinette…"

***Wonders of World Aviation*, ca. 1938**

V-type





"…In America, the Curtiss V-type engine, developed from a motorcycle engine, came into use in 1905-6 and the first water-cooled example of this type was used in the Curtiss bi-plane which won the Rheims speed contest in 1909, although its air-cooled form had previously been used with success in the U.S.A…"

***Wonders of World Aviation,* ca. 1938**

RE: the Curtiss B-8 was an early air-cooled, 8-cylinder engine used for a number of aircraft and one motorcycle designed by *Glenn Curtiss*. It powered the *June Bug,* in 1908, becoming the first Curtiss engine to power a heavier-than-air aircraft in sustained flight.

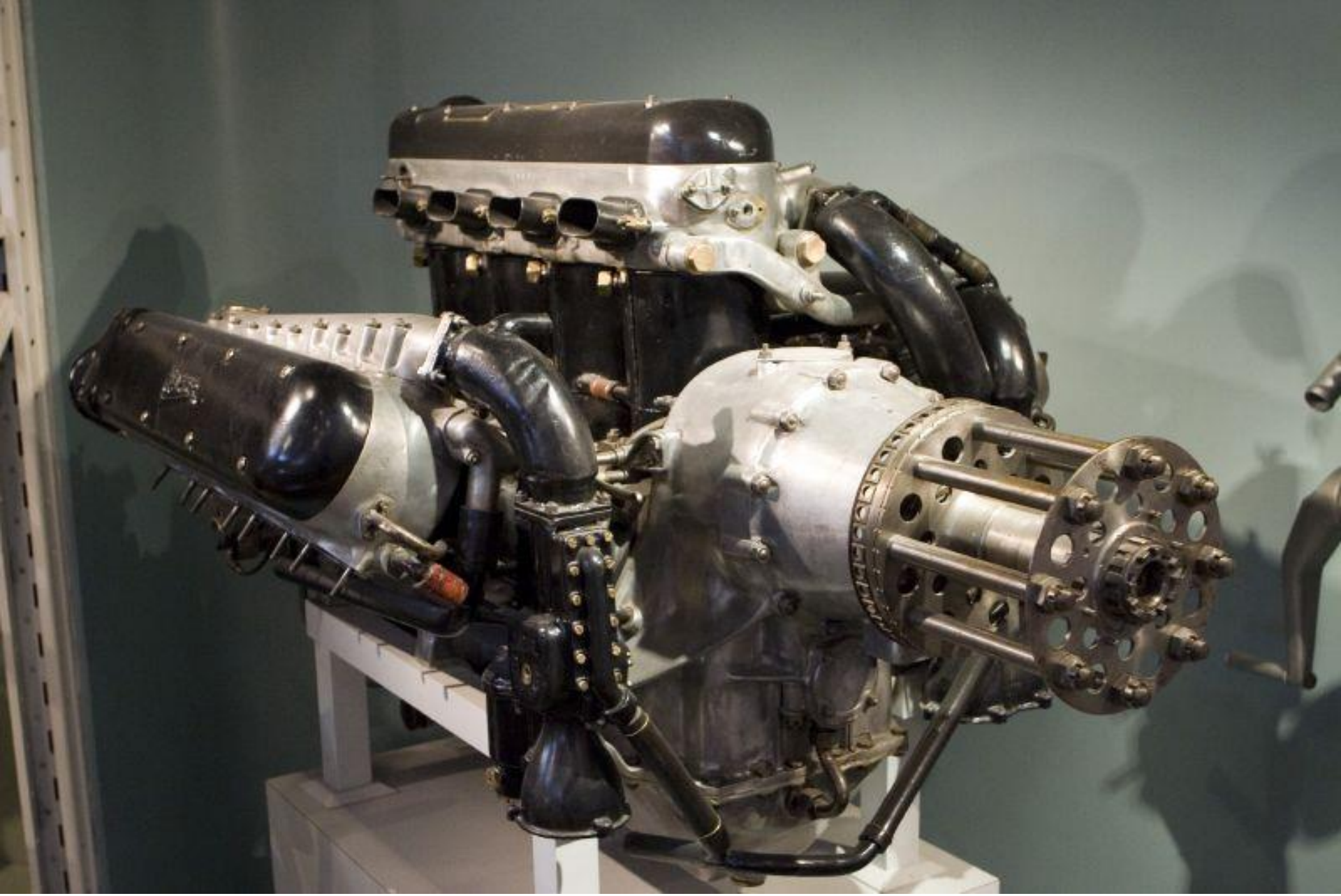
<u>Left</u>: caption: "Glenn Curtiss in the cockpit of the June Bug"

<u>Right</u>: caption: "The June Bug in flight on July 4, 1908"

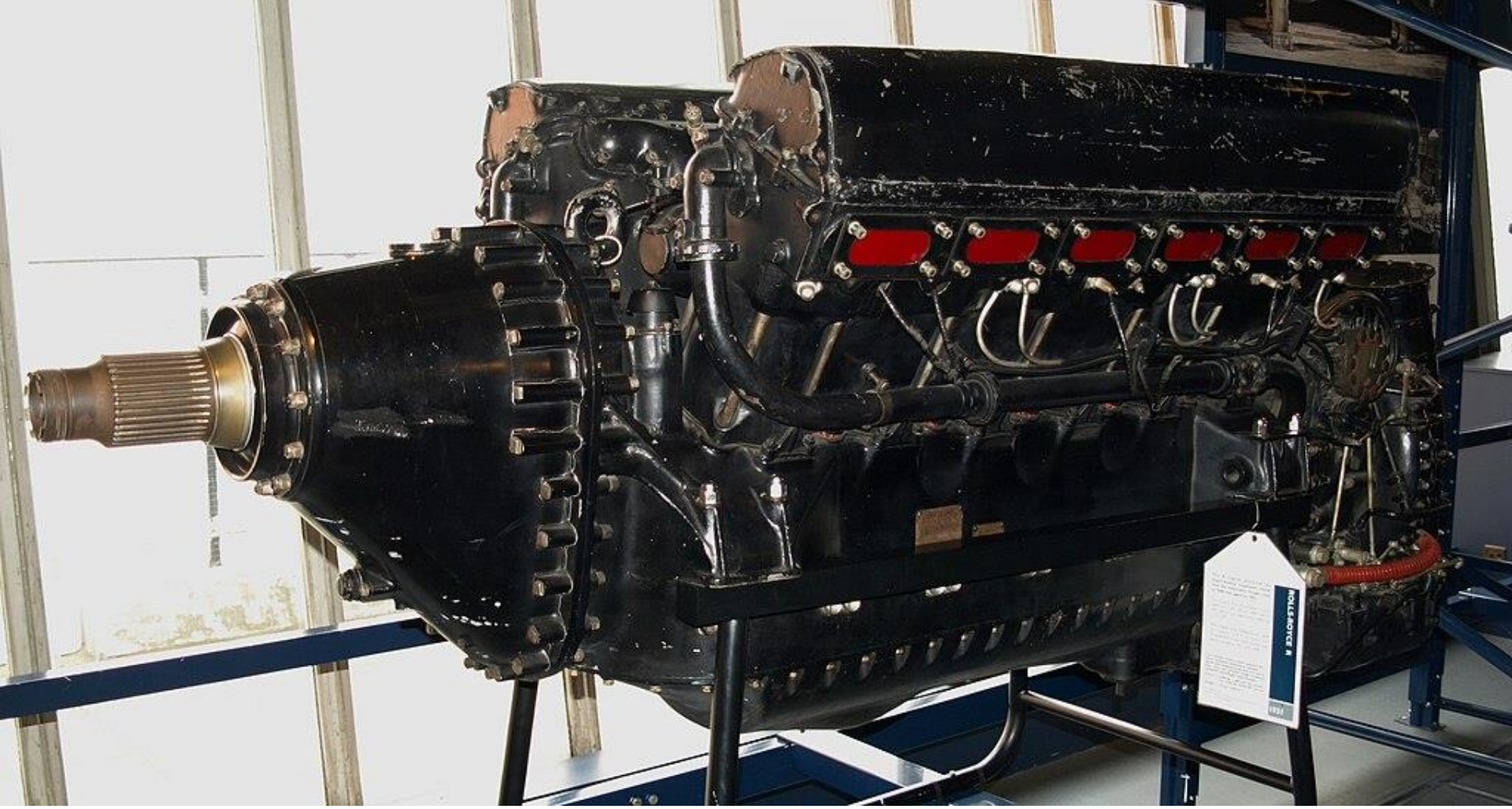
"…The V engine underwent worldwide development until 19-18. Prominent manufacturers of the type were Fiat and Isotta-Fraschini in Italy, Curtiss in America and Wolseley, Sunbeam, Napier and Rolls-Royce in Great Britain. By logical stages of development the V-type of engine reached the high pitch of efficiency typified by the Napier Lion and the Rolls-Royce R-type…"

***Wonders of World Aviation,* ca. 1938**

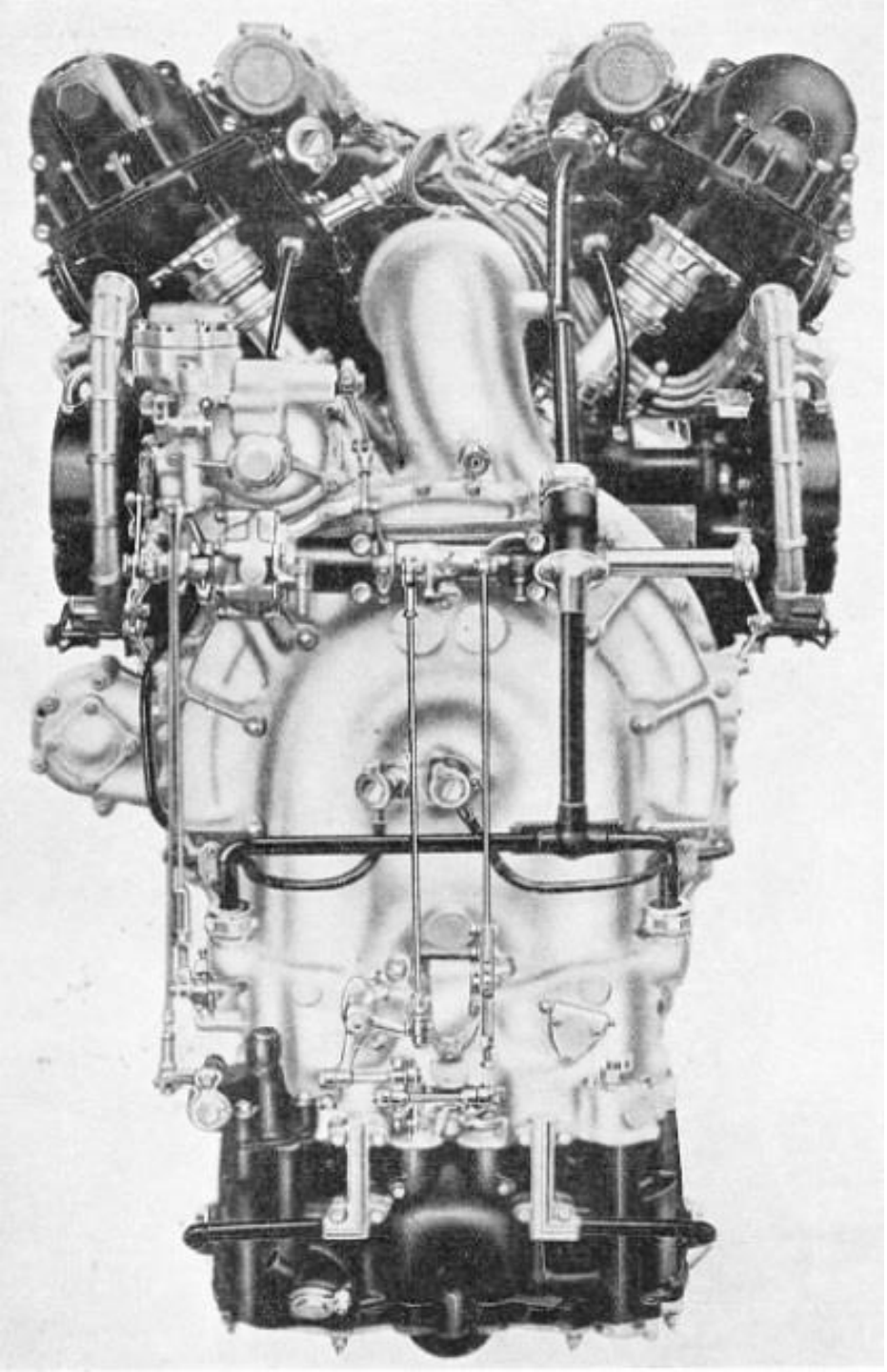
RE: the Napier Lion was a 12-cylinder, petrol-fueled "broad arrow" W-12 configuration aircraft engine built by D. Napier & Son from 1917 until the 1930s. A number of advanced features made it the most powerful engine of its day and kept it in production long after other contemporary designs had been superseded. It's particularly well-known for its use in a number of racing designs for aircraft, boats and cars. The Rolls-Royce R was a British aero-engine designed and built specifically for air racing purposes by Rolls-Royce Ltd. Nineteen R engines were assembled in a limited production run between 1929 and 1931. Developed from the Rolls-Royce Buzzard, it was a 37-liter capacity, supercharged V-12 capable of producing just under 2,800-hp and weighed 1,640 pounds.



<u>Caption</u>: “Napier Lion II at Canada Aviation Museum”



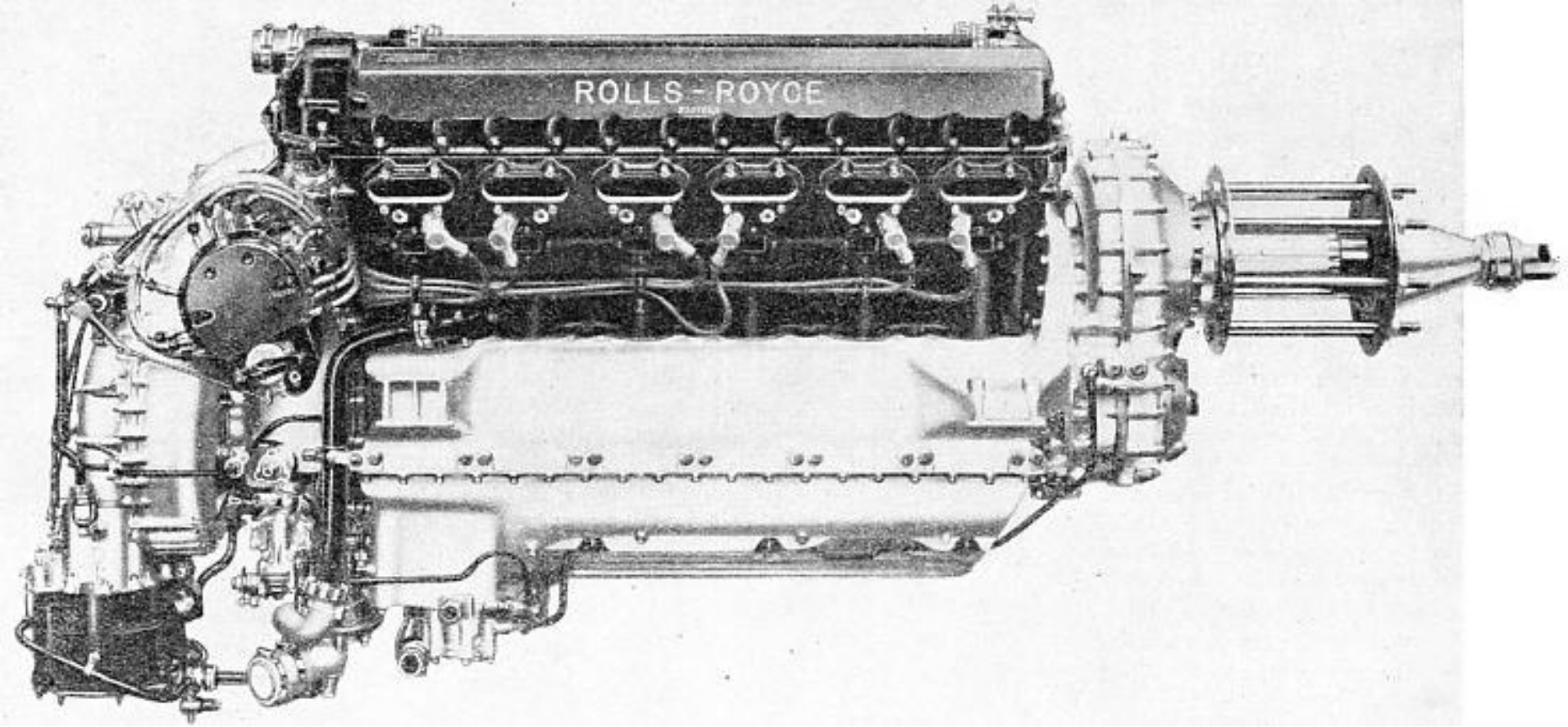
<u>Caption</u>: “Rolls-Royce R (R27) on display at the London Science Museum. The rectangular red objects are the exhaust ports blanking plates which would be replaced by the exhaust stubs/pipes when fitted to an aircraft or other vehicle”



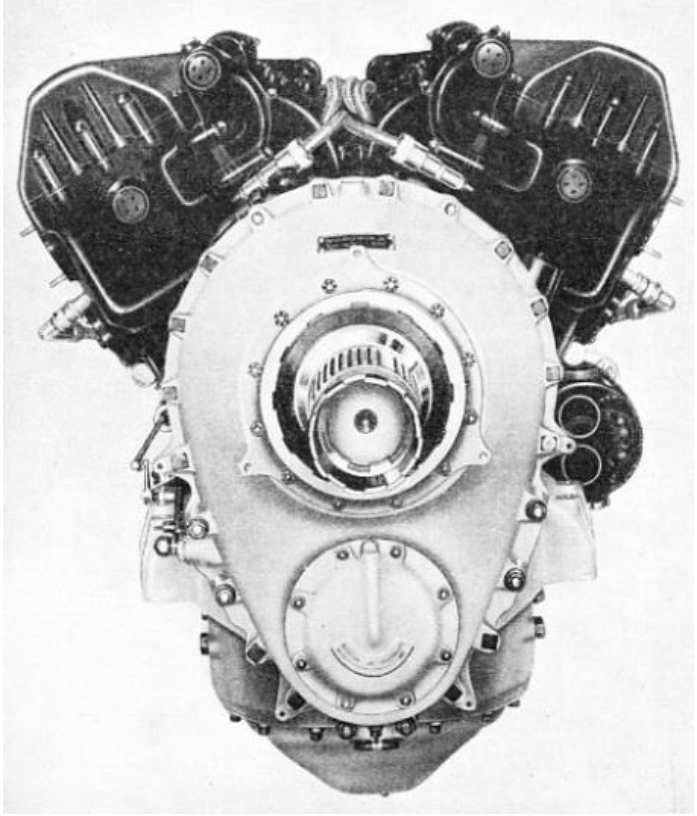
"…Present-day examples of the type are the Rolls-Royce Kestrel and Merlin, extensively used in RAF machines. These power units have twelve cylinders in two banks of six, mounted at an angle of 60-degrees to each other…"

***Wonders of World Aviation,* ca. 1938**

Caption: "ROLLS-ROYCE KESTREL. This power unit has twelve water-cooled cylinders, arranged in two banks of six at an angle of 60-degrees. It is in striking contrast to the air-cooled V-type Renault of 1913. The cylinder capacity is 21 liters and the engine develops, in unsupercharged form, 570-625-hp; its weight is 900 lbs. Rolls-Royce Kestrel engines are extensively used by the RAF. A development of the Kestrel is the Merlin, introduced in 1937. This fully supercharged engine, rated at 970 hp, with a maximum of 1,040 hp, weighs about 1,325 lbs."



<u>Caption</u>: "COMPOSITE COOLING is a feature of the Rolls-Royce Kestrel engines. In level flight the engines are entirely water-cooled. When climbing a slight amount of boiling is allowed for, thus permitting a smaller radiator to be used than would otherwise be permissible. Reduction gearing for driving the propeller is provided and a choice of three gear ratios is available."



"…The Merlin, introduced in 1937, is fully supercharged and may be co-oled by ethylene glycol, the use of which makes it possible to reduce the size of the radiator - an important point with the streamlined aero-planes of today…"

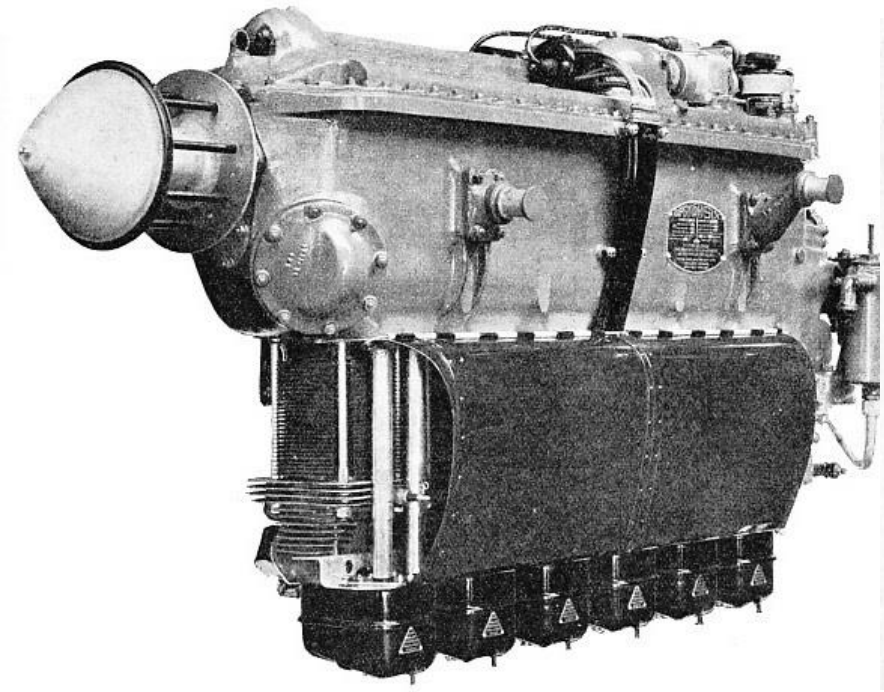
***Wonders of World Aviation,* ca. 1938**

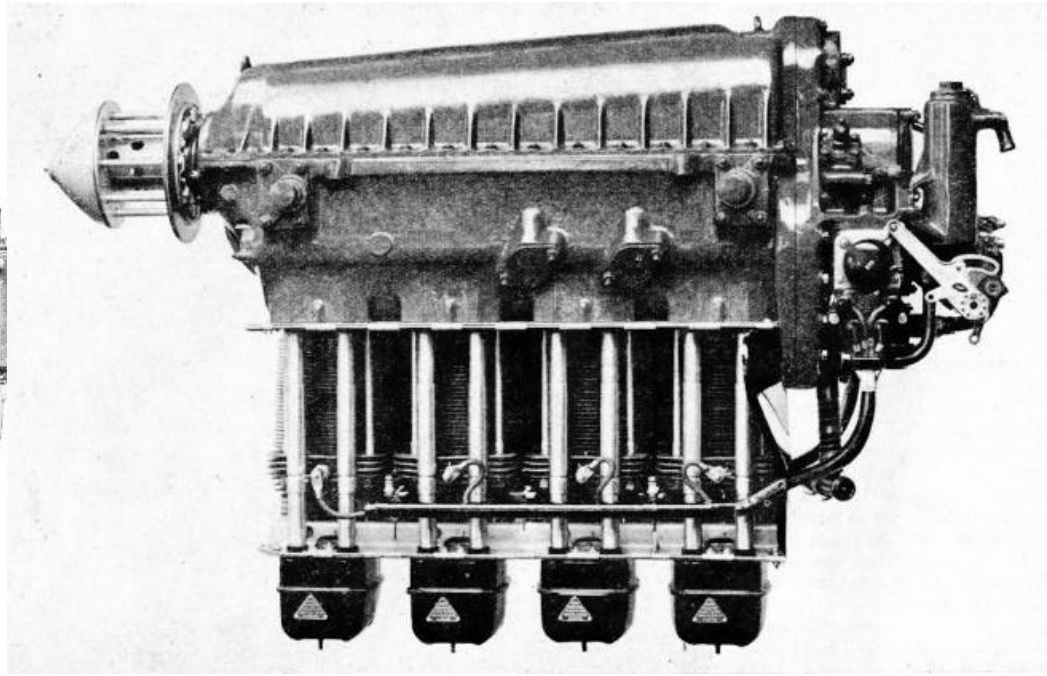
Capton: "MANY MILITARY TYPES OF AIRCRAFT are fitted with Rolls-Royce Merlin engines. These engines are high powered units, fully supercharged and cooled with ethylene glycol. The twelve cylinders give a total displacement capacity of 27 litres. These engines are used where the maximum performance of aircraft is required at altitudes of the order of 15,000 feet."

"…Power units with horizontally-opposed cylinders found favor for a time, but at present they have only a limited application, most light aeroplanes using vertical air-cooled engines of 80-horsepower and upwards…"
***Wonders of World Aviation*, ca. 1938**

"…An example of this type of engine is the De Havilland Gipsy Major, used in the Tiger Moth and other aircraft, British and foreign. This inverted vertical engine weighs only 300 lbs. and develops 120 horsepower at 2,100 revolutions-a-minute…"

***Wonders of World Aviation*, ca. 1938**





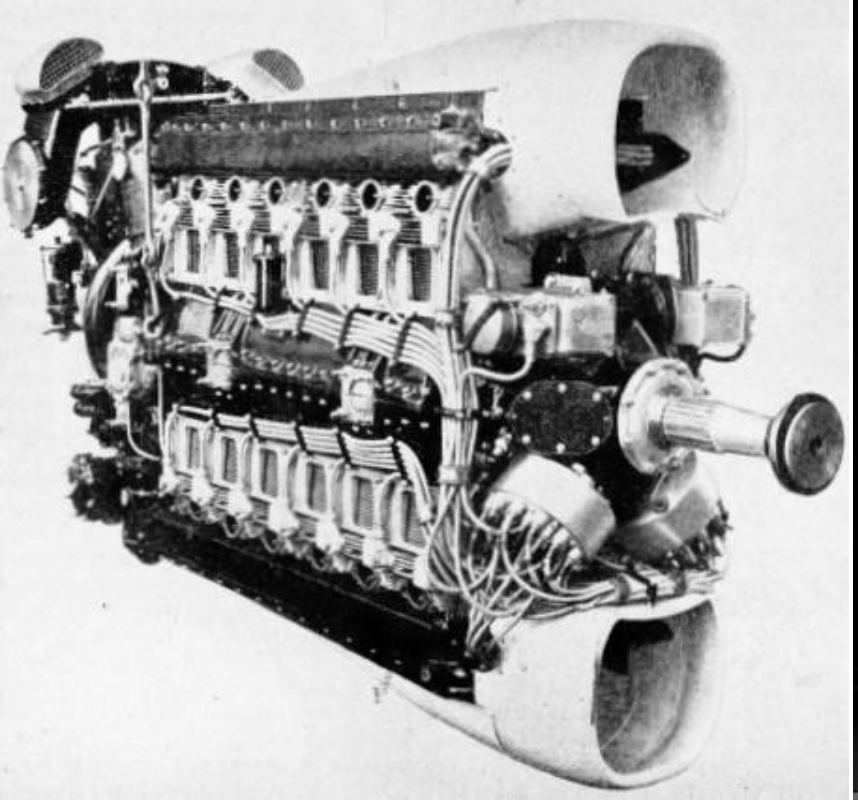
<u>Left</u>: caption: "INVERTED. The Gipsy Six I is a six-cylinder air-cooled motor of 200 horse-power and weighs 468 lb. The cylinders are below the crankcase. Two Gipsy Six engines were used in the D.H. Comet, which won the England-Australia race in 1934 in 2 days 22 hours 58 minutes. A smaller model, the Gipsy Major I, is fitted in the Tiger Moth and similar aeroplanes."

<u>Right</u>: caption: "UPSIDE DOWN. The "Gipsy Major" is a four-cylinder inverted engine, with the cylinders below the crankcase. This air-cooled 'in-line' engine is used with great success in the smaller types of aircraft, such as the 'Tiger Moth'. The 'Gipsy Major' has a single carburetor, two magnetos and overhead valves. The normal horse-power at 2,100 revolutions-a-minute is 120; the weight is 300 lbs. A development of this engine is the 'Gipsy Six,' a six-cylinder motor of 200-horsepower."

"…A notable 'in-line' arrangement is that of the Napier-Halford Dagger, which uses twenty-four cylinders in four banks of six in H formation, with two banks above the crankshaft and two below. This engine is air-cooled and supercharged and has a normal output (Series III) of 700-725-horsepower at 3,500 revolutions…"

***Wonders of World Aviation,* ca. 1938**

RE: the Napier Dagger was a 24-cylinder H-pattern (or H-Block) air-cooled engine built by Napier prior to WWII. It was a development of the earlier Napier Rapier. The H-Block has a compact layout, as it essentially consists of two vertically opposed, flat-twelve inline engines lying side-by-side and driving side-by-side crankshafts. Another advantage is that since the cylinders are opposed; the motion in one is balanced by the opposite motion in the one on the opposite side, leading to very smooth running. The Dagger ran at up to 4K rpm but unlike the later Napier Sabre, it had conventional poppet valves. Although considered a masterpiece of engine design, there were problems with cooling, maintenance, manufacturing and weight, which went unresolved.





<u>Left</u>: caption: “THE NAPIER-HALFORD ‘DAGGER’ has no fewer than twenty-four cylinders. These are arranged in four banks of six in ‘H’ formation - that is, in two parallel rows above and below the crankcase. The horsepower developed is over 700 and the weight 1,280 lbs. Special features are the low weight, the compactness and the small frontal area.”

<u>Right</u>: “Napier-Halford Dagger Series II, H-24 engine. One-half left front view. National Air and Space Museum collection.” 530

Type Follows Function

"…Today there is little difference between the power, weight and fuel consumption of the three main types of engine. The type selected for a particular aeroplane is dictated by the conditions in which it has to operate - duration of flight, rate-of-climb desired, total weight allowed for powerplant and fuel and length of periods between overhauls…"

***Wonders of World Aviation,* ca. 1938**

"…Service single- and two-seater fighters are always fitted with a single engine, of high-power, in the nose of the fuselage. Service aircraft designed to carry heavy loads over long distances are fitted with two, four or six engines mounted on the wing structure. Large private and commercial machines are generally equipped with two or more engines on the wing structure and light aeroplanes with a single engine of medium power in the nose of the fuselage…"

***Wonders of World Aviation*, ca. 1938**

Compression Ignition

"…Compression-ignition engines will undoubtedly have an important bearing of the design of future aircraft, although they are seldom used at the time of writing. The fuel used in such engines is almost immune from the risk of fire and the compression-ignition engine has the further advantages of simplicity, reduced liability to valve failure and a cool exhaust. Their weight is their chief disadvantage…"

***Wonders of World Aviation,* ca. 1938**



"…Engines of this type have recently been developed by the Bristol Company, by the Royal Aircraft Establishment, Farnborough (Hampshire), which has converted a Rolls-Royce Condor and by the German Junkers firm…"

Wonders of World Aviation,
ca. 1938.

<u>Caption</u>: "AN AIRCRAFT ENGINE BEING TESTED at the Royal Aircraft Establishment, Farnborough, Hants. The engine is set on a frame in front of an enormous wind tunnel specially designed for the testing of aircraft equipment. The tunnel is built of steel and reinforced concrete and is capable of dealing with aircraft having a span of up to 56 feet. Air is driven through the tunnel by a fan with a diameter of 30-feet."

The R-R Condor aircraft piston engine was a larger version of the R-R Eagle, developing up to 675-hp. The engine first ran in 1918 and a total of 327 engines were built. In 1932, the Air Ministry initiated a conversion of the Condor petrol engine to the compression ignition system. The conversion was developed at the RAE, Farnborough, with the cooperation of R-R. Engine layout, bore and stroke remained the same as for the petrol version; the compression ratio increased to 12.5:1. The more robust construction required to withstand the increased stresses increased the engine weight to 1,504 lbs. At its maximum 2K rpm, the engine developed 500-hp, giving a power-weight ratio of 0.33-hp/lb. The engine passed the 50-hr civil type test for compression ignition engines, being only the second British engine to do so. The only previous engine to pass this test was the much larger Beardmore Tornado fitted to the R101 airship. The diesel Condor was experimen-tally flown in a Hawker Horsley to explore the practical operation of a diesel engine in flight.

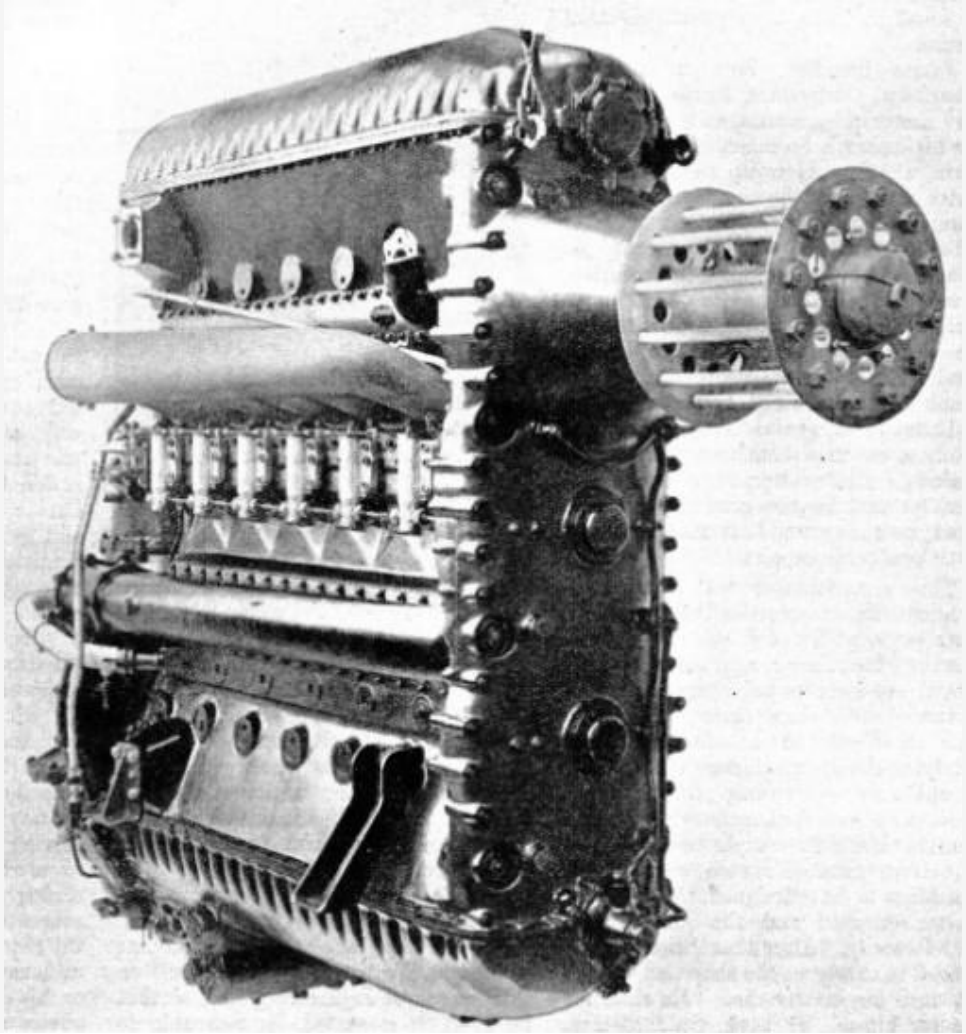


Caption: "Rolls-Royce Condor III on display at the Rolls-Royce Heritage Trust, Derby"

"…A Junkers engine is built by Napier and is known as the 'Napier-Junkers Culverin.' It is a six-cylinder two-stroke engine, with two crankshafts which are coupled together by a train of gearwheels. Incorporated in this train is the drive for the airscrew. The engine is water-cooled and develops 720 horsepower, its weight being 1,785 lbs. In Germany this type of engine is known as the 'Jumo'…"

***Wonders of World Aviation,* ca. 1938**

RE: the Napier Culverin was a licensed-built version of the Junkers Jumo 204 six-cylinder vertically opposed liquid-cooled diesel aircraft engine built by D. Napier & Son. The name was derived from the French word, "culverin," for an early cannon or musket. The six cylinders were arranged vertically. Two crankshafts were located at the top and bottom of the engine and coupled together by gears. The inlet and exhaust ports were controlled by the pistons, as in a petrol-fueled two-stroke engine. The Jumo 205 aircraft engine was the most numerous of a series of aircraft diesel engines produced by Junkers.



<u>Caption</u>: “THE NAPIER-JUNKERS “CULVERIN” is a compression-ignition engine using crude oil instead of petrol. With this type of engine the risk of fire is largely eliminated. The ‘Culverin’ is a two-stroke six-cylinder water-cooled engine, with opposed pistons. There are two crankshafts, one above and one below the cylinders. The horsepower is 720 and the weight 1,785 lbs.”

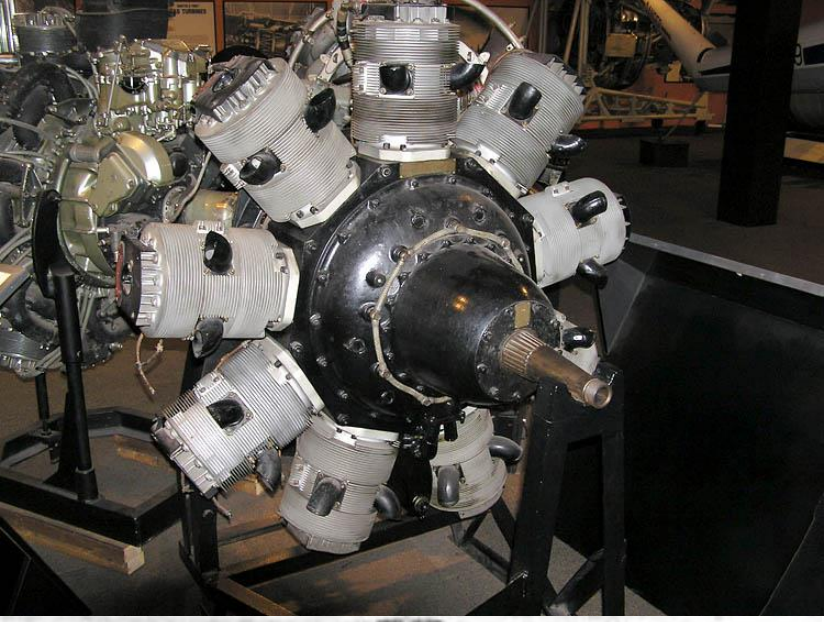


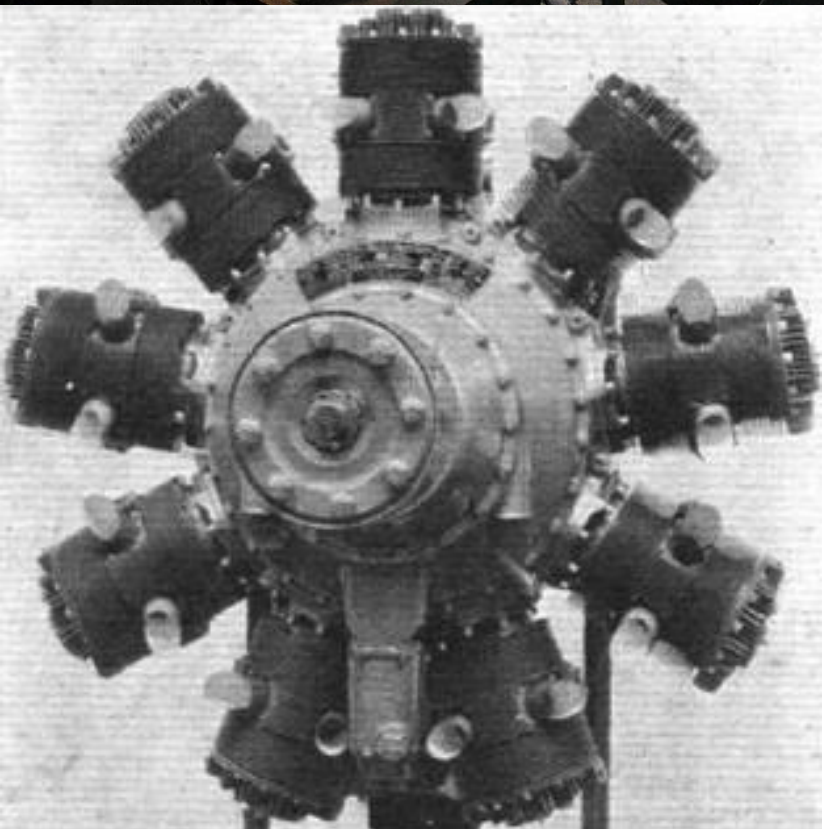


First flown in 1938, the Napier Culverin engine went into limited production, with testing carried out on a Blackburn Iris V biplane flying-boat aircraft and Fairey IIIF biplane. The Jumo 204 first entered service in 1932. Later engines of this type comprised the experimental Jumo 206 and Jumo 208, with the Jumo 207 produced in quantity. All three variants differed in stroke and bore and supercharging arrangements.

Left: caption: "Rolls-Royce Condor-powered Blackburn Iris seaplane"

Right: caption: "Jumo 205 cutaway"





"…Many advantages are claimed for the sleeve-valve engine. The Bristol Company has developed the single sleeve-valve engine with conspicuous success. In 1933 appeared the Bristol Perseus, of 24.9 litres capacity. This was followed by the Aquila; a radial air-cooled sleeve-valve engine of about 15-1/2 litres capacity…"

***Wonders of World Aviation,* ca. 1938**

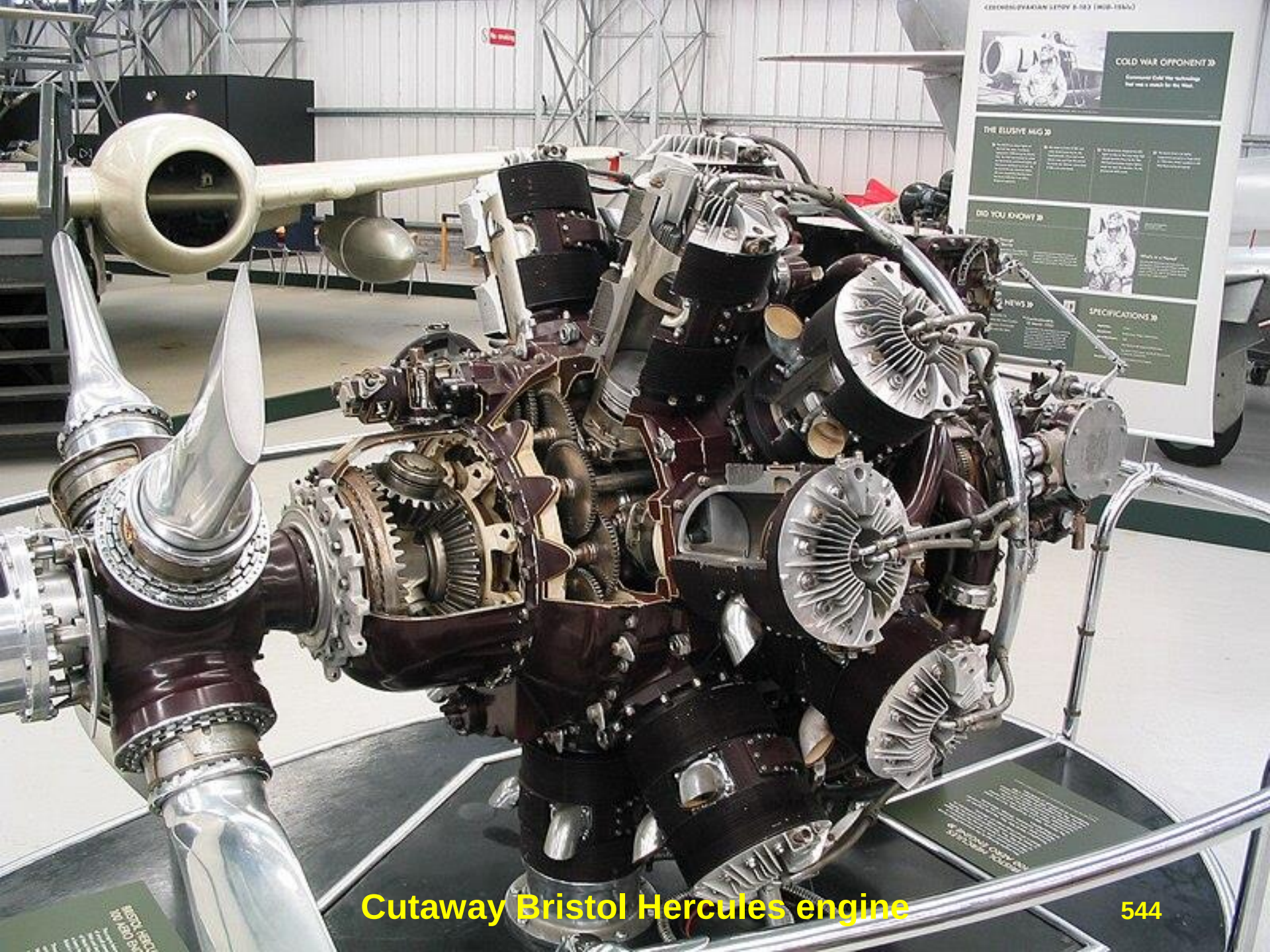
<u>Upper</u>: the Bristol Perseus was a British nine-cylinder, single-row, air-cooled radial aircraft engine produced by the Bristol Engine Co. beginning in 1932. It was the first production sleeve-valve aero-engine.

<u>Lower</u>: the Aquila was a nine-cylinder single-row radial aircraft engine designed by the Bristol Engine Co. starting in 1934. A sleeve-valve engine, its basic design was developed from the Bristol Perseus. The Aquila was never used in production, but further developments led to the Bristol Hercules, Bristol Taurus and Bristol Centaurus.

"…One of the most powerful British aero-engines is the fourteen-cylinder double-row Bristol Hercules, first tested in 1936. Its total capacity is 38.7 litres and the international rating of the medium supercharged model is 1,100-1,150 brake horsepower at 2,400 revolutions-a-minute at 5,000 feet."

***Wonders of World Aviation,* ca. 1938**

RE: the Bristol Hercules is a 14-cylinder two-row radial aircraft engine produced by the Bristol Engine Company beginning in 1939. It was the most numerous of their single sleeve valve designs, powering many aircraft in the mid-WWII timeframe. The Hercules powered several aircraft types, including Bristol's own Beaufighter heavy fighter design, although it was more commonly used on bombers. The Hercules also saw use in civilian designs, culminating in the 735 and 737 engines the Handley Page Hastings C1 and C3 and Bristol Freighter. The design was also licensed for production in France by SNECMA.



Cutaway Bristol Hercules engine

Part 4

Modern Aero-Engines

Three Types

Aircraft of today generally use in-line, V or radial types of power unit

***Wonders of World Aviation,* June 28, 1938**

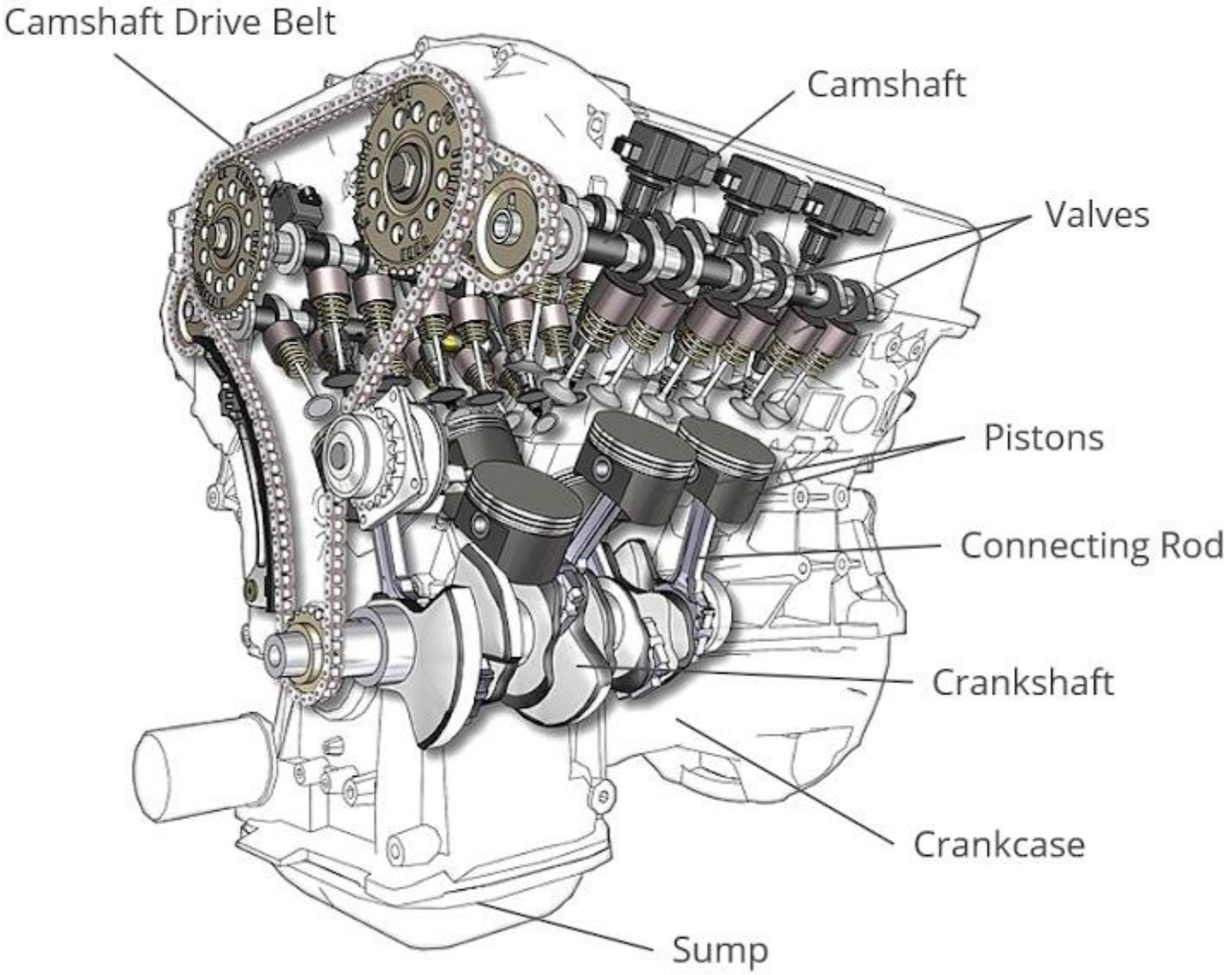
RE: introduction to an article entitled: “Modern Aero-Engines”

ICE

"THE normal aero-engine of today works on the same principle as the ordinary motor car engine. Both are internal combustion engines; that is to say, the firing of a mixture of petrol and air in the cylinders forces the pistons, through connecting rods, to drive a crankshaft…"

***Wonders of World Aviation,* June 28, 1938**

RE: in an *Internal Combustion Engine* (ICE), the ignition and combustion of the fu-el occurs within the engine itself. The engine then partially converts the energy from the combustion to work. The engine consists of fixed cylinders and moving pistons.



Cut-away of a typical aircraft internal combustion engine

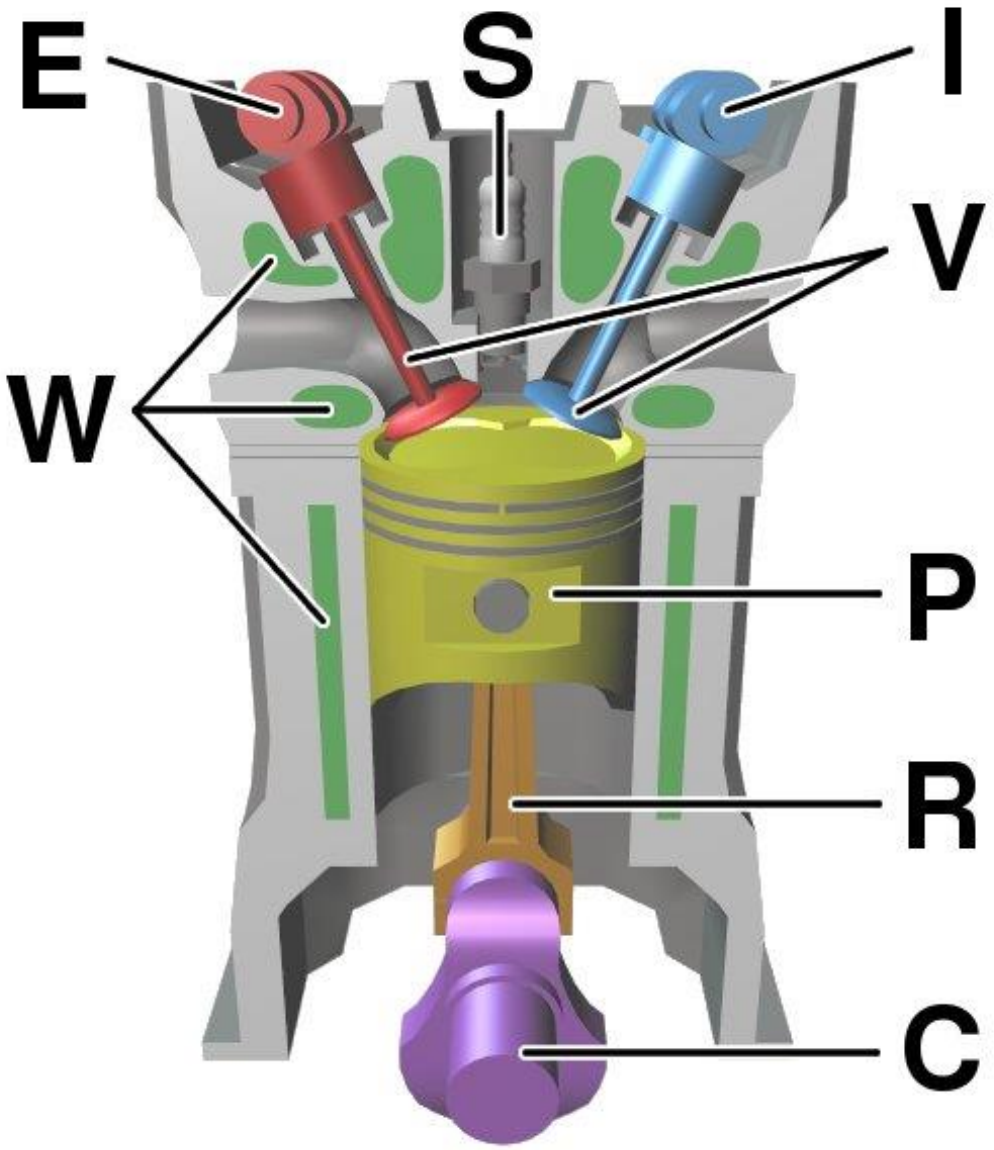


Diagram of a cylinder as found in an overhead cam 4-stroke gasoline engine: C – crankshaft / E – exhaust camshaft / I – inlet camshaft / P – piston / R – connecting rod / S – spark plug / V – valves / red: exhaust / blue: intake

"…Early aero-engines were developed from motor car engines. In the aero-engine, however, better petrols have to be used than in car engines. Motor spirits go through a number of refining processes and it is possible, knowing the constituents of any particular variety, to estimate the power it will give when mixed with a certain amount of air in an engine cylinder of known bore and stroke…"

***Wonders of World Aviation,* June 28, 1938**

"…Petrol evaporates comparatively easily and the vapor which it gives off lights at a comparatively low temperature, known as the 'flash point.' The low flash point makes the spirit dangerously inflammable, but it is of great advantage for firing the mixture of petrol and air in an engine. The sparking plug supplies the necessary spark, which is produced by the magneto. As it is vital that there shall be the minimum chance of failure in an aero-engine, the magneto has been developed into a most reliable instrument. Modern aero-engines have two sparking plugs to each cylinder and two magnetos…"
***Wonders of World Aviation*, June 28, 1938**

"…It is important that the spark should take place at the correct instant after the mixture of petrol vapor and air has been compressed by the piston. This is ensured by the platinum points in the make-and-break device that breaks the primary electrical circuit at the appropriate instant and which can be advanced or retarded - either manually or automatically - to suit the running conditions. Because an aero-engine is called upon to run at different speeds, a variable ignition timing is generally provided…"

***Wonders of World Aviation*, June 28, 1938**

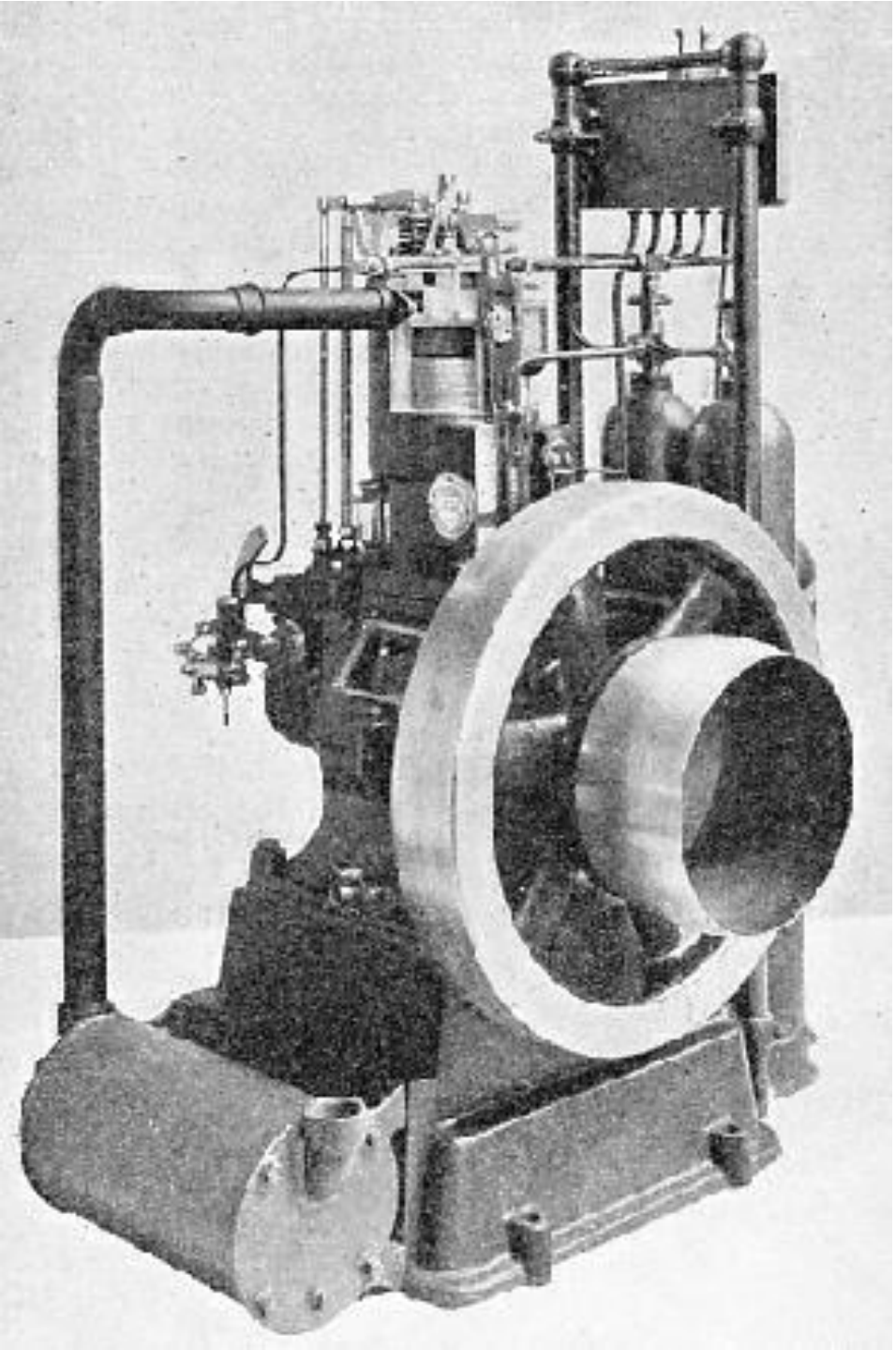
"…The sparking plugs used in aero-engines are of a special type. The central electrode is insulated with materials such as porcelain or mica or - in the newest types of sparking plug - a material made from aluminum oxide, which has a high melting point of over 2,000-degrees centigrade…."

***Wonders of World Aviation*, June 28, 1938**

"…As a heat conductor, this new material is over fifty times as effective as mica. Magnetos, sparking plugs and their leads have to be bonded (joined together) in aircraft engines to avoid electrical interference with the wireless installation. Every metal part in an aeroplane is nowadays bonded as a safeguard against fire risk due to electrical charges…"
***Wonders of World Aviation,* June 28, 1938**

"…The ratio of the volume of the cylinder to the volume of the space into which the mixture is compressed is known as the 'compression ratio.' The importance of the compression ratio is this; the higher the ratio the greater the economy of fuel for a given power. It is not possible to increase the compression ratio much above about 6- or 8-to-1, because the petrol and air mixture detonates unless special substances are mixed with the petrol to retard the rate of burning…"

***Wonders of World Aviation*, June 28, 1938**



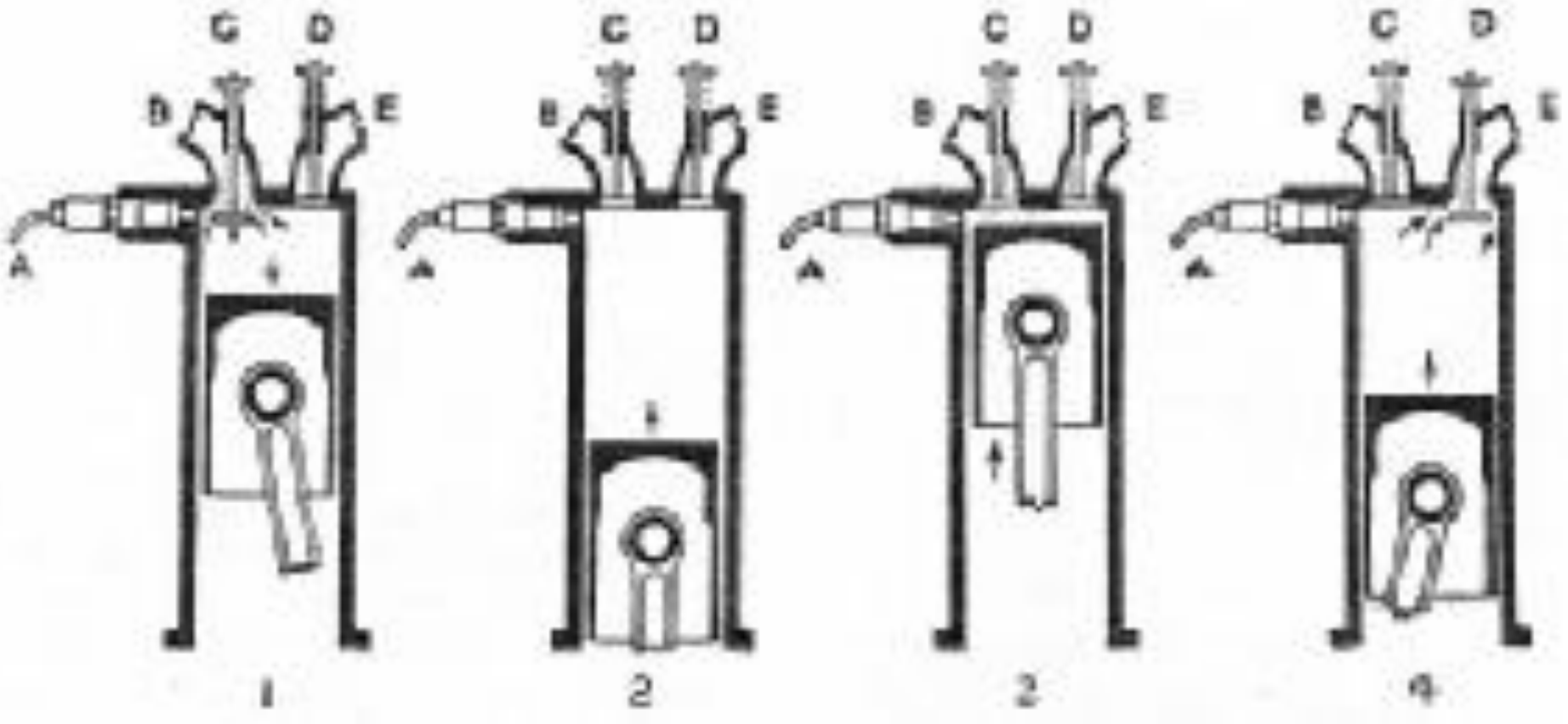
"…Advantage has been taken in the diesel engine of the fact that compression of a combustible mixture raises its temperature to a point where it will ignite by itself. High compression ratios up to 12- or 15-to-1 are used in these engines, which are often called compression-ignition engines…"

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RE: a diesel engine is an internal combustion motor which differs from the petrol engine in that no sparking agency is required to effect internal combustion in the cylinders

<u>Caption</u>: "EARLY DIESEL ENGINE. Dr. Rudolf Diesel was born in Paris on March 18, 1858. He developed the principle of Akroyd-Stuart's oil engine by using high-compression in the cylinders to provide the heat to ignite the mixture of fuel and air.



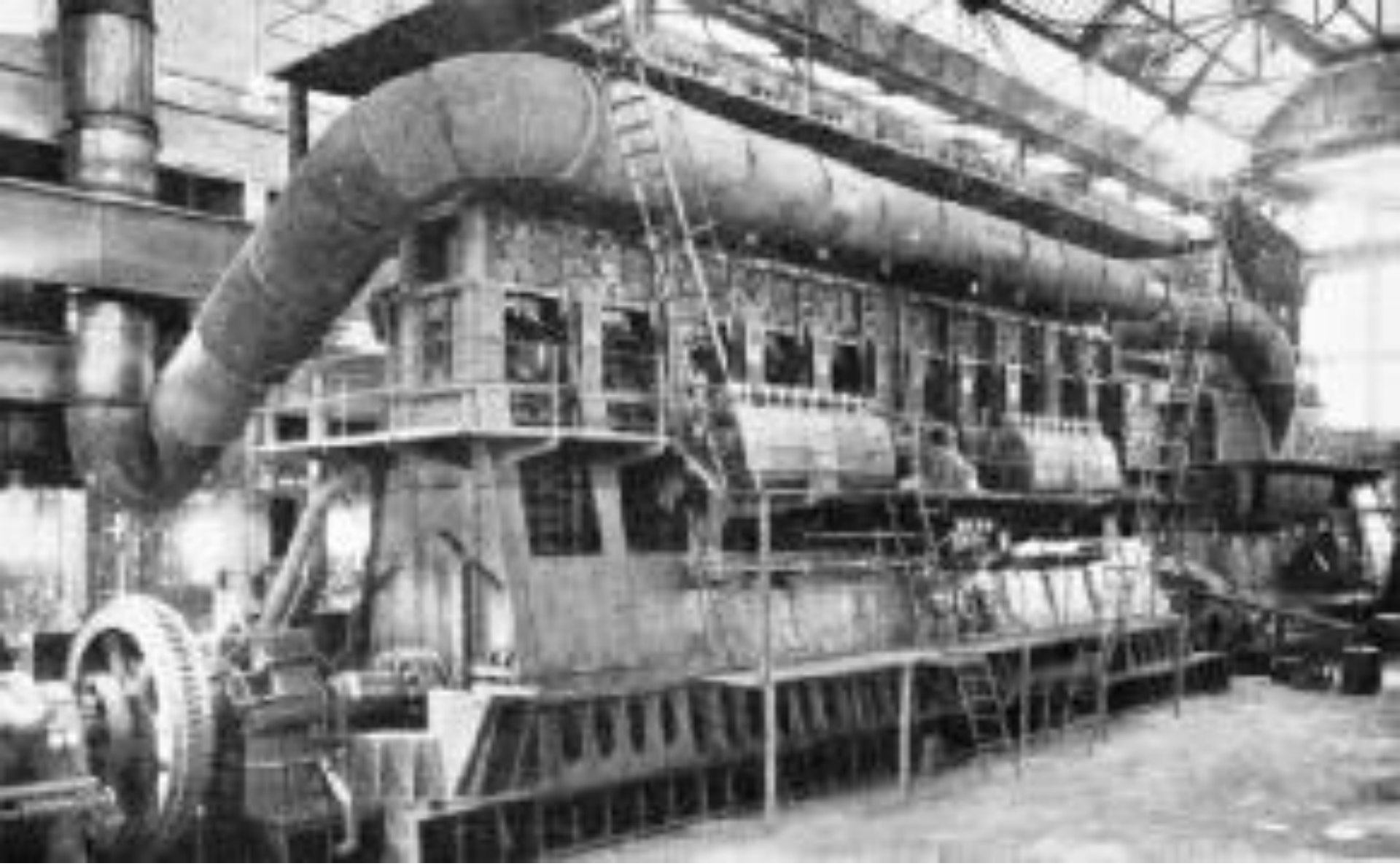
<u>Caption</u>: "THE FOUR-STROKE CYCLE of diesel engines is illustrated diagrammatically. The induction valve, through which air is drawn on the downstroke of the piston, is marked C. The third stroke effects compression. At the critical moment fuel is injected through the nozzle A and the heat of the compressed air causes combustion. The exhaust valve D opens for the fourth stroke. B and E mark the air intake and exhaust pipes respectively."

"…The petrol engine uses motor spirit with low flash points; diesel and compression-ignition engines use fuel - heavy oils - with high flash points. The diesel engine for aircraft is still, in many ways, considerably less developed than the ordinary petrol engine, although a considerable number of diesels are in use, especially in Germany, where a more intensive study of them has been made than elsewhere…"

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"…The diesel engine has no sparking plugs or electrical apparatus for firing it, so that the danger of fire is lessened. Compared with the use of petrol, the use of heavy oil as fuel considerably lessens the risk of fire due to accidental causes. On the other hand, the diesel engine is considerably heavier than the petrol engine and, though it burns less fuel, the advantage of low fuel consumption is seen only in long-distance flights…"

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Caption: "DOUBLE-ACTING MARINE DIESEL of the two-stroke cycle type built for the Italian liner *Vulcania,* a twin-screw vessel of 23,970-tons gross. The *Vulcania* is driven by two ten-cylinder engines of this type. They have a combined output of about 26,000 shaft horsepower at 128 revolutions-a-minute.

Air-cooled and Liquid-cooled

"…Modern aero-engines may be classified broadly as air-cooled and liquid-cooled. In both classes there is a variety of types. Air-cooled engines may have from four to six cylinders in-line; they may be upright or inverted, in powers up to about 200-horsepower; or they may be single-row or double-row radials, having five, seven or nine cylinders in each row…"

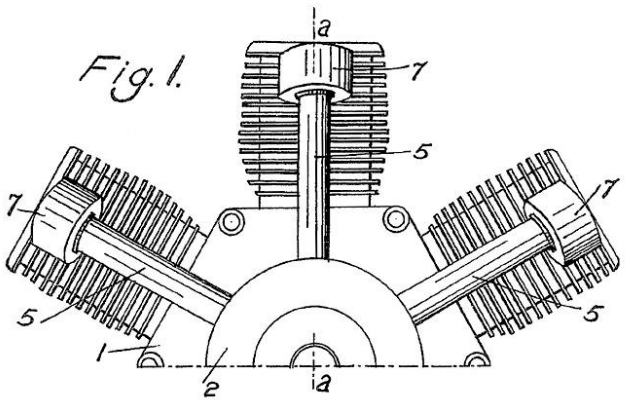
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"…Single-row radial engines have a number of cylinders arranged round a single-throw crankshaft; a double-row radial engine has a two-throw crankshaft. In a double-row the cylinders of each row are staggered so that the cooling air can flow round each cylinder. Radial engines may have horsepowers as high as 1,500…"

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<u>Caption</u>: "A cylinder from an air-cooled aviation engine, a Continental C85. Notice the rows of fins on both the steel cylinder barrel and the aluminum cylinder head. The fins provide additional surface area for air to pass over the cylinder and absorb heat."



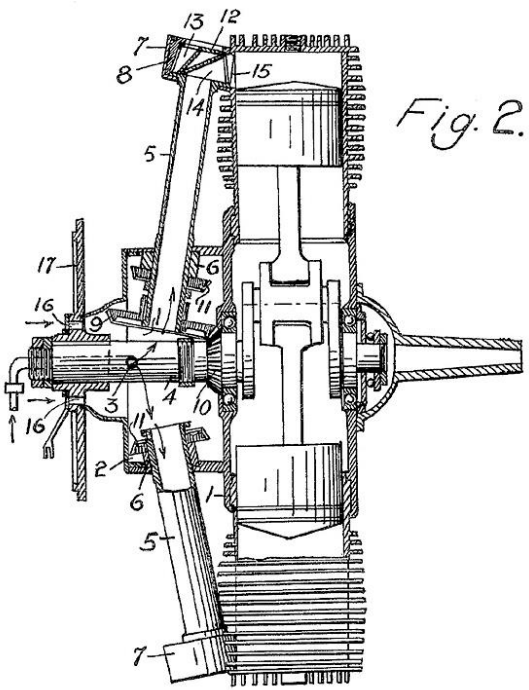
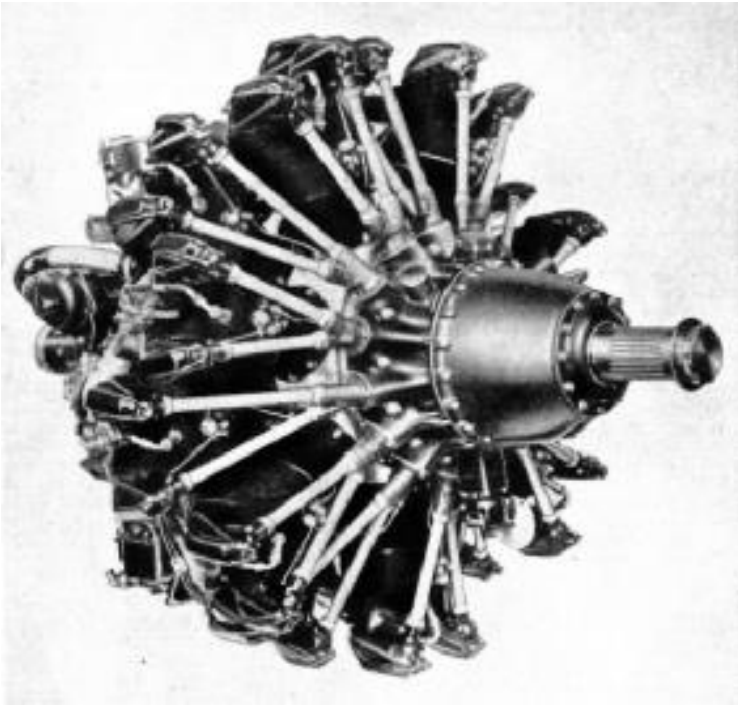
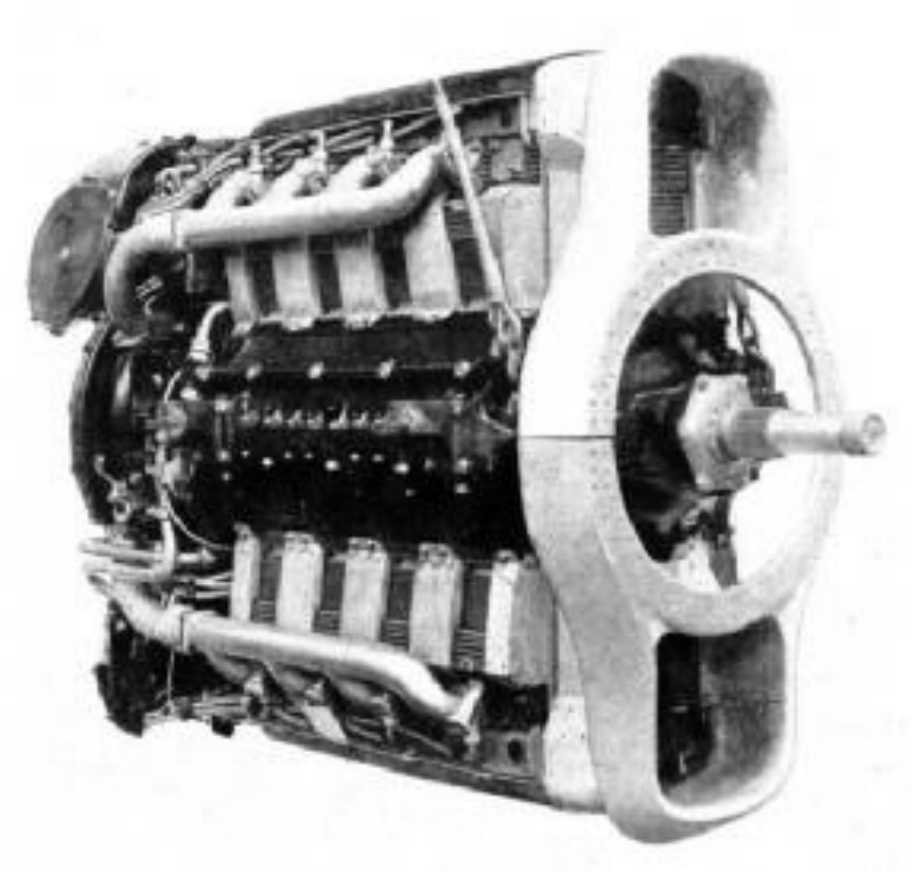


Fig. 2.



Left: caption: "Drawings of a 25-hp Tips engine of 1912. Air was drawn through the rotating suction tubes (5) which enable the intake port (14) and exhaust port (13) to align with the cylinder. The suction tubes were geared (9 and 10) to the stationary crankshaft (4)."

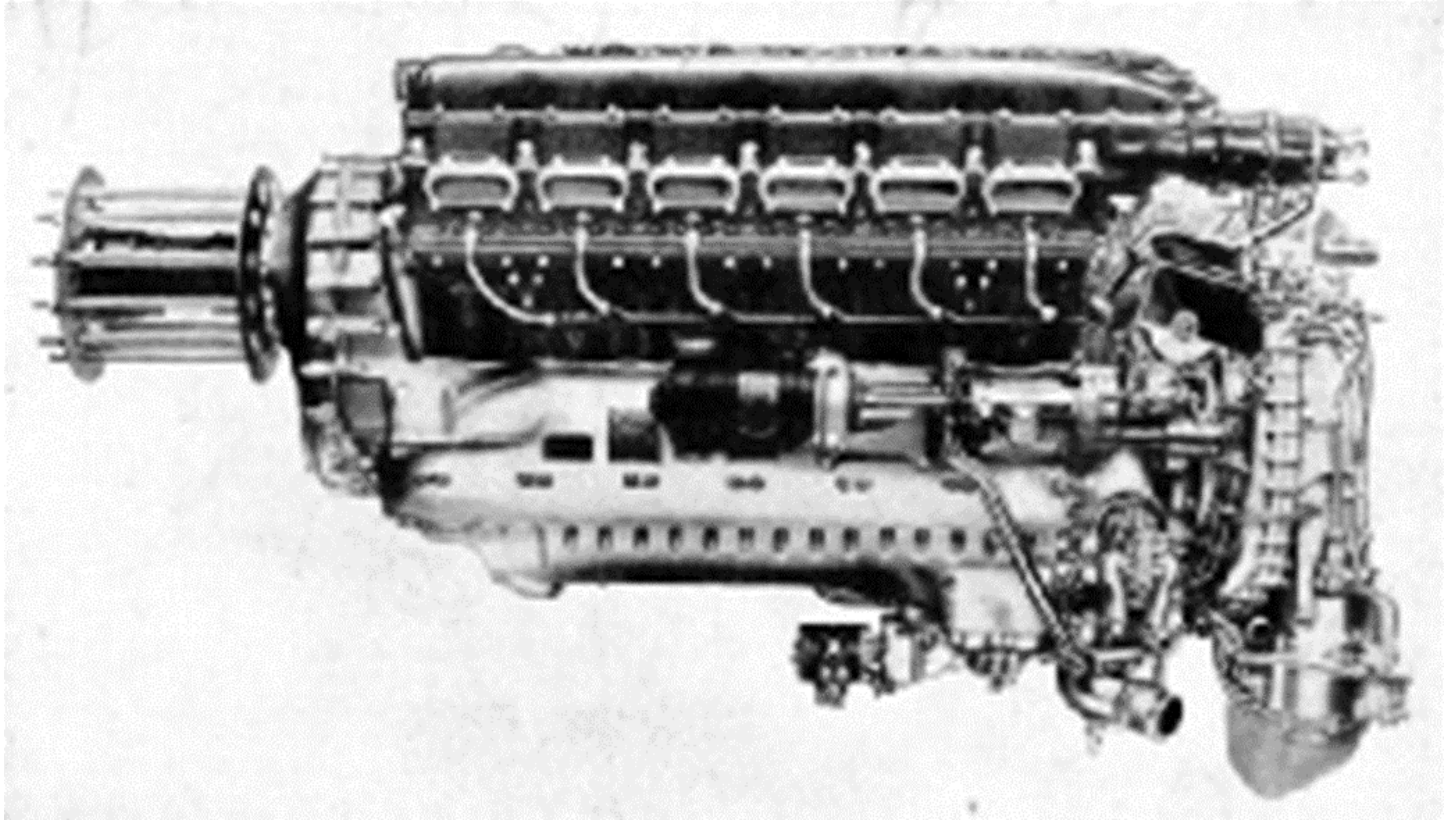
Right: caption: "A DOUBLE-ROW TYPE OF RADIAL ENGINE. This is similar to a single row radial, but with each alternate cylinder offset in relation to the two adjacent cylinders to give a compact design. The engine illustrated is an Alvis Pelides Major which has fourteen cylinders, is fully supercharged and develops a maximum of 1,110-horsepower. Direct or geared-drive can be fitted for the propeller."



"…Another type of air-cooled engine is known as the H because the cylinders are so arranged that the cross-section of the engine resembles the letter H. Engines of this type have as many as twenty-four cylinders operating on two crankshafts geared together…"

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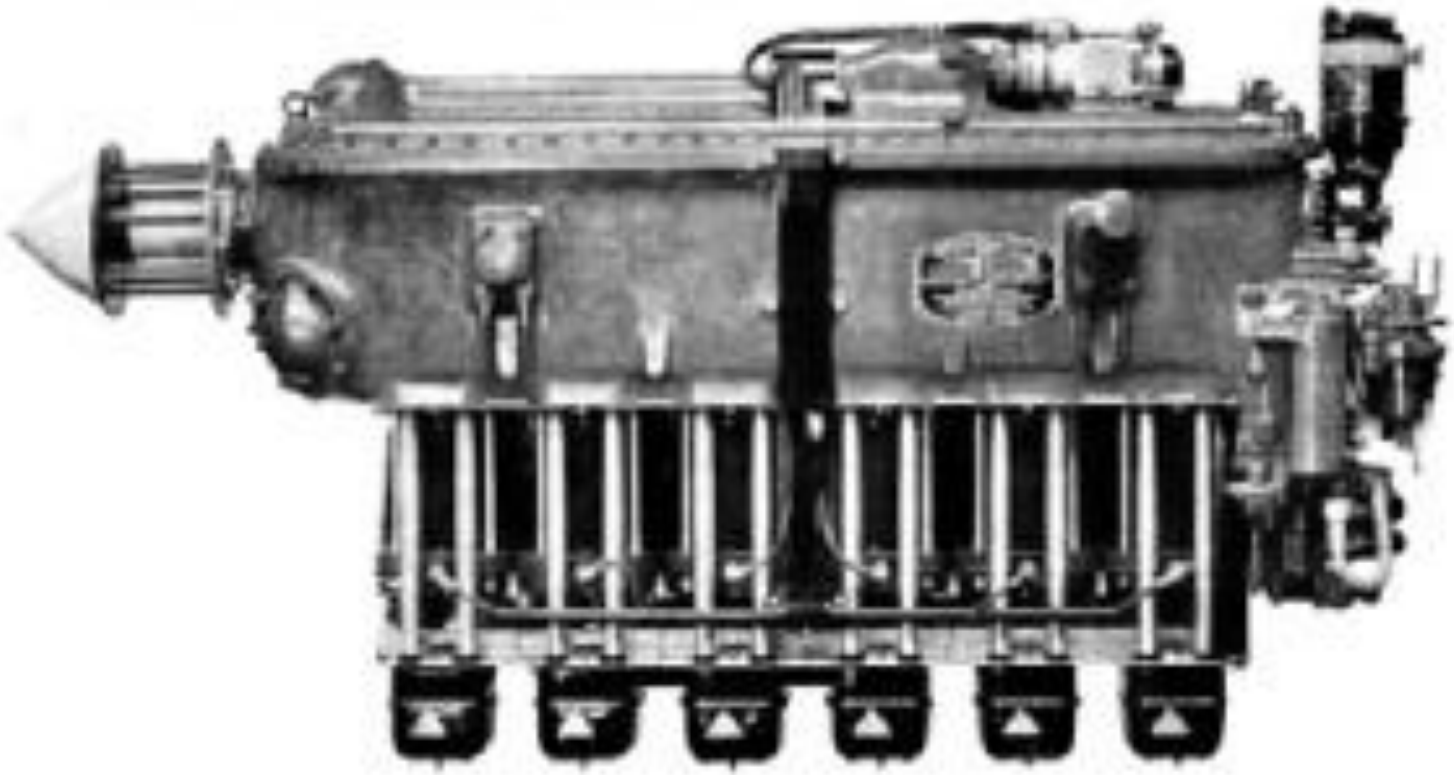
<u>Caption</u>: SMALL FRONTAL AREA is a feature of the Napier Rapier engine. It has sixteen cylinders, which are arranged in H fashion. There are two rows of four above the crankcase and two similar rows below. The Rapier Series VI engine has a maximum horsepower of 395 and uses a supercharger."



"…The V engine has two rows of cylinders arranged at an angle to each other, the two rows thus making the Y; all the cylinders are connected to a single multi-throw crankshaft…"

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<u>Caption</u>: "THE CYLINDERS ARE ARRANGED IN THE FORM OF A V in the Rolls-Royce Merlin engine. There are twelve cylinders in all, six on one side of the V and six on the other. High-temperature liquid-cooling is used, the cooling medium being ethylene glycol. The two rows of cylinders are set at an angle of 60-degrees to each other. The capacity of the engine is 27 liters and the maximum horsepower is 1,050 for the fully supercharged model."

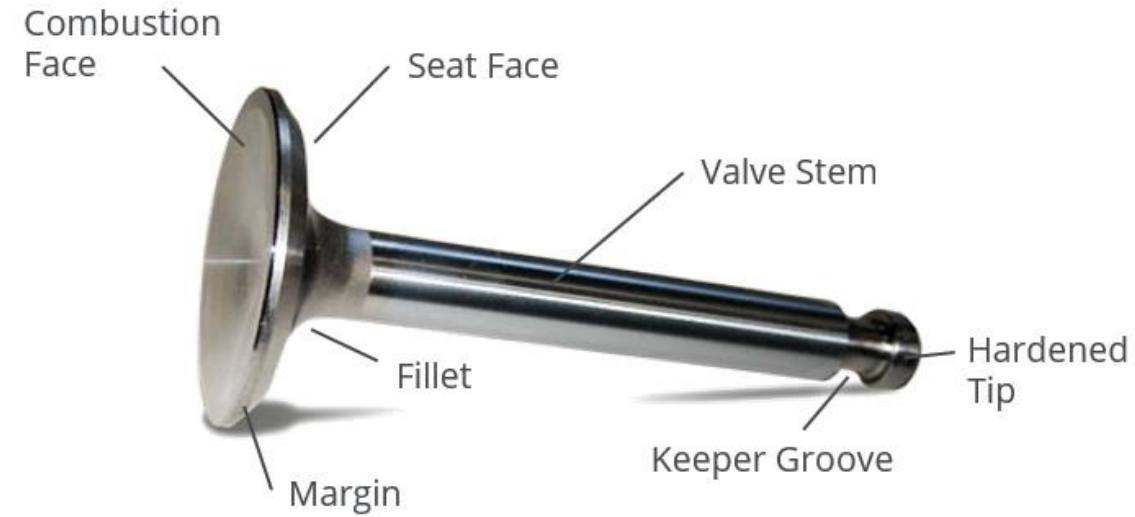


"…Liquid-cooled engines may be in-line or V-shaped. Liquid-cooled engines in-line generally have six cylinders and V-shaped engines, twelve cylinders. The engines may be cooled with water or with ethylene glycol, which has a much lower freezing point than water…"

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<u>Caption</u>: "TYPICAL OF IN-LINE ENGINES is this De Havilland Gipsy Six Series I engine with its six cylinders one behind the other in a straight line. The engine is known as an inverted-type, that is, the cylinders are arranged below the crankcase; air cooling is used. The engine has a maximum output of 200-horsepower for a capacity which is just over nine liters."





"…Most aero-engines use poppet valves, similar to those of the ordinary motor car engine and some employ two exhaust and two inlet valves for each cylinder…"

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RE: a poppet valve (a/k/a "mushroom valve") is a valve typically used to control the timing and quantity of petrol (gas) or vapor flow into or out of an engine

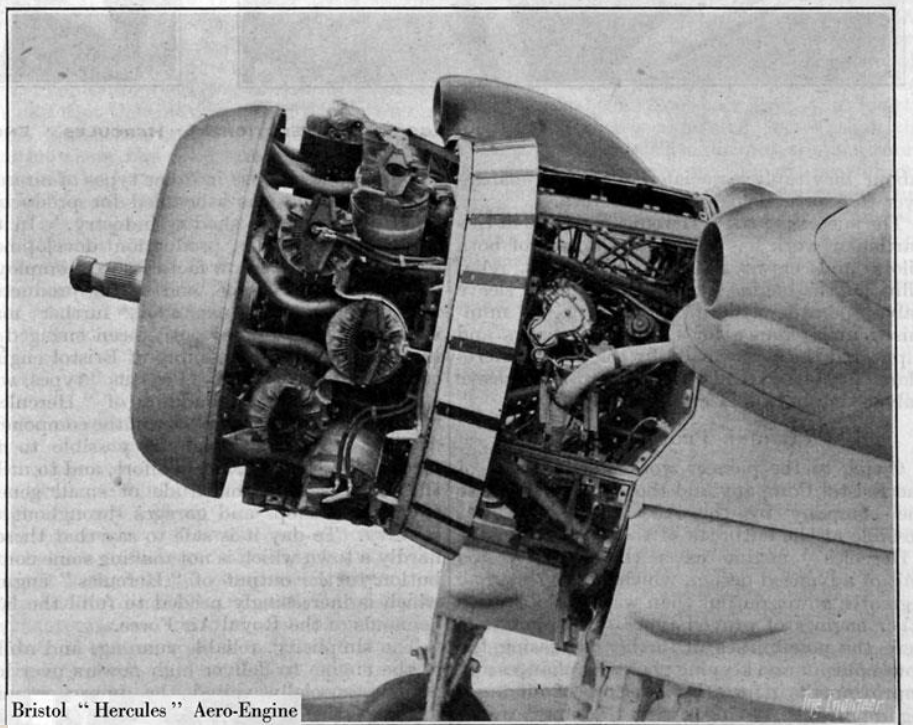
<u>Above & Left</u>: caption: "A typical poppet valve and components"

"…In recent years, the Bristol Aeroplane Company has developed the sleeve-valve engine. A cylindrical sleeve reciprocates in the bore. Specially shaped ports are provided in the sleeve and the cylinder barrel for exhaust and inlet purposes…"

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Bristol "Hercules" Aero-Engine

"…The air-cooled sleeve-valve Perseus engine of that company has an International rated output of 890-horsepower and the double-row Hercules 1,375-horsepower…"

Wonders of World Aviation,

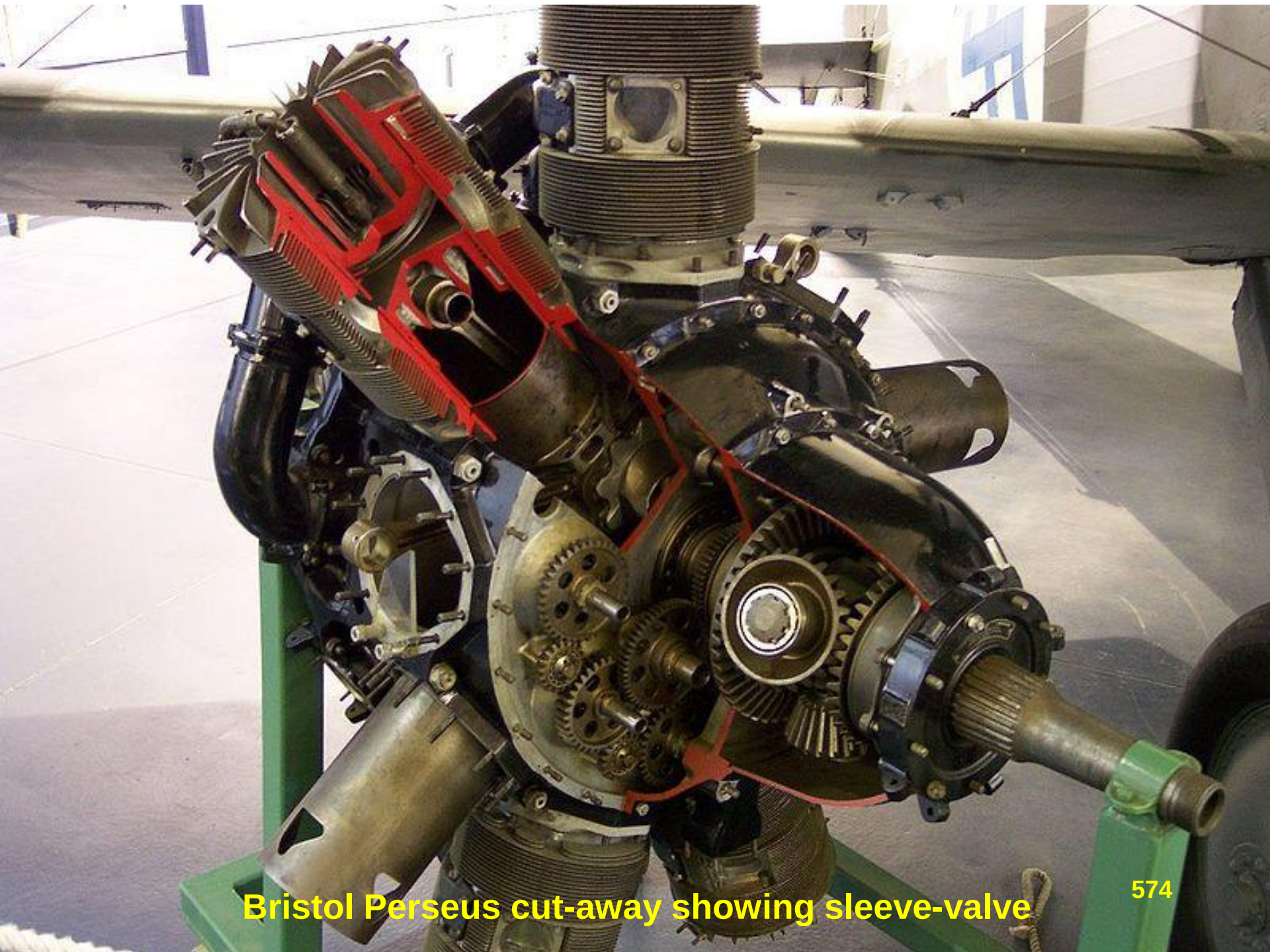
June 28, 1938

<u>Left</u>: Bristol Perseus ad

<u>Above</u>: Hercules aero-engine installed in a Beaufighter



Caption: "SLEEVE-VALVE RADIAL ENGINES in production. They are nine-cylinder Bristol Perseus engines developing a maximum horsepower of 890. The advantages of sleeve-valves include the entire elimination of valve maintenance and top overhauls and a reduction in mechanical and exhaust noises. Reduction gearing is used to drive the propeller, which may be of the controllable-pitch type."



Bristol Perseus cut-away showing sleeve-valve



"…The sleeve valve engine has a number of advantages over the poppet-valve type. The parts are fewer in number and cheaper to manufacture; there are no springs to fracture; the engine is easier to maintain; the mechanism enables high speeds to be obtained; greater power and economy can be obtained from a given fuel; noise is reduced and, because higher compression ratios can be used, the fire risk is lessened owing to the lower exhaust manifold temperatures…"

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<u>Caption</u>: "Sleeve-valve close-up from a Bristol Centaurus Mark 175"

Two Types

"…In general, aero-engines in present production - apart from the in-line variety - have settled down to two highly specialized types; the air-cooled radial and the liquid-cooled V. Each has its own advantages and disadvantages…"
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Pros and Cons

"…The air-cooled radial engine is less vulnerable, is lighter by the weight of the radiator and water system and is easier to overhaul. Although it is suitable for use in cold countries, it has the disadvantage of a large frontal area, high cylinder temperatures with local hot spots and, if it has poppet valves, a hot exhaust valve inadequately cooled. The efficiency is lower and the oil consumption higher than in the liquid-cooled engine. The sleeve-valve radial engine has lessened these disadvantages, but the in-line engine will probably retain its position when the sleeve-valve has been adapted to it…"
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Caption: "THE FOUR BRISTOL JUPITER ENGINES of the Imperial Airways liner *Scylla*. At a height of 5,000-feet these air-cooled radial engines develop a maximum of 600-horsepower each at 2,200 revolutions-a-minute. Each engine is mounted in the font of a metal nacelle which is supported by two vertical tubes, one at the front and one at the back. An oil tank for each engines is contained in the streamline nacelle behind the engine; each tank holds sixteen gallons. The petrol tanks, of which there are three, are in the center section of the upper plane; these tanks feed petrol to the engines by gravity. The total capacity of the petrol tanks is 720 gallons. The *Scylla* has a cruising speed of approximately 105 miles-an-hour at 5,000-feet."

"…Improvements in the air-cooled radial engine are counter-balanced by advantages in the liquid-cooled engine. The improvements in radial engines include the use of high-conductivity alloys for cylinder heads, improved cylinder finning, scientifically designed baffles to control the cooling air flow and more efficient engine cowlings to reduce head resistance…"
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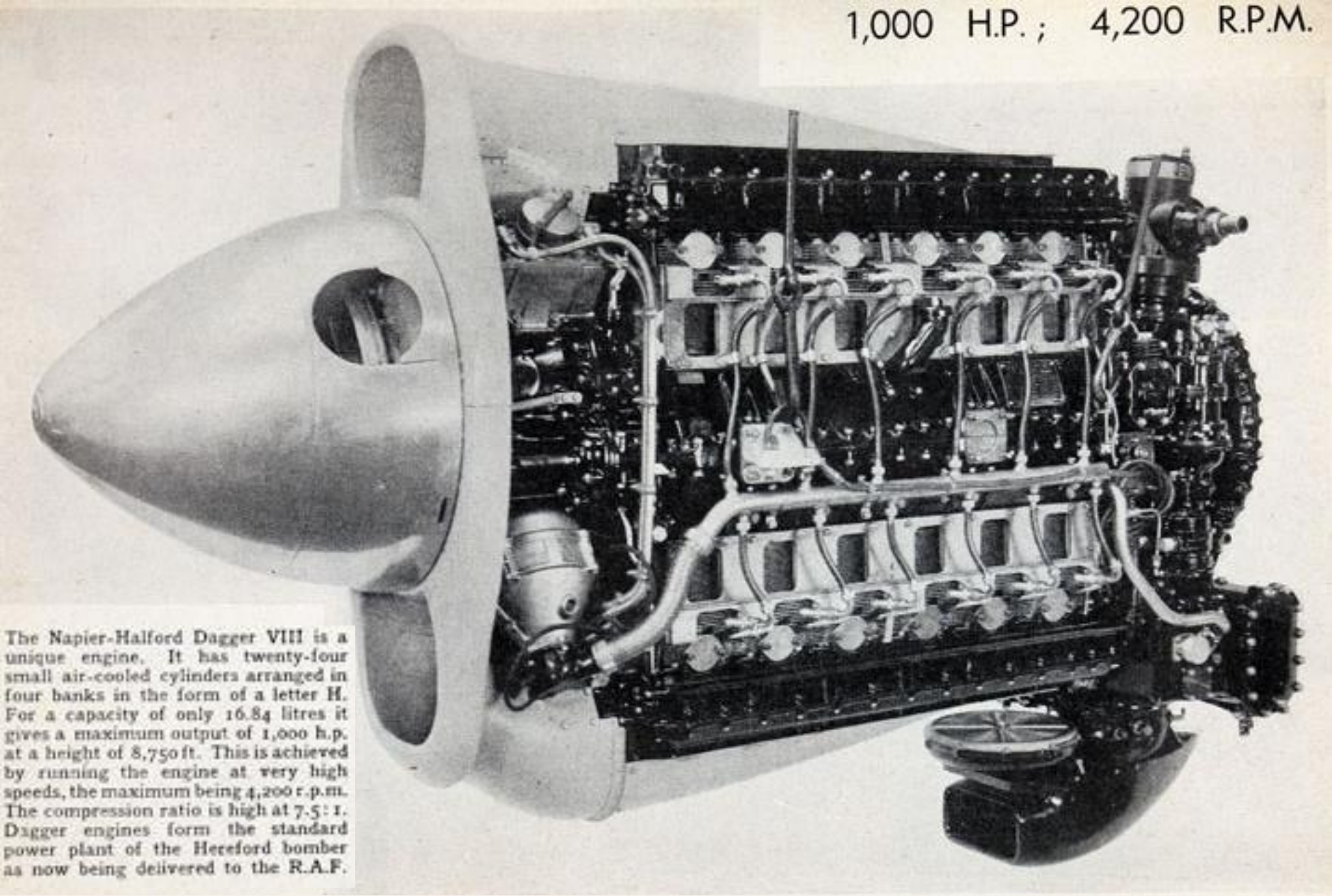
"…The liquid-cooled engine may have the advantage of higher rotational speeds, water-cooling under pressure to maintain a high boiling temperature when flying at high altitudes, or even cooling by liquids of high natural boiling point such as ethylene glycol…"

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"…The present tendency in design is towards higher rotational speeds and exceptional power output from each cylinder. The first requirement demands light reciprocating parts such as pistons, connecting rods and valve gear, the second requirement leads ultimately to small cylinders having an approximately equal bore and stroke of about 3-1/2 to 4-1/2 in. The air-cooled twenty-four cylinder 800-horsepower Napier-Halford Dagger engine is a good example of the above trend…"

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1,000 H.P.; 4,200 R.P.M.



The Napier-Halford Dagger VIII is a unique engine. It has twenty-four small air-cooled cylinders arranged in four banks in the form of a letter H. For a capacity of only 16.84 litres it gives a maximum output of 1,000 h.p. at a height of 8,750 ft. This is achieved by running the engine at very high speeds, the maximum being 4,200 r.p.m. The compression ratio is high at 7.5 : 1. Dagger engines form the standard power plant of the Hereford bomber as now being delivered to the R.A.F.

A Schneider Trophy Example

"…In general, the average power output for a given cylinder capacity is being steadily increased step-by-step. During the period from 1929 to 1933 there has been an overall increase from 18 to about 40 horsepower-per-liter. One particular engine of the high-speed small-cylinder type has completed 100 hours at 47 horsepower-per-liter at a crankshaft speed of 4,000 revolutions-a-minute. The general speed increase has been from about 1,900 to over 3,500 revolutions-a-minute; the corresponding take-off mean effective pressures in the cylinders have been increased from 125 to over 200 lbs. to the square-inch. The weight-per-horsepower has, on the other hand, decreased from 1.8 to 1.2 lbs. and the average period of operation between overhauls has been safely increased from 300 to 600-hours. These figures represent the general and average improvements in performance during the period reviewed. In some instances, these figures have been greatly exceeded for special duty…"

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"…An outstanding example is the Rolls Royce 'R' engine fitted to the seaplane that won the 1931 Schneider Trophy race. This water-cooled twelve-cylinder 60-degree V engine had a bore of 6 in. and a stroke of 6.6 in., with a piston displacement of 36.7 liters. The two banks of cylinders were set at an angle of 60-degrees to each other. The special fuel used consisted of 20 per cent petrol, 70 per cent benzol and 10 per cent methanol, with the addition of 4 cubic-centimeters of tetra-ethyl-lead as an anti-detonant, that is, to prevent knocking…"

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"…The 1929 engine gave 1,900 horsepower at 2,900 rpm and weighed 1,530 lbs. The 1931 engine was run at 2,400 horse-power at 3,200 rpm and weighed 1,630 lbs. This represented a power increase of 26 per cent for a weight increase of 6-1/2 per cent…"

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Caption: "ONE OF THE ITALIAN ENTRIES in the 1929 race, which was won for Great Britain by Flying Officer H.R.D. Waghorn in a Supermarine S.6 at a speed of 328.63 miles-an-hour. The Italian machine illustrated here is a Macchi 67, of which there were two in the race. Both these aircraft had to retire because of engine trouble, but the third Italian entry; an old Macchi 52, gained third position in the race."



Caption: "A TECHNICAL VICTORY for Great Britain in 1931 won the Schneider Trophy permanently for Great Britain. It had been expected that aircraft from France, Italy and the United States would compete, but misfortune prevented this. Flight Lieutenant J.N. Boothman flew round the course in the Supermarine S.6B, illustrated here, at a speed of 340.08 miles-an-hour. The funds for the British machines in 1931 were provided by Lady Houston, after the Government had decided not to compete because of the high cost."

"…The oil and water-cooling systems were remarkably ingenious, virtually the whole surface of the seaplane being used for cooling purposes. The cooling water was passed from the engine cylinder jackets to special radiators within the wings and on the floats; the oil was passed through special coolers on the body and inside the tail fin, where it was sprayed through nozzles on to the inside surface. The oil left the engine at about 140-degrees cent. and, after having cooled, returned at about 80-degrees cent. - a reduction of 60-degrees cent. Pure castor oil was used, the consumption being about 14 gallons-an-hour…"

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The Military Standard

"…As aero-engines used for military purposes have certain points-of-design and auxiliary apparatus peculiar to their specialized use, it will be advantageous to confine this chapter to the outstanding features of engines used in military aeroplanes…"

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"…For civil aircraft the same power units may be used, with many of the chief features retained; but the aircraft operate in easier conditions and use fuels not necessarily of a quality up to the military standard…"

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Fit-for-Purpose

"…The different functions of aeroplanes call for engines of different horsepowers in widely differing conditions. Thus, some aircraft may require average powers for long journeys with great economy of fuel; others will need enormous power for leaving the ground with heavy loads and climbing quickly to operating altitude; others again will be required to travel exceedingly fast at great heights for short periods…"

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Five Classes

"…Five classes of aeroplane duties may be distinguished by speed and cruising range. The maximum speed for single-seater interceptor fighters may be put at 400-450 and that for multi-seater fighters at 400 miles-an-hour. Medium bombers and heavy bombers cruise at 300 and 275 miles-an-hour respectively, naval aeroplanes at 220 miles-an-hour. The cruising range of the five classes is respectively two, two, seven, nine and ten-hours…"

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Four Classes of the Future

"…A well-known authority has expressed the opinion that the engines suitable for performances such as these might be chosen in the near future from a range of four types. These four types would develop respectively 750, 1,150, 1,550 and 2,000-horsepower for a corresponding weight-power ratio of 1.093, 1.087, 1.00 and 1.05 lbs. per-horsepower. Some or all of the above aeroplanes would have more than one engine up to, probably, a maximum of four located in the wings…"

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"…The problems facing an engine designer are complex and detailed consideration requires to be given to the whole aero-dynamic structure for a given duty and performance before the designer can make his choice of the many alternatives open to him…"

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The Aero-Powerplant

"…An aero-powerplant may be said to comprise a cylinder unit, including pistons, connecting rods and crankshaft; a breathing unit, consisting of induction system and carburetor; an auxiliary unit, with drives for supercharger, ignition system, petrol, oil and water pumps and the like; and a drive unit, including the airscrew…"

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Cylinder Unit

"…The cylinder unit comprises the crankcase, cylinders, pistons, connecting rods, main bearings and crankshaft. The chief difference between radial and in-line types lies in the design; the same materials are common to both. In radial engines there are a number of pistons operating on one crankpin. This requires a special connecting rod arrangement known as a master rod, containing the big end bearings and auxiliary rods; these have their bearings located in flanges round the master rod end…"

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"…Air-cooled cylinders are of composite construction; they have a steel barrel and a screwed and shrunk-on light alloy head containing inserted valve seats. In radial engines, the cylinders are necessarily separate. Certain in-line air-cooled engines have a number of cylinder heads attached by bolts to a common casing carrying the overhead camshaft. Special alloys of aluminum, copper and nickel are used for cylinder heads and pistons, the essential properties being good thermal conductivity, low specific weight and, for pistons, high resistance to wear…"

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"…Valves are made of steel containing a percentage of carbon silicon, nickel, chromium, tungsten and manganese. To increase the cooling capacity of poppet valves, metallic sodium is used inside the hollow stem to assist in the transfer of heat from valve head to stem and thence to the valve guide and cylinder head. Sodium has a low melting point of 97.5-degrees cent., a high specific heat and a boiling point of 880-degrees cent. and is the most effective substance for this purpose…"

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Bearing Materials

"…Bearing materials have received much attention from metallurgists and the present practice inclines towards either white metal or lead bronze alloys. Lead-bronze, a comparatively recent development, consists of about 70 per cent copper and 30 per cent lead. It is effective in bearings under high temperatures and pressures. Crankshafts and connecting rods are made in steel of high quality such as 65-ton nickel chrome and a similar steel containing molybdenum suitable for nitrogen hardening…"

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Breathing Unit

"…In the breathing unit are included the induction manifold and carburetor and any special means adopted to deal with the effect of altitude on engine performance. Difficulties of operation at high altitudes are due to the decrease of atmospheric pressure and temperature with height…"

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The I.C.A.N. Standard

"…A standard day is a day during which the atmospheric pressure and temperature at any height conform with agreed standard conditions which approximately represent the average conditions in the Western Hemisphere. Such a standard atmosphere is known as the 'I.C.A.N. Standard,' the initials standing for the International Committee for Aerial Navigation…"

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"…On a standard day the air density at 10,000-feet is only 74 per cent and at 30,000-feet about 37 per cent of that at sea-level. The corresponding temperatures are -5-degrees cent., and -45-degrees cent., respectively. The main effects of these conditions on an engine are twofold…"

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"…The mixture strength as supplied by the carburetor becomes richer with decrease of pressure and the engine power decreases. The effect of reduced air density on the carburation is to reduce the weight of air passing the jet in a given time. The velocity of the air is not appreciably diminished, so that there is approximately the same suction on the jet as before…"

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Mixture Control

"…Relatively the same amount of petrol flows through the jet and the mixture becomes richer in petrol. The tendency of the reduced air temperature is to weaken the mixture strength. The overall effect is an enrichment of mixture strength and this is corrected by a device on the carburetor known as the 'mixture control'…"

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"…The mixture control is operated by a lever in the pilot's cockpit and consists of means for reducing, at will, the fuel flow through the jet. This may be effected either by a variable jet or by a 'pressure balance' system in which a controllable air leak is provided between the carburetor float chamber and the choke tube. This control is sometimes operated by an automatic device controlled by an aneroid capsule which responds to changes of atmospheric pressure…"

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Altitude Effects

"…The effect of reduced air density on the power developed is due to the reduced weight of air inhaled in a given time. The effect of reduced air temperature, on the other hand, tends to increase the power. The overall effect is a decrease of engine power with altitude. This is one of the unsatisfactory features of the normal or naturally aspirated engine…"
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Offsetting the Disadvantage

"…One way of offsetting this disadvantage is to use forced induction or supercharging; a means for supplying a relatively greater weight of air to the cylinders than would normally be inhaled…"

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Three Systems

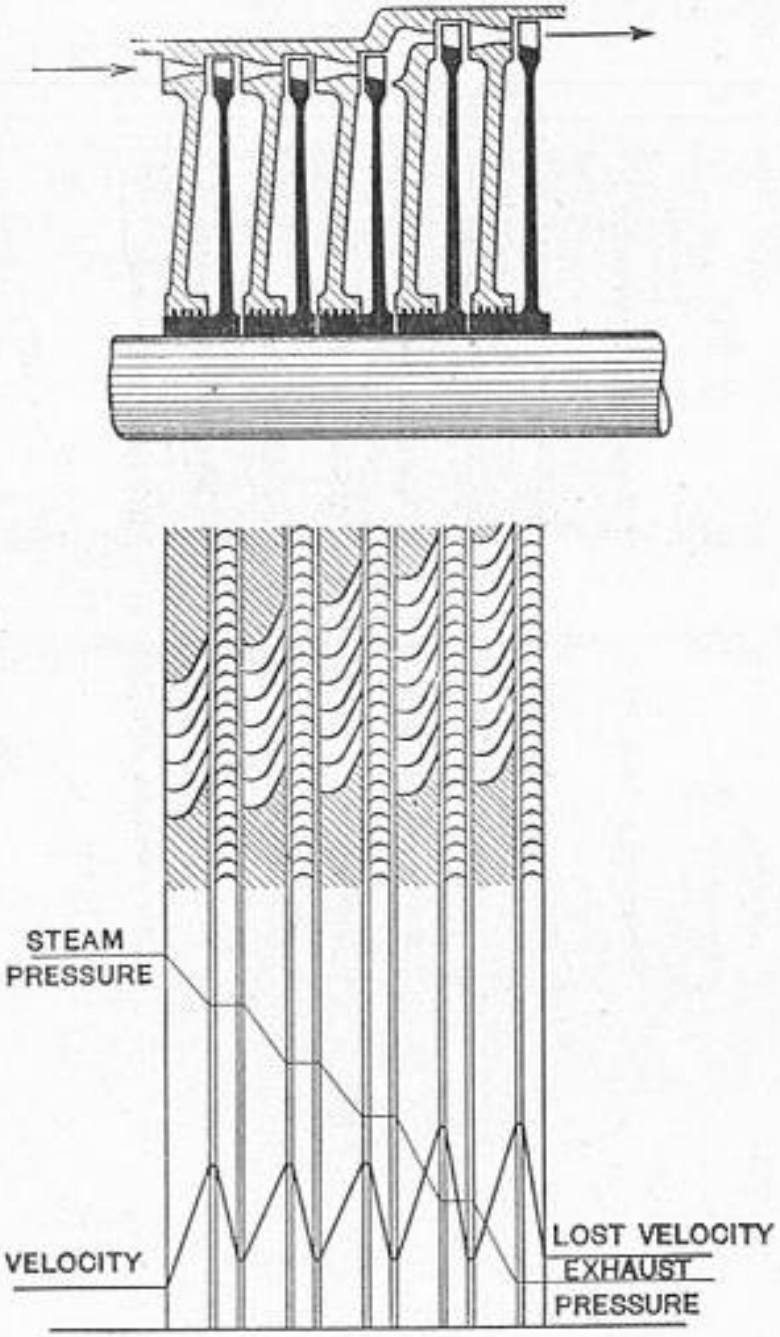
"…Three general systems of supercharging aero-engines have been proposed of which the first two are in practical use. These are the exhaust-driven centrifugal blower, the gear-driven centrifugal blower and the positive-displacement type of blower, gear-driven…"

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Exhaust-Driven Type

"…The exhaust-driven blower was developed during and after the war of 1914-18, but various practical difficulties prevented the success which theoretical considerations had suggested. The exhaust gases from the cylinders are collected in a nozzle box, from which they pass at about 850-degrees cent. through nozzles to a Rateau-type turbine wheel coupled directly to the blower…"

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"…The Rateau turbine is of the single wheel impulse type and was invented by the French scientist Professor Rateau…"

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RE: *Pressure Compounding* is the method in which pressure in a steam turbine is made to drop in a number of stages rather than in a single nozzle. This method of compounding is used in Rateau and Zoelly turbines. The arrangement consists of a number of simple impulse turbines in series mounted on a common shaft. The exit steam from one turbine is made to enter the nozzle of the succeeding turbine. Each of the simple impulse turbines would then be termed a "stage" of the turbine. Each stage comprises its ring of nozzle and blades.

<u>Caption</u>: "Diagram of a Rateau turbine"

"…Efficiencies up to the recent times have been low and large back pressures have been imposed on the exhaust. Modern developments in exhaust turbine driven superchargers have raised the overall efficiencies into the region of 40 to 60 per cent. In theory, an overall efficiency of 25 per cent should suffice for a turbine and compressor unit combined because the energy in the exhaust gases as they leave the engine is some four times that required to maintain sea-level induction pressure in the engine…"

***Wonders of World Aviation*, June 28, 1938**

Gear-Driven Type

"…The gear-driven type of centrifugal fan is the only one that has reached the stage of universal application on engines. The gear ratio is of the order of 10-to-1 and rotational speeds of 15,000-25,000 rpm are common. Although the gear-driven type, in contrast to the exhaust-driven type, absorbs some of the horsepower of the engine it can be used up to 17,000-feet…"

***Wonders of World Aviation,* June 28, 1938**

"…The exhaust-driven blower has the advantage of the equivalent of an infinitely variable speed gear by virtue of its controllable exhaust flow so that at ground level, only the required supercharger speed need be developed by the gases. On the other hand, the gear-driven supercharger necessarily runs at full speed, which entails a large temperature rise in the air, although the air supply is throttled to give the required supercharging pressure…"

***Wonders of World Aviation,* June 28, 1938**

Positive-Displacement Type

"…The positive displacement blower of the Roots or Power-plus type produces its compression by delivering air into a capacity chamber. Blowers of this type have the great advantage that unwanted air may be valved to atmosphere with a corresponding reduction in the power required to drive them…"

***Wonders of World Aviation*, June 28, 1938**

Suction vs. Pressure Carburetion

"…Modern centrifugal superchargers can use a 'suction carburetor' system, so that petrol-air mixture passes through the impeller. Alternatively they may use a 'pressure carburetor' system in which the carburetor choke-tubes are placed in the air supply line between the cylinders and the supercharger. This has an advantage that only air is compressed; a further advantage is that the freezing troubles that may occur in a 'suction carburetor' system can be avoided…"

***Wonders of World Aviation*, June 28, 1938**

Air-Intercooling

"…When large blower compression ratios are involved, however, it becomes desirable to use an air-intercooler between the blower and the carburetor if power loss due to increased air temperature is to be avoided as well…"
***Wonders of World Aviation*, June 28, 1938**

Three Disadvantages

"…Three disadvantages are inherent. First, a pressure carburetor requires to be specially constructed against the fire risk of air and petrol leaks. Secondly, the petrol supply pressure must be maintained at the proper value (generally 2 lbs. or 3 lbs. per square-inch to the float chamber) above the choke-tube pressure in all conditions of flight to ensure the correct continuity of flow. Thirdly, the intimate mixing of fuel and air is less efficient and, therefore, the distribution to the various cylinders tends to be less uniform than in the suction system, in which the fuel and air are well mixed in their passage through the supercharger impeller…"

***Wonders of World Aviation*, June 28, 1938**

Rated Altitude

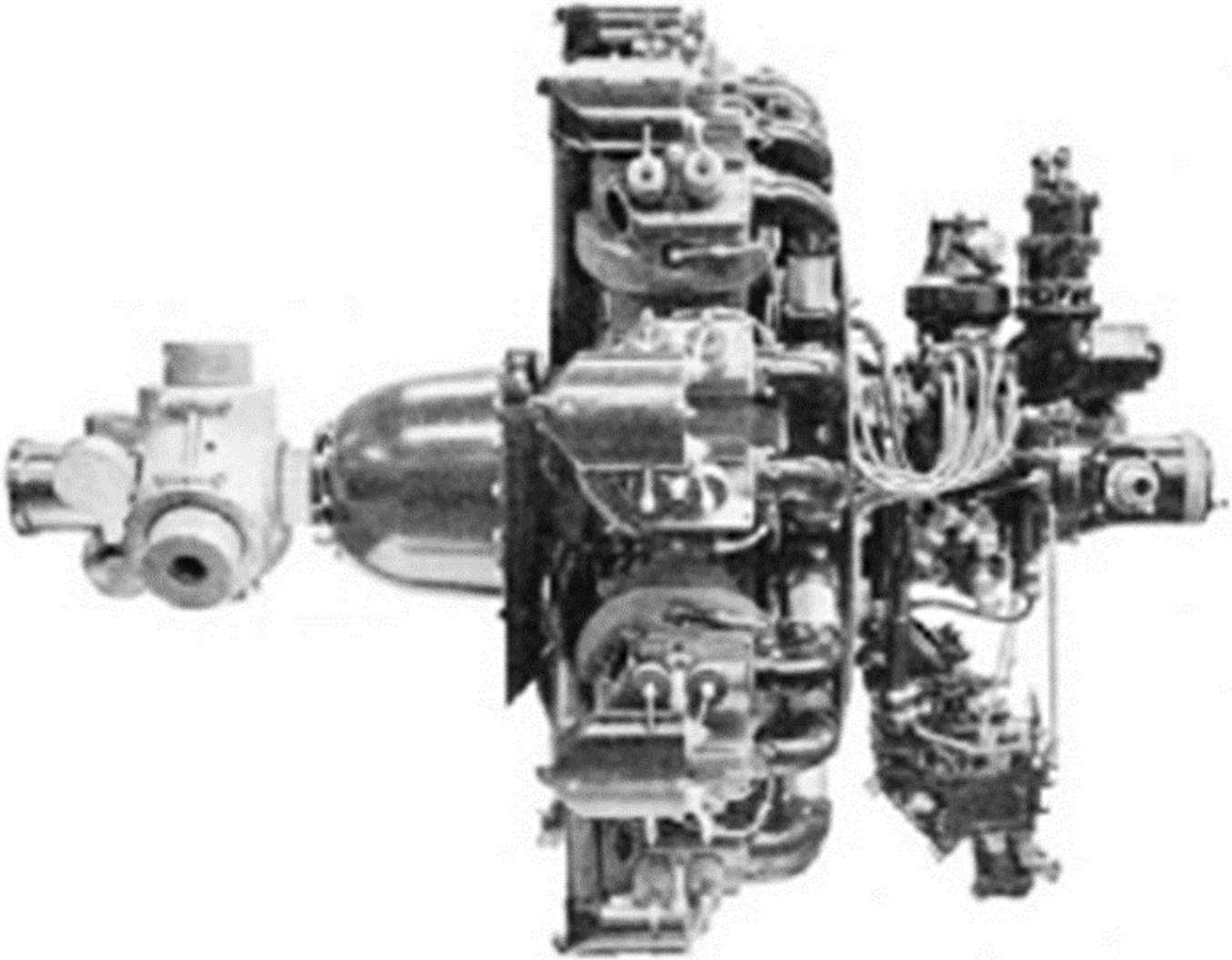
"…For a given rotational speed the height to which a supercharger will maintain the sea-level or other predetermined air-pressure will depend on its compression ratio. The compression ratio of the supercharger is the ratio of the delivery pressure or 'boost-pressure' to the intake-pressure. This decides what is called the 'supercharge height' or 'rated altitude' and is defined as the height in the standard atmosphere to which the engine will maintain the required boost-pressure at its normal rate-of-revolution…"

***Wonders of World Aviation*, June 28, 1938**

Maximum Power Height

"…As there is also a maximum permissible engine speed in level flight which, generally, is never used for more than five minutes, there will be a slightly higher altitude to which the same boost-pressure will be maintained because of the correspondingly higher rotational speed of the supercharger. This is called the 'maximum power height of the engine' and is generally two or three-thousand feet higher than the 'rated altitude'…"

***Wonders of World Aviation*, June 28, 1938**



<u>Caption</u>: “FULL SUPERCHARGING is used on this nine-cylinder air-cooled radial engine. It is a Bristol Mercury VIII designed for high-altitude flying and intended primarily for fighters and light bombers. The maximum horsepower is 840 at 2,750 revolutions-a-minute at 14,000-feet. The capacity is nearly twenty-five liters.”

Fuel Consumption

"…In the matter of fuel consumption, it is well known that the mixture strength ratios that can be used in single-cylinder tests vary from about 15 per cent rich for maximum power to 15 per cent weak for maximum economy. In a multi-cylinder engine the average ratio is not much weaker than the correct one and for maximum power some greater enrichment than 15 per cent is generally necessary to lessen the dangers of overheating the cylinders…"

***Wonders of World Aviation*, June 28, 1938**

"…In general the fuel consumption for naturally aspirated and supercharged engines varies from 0.475 to 0.6 lbs. per-brake-horsepower per-hour, depending on the conditions of operation…"

***Wonders of World Aviation,* June 28, 1938**

"…As the fuel economy of an engine for a given power output is improved by increasing the expansion ratio, this implies an increased compression ratio. To get much more power from this engine it becomes necessary to burn a greater weight of air in the same time and it has been shown how this is done by supercharging…"

***Wonders of World Aviation,* June 28, 1938**

Detonation vs. Pre-ignition

"…With certain grades of petrol, however, there are limits to the amount of supercharging that can be used, because of the high temperatures reached at the end of compression in the cylinder. This leads to the charge detonating rather than to steady combustion and gives rise to the characteristic knocking sound associated with the condition…"

***Wonders of World Aviation,* June 28, 1938**

"…Detonation or knocking has been defined as 'a noise caused by a blow delivered against the cylinder wall by a wave of high-pressure travelling at great speed through the gas.' Pre-ignition, on the other hand, is caused by firing of the mixture before the spark has occurred. These phenomena are quite distinct from each other, pre-ignition occurring before the spark and detonation after the spark has passed. Detonation is extremely harmful to engines as it leads to very high cylinder temperatures with consequent damage to valves and piston…"

***Wonders of World Aviation,* June 28, 1938**

Development of Special Fuels

"…In order to take full advantage of high compression ratios without detriment to the engine, it is necessary to use fuels having what is known as 'high anti-knock' properties. The development of such fuels has become a matter of some urgency in the effort to keep pace with the great advances in engine performance…"

***Wonders of World Aviation*, June 28, 1938**

"…Two pure hydrocarbons, differing only in their chemical structure, are used at present as a scale-of-degree of detonation or anti-knock value. They are called heptane and iso-octane; heptane knocks worse, iso-octane knocks less, than any known petrol…"

***Wonders of World Aviation*, June 28, 1938**

"…In general, the anti-knock value of any fuel is obtained from its performances in a special test engine and is defined in terms of the percentage of octane in a special blend of heptane and octane giving the same degree of detonation. This percentage is called the 'octane number' for the fuel. No definite relationship can be stated between the octane number of a fuel and its permissible compression ratio: this depends entirely on the cylinder design…"

***Wonders of World Aviation,* June 28, 1938**

"…As a dope for treating existing fuels to reduce or accelerate the rate of burning, which is a contributing factor in detonation, there are tetra-ethyl-lead used as an anti-knocking agent in petrol engines and amyl-nitrate, which can be used as an accelerating agent if required in compression-ignition engines. Another useful anti-detonant is water, which can be introduced into the cylinder by special means and has proved most effective…"

***Wonders of World Aviation,* June 28, 1938**

Auxiliary Units

"…The auxiliary units must now be described…"
***Wonders of World Aviation*, June 28, 1938**

"…The present practice is to situate all the engine auxiliary units at the rear of the engine, grouped round the supercharger and carburetor. Here are found the magnetos in duplicate, the automatic mixture control and the automatic boost-control, which saves the pilot the trouble of continually moving his throttle lever to keep the boost-pressure constant. An aneroid capsule and mechanism provide the necessary relay control and the carburetor butterfly throttle is actuated by an oil or air-servo piston and linkage…"

***Wonders of World Aviation*, June 28, 1938**

"…Other auxiliaries are the petrol, water and oil pumps, all of specialized type and construction and a number of other pumps such as hydraulic units to actuate the retractable undercarriages, air pumps to operate simultaneously blind flying instruments and a certain type of wing de-icing device known as the Goodrich de-icer…"

***Wonders of World Aviation,* June 28, 1938**

"…Another engine-driven auxiliary is an electrical generator of 500 or 1,000-watts output to charge the battery and supply power for radio communication and, up to the introduction of cabin aeroplanes, the electrically heated clothing worn by the crew…"

***Wonders of World Aviation*, June 28, 1938**

"…Not the least of the auxiliaries is the engine-starting mechanism. This may be electrically or manually operated. The electrical types comprise suitable starting motors of adequate power run off the starting battery; in the inertia type a small flywheel is spun-up to a high speed and clutched in to the engine crankshaft to provide the necessary turning energy…"
***Wonders of World Aviation,* June 28, 1938**

"…Another method is gas starting, where combustible mixture is pumped by a small engine into the cylinders, where it is fired by a hand-operated starting magneto…"
***Wonders of World Aviation*, June 28, 1938**

"…There is also an effective cartridge starter now in general use. This starter fires a cartridge in a breech and the expanding gases operate a piston mounted on a quick-pitch thread. The axial motion of the piston provides rotary motion of a starting dog in engagement with the crankshaft. This is a successful and convenient method of starting large engines and will, no doubt, be in great demand for the much larger types of the future…"

***Wonders of World Aviation,* June 28, 1938**

The Drive Unit

"…Finally, the drive unit must be considered…"
***Wonders of World Aviation,* June 28, 1938**

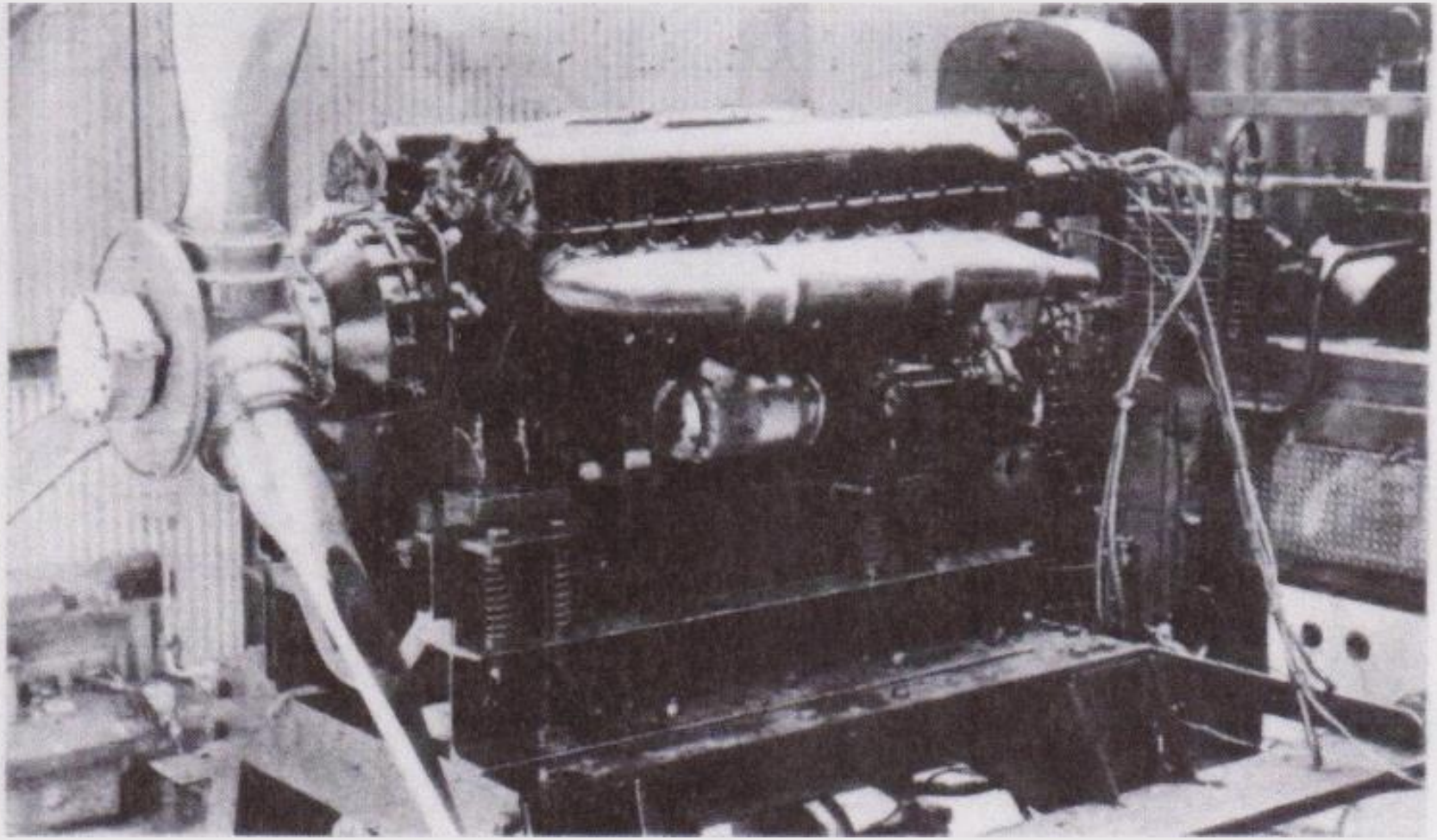
"…The reduction gear units are generally of two types - the straight spur gear and the concentric type. The concentric type permits the driving and driven shafts to be co-axial and involves a stationary gear member giving a torque reaction on the casing. The airscrew shafts are more or less standardized to take the various types of airscrew having either taper or parallel splined hubs. The wooden fixed pitch airscrew is now being replaced by the all-metal variable-pitch type having usually three blades at 120-degrees…"

***Wonders of World Aviation,* June 28, 1938**

"…Well-known British variable pitch airscrews are the De Havilland Hamilton two-pitch and constant speed infinitely variable-pitch, hydraulically operated by a governor and oil pump unit or by oil supply from the engines; the Hele-Shaw-Rotol hydraulically operated constant speed airscrew; and the Curtis-Rotol, which has an electrically operated variable-pitch mechanism…"

***Wonders of World Aviation,* June 28, 1938**

RE: the *Rotol* airscrew was the modern development of the Gloster-Hele-Shaw-Beecham unit originally designed by Dr. Hele-Shaw, developed by the Gloster Aircraft Company and test flown in various airplanes. This early British airscrew anticipated the demand for constant-speed control. The first models, which were arranged either for hydraulic or electric operation, had welded hollow steel or forged aluminum alloy blades, however, the constant-speed and fully feathering hydraulic models could be fitted with wooden blades.



Caption: “An experimental Merlin II engine on test with Rotol Airscrew. The exhaust manifold fitted is not standard and the airscrew is without its spinner.”

"…These airscrews enable high engine speeds to be used for take-off and permit more uniform engine operation throughout all the flight conditions. The control of the variable pitch mechanism will eventually be fully automatic and the various settings at which different constant engine speeds are required will be decided merely by the position of the pilot's throttle lever, ranging from full power to economical cruising…"

***Wonders of World Aviation,* June 28, 1938**

Aerodynamics

"…The aerodynamic qualities of aeroplanes steadily improve as a result of the vast amount of research work now proceeding in most countries. Theoretical considerations serve to indicate the limits of performance which - in the absence of some appropriate invention or aerodynamic discovery - will be reached within the next few years…"

***Wonders of World Aviation,* June 28, 1938**

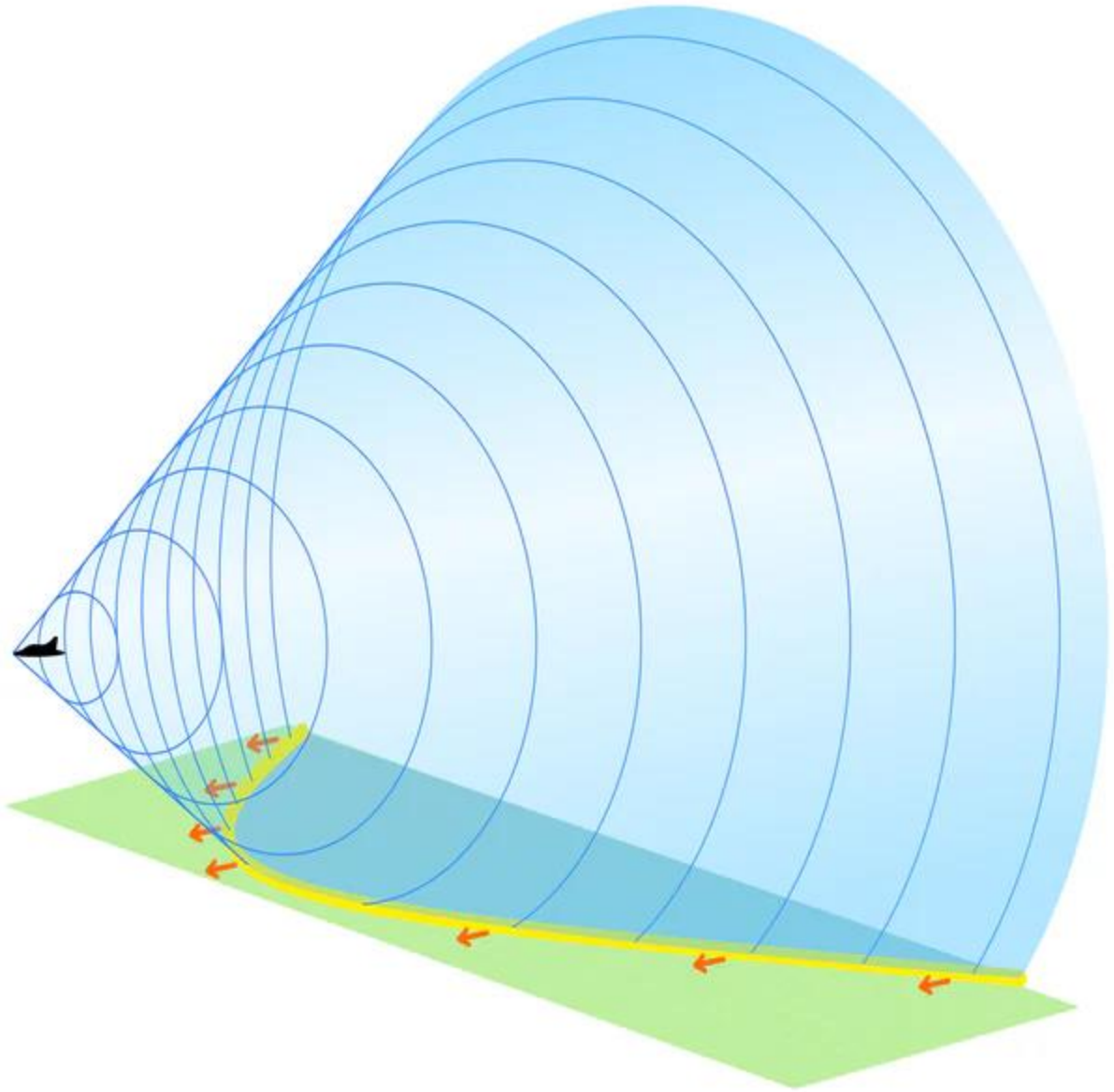
"…For example, airscrew efficiencies are seriously affected by blade tip speeds approaching the speed of sound in air, approximately 1,120-feet-per-second. Therefore, much ingenuity is exercised to provide airscrew designs for the required purpose without approaching too closely this limit of speed. A speed of 900-feet per-second is seldom exceeded…"
***Wonders of World Aviation,* June 28, 1938**

"…Similarly, the maximum speed of flight will soon approach the same limit at which compressibility effects of the air become operative. This means that the resistance to motion, or air drag, of the aeroplane becomes exceedingly large and enormous engine powers would be necessary to propel the aeroplane at such speeds."

***Wonders of World Aviation,* June 28, 1938**

RE: breaking the sound barrier was one of the most significant milestones in aviation history. When *Chuck Yeager* piloted the Bell X-1 to surpass Mach 1 in 1947, it marked the moment when mankind first conquered the limits of air-speed. When an aircraft approaches the speed-of-sound, typically around 767 mph at sea-level (a/k/a "Mach 1), it encounters a series of aerodynamic effects, including increased drag, turbulence and shock waves. These forces make it difficult to accelerate through Mach 1. The most critical event that occurs when an aircraft breaks the sound barrier is the formation of shock waves. At subsonic speeds, sound waves generated by the aircraft's movement travel ahead of the aircraft in all directions. However, as the plane approaches the speed of sound, it begins to compress the air in front of it, creating pressure waves that stack-up and form a single, intense shock wave.

These shock waves create sudden changes in air-pressure, temperature and density and they have a profound effect on the aircraft's performance. The plane essentially pushes through the build-up of these waves and once it surpasses Mach 1, it's flying faster than the pressure waves can propagate. This is when the plane has officially "broken the sound barrier." One of the most well-known effects of breaking the sound barrier is the "sonic boom." When an aircraft flies faster than the speed of sound it generates shock waves that propagate outward from the plane in a cone-shaped pattern. These shock waves reach the ground, where they are perceived as a sudden, loud boom.



This sonic boom is not a one-time event; it continues as long as the aircraft remains supersonic. It's the result of the compressed-air pressure that builds-up along the plane's flight path being released in a sharp, thunderous sound when it reaches listeners on the ground. The boom can be startling and, in some cases, even cause structural damage, which is why civilian aircraft are typically prohibited from flying at supersonic speeds over populated areas.



Part 5

Propulsion

Practical Solutions

Practical solutions of varied problems of propulsion
***Wonders of World Aviation,* May 31, 1938**
RE: introduction to an article entitled: “Airscrews and Their Design”

The Airscrew

"ONE of the most interesting parts of an aeroplane is the airscrew, the mechanism which converts the engine energy into the work which has to be done to drive the aeroplane against the air resistance due to its motion. An airscrew derives its thrust, or driving force, from the reaction of the air which it pushes backwards…"

***Wonders of World Aviation,* May 31, 1938**

RE: an aircraft propeller, a/k/a "airscrew," converts rotary motion from an engine or other power source into a swirling slipstream which pushes the propeller forwards or backwards. It comprises a rotating power-driven hub, to which are attached several radial airfoil-section blades such that the whole assembly rotates about a longitudinal axis. The blade pitch may be fixed, manually variable to a few set positions or of the automatically variable "constant-speed" type. The propeller attaches to the power source's driveshaft either directly or through reduction gearing. Propellers can be made from wood, metal or composite materials. Propellers are only useful at sub-sonic airspeeds; generally below about 480 mph.

"…The blades of an airscrew revolving at high-speed form what is known as an 'airscrew disk.' In operation, there is a suction over the front surface of the airscrew disk and a pressure over the back surface. As the airscrew moves forward the suction at the front draws air towards the airscrew so that the quantity of air flowing through the airscrew disk is greater than the quantity which would flow through a circular ring of the same diameter as the airscrew and moving forward with the same speed…"

***Wonders of World Aviation,* May 31, 1938**

RE: disk-loading is the average pressure change across an actuator disk, such as an airscrew. Airscrews with a relatively low disk-loading are typically called rotors, including helicopter main rotors and tail rotors; propellers typically have a higher disk-loading than rotors.

"…The pressure at the back gives additional energy to the air passing through the airscrew and as this energy eventually appears as energy of motion, the air sucked into the airscrew increases in speed as it flows through the disk…"
***Wonders of World Aviation,* May 31, 1938**

"…Efficiency is measured by the ratio of the rate of useful work done to the rate at which energy is supplied. High-efficiency can be obtained only when the speed at which air is sucked into the airscrew is small compared with its forward speed…"

***Wonders of World Aviation,* May 31, 1938**

RE: in reciprocating and propeller engines, disk-loading is defined as the ratio between propeller-induced velocity and freestream velocity. Lower disk-loading will increase efficiency, so it is generally desirable to have larger propellers, from an efficiency POV. Maximum efficiency is reduced as disk-loading is increased due to the rotating slipstream; using contra-rotating propellers can alleviate this problem, allowing high maximum efficiency even at relatively high disk-loading.





Aircraft equipped with contra-rotating propellers (a/k/a counter-rotating propellers) apply the maximum power of, typically, a single engine piston-powered or turboprop engine to drive a pair of co-axial propellers in contra-rotation. Two propellers are arranged one behind the other and power is transferred from the engine via a planetary gear or spur gear transmission.

Left: caption: "Contra-rotating propellers of a Spitfire Mk.XIX"

Right: caption: "Contra-rotating propellers on the R-R Griffon-powered P-51XR Mustang *Precious Metal* at the 2014 Reno Air Races

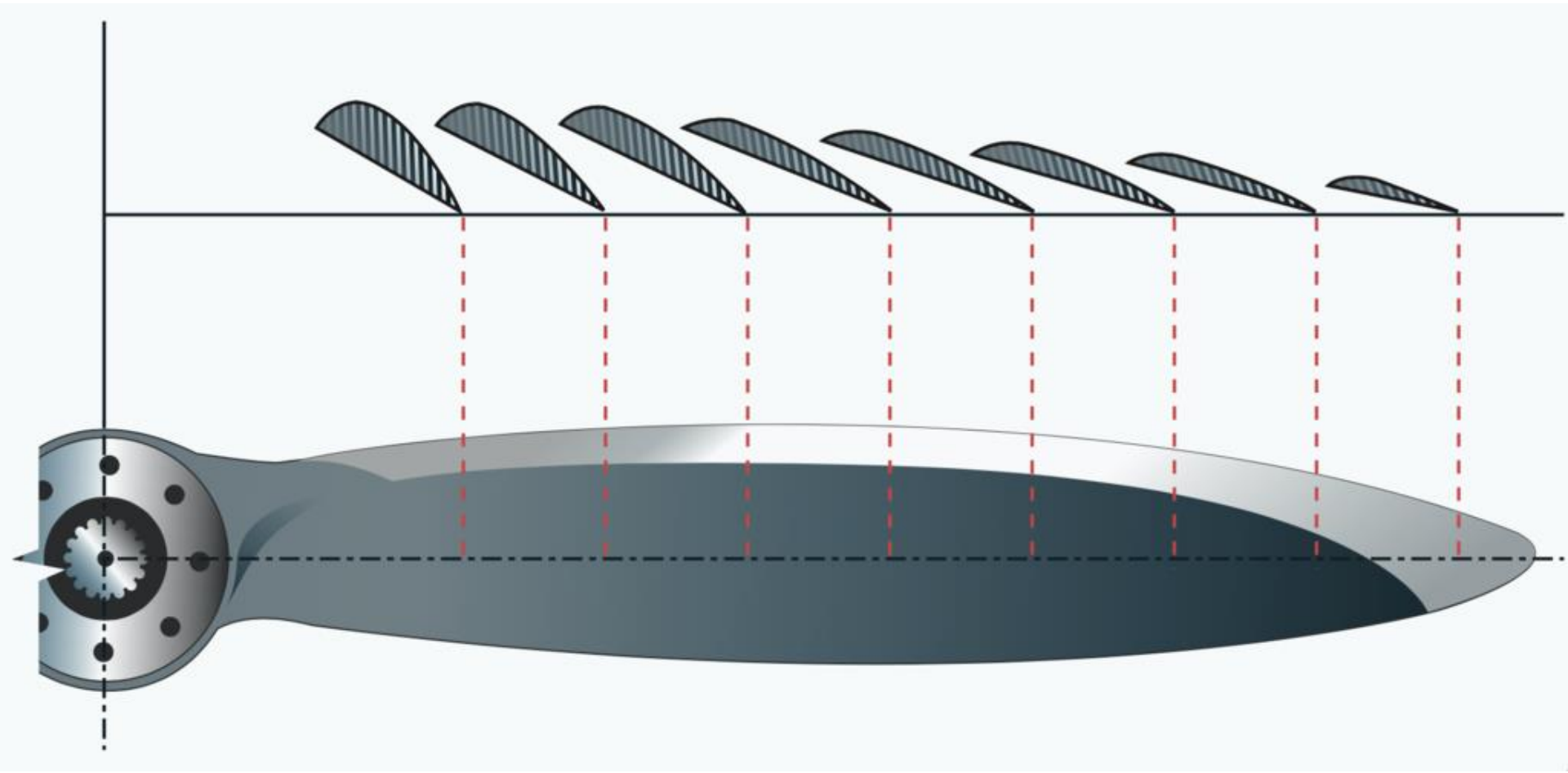
"…For a given forward speed, a given thrust is most efficiently developed when the largest possible quantity of air flows through the airscrew. It is therefore advantageous to make the diameter of an airscrew as large as possible; but, in practice, considerations of weight, strength and ground clearance impose limits on the maximum diameter that can be used…"

***Wonders of World Aviation,* May 31, 1938**

"…The blades of an airscrew have, except near their roots, good aerofoil forms. The blades resemble twisted aerofoils, both the angle of twist and the blade thickness decreasing from the root outwards…"

***Wonders of World Aviation,* May 31, 1938**

RE: the tip of a propeller blade travels faster than the hub. Therefore, it is necessary for the blade to be twisted so as to decrease the angle-of-attack of the blade gradually and, therefore, produce uniform lift from the hub to the tip.



The greatest angle-of-incidence, or the highest pitch, is at the hub while the smallest angle-of-incidence or smallest pitch is at the tip. A propeller blade designed with the same angle of incidence throughout its entire length would be inefficient because as airspeed increases in flight, the portion near the hub would have a negative angle-of-attack while the blade tip would be stalled.

<u>Caption</u>: "Changes in propeller blade angle from hub-to-tip"

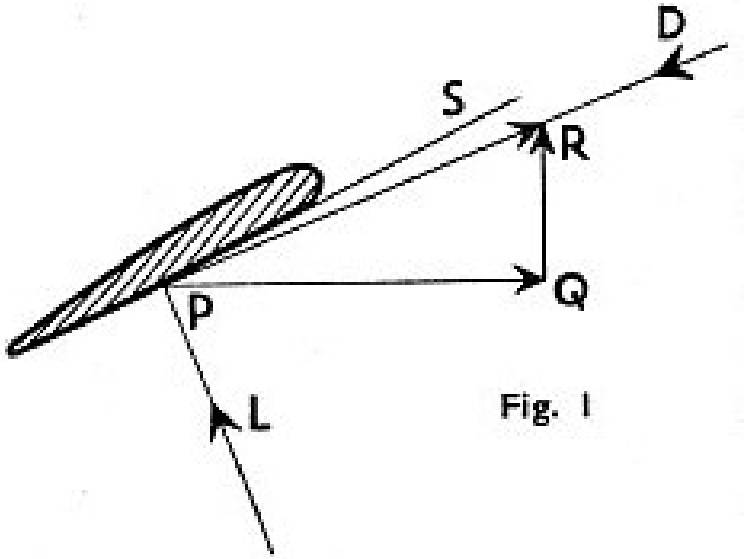


Fig. 1

"…The manner in which the blades work can best be illustrated by considering what is happening on an element, a thin section of the blade, contained between two planes at right angles to the length of the blade. Such an element is represented in Fig. 1…"

***Wonders of World Aviation,* May 31, 1938**

<u>Caption</u>: "FIG. 1. HOW THE BLADES WORK can best be shown by a diagram of what happens to a section, or element, of an airscrew. The aerofoil in the diagram represents the section of a blade contained between two planes at right angles to the length of the blade. Because of the rotation about the airscrew axis, the element moves in the direction PQ. The element also has a forward velocity QR, so that the effective velocity is PR. In this position the element acts as an aerofoil, the angle of incidence being SPR. This gives a lifting force and a drag D."

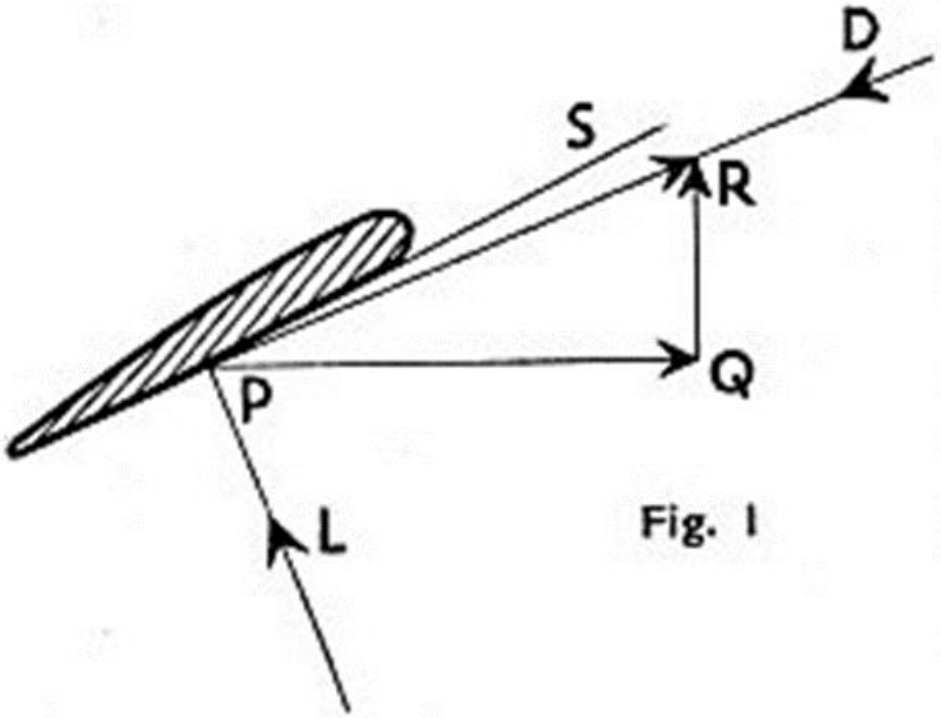


Fig. 1

"…Because of the rotation about the airscrew axis, the element moves in the direction PQ with a velocity which can be represented by the length of PQ. But the element moves forward with the aeroplane and also sucks in air, so that, in addition to the rotational velocity, there is an axial velocity which can be represented by the line QR. The sum of these two velocities PQ and QR is the velocity PR…"

***Wonders of World Aviation*, May 31, 1938**

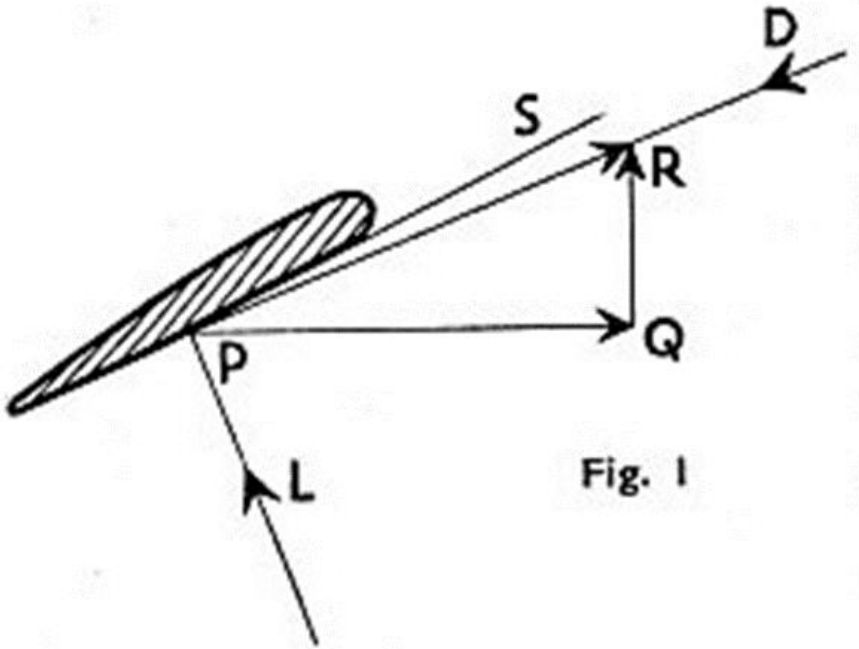


Fig. 1

"…The element behaves, therefore, as if it were an aerofoil, or an aeroplane wing, inclined at an angle SPR, called the angle-of-incidence, to the local air and moving through the air with a velocity PR. When a blade section has a good aerofoil shape and moves through the air at a small angle of incidence, it has a large lifting force at right angles to a direction of motion at the expense of the small resistance, or 'drag,' as it is commonly called, opposing the motion…"

***Wonders of World Aviation*, May 31, 1938**

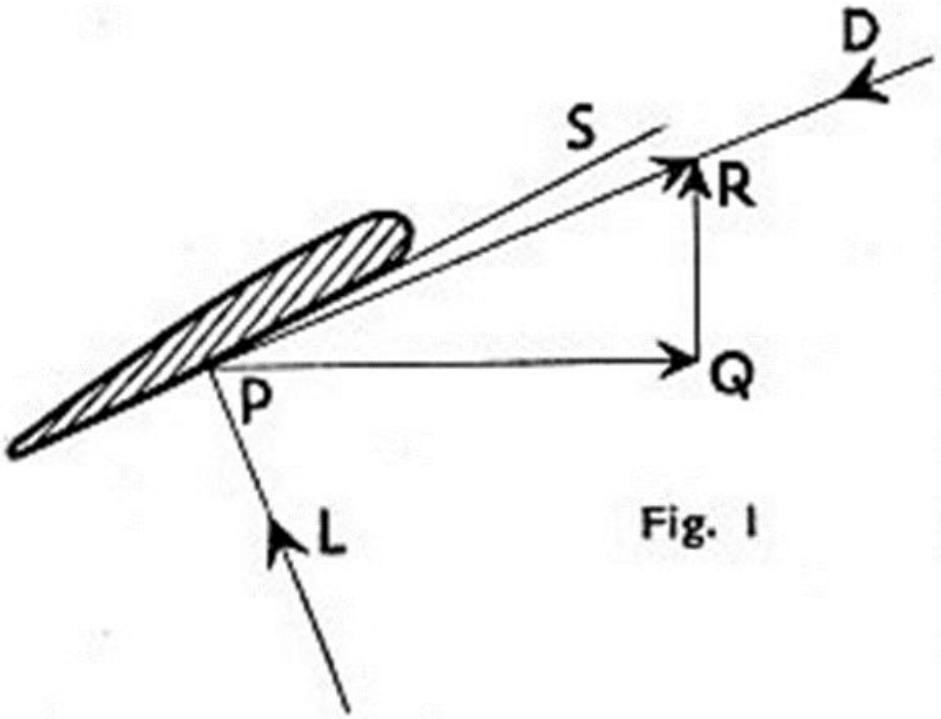


Fig. 1

"…A large lift force, L in Fig. 1, therefore acts on the element in a direction at right angles to PR, and a small drag force D in the direction RP. The resultant of these two forces, obtained by the parallelogram of forces, can be resolved into a thrust force acting in the direction of a forward motion QR, and a resisting force in the direction QP opposing the rota-tion of the element…"

***Wonders of World Aviation*, May 31, 1938**

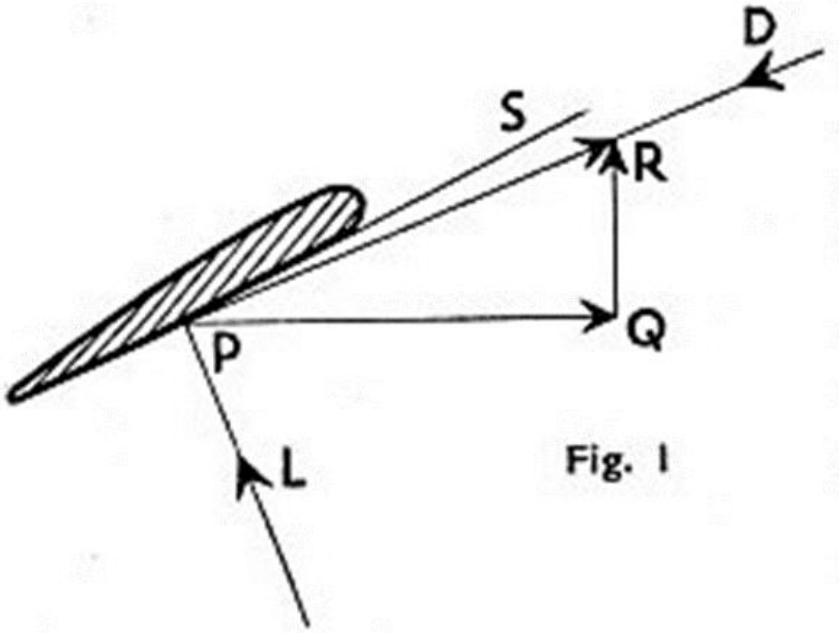


Fig. 1

"…The sum of the thrust forces acting on the blades gives the thrust of the airscrew; and the torque, or turning moment, which the engine must supply to drive the airscrew, depends on the magnitude of the resisting forces. High efficiency is possible only when the elements of the blade are working at angles of incidence (SPR in Fig. 1) which give high values of the ratio of the lift force L to the drag force D. The rotational velocity PQ increases with the distance of the element from the axis of rotation, so that the angle RPQ decreases with this distance and the angle SPQ, known as the 'blade angle,' must also decrease outwards…"

***Wonders of World Aviation*, May 31, 1938**

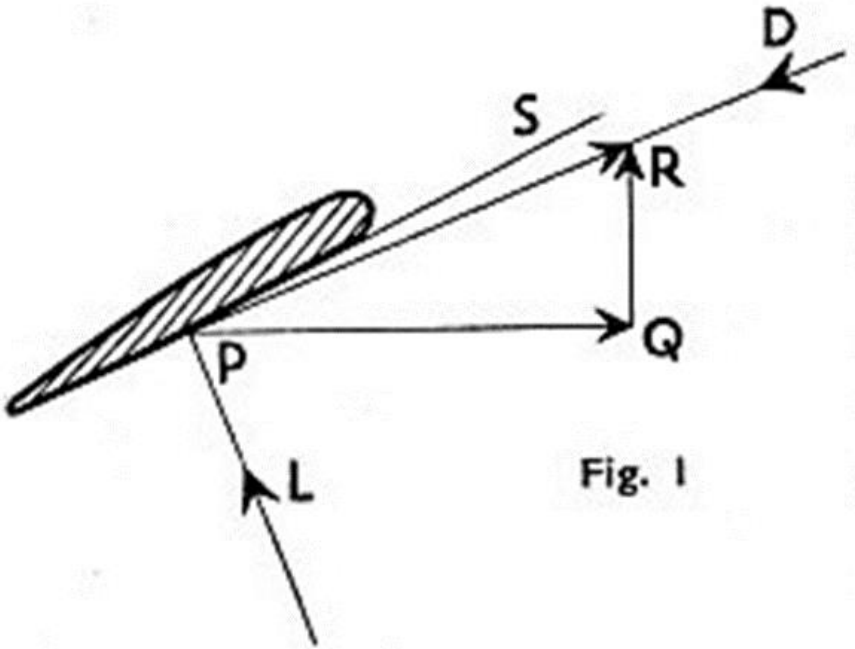


Fig. 1

"…The efficiency of an airscrew with fixed blade angles depends on the ratio of its forward speed to its rotational speed, for the angle RPQ changes with this ratio and so the angle of incidence SPR and the ratio of the lift to the drag force change also. An airscrew is generally designed to have its maximum efficiency at, or near, the normal cruising speed of the aeroplane. The maximum efficiency of a good airscrew is ab-out 85 to 90 per cent…"

***Wonders of World Aviation*, May 31, 1938**

"…The thrust of an airscrew depends not only on its efficiency but also on the horsepower input from the engine. Horsepower depends on the product of the rotational speed and the torque and, for a given throttle position, the torque of an aircraft engine is almost independent of the rotational speed…"

***Wonders of World Aviation,* May 31, 1938**

"…On the other hand, the torque of an airscrew varies with the air density, the square of the rotational speed and a number, known as the 'torque coefficient,' which depends on the working conditions and on the type of airscrew…"
***Wonders of World Aviation*, May 31, 1938**

"…For a fixed-pitch airscrew, this coefficient increases as the aeroplane speed decreases, so that the rotational speed falls, as the resisting airscrew torque must always be equal to the driving engine torque. The fall in the rotational speed means that less horsepower is supplied by the engine. The speed of an aeroplane when taking-off is low and it is then that as much power as possible is needed, especially with modern heavily loaded aeroplanes…"

***Wonders of World Aviation,* May 31, 1938**

"…The falling-off of power as the forward speed decreases can be overcome by the use of controllable-pitch blades, the pitch being adjusted to suit the flight conditions…"
***Wonders of World Aviation,* May 31, 1938**

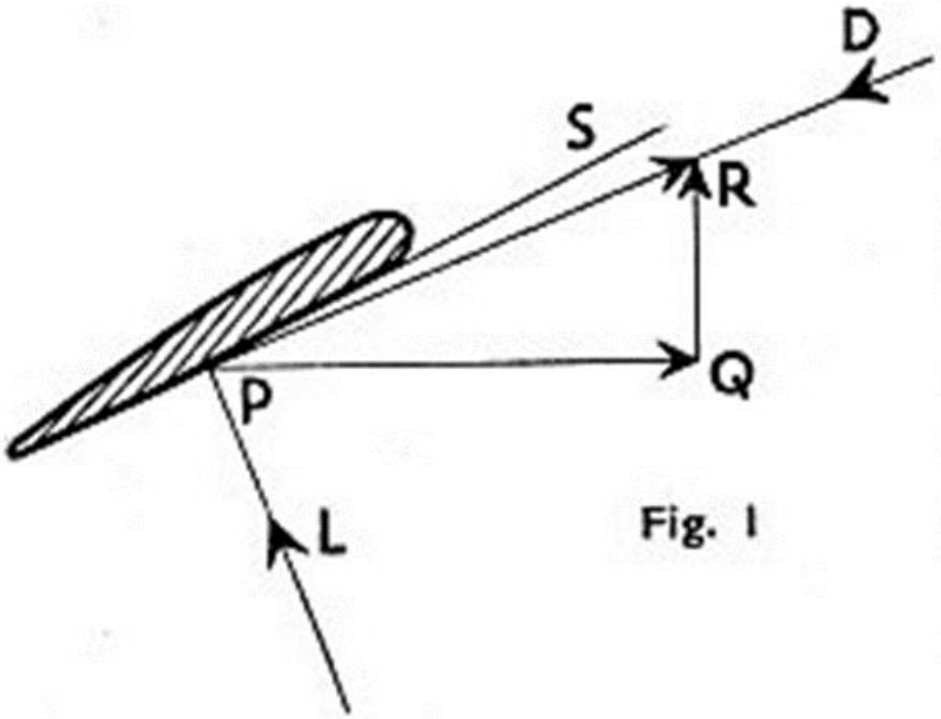


Fig. 1

"…It can be seen from Fig. 1 that, as the forward speed falls, the velocity component QR becomes smaller and the angle of incidence SPR becomes greater. If the pitch of the blades is not altered, the blades eventually stall, that is, the lift falls and the drag increases considerably, so that there is a sacrifice of thrust, an increase in torque, a slowing-up of the engine and a falling-off in engine horsepower…"

***Wonders of World Aviation,* May 31, 1938**

Control of Pitch

"…If the airscrew is fitted with a device which reduces the pitch angle, the blades can be set at efficient angles of incidence, the falling-off of engine power can be prevented and a much larger thrust can be developed at speeds of take-off and climb. Such a device is well exemplified in the Hamilton controllable-pitch airscrew, for this airscrew combines in one unit efficient take-off and climb performances with a high cruising speed…"

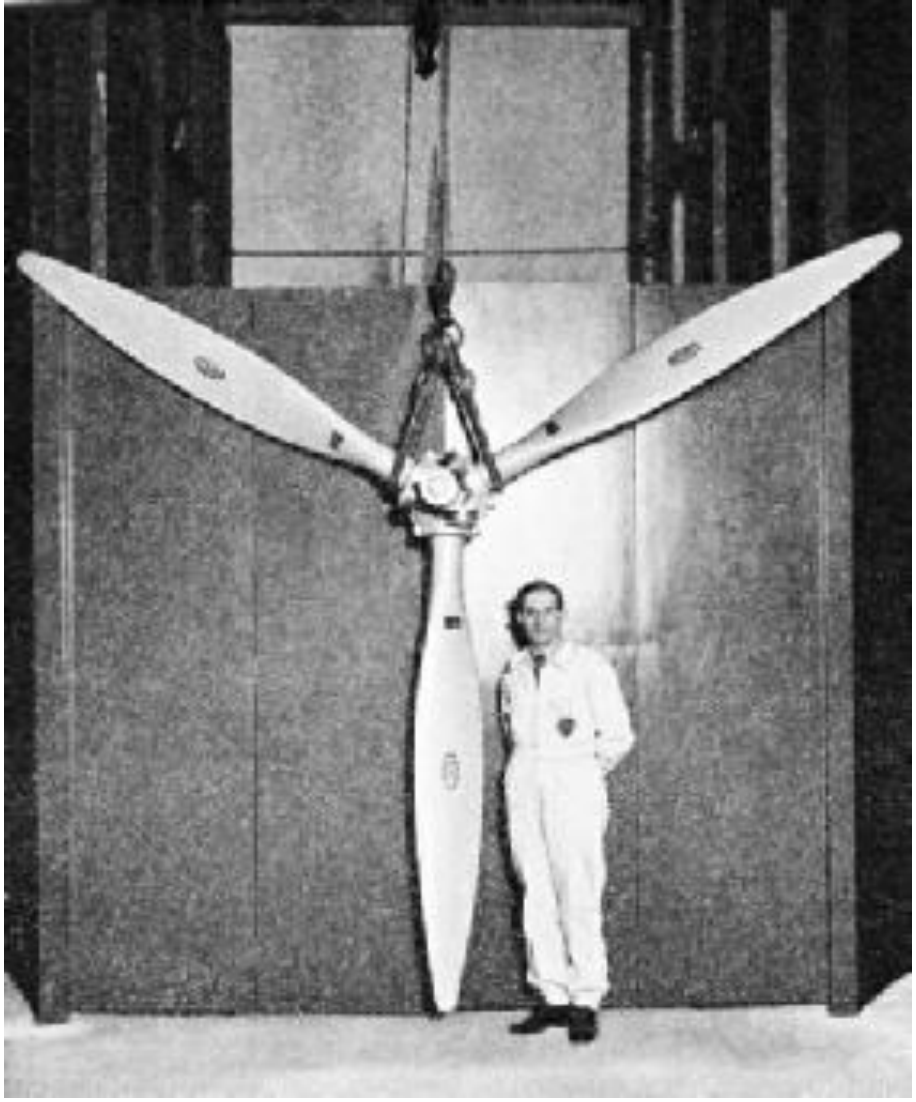
***Wonders of World Aviation,* May 31, 1938**

RE: early pitch control settings were pilot operated; either with a small number of preset positions or continuously variable

"…Controllable-pitch airscrews, in sizes covering a power range from about 130-horsepower to that of the largest aero-engine, are made by the De Havilland Aircraft Co, Ltd., under the Hamilton patents. These airscrews are designed for constant-speed operation with automatic pitch variation subject to a master control; but on engines which are not adapted to take the controlling constant-speed governor, a control is fitted which gives the choice of two pitch positions - fine, for take-off and climb; coarse, for high-speed cruising…"

***Wonders of World Aviation,* May 31, 1938**

RE: the most common variable-pitch propeller is the constant-speed propeller. This is controlled by a hydraulic *Constant Speed Unit* (CSU). It automatically adjusts the blade pitch in order to maintain a constant engine speed for any given power control setting. By 1932-33, a propeller who's pitch could be controlled by the pilot in flight was being manufactured by Hamilton Standard and being fitted to some airplanes. For this propeller, Hamilton Standard won the 1933 Collier trophy.

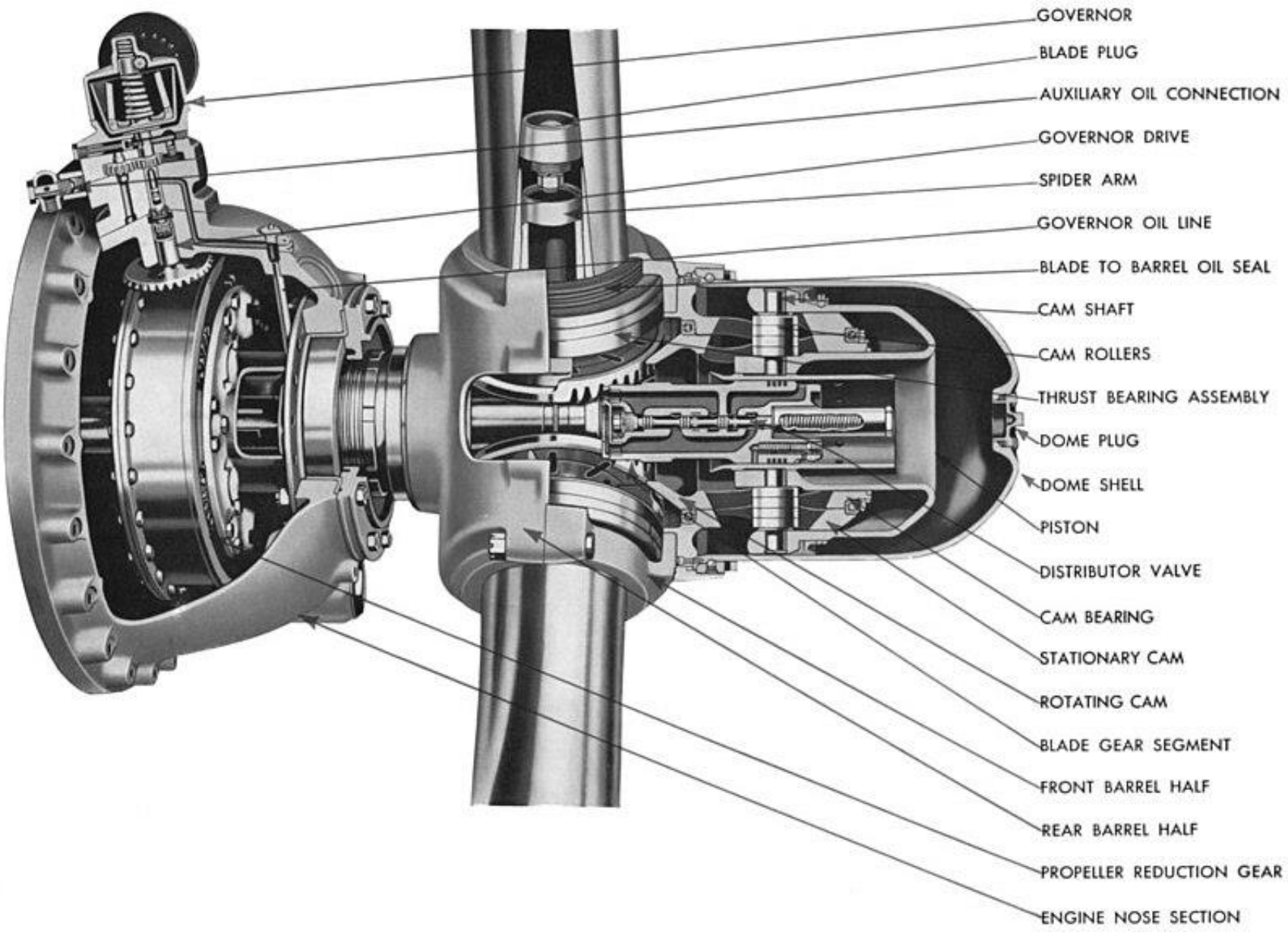


<u>Caption</u>: “CONTROLLABLE-PITCH AIRSCREW manufactured by the De Havilland Aircraft Co. Ltd, under the Hamilton patents. This three-bladed airscrew is designed for an aero-engine of 1,009-horsepower. It has a diameter of 13-feet and weighs 360 lbs. The pitch of the blades can be altered as required for take-off, climb or high-speed level flight.

"…Engine oil-pressure is used to move the blades into fine pitch and centrifugal forces acting on counterweights attached to the blade roots return the blades to coarse pitch when the oil-pressure is released. Pitch limits, from 9 to 20-degrees, may be independently set…"

***Wonders of World Aviation,* May 31, 1938**

RE: constant-speed propellers allow the pilot to set a rotational speed according to the need for maximum engine power or maximum efficiency and a propeller governor acts as a closed-loop controller to vary propeller pitch angle as required to maintain the selected engine speed. In most aircraft this system is hydraulic, with engine oil serving as the hydraulic fluid. However, electrically controlled propellers were developed during WWII and saw extensive use on military aircraft.



<u>Caption</u>: "Cut-away view of a Hamilton Standard propeller. This type of constant-speed propeller was used on many American fighters, bombers and transport aircraft of World War II."

"…Other examples include the Curtiss Wright airscrew, in which the blades can be rotated to any required angle by a 36,000-to-1 gearing driven by an electric motor of 1/4-horse-power. The Hele-Shaw-Beacham variable pitch airscrew is a constant-speed type, operated by oil pressure from a variable stroke pump driven by the engine; yet it is controllable in so far as the pilot can set the blades to run at any predetermined constant rate of rotation…"

***Wonders of World Aviation,* May 31, 1938**

"…Airscrews have to be specially designed for the particular aeroplane and engine on which they are to be used. The design can be based on theory and this method yields, with experience, satisfactory results…"

***Wonders of World Aviation,* May 31, 1938**

FIGURE 11.—Power-coefficient curves for propeller 5868-9, Clark Y section, 3 blades.

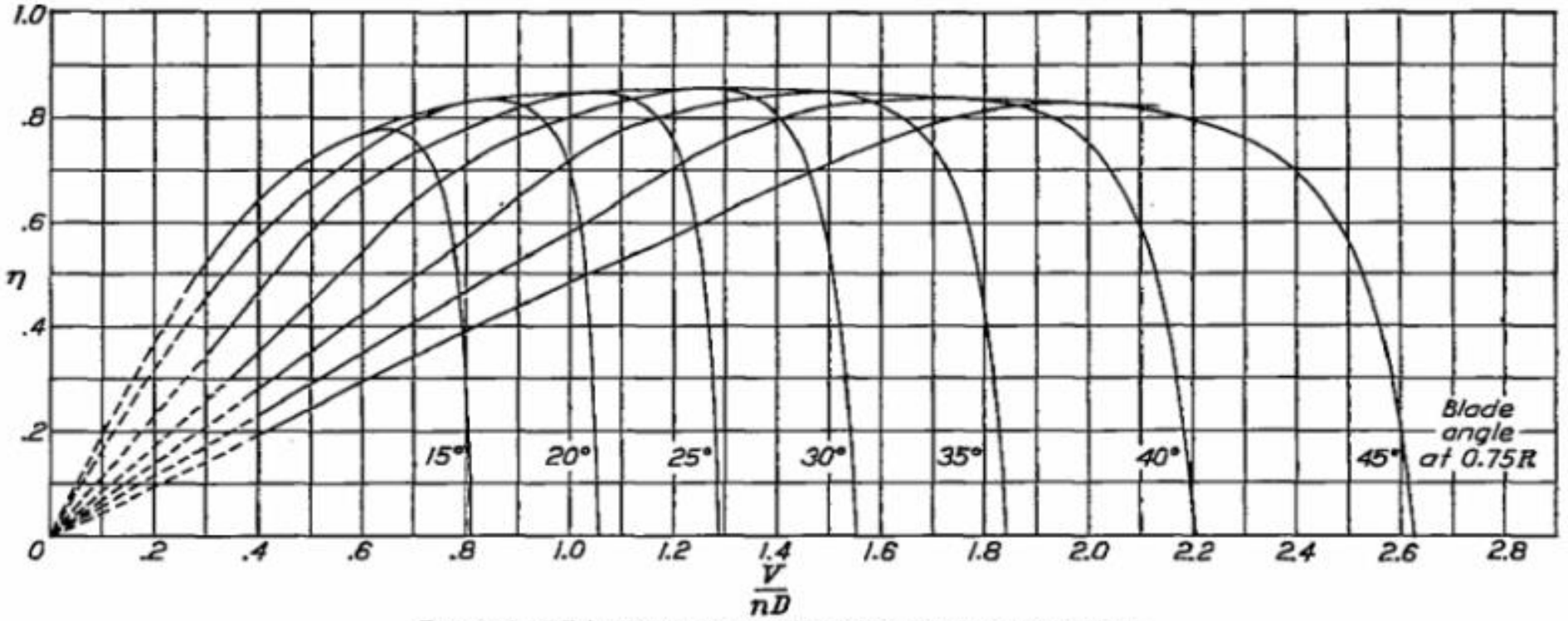


FIGURE 12.—Efficiency curves for propeller 5868-9, Clark Y section, 3 blades.

"…Moreover, theory is necessary for an understanding of the airscrew problem and for the complete analysis of the performance of an airscrew. On the other hand, performance tests on many full-scale and model airscrews have been made and the results of such tests have been coordinated in the form of charts suitable for design purposes…"

***Wonders of World Aviation,* May 31, 1938**

Caption: "Three-bladed propeller chart from NACA Report 640"

"…Many factors influence the performance of an airscrew - for example, forward speed, rotational speed, diameter, pitch, blade shape, blade interference and so forth. Thus it is impossible to prepare charts applicable to all airscrews in all conditions of working; but, in spite of this limitation, charts are in general use, for they allow quick predictions of performance to be made and prove extremely valuable when used in conjunction with experience correction factors…"

***Wonders of World Aviation*, May 31, 1938**

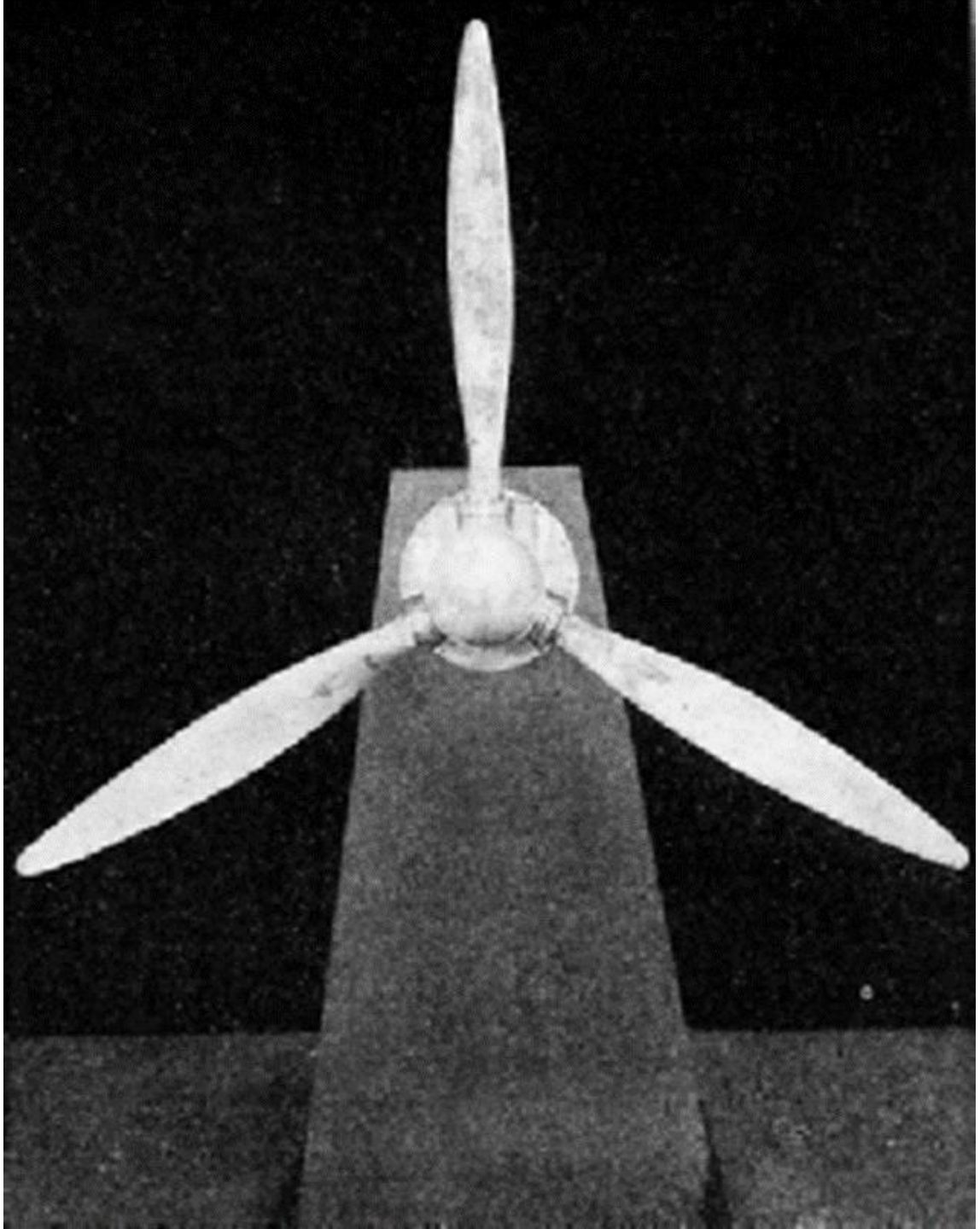
Advantages of Wood

"…In design, the stresses and strains due to centrifugal and aerodynamic loads have also to be calculated; to ensure that they fall within safe limits. The designer has to satisfy himself that the airscrew will withstand the variations of torque and the vibrations peculiar to aircraft engines…"

***Wonders of World Aviation*, May 31, 1938**

"…The weight of an airscrew has to be kept as small as possible, consistent with aerodynamic and strength considerations. The weights of three-bladed De Havilland controllable-pitch airscrews (solid aluminum alloy blades) range from 175 lbs. for a 550-horsepower airscrew of 9 ft. 6-in. diameter to 545 lbs. for a 1,700-horsepower airscrew of 14 ft. 6-in. diameter. The weights of the smaller two-bladed airscrews range from 70 lbs. for a 250-horsepower airscrew of 7 ft. 6-in. diameter to 180 lbs. for a 550-horsepower airscrew of 10 ft. 9-in. diameter…"

***Wonders of World Aviation,* May 31, 1938**



"…Airscrews are commonly made of wood (mahogany and specially prepared softwood), aluminum alloy and duralumin…"

Wonders of World Aviation, **May 31, 1938**

<u>Caption</u>: "ALL-METAL AIRSCREW made by the Fairey Aviation Co, Ltd. This three-bladed airscrew is made of duralumin and is of the variable-pitch type. It has a diameter of 7 ft. and absorbs 350-horsepower at 2,400 revolutions a minute, direct-drive."

"…The outstanding advantages of wood are its cheapness and lightness, its safety and its freedom from fatigue. It readily absorbs energy of vibration and so is an ideal material for use on an aero-engine, with its periodic torque fluctuations…"

***Wonders of World Aviation,* May 31, 1938**

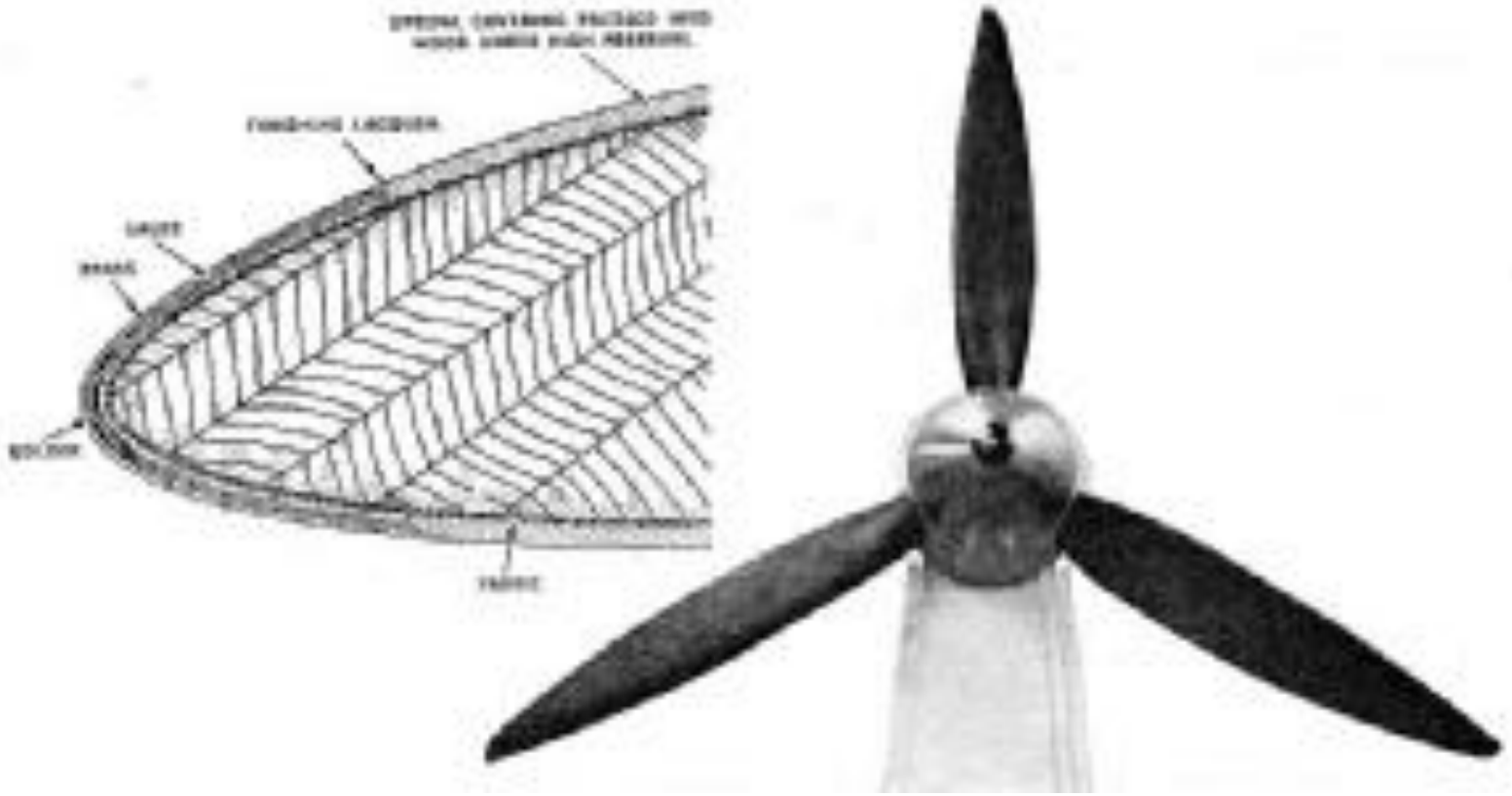
RE: Mahogany was the wood preferred for propellers through WWI, but wartime shortages encouraged the use of walnut, oak, cherry and ash

"…With good attention and maintenance the life of a wooden airscrew, protected by metal sheathing on the leading edges of the blades, exceeds 3,000-hours of flight. Wood suffers, however, from two disadvantages: it absorbs and gives up moisture and so tends to distort and it is not hard enough to resist erosion…"

***Wonders of World Aviation,* May 31, 1938**

"…Both of these disadvantages have been successfully overcome by the Schwarz process of protection, the patent rights of which are held in Great Britain by the Airscrew Company, Ltd., Weybridge, Surrey. The process consists in covering the leading edges of the blades with thin strips of cellulose material. Over this and the whole of the blades and the central boss is a layer of fabric, or high-tensile steel gauze, according to the duty required from the airscrew…"

***Wonders of World Aviation,* May 31, 1938**



"…The leading edge is covered with a nose piece of brass sweated to a woven phosphor bronze wire gauze sheath (see the drawing above)…"
***Wonders of World Aviation,* May 31, 1938**
<u>Caption</u>: "COVERED WOODEN BLADES form this airscrew of 11-foot diameter. To prevent the absorption of moisture, which would distort the blades, and to protect them from erosion they are covered by the Schwarz process, as shown in the diagram The blades are covered with fabric pressed into the wood. The leading edge is then covered with brass, sweated into a sheath of phosphor bronze wire gauze. The whole is then highly polished. The airscrew illustrated was tested to absorb 1,000-horsepower at a tip speed of 1,030 feet-a-second."

"…The airscrew, after having been thus prepared, is covered with cellulose acetate applied in a soft and plastic condition. The necessary adhesion to the wood is obtained by submitting the surface to a pressure of several atmospheres. The resultant surface is perfectly smooth and can be highly polished. The covering is hard, but is also elastic. Blade erosion is prevented and great torsional rigidity is obtained. This protection has been thoroughly tested in the most arduous conditions…"

***Wonders of World Aviation*, May 31, 1938**

"…For detachable blades suitable for variable-pitch airscr-ews, designers are using compressed and impregnated wood having a high strength. The use of this wood for the whole blade would make it very heavy and therefore compressed wood is used only at the root, with a steel sleeve…"

***Wonders of World Aviation*, May 31, 1938**

"…The main part of the blade is composed of softwood, such as spruce, having a specific gravity of 0.5. The illustration shows a detachable blade airscrew with Schwarz covered wooden blades built in this way by The Airscrew Company, Ltd. The airscrew is 11-feet in diameter and is adjustable in pitch…"

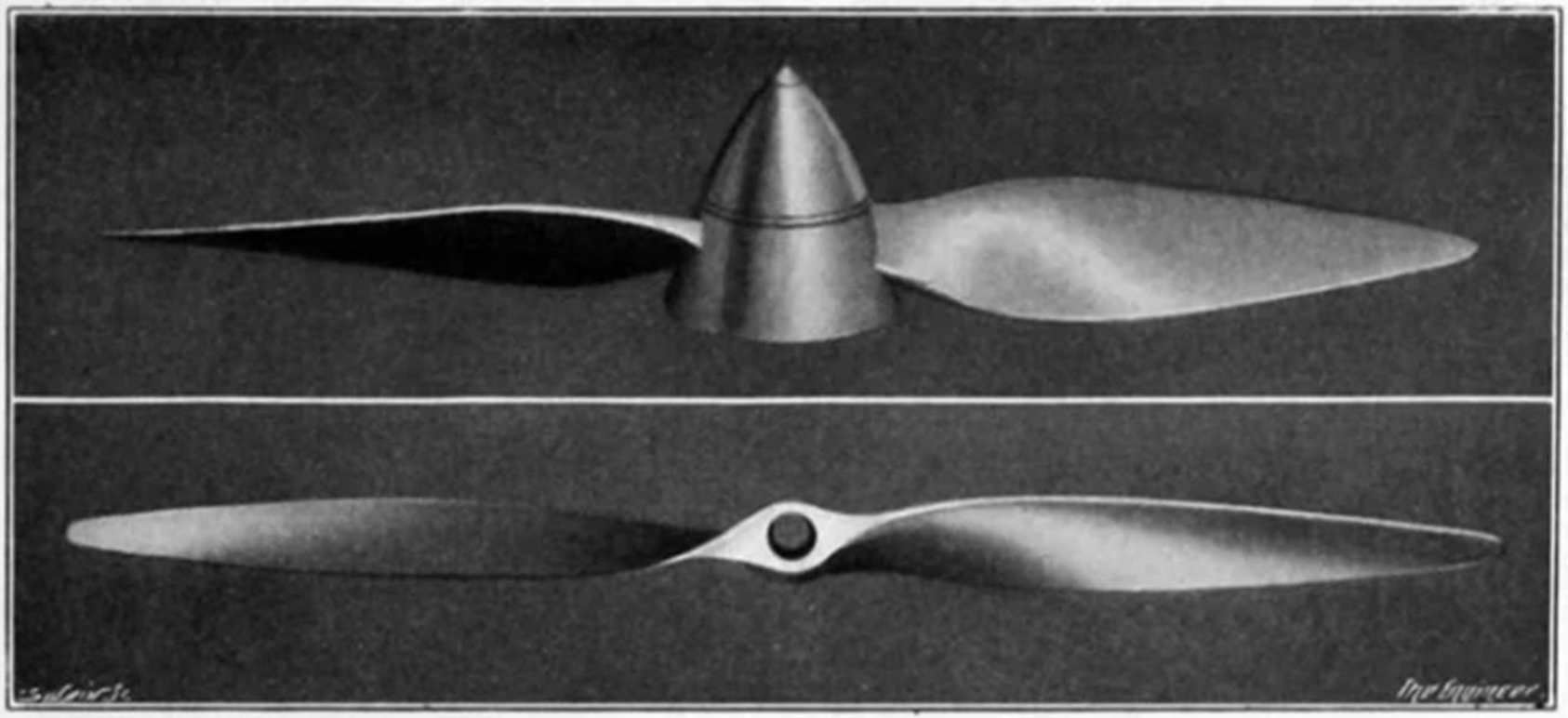
***Wonders of World Aviation,* May 31, 1938**

"…This airscrew was tested to absorb 1,000-horsepower at a tip speed of 1,030 feet-per-second. The complete weight, including the spinner, which also is of wood, is only 175 lbs. The maximum centrifugal force on the blades is 24-tons and the centrifugal and air loads are equivalent to a straight pull on the blade root of 43-tons…"

***Wonders of World Aviation,* May 31, 1938**

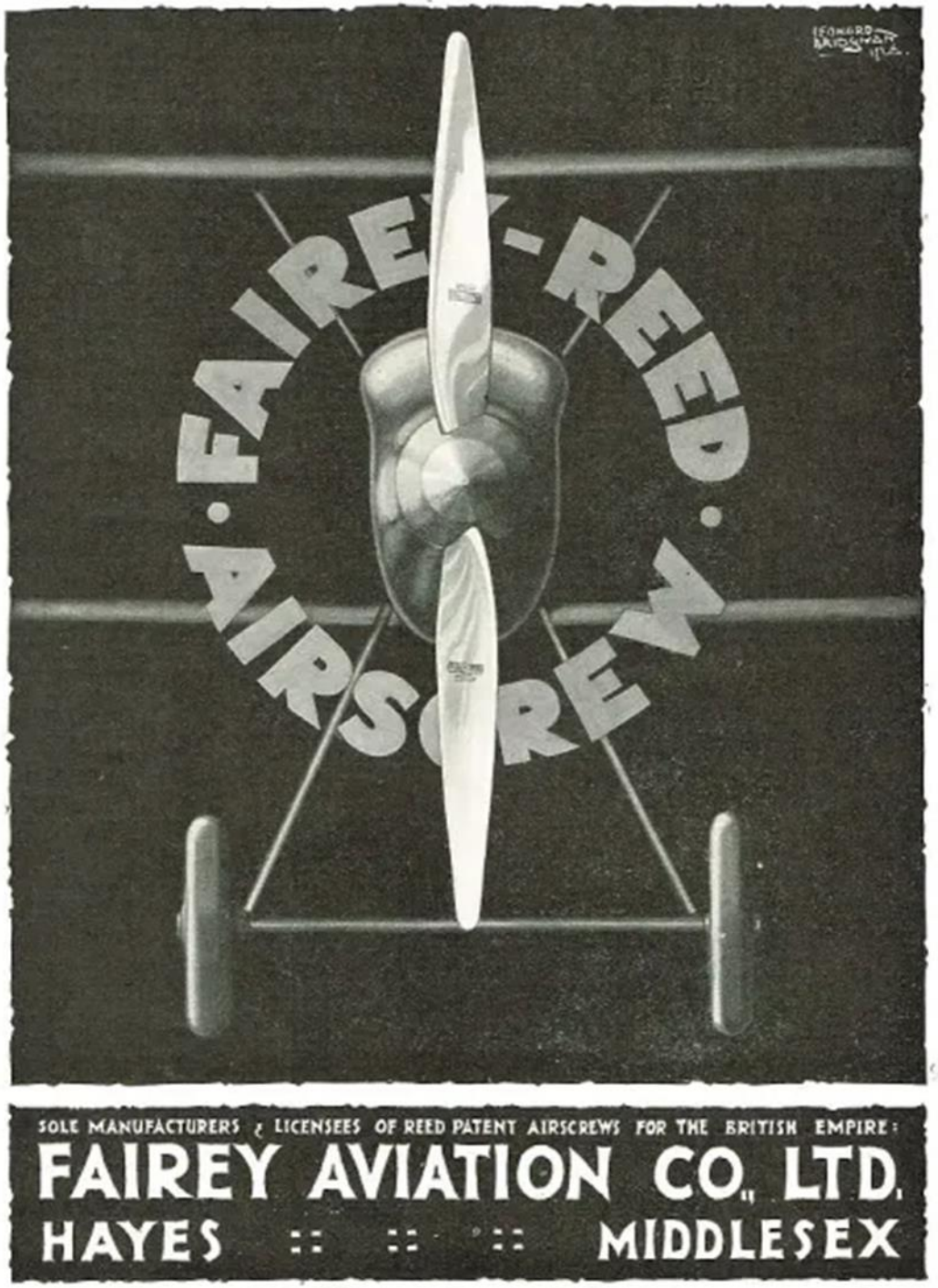
"…The Reed airscrew was one of the first successful types of metal airscrew made of aluminum alloy. The blades of this airscrew are thin and sufficiently flexible to set themselves along the direction of the resultant loads so that the bending moment stresses are small. Metal airscrews with thicker blades followed…"

***Wonders of World Aviation,* May 31, 1938**



FAIREY-REED SCHNEIDER TROPHY METAL AIRSCREW
FAIREY-REED SILENT METAL AIRSCREW

<u>Above</u>: in March 1921, *Dr. S. Albert Reed* filed a patent for a metallic screw propeller. From that patent, Reed developed a series of twisted, solid duralumin propellers designed for both durability and efficiency. For a few years, and until the arrival of more modern designs, these neat "thin blades" were the leading-edge of aviation technology.



"…An outstanding advantage of this type of airscrew, and one which favors mass production, is that detachable blades, housed in a central hub and adjustable in pitch, can be used…"

May 31, 1938

RE: in 1925, Reed received the Collier Trophy. The use of the Reed propeller proved to be essential to increase an aircraft's overall performance, especially in extracting the most of high-power engines. The British Fairey Aviation Co. knew that, so they bought license production rights.

Higher Power Outputs

"…The trend in modern engine design is towards higher power output and a stage will soon be reached when further increase in engine size and power will be dependent on the progress made in airscrew development…"
***Wonders of World Aviation,* May 31, 1938**

"…The special problems involved, and the difficulties which will have to be overcome in the design of airscrews for high-powered engines, have been discussed in an interesting paper by Mr. Frank W. Caldwell, Engineer Manager of Hamilton Standard Propellers, East Hartford, Connecticut, U.S.A., read at a meeting of the Lilienthal Gesellschaft fur Luftfahrlforschung (Lilienthal Association for Aeronautical Research), held at Munich, in October 1937…"

***Wonders of World Aviation,* May 31, 1938**

RE: *Frank Walker Caldwell* was a leading American Propeller Engineer and designer. As the U.S. government's Chief Propeller Engineer, he pioneered propeller engineering and propeller testing facilities and techniques.



Mr. Caldwell's many contributions to aviation in propeller technology highlighted by his winning, with Hamilton Standard, the 1933 Collier Trophy for design of the controllable-pitch propeller. His design innovations led to the Hydromatic constant-speed propeller used by virtually every front-line U.S. aircraft in WWII and his pioneering whirl test procedures were indispensable to the development of all modern high-performance propellers during the 20th Century.

<u>Caption</u>: "Frank W. Caldwell being congratulated on winning the 1933 Collier Trophy (visible in the background) for his work with Hamilton Standard on the controllable-pitch propeller"

"…The problem considered by Mr. Caldwell was the design of metal airscrews with a power input of about 2,000-horse-power at an altitude of 20,000-feet. An idea of the severity of this problem can be gathered from the fact that, because of the lower air density at 20,000-feet, an airscrew designed for this altitude is about the same size as one absorbing 4,000 horsepower at sea-level…"

***Wonders of World Aviation,* May 31, 1938**

"…In practice, the airscrew would be larger because the tip speed of an airscrew must not exceed an upper limit, if the losses of efficiency and thrust due to compression of the air at high tip speeds are to be kept small; and the permissible upper limit of tip speed is lower at high altitudes because of the lower air temperature…"

***Wonders of World Aviation,* May 31, 1938**

"…Further, the advantages of controllable-pitch and constant-speed airscrew operation are so great that it seems certain that these features will be included. Airscrews of three, four and six blades driven through gearings with appropriate reduction ratios, to prevent the tip speeds from exceeding the permissible upper limit, were considered…"

***Wonders of World Aviation,* May 31, 1938**

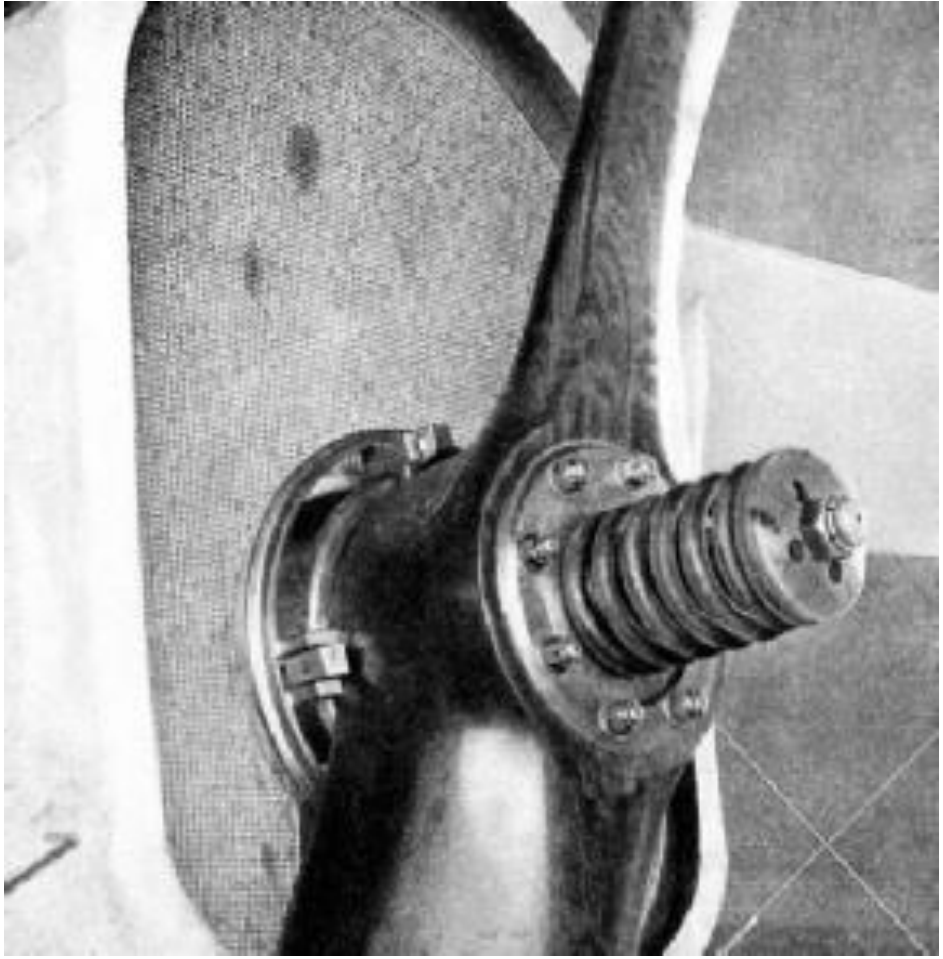
"…It was predicted that, for a speed of 250 miles-an-hour, the diameter of a six-bladed airscrew would be 15-feet, against 21-feet for a three-bladed airscrew and that the weight of a six-bladed airscrew would be 1,050 lbs. against 1,400 lbs. Roughly speaking, the weight in pounds-per-horsepower, calculated on the basis of present design, was 0.6, as against the present figure of 0.35 for smaller airscrews…"
***Wonders of World Aviation,* May 31, 1938**

"…It appears, therefore, that the main problem confronting the designer will be one of reduction of weight without a reduction of strength…"

***Wonders of World Aviation,* May 31, 1938**

"…It is not improbable that the airscrew of the future may have to function as a brake. By turning the blades into a negative pitch position, an airscrew may be made to give a negative thrust and to act as a powerful brake. The pitch adjustment from forward to reverse, and vice-versa, will have to be made with great rapidity, if the device is to be effective, and problems of aeroplane control are almost certain to arise when the airscrew is giving a negative thrust."

***Wonders of World Aviation,* May 31, 1938**



Caption: “TO MEASURE THE THRUST of an airscrew, an instrument known as a ‘thrustmeter’ is assembled with the airscrew. The thrust of the airscrew exerts pressure on the spring incorporated on the central boss and this pressure is recorded by an instrument in the cockpit of the aeroplane.”

Part 6

A Motor of Our Own

On a Quantity Basis

The lightest and most powerful airplane engine produced on a quantity basis

***Scientific American,* June 1, 1918**

RE: introduction to an article entitled: "The True Story of the Liberty Motor"

Doubting Thomases

"WHEN Secretary Baker made the dramatic announcement last summer that a new motor, christened the 'Liberty' had been developed by two American Engineers in a five-day conference behind locked doors, men who were experienced in machine design shrugged their shoulders. They knew the impossibility of designing so highly refined a machine as an airplane motor in such a brief time…"

***Scientific American,* June 1, 1918**

"…They assumed, therefore, that the so-called new motor was probably a standard motor in which a few modifications had been introduced; and speculation was rife as to what particular standard motor had been adopted…"

***Scientific American,* June 1, 1918**

"…It was at first claimed that the German motor, known as the 'Mercedes,' formed the basis for the Liberty Motor; then other claimants came forward…"

***Scientific American*, June 1, 1918**

Air of Mystery

"…An air of mystery has surrounded the Liberty Motor from its inception and it is high time that this was dispelled…"
***Scientific American*, June 1, 1918**

The Real Story

"…Recent announcements from the War Department disclosing details of the motor and their similarity to other motors of American and foreign design give us the liberty to tell here; for the first time the real story of the development of our standard aviation motor…"

***Scientific American*, June 1, 1918**

Aerial Warfare



"…Shortly after the outbreak of the great European War, Mr. Henry Joy, then President of the Packard Motor Car Company, became impressed with the importance of the airplane in modern warfare. He felt certain that before the conflict was over the United States would be involved; and looking about among our motor manufacturers he realized how poorly prepared we were to produce the motive power for aerial warfare…"

***Scientific American,* June 1, 1918**

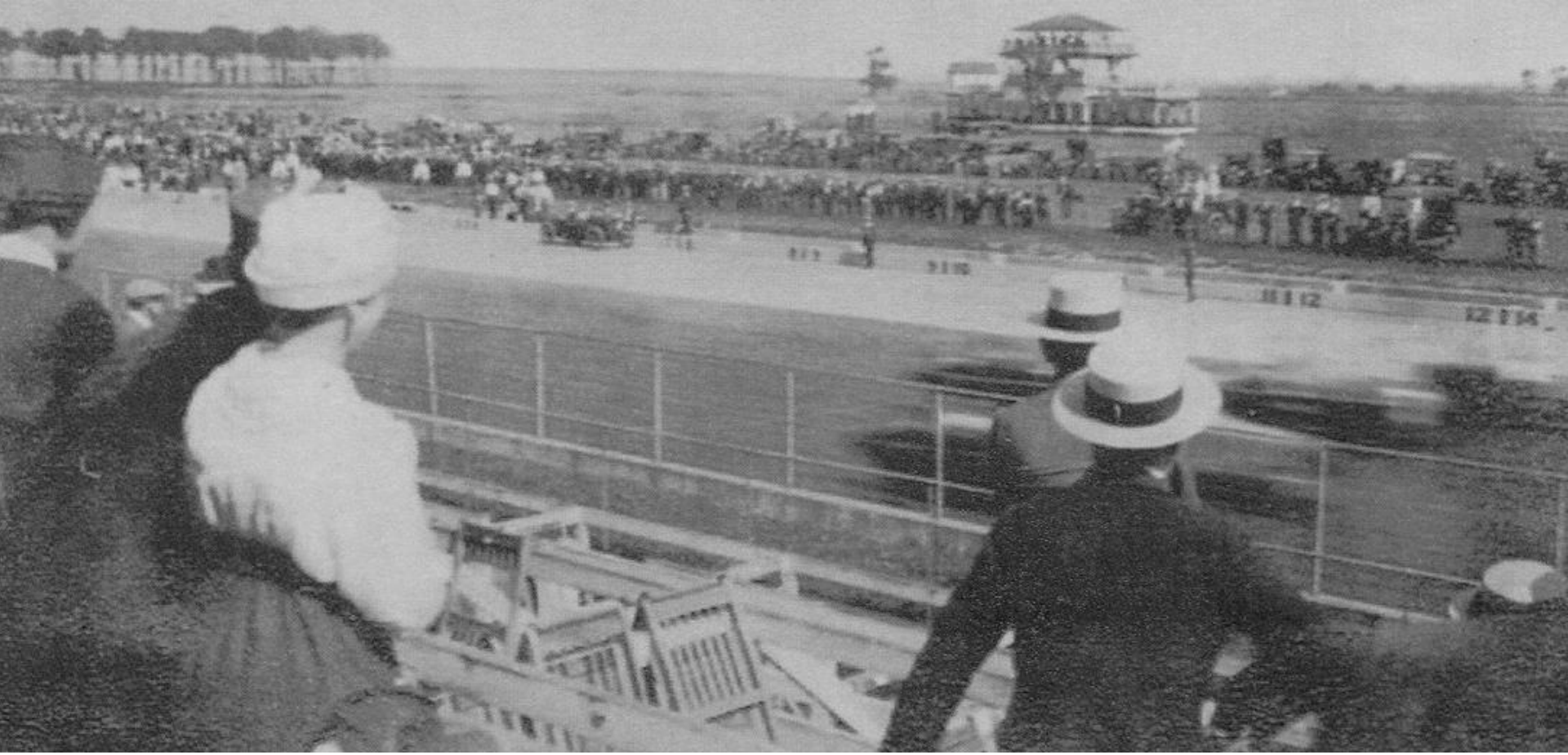
<u>Caption</u>: "Henry Bourne Joy – longtime President of the Packard Motor Car Co."

The Realization

"…There was no question that Europe was far ahead of us in the construction of airplanes and airplane motors and, being a motor manufacturer himself, he realized bow long it would take to develop the manufacture of first-class motors in this country, even after we woke-up to the realization of their necessity. Therefore, he urged his company to proceed at once with the development of an airplane motor which would compare favorably with the very best produced in Europe. This was in the fall of 1914…"

***Scientific American*, June 1, 1918**

A Day at the Races



"…In the spring of 1915 work was started on such a motor and the design was completed in November of that year. The engine was ready for block-test in February of 1916. As there were no facilities for testing airplane engines by actual flights in this country, the new motor was placed in a racing chassis of special construction and was subjected to severe tests at the Sheepshead Bay Speedway…"

***Scientific American,* June 1, 1918**

<u>Caption</u>: "Automobile racing at Sheepshead Bay Speedway, 1917"

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INTERNATIONAL SWEEPSTAKES

JUNE 14, 1919

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J. Burt Young, Manager

V-type

"…The engine was of 299 cubic-inches displacement, or just under the 300-inch racing limit established by the AAA. It was of the 12-cylinder 'V' type, with cast-iron cylinders. After it had been thoroughly tested-out, a second model was designed, based on the principles that had been proved-out on the first model. This was of much larger design with four by six cylinders and of 905 cubic-inch piston displacement…"

***Scientific American,* June 1, 1918**

Propeller Propulsion

"…The new motor was provided with an airplane propeller and mounted on a truck. With this unique powerplant the truck was driven about the streets of Detroit. The air-propelled truck could travel faster than any man would care to drive it. In one test, the wheels were locked and yet the truck was pushed over snow-covered ground…"

***Scientific American,* June 1, 1918**

Setting Records

"…In April, 1917, a second engine of this model was completed and placed in a racing chassis. It established the official world record of 130 miles-per-hour - or a mile in 28.76 seconds…"

***Scientific American*, June 1, 1918**

Trial & Error

"…In this second model, steel forged cylinders were used, fitted with pressed steel jackets welded on. Considerable difficulty was, at first, experienced in attempting to weld the jacket to the cylinder without burning the metal or introducing strains in it. After a considerable experiment, it was found that the meeting edges which were to be welded must be of the same thickness, otherwise the heavier section would carry-off the greater proportion of heat and the two surfaces could not be heated to the same temperature. By reducing the surfaces to exactly the same section, welding with the oxyacetylene torch was readily accomplished…"

***Scientific American,* June 1, 1918**

Head Resistance

"…In the first model, the cylinders were set at an angle of 60-degrees, following the practice used in automobile engines; but in the second model an angle of 40-degrees was adopted so as to cut-down head resistance. Tests of the engine show-ed that there was no noticeable vibration with the cylinders set at this unusual angle, even when the engine was run at considerably reduced speed…"

***Scientific American,* June 1, 1918**

Double-duty

"…In this engine, the cam shaft was placed directly over the cylinders and the housing for the cam shaft acted as a truss to hold the upper-ends of the cylinders rigid…"

***Scientific American*, June 1, 1918**

America Goes to War

"…The third model was begun in April 1917, immediately after war was declared, and the first engine was completed in May. This contained certain improvements over the previous models, aimed particularly at reduction of weight and simplification of manufacture…"

***Scientific American*, June 1, 1918**

"…One of the first demands upon this country when it entered the war was to start the manufacture of airplanes in large quantities. We had a reputation for manufacturing on a quantity basis and it was felt that if we turned our great industrial organizing ability upon this problem we could turn out a fleet of airplanes that would simply overwhelm the enemy…"

***Scientific American,* June 1, 1918**

On an American Basis

"…Our Engineers had studied the foreign airplane motors and a number of them were being made in this country. It was realized, however, that they were not adapted for quantity production on an American basis and it was very necessary for us to develop a motor of our own which would become a standard and which could be produced in enormous quantities…"

***Scientific American,* June 1, 1918**

Patriotic Motives

"…As soon as the United States was drawn into the war, the Packard Motor Car Company offered its models and experience to the Government and, being actuated by patriotic motives, was perfectly willing to abandon, for the time being, all claim to the origination of this motor, although it had expended $400,000 in its development…"

***Scientific American*, June 1, 1918**

Advice and Consent

"…However, there were some changes that the Government called for and it was felt that a representative of some other motor manufacturing concern should be called in to advise with the Packard Engineers on the modifications which would eventually be adopted by the Government…"

***Scientific American,* June 1, 1918**

"…Accordingly, Major Hall of the Hall-Scott Motor Company was called to Washington to confer with Mr. (now Lieutenant-Colonel) Vincent, Chief Engineer of the Packard Company. Mr. Vincent had with him the blueprints of the complete plans of his motor and these were studied by Major Hall who suggested a number of changes…"

***Scientific American*, June 1, 1918**

U.S. Standard Motor

"…When the war first broke-out, airplanes were fitted with 100-horsepower engines. Very soon they were found to be insufficient and engines of 125-horsepower were made. The engine power then gradually increased to 150, 175, 200, 250; and it was about in that neighborhood when Major Hall and Mr. Vincent were called upon to furnish the United States standard motor. It was felt that a motor should be designed so far ahead in power of anything else that had been produced that, by the time it could be turned-out in quantity, it would still be well in the lead…"

***Scientific American*, June 1, 1918**

Modifications

"…Accordingly, a horsepower of between 350 and 400 was sought and the size of the cylinders was changed from 4 x 6 to 5 x 7. Because of the larger cylinders required in the new motor, the angle of the 'V' was changed from 40- to 45-degrees. The larger pistons and cylinders required slightly greater clearances…"

***Scientific American*, June 1, 1918**

"…In-place of the forced lubrication of the crankshaft which was provided in the Packard engine, the scupper system was introduced by Major Hall because it had been found very efficient on the Hall-Scott motor. This is also a feature of the Mercedes motor. The scupper consists of a small cup-like flange on the crank arm which catches the oil and throws it up on the bearing of the crankshaft…"

***Scientific American,* June 1, 1918**

A Herculean Effort

"…These and other slight modifications were thoroughly discussed and decided upon by the two motor experts who worked unceasingly and arrived at the finished design in a conference lasting five days. They had a herculean task before them and deserve the highest praise for the successful outcome of their efforts…"

***Scientific American*, June 1, 1918**

Commence at Once

"…As soon as the conference was over, telegraphic instructions were sent on to the Packard plant and work was started immediately upon the new motor…"

***Scientific American*, June 1, 1918**

Birth of an Aero-Motor

"…Even before blueprints arrived the wood model was prepared in the general form and essential features of the new motor. Work on the new engine was pushed at the highest speed possible and, on the third day of July, it was completed and shipped to Washington. The next day it arrived there, on the Nation's birthday, and was christened the 'Liberty Motor'…"

***Scientific American,* June 1, 1918**

Trying Tests

"…After the first experimental motor had been completed, it was subjected to a great many trying tests and was found to be exceedingly efficient and very light. It developed a horse-power of considerably over 400 and its weight was but little over 800 pounds. Its weight-per-horsepower was therefore about two pounds, which is much lighter than the majority of airplane motors. On endurance tests it stood-up wonderfully. It was tested at the summit of Pike's Peak in order to deter-mine its action under conditions of rarified atmosphere and proved very satisfactory…"

***Scientific American*, June 1, 1918**

"…At the Bureau of Standards in Washington, a special room was set aside in which a partial vacuum was created equivalent to that which exists at the maximum height to which an airplane engine has been carried. In this room the engine was found to operate perfectly. At one of its first altitude tests in a plane, the American record for altitude was smashed. …"
***Scientific American*, June 1, 1918**

Order to Proceed

"…Not until September was the order to proceed with the manufacture of the Liberty Motor definitely given and immediately, work was started in the Packard plant…"

***Scientific American*, June 1, 1918**

For the Time Being

"…It was not considered advisable to build a new plant and purchase new machinery for the manufacture of the new motor because this would consume a great deal of time. Instead, it was decided to give up the manufacture of automobile motors for the time being and rearrange the machine tools to take the new motor…"

***Scientific American*, June 1, 1918**

Day and Night

"…While the plans were being prepared to carry this out, the automobile motor plant was operated day and night at full capacity in order to produce as many automobile motors as possible before the manufacture of them stopped. Under this intensive program, by the end of the year a large stock of motors had been machined and, for the most part, assembled to meet commercial demands…"

***Scientific American,* June 1, 1918**

Maximum Effort

"…In the meantime, work on the new Liberty Motor was going ahead as fast as possible. New jigs had to be constructed, machine tools had to be fitted with new appliances and the work had to be organized so that the motor could be produced on a large scale…"

***Scientific American*, June 1, 1918**

Out of Sight, Out of Mind

"…It is interesting to note that the first experimental motor was delivered to the Government on the 4th day of July and the first production motor was sent to Washington on Thanksgiving Day. This, however, did not mean that the production problems bad all been solved. No one except a man who has actually had experience with such work can realize the infinite amount of detail required in organizing a new industry. Usually, the organization work does not make any showing at all to the general public and, consequently, is not appreciated…"

***Scientific American*, June 1, 1918**

Peerless

"…One of the Engineers of the Ford plant told the writer personally that he thought every one would recognize the right of the Ford Company to an opinion on quantity production manufacture. He said that never in the world's history had a greater piece of work been done on a similar scale. The development of the Liberty Motor was simply short of marvelous and the public, instead of criticizing the manufacturers for slowness, should be thankful that they have had such competent men to carry-on the work and develop a motor of such efficiency in so incredibly short a space of time…"

***Scientific American,* June 1, 1918**

Back to Square-one

"…The motor which was delivered to the Government on Thanksgiving Day developed a number of small troubles. One of these was the difficulty of lubrication and eventually, it was found necessary to change the scupper system to the original forced lubrication system…"

***Scientific American*, June 1, 1918**

Time and Money

"…But the most important change was made in the production of the cylinders. In the first Liberty Motor, the cylinders had to be bored from the solid - an operation that was very costly in time and money. This, however, was a copy of the best foreign engineering practice and was followed as a necessary detail by our Engineers…"

***Scientific American,* June 1, 1918**

"…It was at this juncture that the Engineers of the Ford Motor Car Company made a notable contribution. They developed a cylinder forged out of steel tubing which enabled the manufacturers to turn-out the cylinders at very low cost and in exceedingly large quantities…"

***Scientific American*, June 1, 1918**

"…Seamless steel tubing is used and this, in but four operations under the forge press and bulldozer, is converted into a headed and flanged cylinder blank on which a minimum of machining need be done…"

***Scientific American*, June 1, 1918**

"…The manufacture of these cylinders was not undertaken until the end of January and now they are being turned-out in very large quantity. Each week, the cost of producing the cylinders has been reduced slightly and all the savings made have been turned over to the Government. At the time the writer observed the work on these cylinders, the cost had been cut-down more than half, with even greater economies in prospect…"

***Scientific American,* June 1, 1918**

Troubleshooting

"…One of the difficulties encountered in the Liberty Motor had to do with the form of ignition…"

***Scientific American*, June 1, 1918**

"…In the original Packard motor, the 'Delco' system of ignition was used. This consists in generating current with a small electric generator geared to the engine shaft and then transmitting the current by means of a pair of distributors to the spark plugs. Magneto ignition was tried, but it proved impossible to design a single magneto which would operate with the irregular timing required in an engine in which the cylinders were set at the unusual angle of 45-degrees. A single magneto could not be used and so a battery of four magnetos had to be employed. This added somewhat to the weight of the engine…"

***Scientific American*, June 1, 1918**

"…Then further difficulties were encountered…"
***Scientific American,* June 1, 1918**

Revert to the Original

"…Owing possibly to the vibration of the engine at high speed, the magnets of the magneto showed fatigue and gradually lost their magnetic property. Eventually, it was decided to return again to the original system of ignition…"

***Scientific American*, June 1, 1918**

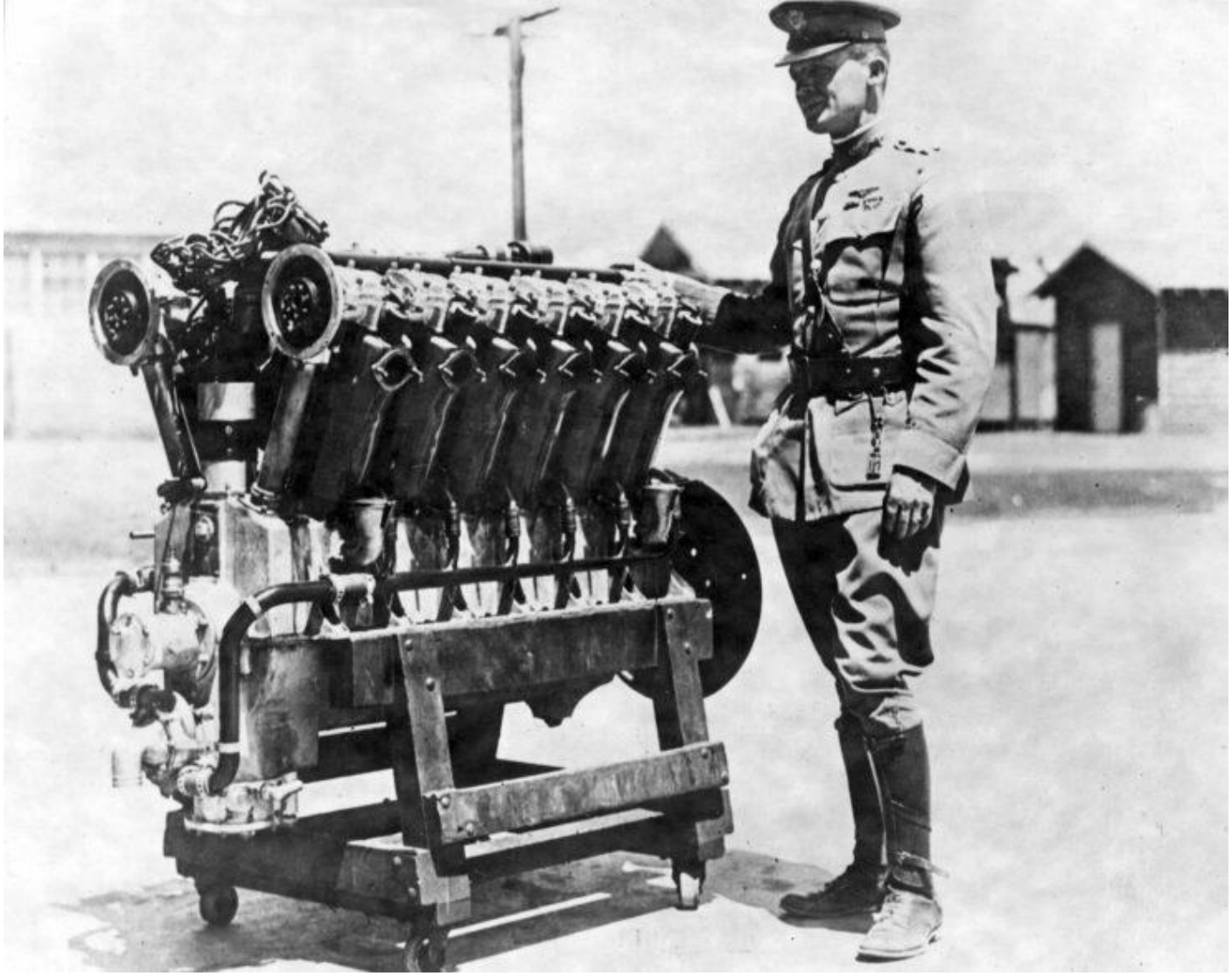
"…One of the marked differences in appearance of the Liberty and Packard '900' is due to the fact that the latter is provided with reduction gearing. The advantage of this is that it places the hub of the propeller more nearly in line with the center of area of the engine so that far more efficient driving results are produced in the air. For this reason the reduction gearing is being looked upon with favor now and it is highly probable that there will be a return to this feature of the original Packard '900.' Furthermore the ideal speed for the engine is higher than ideal propeller speed…"

***Scientific American*, June 1, 1918**

"…It is rather remarkable that, in a number of very important features, it has been necessary to revert to the original design…"

***Scientific American*, June 1, 1918**

A Very Satisfactory Pace



"…Production of the Liberty Motor is now proceeding at a very satisfactory pace. More motors are being produced than there are planes to carry them…"

***Scientific American,* June 1, 1918**

<u>Caption</u>: "Major Henry H. Arnold with first Liberty V-12 engine completed"

"…When the writer visited the Packard plant several weeks ago they were being turned-out at the rate of 15 per-day and it was hoped that inside of two months a production of 50 per-day would be attained. No expense was being spared to reach this rate of production, but again the matter of organization was holding-up the work so that it was considered impossible to attain that rate before the end of June…"

***Scientific American,* June 1, 1918**

"…In the Ford plant, manufacture of the Liberty Motor was just about to start with a program of 100 complete engines per-day when the plant is in full operation. Here, as in the Packard plant, the standard equipment of the machine shop was being overhauled and reorganized for work on the Liberty Motor. This was being done at the expense of the regular commercial motor…"

***Scientific American,* June 1, 1918**

"…In several other factories work on the Liberty Motor has either just begun or is about to begin and certainly by the middle of the summer the Liberty Motor ought to be produced in very large quantities…"

***Scientific American,* June 1, 1918**

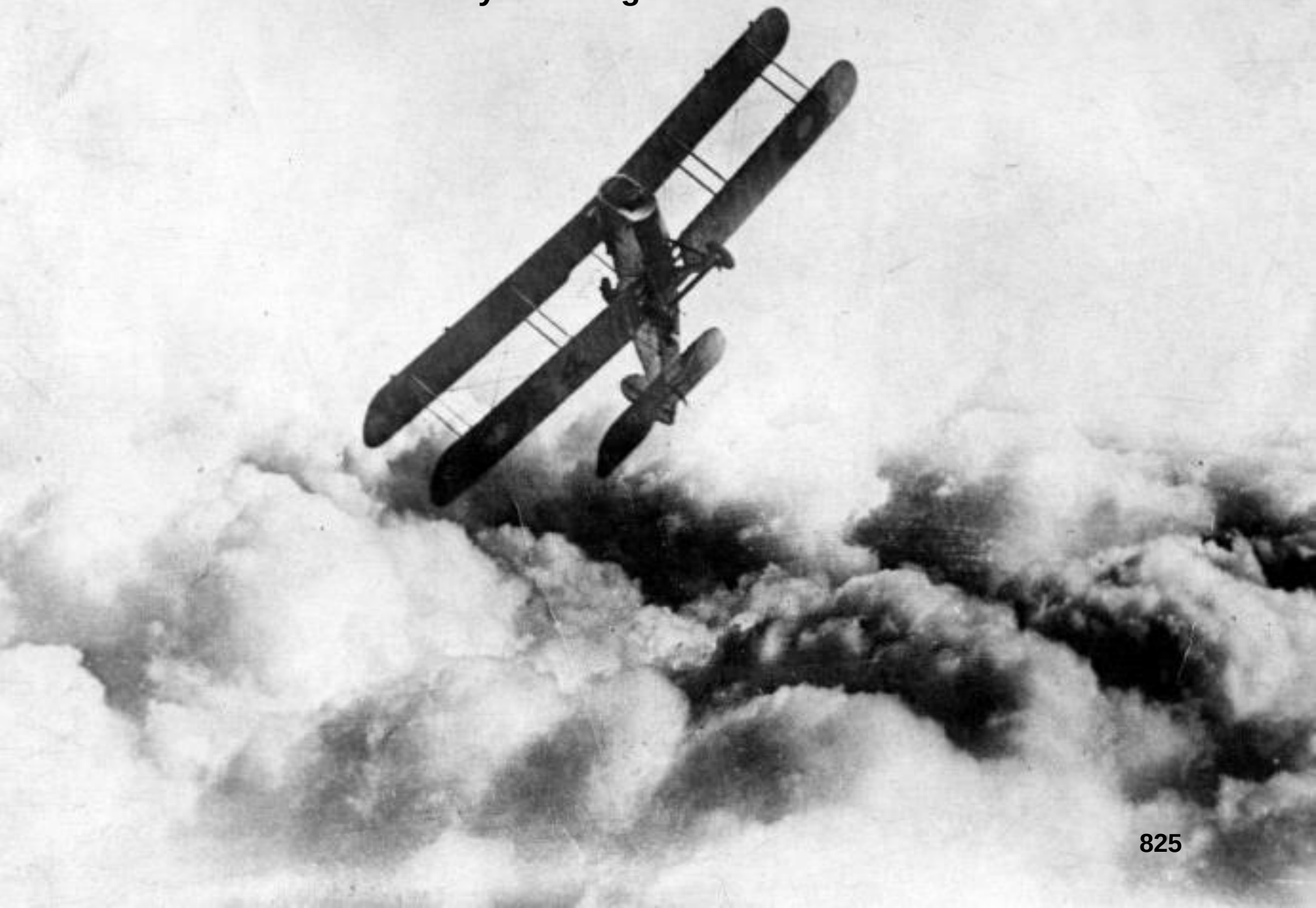


"…The only thing that is retarding the airplane program now is the manufacture of planes to carry the motors…"

***Scientific American,* June 1, 1918**

<u>Caption</u>: "The DH-4 Liberty single-engine biplane was the only U.S.-built aircraft used in World War I"

This photograph was taken in France in 1918, the aircraft is a De Havilland DH-4 that's been fitted with a Liberty L-12 engine



Exceeding Expectations

"…The efficiency of the Liberty Motor is not to be questioned by anyone who has examined it thoroughly. It is far more powerful than any other airplane engine ever produced on a quantity production basis. It exceeds in power all but a few experimental machines. Although rated at 400-horsepower it has shown on test as high as 485-horsepower; and its weight is 820 pounds…"

***Scientific American,* June 1, 1918**

Universal Utility

"…It is a mistake to assume that any one motor is adapted to all classes of airplane service. There is no single motor abroad which is of such universal utility…"

***Scientific American*, June 1, 1918**

"…The Liberty Motor is one of the most powerful airplane motors in the world and the lightest for its power. Obviously, it would be impracticable to use it on light machines which do not require such power, or on slow observation machines. But it is ideal for bombing purposes, for here we have large airplanes of great carrying capacity that must travel long distances at high-speed…"

***Scientific American*, June 1, 1918**

"…The Liberty Motor should also be available for fighting machines of the larger types. We are making a great many motors of other types for our training machines and for our lighter fighting machines…"

***Scientific American*, June 1, 1918**

A Very Satisfactory Basis

"…Altogether, the airplane situation is fast approaching a very satisfactory basis and before the end of the year, it should play an important part in the great struggle on the other side of the water."

***Scientific American*, June 1, 1918**

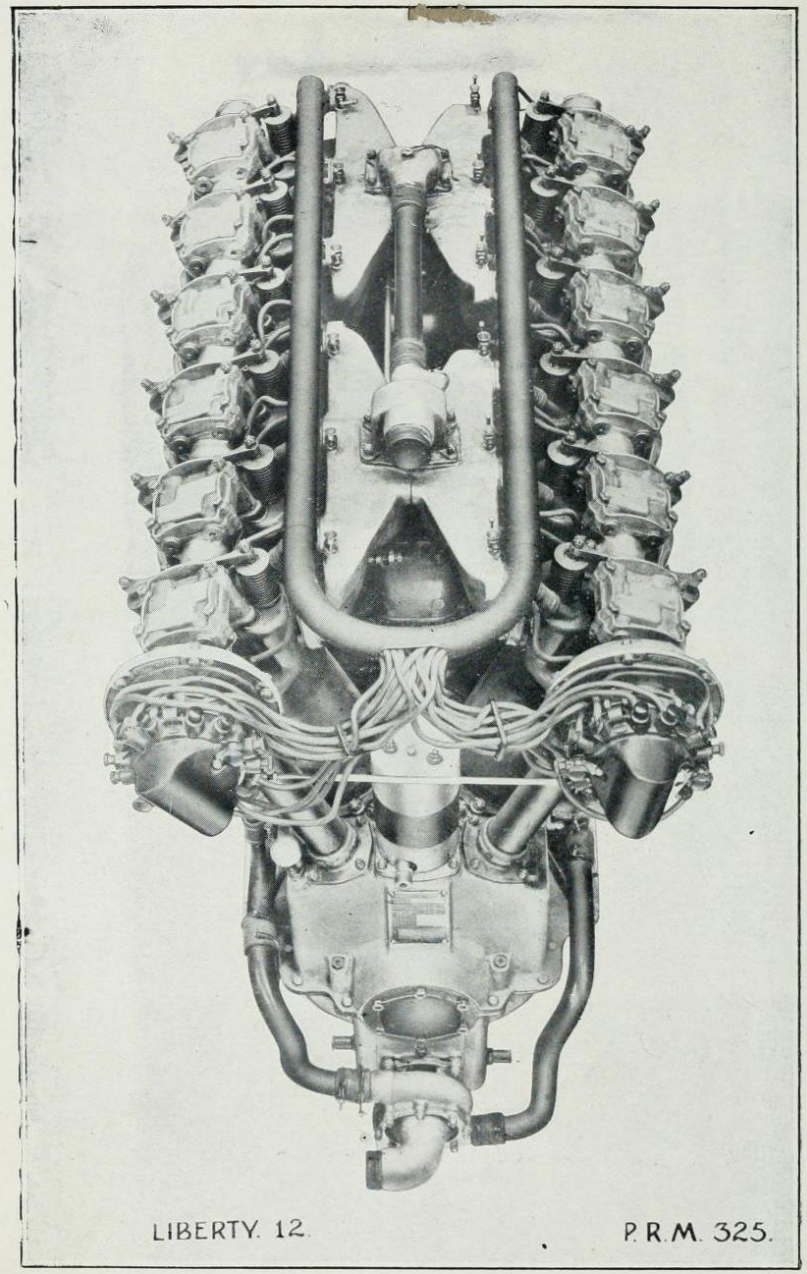
THE

LIBERTY

12-Cylinder Aero Engine

Handbook.

(1918)



The Liberty Engine.

Introductory Note.

The Liberty engine is of the ungeared twelve-cylinder Vee type, with cylinders set at 45°. The bore is 5 in. (127 mm.), and the stroke 7 in. (177.8 mm.). The "dry" weight is 820 lbs. The engine is constructed in two models, the army type having a higher compression ratio (5.3 : 1) than the naval type (4.78 : 1); the maximum r.p.m. of both types are 1750, at which speed 425 b.h.p. is developed by the army type, its normal b.h.p. being 405 at 1650 r.p.m. The naval type is not used in the British Service at present; it gives 396 h.p. at 1,650 r.p.m.

The water-cooled cylinders are constructed from steel tube with welded jackets: there are two valves per cylinder.

The pistons, cylinders, and gudgeon pins are lubricated by splash. Oil is pressure-fed to the rest of the engine, including the camshafts. The sump is scavenged by a three-pinion pump combined in a unit with the pressure pump, and located in the rear oil well.

Ignition is by the Delco system. A twelve-point distributor, embodying two contact breakers in parallel, is mounted on the rear end of each camshaft, and supplied with current for starting and at low engine speeds by an accumulator. When the engine attains 650 r.p.m., the current is furnished by a dynamo generator, mounted between the inclined camshaft drives at the rear of the engine. This generator further charges the accumulator. An auxiliary circuit breaker on each distributor head prevents the engine from firing in a reverse direction.

Two duplex Zenith carburettors (type 52 D.F.) of American manufacture are fitted on the engines now being delivered, but later engines will be equipped with two Claudel-Hobson carburettors, type H.C. 7.

An electric starter is to be fitted, for which a special handbook will be published in due course.

Leading Particulars.

Number and arrangement of cylinders.—12. Vee at 45°.
Bore.—5 ins. (127 mm.).
Stroke.—7 ins. (177.8 mm.).
Stroke : bore ratio.—1.4 : 1.
Stroke volume of one cylinder.—137.45 cub. ins. (2,252 cub. cms.).
Total stroke volume of engine.—1,648.8 cub. ins. per rev. (27,040 cub. cms.).
Area of one piston.—19.63 sq. ins. (126.6 sq. cms.).
Total piston area of engine.—235.6 sq. ins. (1,520 sq. cms.).
Clearance volume of one cylinder.—36.4 cub. ins. (naval type), 31.9 cub. ins. (army type).
Compression ratio.—4 : 78 (naval type), 5 : 3 (army type).
Normal B.H.P. and speed.—405 h.p. at 1,650 r.p.m.
Maximum r.p.m. near ground.—1,500 r.p.m.
Maximum r.p.m. at altitude.—1,750 r.p.m. (above 6,000 ft. only).
Piston speed.—1,925 ft./min. at 1,650 r.p.m.
Brake mean effective pressure.—118 lbs./sq. in for 405 h.p. at 1,650 r.p.m.
Cub. in. of stroke volume per b.h.p.—4.07 cub. ins. (66.69 cub. cms.).
Sq. in. of piston area per b.h.p.—.582 sq. in. (3.75 sq. cms.)

H.P. per cub. ft. of stroke volume.—424 (15.0 h.p. per cub. metre).
H.P. per sq. ft. of piston area.—247 (2.666 h.p. per sq. metre).
Rotation of crank.—Right-hand tractor (left-hand pusher).
Rotation of propeller.—As above.
Speed of propeller.—Ungeared.
Lubrication system.—Force feed to main bearings, big ends, and camshafts. Splash to pistons and gudgeon pins. Dry sump.
Oil recommended.—Mobiloil B B.
Oil pressure recommended.—Minimum, 25 lbs. per sq. in.; Maximum, 35 lbs. per sq. in.—at 1,650 r.p.m.
Oil temperature recommended.—40° Centigrade.
Oil consumption per hour.—8 to 12 pints per hour.
Oil consumption per b.h.p. hour.—Average .03 pint H.P. hour.
Specific gravity of oil.—.9.
Carburettors.—Two American Duplex Zenith, type 52 D.F., with modified altitude control (vacuum); or two Claudel-Hobson, type H.C. 7.
Fuel consumption per hour.—198.5 lbs.
Fuel consumption per b.h.p. hour.—.49 lbs.
Specific gravity of fuel.—.72.
Ignition.—Delco system. Two distributors: four contact breakers in parallel; dynamo generator, supplemented by accumulator for starting and slow running.

Firing sequence of engine.—
Left, 1, 9, 5, 11, 3, 7 } Propeller.
Right, 8, 4, 12, 6, 10, 2 }
Numbering of cylinders.—Left, 1, 2, 3, 4, 5, 6 } Propeller.
Numbering of cylinders.—Right, 1, 2, 3, 4, 5, 6 }
Speed of low tension generator.—1½ times engine speed.
Maximum ignition advance.—30°.
Inlet valve opens.—10° after T.D.C.
Inlet valve closes.—45° after B.D.C.
Inlet tappet clearance.—.015 in. (.0381 cm.).
Number of inlet valves.—One per cylinder.
Maximum lift of inlet valve.—$\frac{7}{16}$ in. (1.11 cms.).
Smallest diameter of inlet valve.—2½ ins. (6.35 cms.).
Area of inlet valve opening.—3.44 sq. ins. (22.2 sq. cms.).
Mean gas velocity through inlet valve.—177.7 ft. per sec.
Exhaust valve opens.—50° before B.D.C. (now 48°).
Exhaust valve closes.—10° after T.D.C. (now 8°).
Exhaust tappet clearance.—.020 in. (.0508 cm.) (now .019 in.).
Maximum lift of exhaust valve.—$\frac{3}{8}$ in.
Rev. counter drive rotates.—Clockwise, facing shaft on engine.
Weight of engine, minus water, fuel and oil.—820 lbs.

Weight per b.h.p., minus water, fuel and oil.—2.02 lbs.
Weight of exhaust manifold.—
Weight of oil carried in engine.—Nil.
Weight of starting gear.—
Weight of water carried in engine.—45.8 lbs. (4.58 gallons.
Weight of fuel per hour.—
Weight of oil per hour.—
Total fuel and oil weight per hour.—
Gross weight of engine in running order, minus fuel and oil.—1,083 lbs.
Weight per b.h.p. minus fuel and oil.—2.67 lbs.
Gross weight of engine in running order, plus fuel and oil for six hours.—
Weight per b.h.p. plus fuel and oil for six hours.—

In the following descriptions, the propeller end of the engine is termed the "front"; the words "right" and "left" are used on the supposition that the engine is viewed from the rear or distribution gear end.

CHAPTER I.

General Description.

CYLINDERS.

Each cylinder is formed from a steel tube, the head, barrel, flange and spigot being all in one piece. One end of the tube is closed down to form the cylinder head, and seatings for the two valves are machined in it. The holding-down flange is "jumped up" after local heating, leaving a spigot $2\frac{15}{16}$ in. deep. The water jacket is made of two sheet steel pressings, welded together: the line of the main vertical joint is at right angles to the crankshaft axis. There are further welded joints at the two valve pockets, sparking plug bosses, upper and lower water connections, camcase studs, and round the base of the jacket.

The cylinders are interchangeable, though the long and short studs supporting the camcase must be interchanged before a right-hand cylinder can be mounted in the left-hand block and *vice versâ*. (See Fig. 2.)

The holding-down flanges are drilled for ten studs apiece. Flats are cut through the two stud holes on the fore and aft sides of each flange, so that the two studs between a pair of cylinders secure both flanges. The holding-down nuts are made with circular bases of greater diameter than their hexagons.

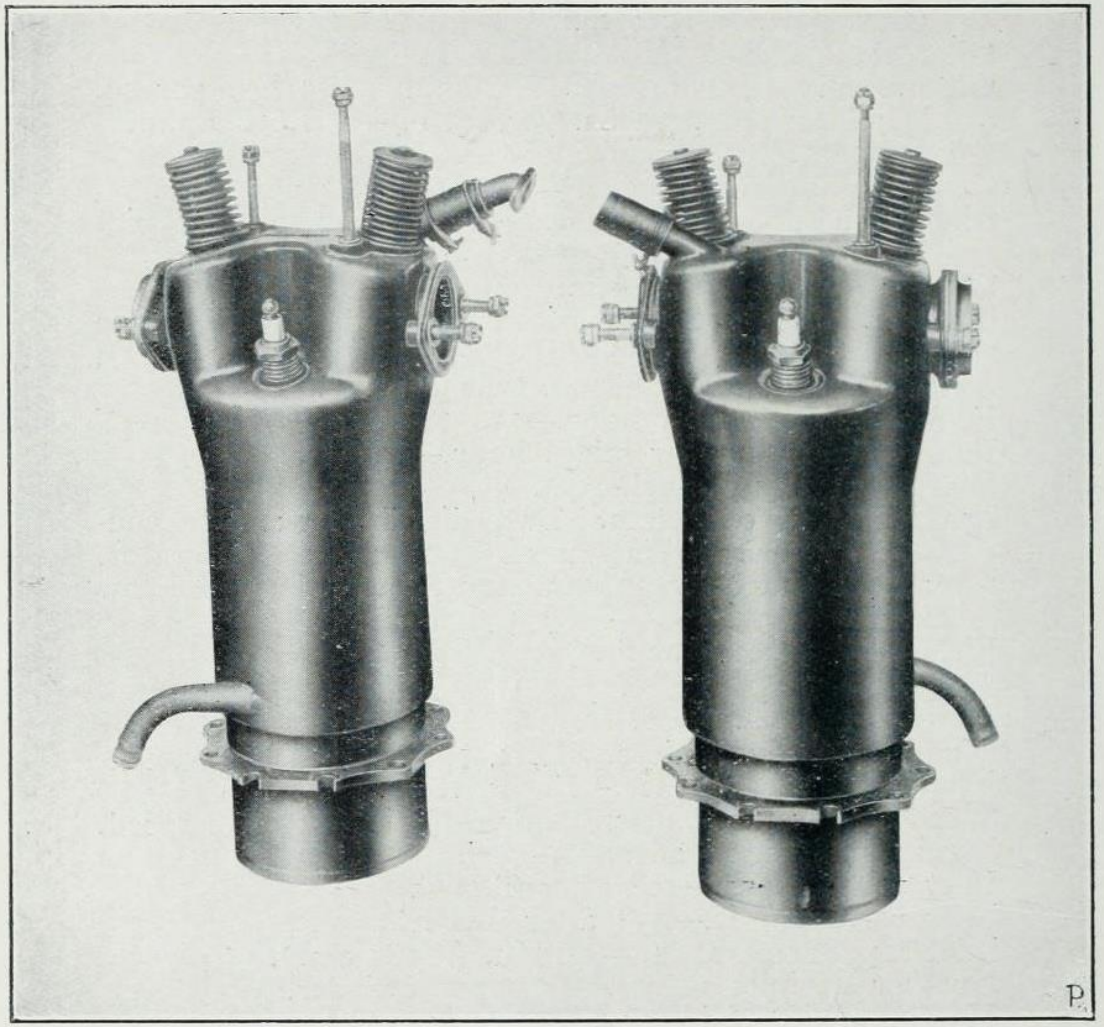


Fig. 2.

Cylinders.

Fig. 4 affords a plan view of a cylinder head, illustrating the large water space round each valve pocket and the positions of the sparking plug bosses, camcase studs, and water exit pipe: the latter is jointed by a rubber connection to a short pipe projecting from the water jacket of one of the four induction manifolds. The circumference of each cylinder jacket increases gradually towards the top of the piston stroke. The water entry connections are short pipes, curving downwards from the base of each jacket on the outside of the block.

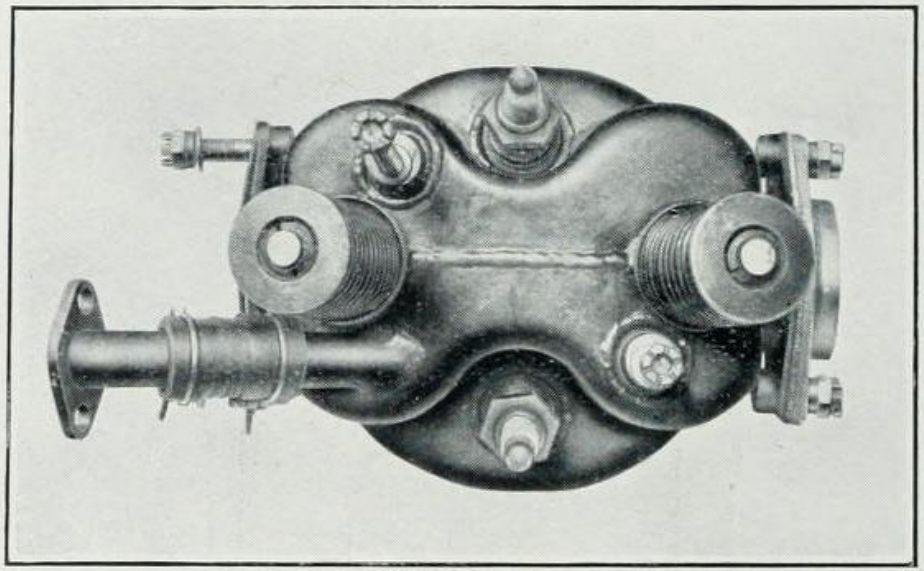


Fig. 4.
Cylinder Head (plan view).

PISTONS.

The high compression pistons (Fig. 7) are of cast aluminium alloy with externally domed tops, flattened at the centre over a circle $2\frac{3}{8}$ in. in diameter. (The low compression pistons have flat tops). There are no internal ribs, but the crown is $\frac{3}{8}$ in. thick, and the upper part of the wall tapers down towards the gudgeon pin bosses. There are three compression rings above the gudgeon pin: each ring has a diagonal gap, and a shallow circumferential oil groove is machined round the centre of its working face. No scraper rings are employed. Beneath the rings seven shallow oil grooves are machined circumferentially on the outside of the skirt, which is not drilled at any point,

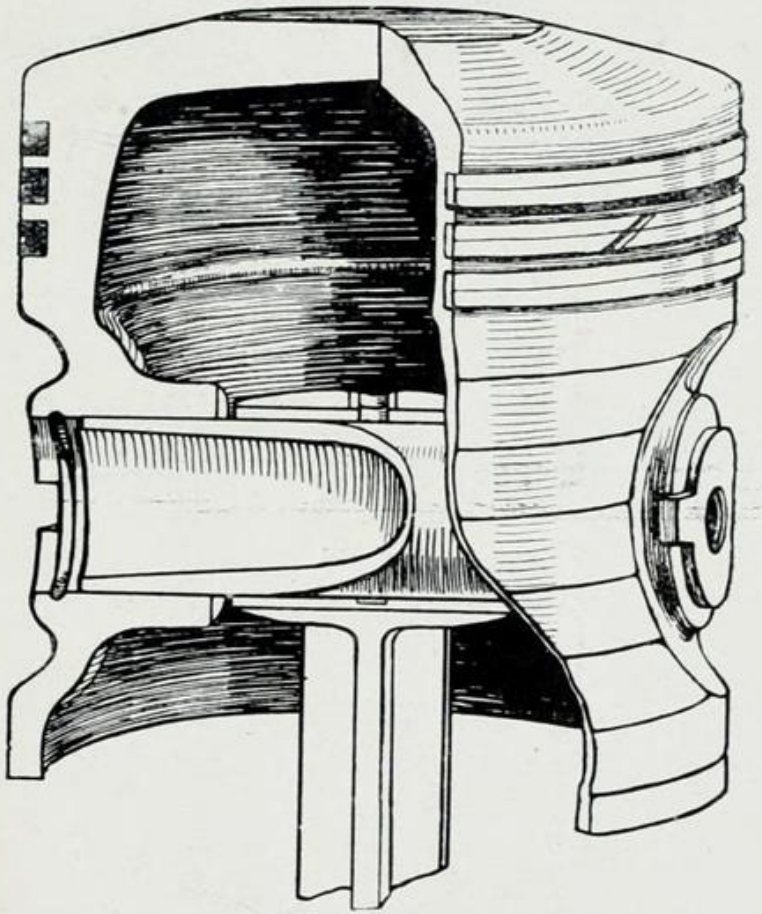


Fig. 7.

Broken View of "Army" Piston.

The hollow steel gudgeon pin is parallel-sided, and is a push fit in the bosses, which are cast on the skirt. It is located endways by the two caps shown in Fig. 8. Their outer faces are radiused to the contour of the cylinder walls, and they are positioned in the bosses by the rectangular projections shown in the photograph. They were originally fixed by spring wire clips, which have since been dispensed with. The holes in their centres are threaded to take an extractor. The gudgeon pin is allowed to float in the piston bosses and in the small end bush.

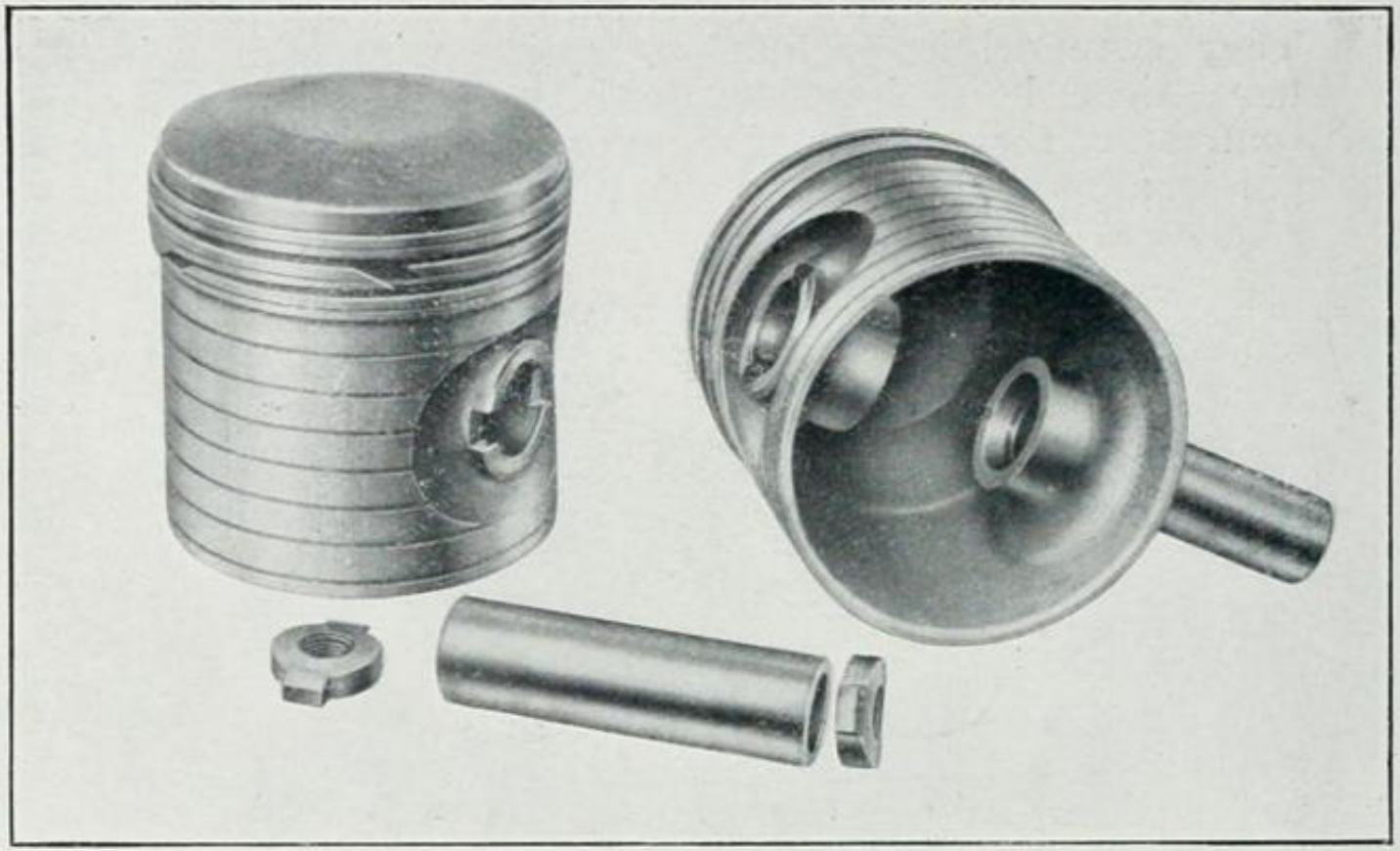


Fig. 8.
Pistons and Gudgeon Pins.

CONNECTING RODS.

The connecting rods are illustrated in Fig. 9. The forked rods may be fitted on either side of the engine, provided that they are all assembled on the same side. The forked big ends grip a split phosphor bronze shell, which is fixed in them by dowel pins, whilst annular grooves machined on its exterior locate the forked rods and prevent them from "spreading"; the caps are not bridged. The shell is lined with white metal, and works on the crank-pin in the usual way. The single rod works on the outside of the phosphor bronze shell between the forked ends of the double rod. The little ends are bushed with phosphor bronze. Details of the lubrication are given on page 36.

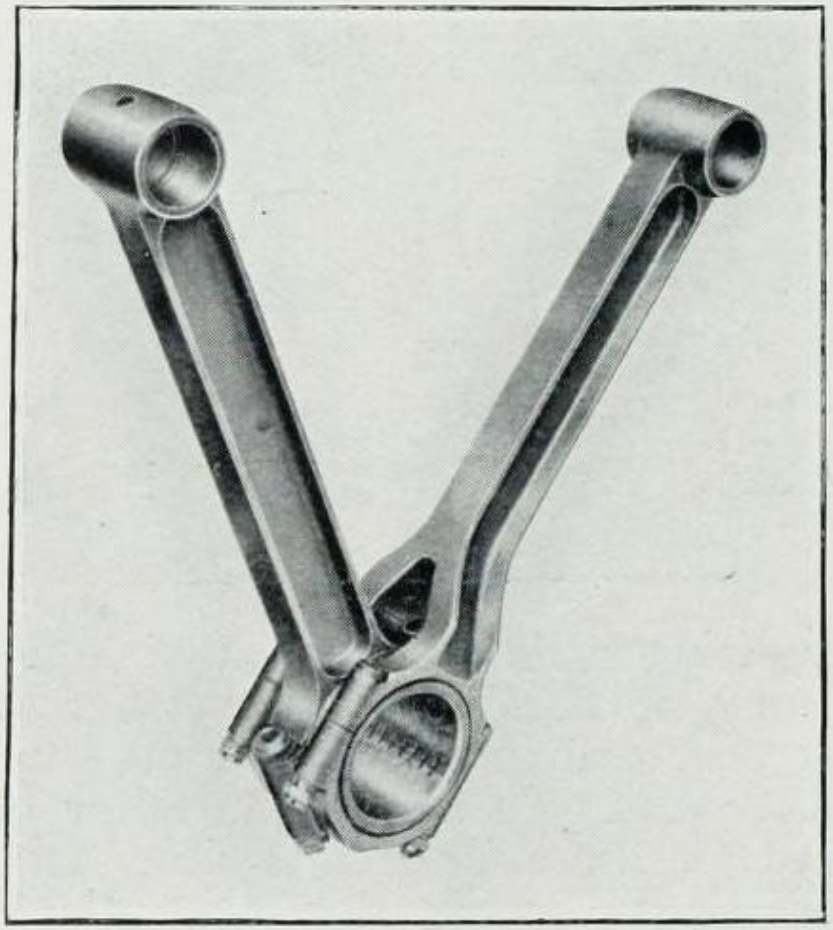


Fig. 9.
Connecting Rods.

CRANKSHAFT.

The crankshaft runs in seven bearings, consisting of horizontally split phosphor bronze shells, lined with white metal and housed in the crosswebs of the base chamber. The bearing next the propeller is 115 mm. in length, and the six rear bearings are 49 mm. long. The ends of the journals and crankpins are sealed on early engines by brass discs, soldered into position, but the standard system will consist of steel caps, drawn up by bolts. Details of the lubrication are given in Chapter II.

The main driving bevel is machined in one piece with a starting claw, and is bolted to a flange machined on the rear end of the shaft. Shims are threaded over the bolts between the flange and the bevel for the purpose of adjusting the mesh of the distribution gears. The centre of the bevel is internally splined to provide a drive for the gun interrupter gear.

Fig. 85, p. 114, illustrates in detail the double thrust bearing, which is located between the propeller hub taper and the front main bearing, and is provided with cast housings in the base chamber. Its terminal stops consist of a flange machined on the shaft, and a large flanged and castellated nut, screwing on to a thread on the shaft.

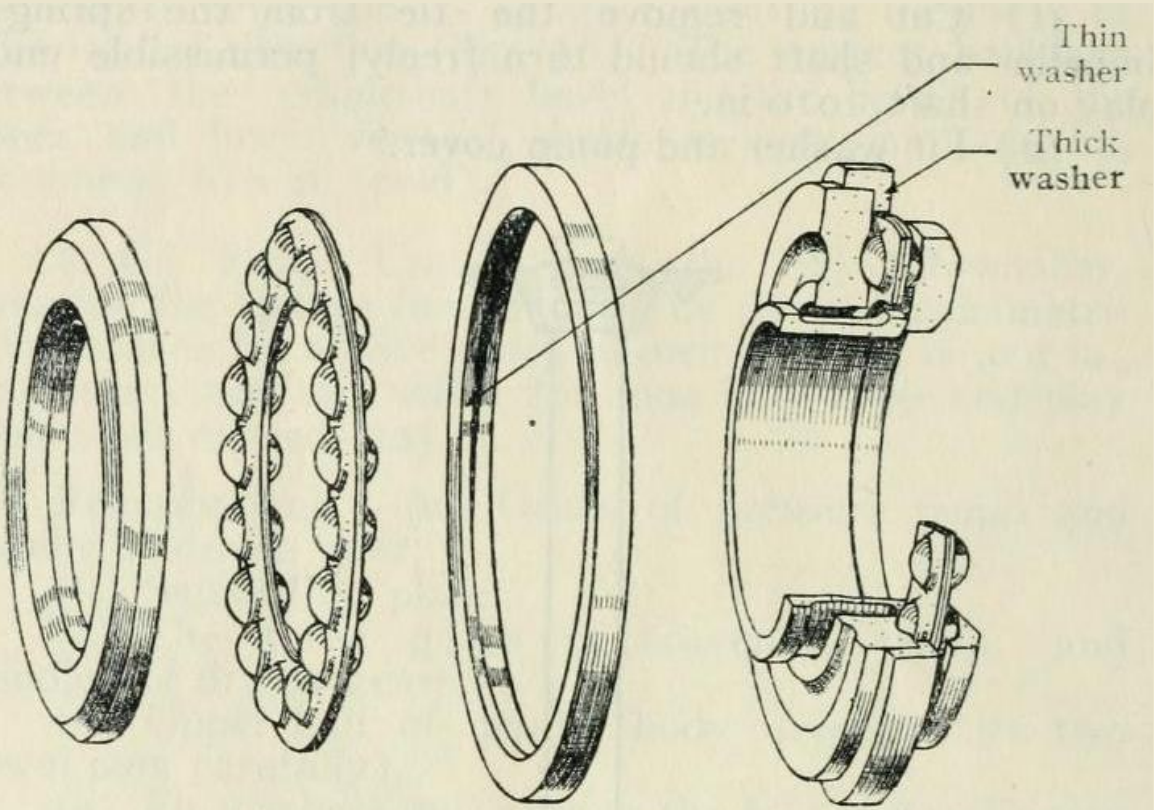


Fig. 85.

Main Thrust Bearing.

The maximum end play should not exceed .008 in. The washers locating the thrust in the crankcase are thick and thin respectively. They should be selected so that when assembled they leave .001 in. end play in the grooves in the crankcase.

The propeller hub is mounted by a taper and key in the usual way. The key is fixed by a grubscrew at its centre, fore and aft of which there are two threaded holes in the key, by means of which the grubscrew may be utilised to lift the key.

The locking device is illustrated in Fig. 77, p. 105.

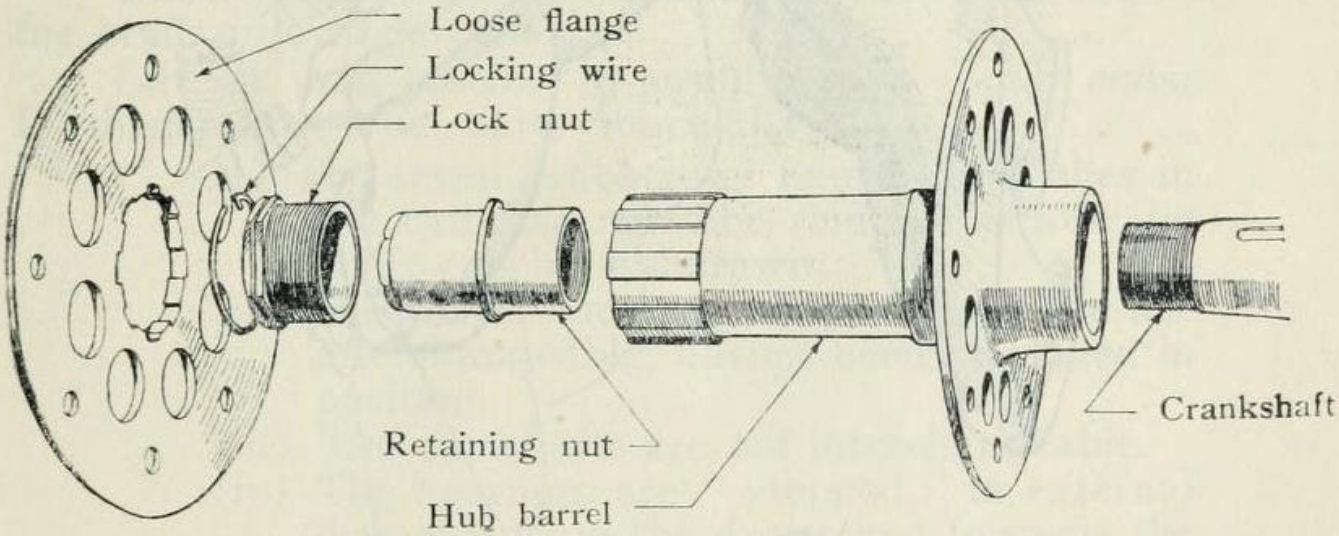


Fig. 77.

Details of Propeller Hub.

BASE CHAMBER.

The base chamber is made of two aluminium alloy castings bolted together: the horizontal joint comes at the level of the main bearing centres, as usual. There are no "feet" or bearer brackets on the upper half: its flange overhangs the lower half for the full length of both sides, and is attached direct to the engine bearers in the fuselage by seven bolts on each side. This projecting flange is stiffened by seven pairs of vertical ribs on both sides.

The main bearings are housed in the cross webs, so that the crankshaft can be freed by unbolting the sump. Similarly, the cylinders can be removed without disturbing the crankshaft.

The two parts of the base chamber are secured together by fifty small bolts distributed along the flange. In addition, eight pairs of heavy studs are fixed in the lower half along the centre line, two pairs at the front bearing, and one pair at each of the six shorter bearings; and two pairs of external bolts are employed at the extreme front and rear ends of the base chamber respectively.

The top half is cross-stiffened by eight webs, which incorporate tubular housings for the studs above mentioned. The rear web and the two nose piece webs are solid, but the other five webs have panels cut out of them. The formation of the rear end is unusual, being designed to provide a moisture-proof chamber for the ball bearings of the distribution gears. This chamber is enclosed by means of the rear wall and top end of the casting, together with solid vertical and horizontal webs. In the top of the compartment so formed there are four apertures, respectively closed (when the engine is assembled) by a breather cap, the vertical shaft, and the two inclined shafts. In the base of the compartment there are two apertures, closed respectively by the vertical shaft and the oil trap shown in Fig. 87, p. 116. This trap is kept permanently brimming with oil, which drains into it from the casings of the inclined shafts. When condensed moisture is surging about in the main base chamber under the influence of crankcase compression, it can find no entry into the distribution gear compartment, seeing that the oiltrap is sealed by oil. Thus the ball races within the compartment are protected from rust.

Two large breathers are bolted to the right-hand side of the upper half of the base chamber. An engraved plate on the rear end gives the firing sequence of the cylinders, and the name of the manufacturer.

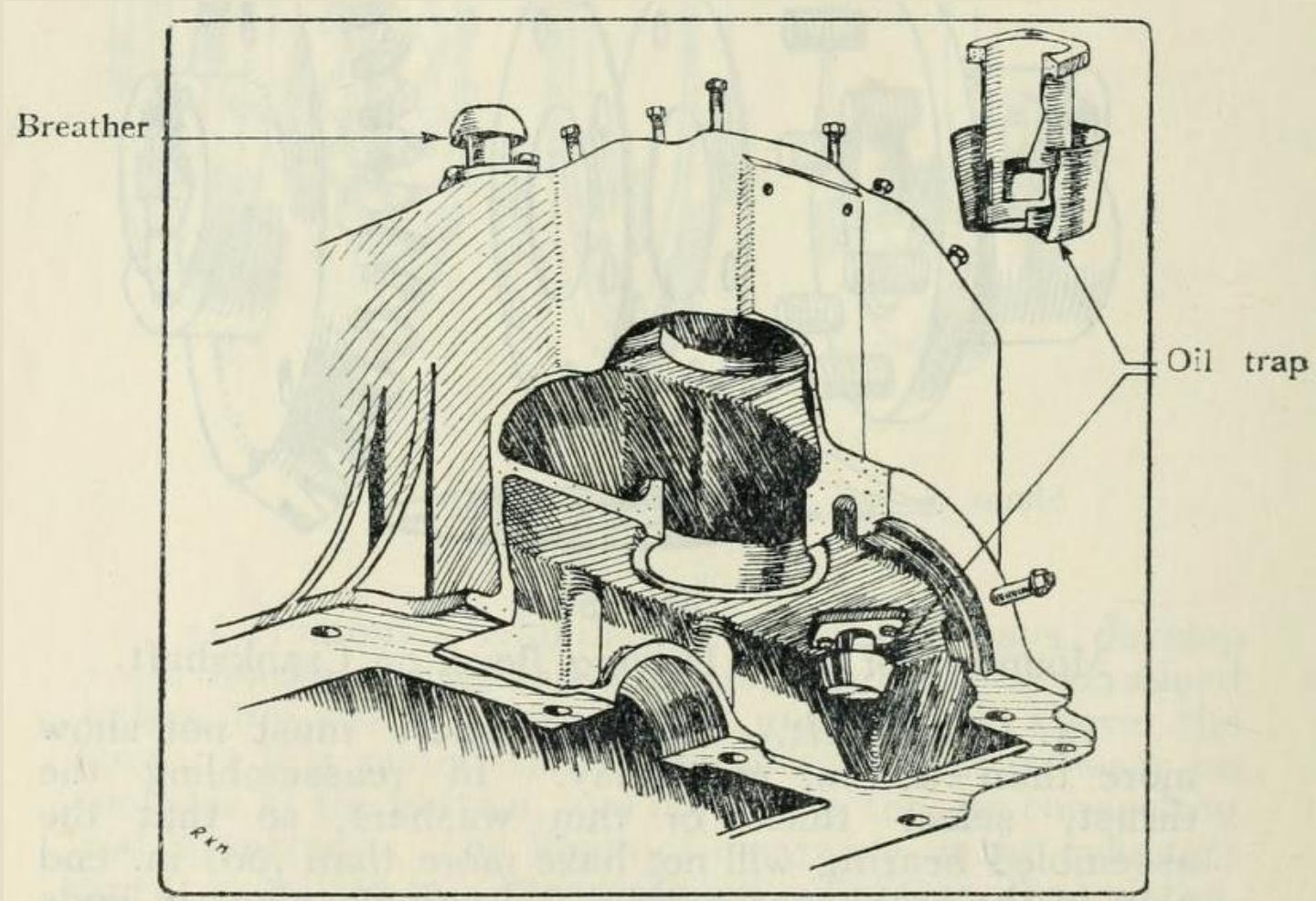


Fig. 87.
Upper Half of Crankcase (rear end), showing Oil Trap.

The lower half of the base chamber is flat-bottomed, with fore and aft oil wells. It is cast with cross webs at each of the six shorter main bearings, and its nose piece is heavily ribbed, both laterally and longitudinally, to support the front main bearing.. The lower half of the housing for the thrust race is cast in the nose piece. Towards the rear the casting is given an approximately rectangular section, and houses the drive for the oil and water pumps. The base of the sump is cast with a narrow trough to accommodate the main pressure oil pipe and the oil return pipe from the front oil well.

The lower halves of the main bearings are housed in the cross webs, as stated above, and are not slung in caps from bolts.

A cylindrical housing for the plain bearing of the lower vertical shaft is cast as part of the lower half at the rear end, immediately below the main crankshaft bevel. The water pump unit is bolted to the rear end of the sump, and driven by bevel gearing off the lower vertical shaft. A splined extension of this shaft drives the oil pumps, the oil pump unit being bolted beneath the rear end of the sump.

Two straight steel oil pipes are inserted from the rear end, and pushed through housings in the bases of the cross webs. The right-hand pipe is the main supply pipe, and communicates with the bottom centre of each main bearing by means of a steel pipe screwed vertically into each web; the supply for the camshaft is taken from the front main bearing through a lead in the upper half of the base chamber. Screwed plugs at either end facilitate the cleaning of the main pressure pipe: the forward plug is beneath the sump; the rear plug is visible when the pump unit is dismounted. The left-hand pipe connects the forward oil well to the scavenging pump in the rear oil well. The front oil well contains a filter: its cover is secured by a spring clip.

A felt oil-retaining washer is fitted at the front of the nose piece.

The circular orifice opposite the rear end of the crankshaft may be closed by a coverplate if a gun interrupter gear or mechanical starter are not fitted.

VALVES.

There are two valves per cylinder, working in cast iron guides pressed into the valve pockets. The valve stems are inclined towards the cylinder axis at 13½°, the exhausts being on the outside of each cylinder block, and the inlets on the inside. The camcase is accommodated within the included angle. All the valves are interchangeable, their smallest diameter measuring 63.5 mm.

Double concentric coiled springs are fitted. The inner springs are interchangeable. The outer springs of the inlet valves are longer than the corresponding exhaust springs, which are of stouter gauge. A female taper in the upper spring cap presses a pair of internally shouldered split cones against three annular grooves machined on the valve stem.

CAMSHAFTS AND VALVE GEAR.

The camshafts are not interchangeable, and are marked "R" and "L" respectively. The camcases are interchangeable.

They are machined in one piece, and drilled for pressure lubrication, of which details are printed on p. 37. The driven bevel pinions are bolted to flanges on the rear ends of the shafts. Notched flanges or "hubs," secured to these studs behind the bevel pinions, drive the rotating portions of the distributor heads.

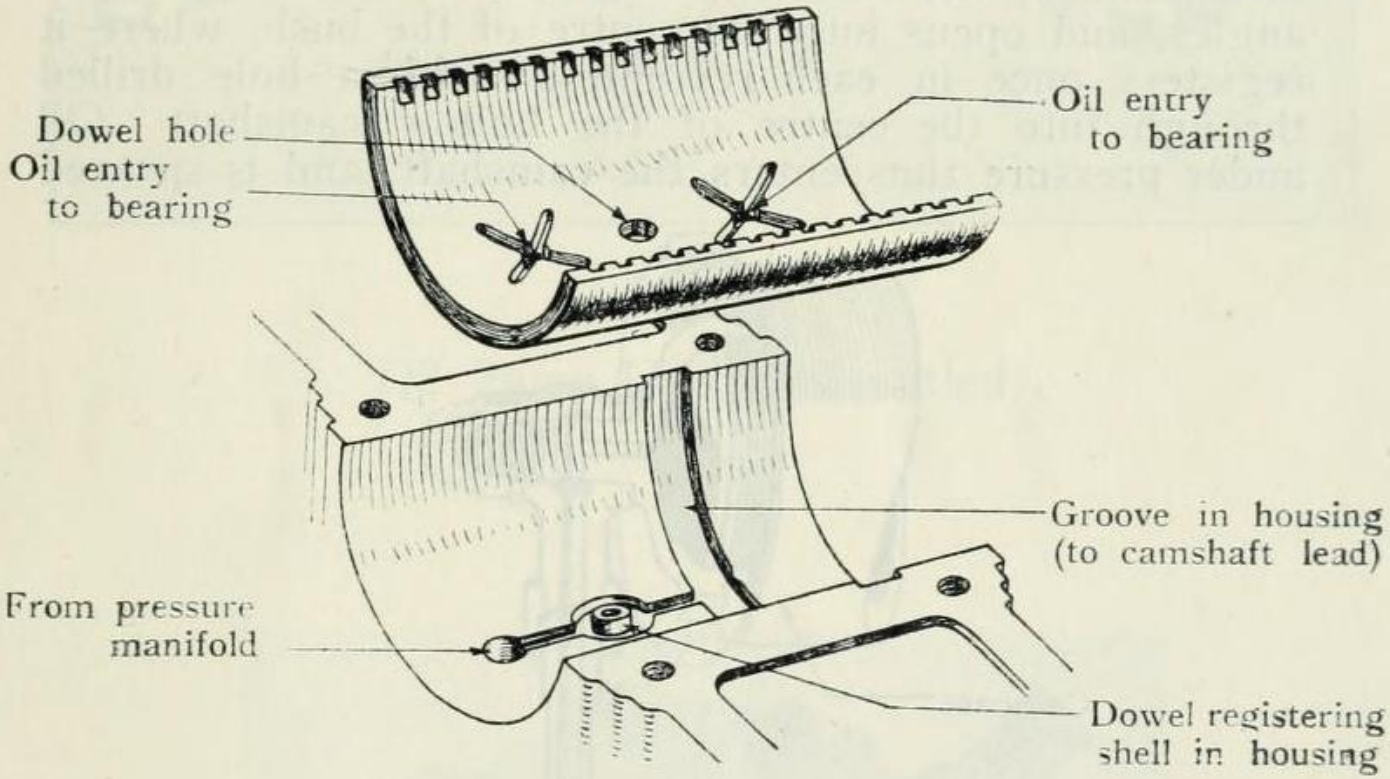
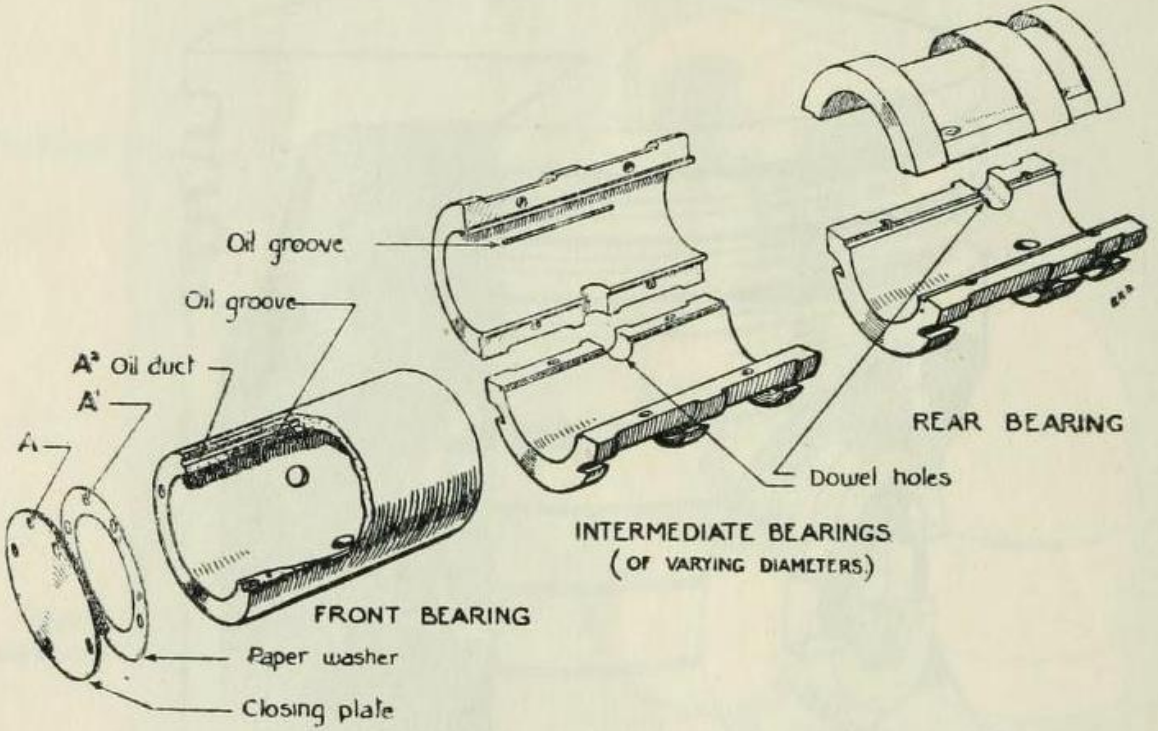


Fig. 31. (p. 37)

Front Main Bearing, showing oil leads.
Top: Bearing shell.
Bottom: Bearing housing.

Each camshaft runs in seven bushes (see Fig. 81, p. 110), which are a driving fit in the camcase. They are "stepped" in outside diameter, that at the rear end being the largest, the next $\frac{1}{32}$ in. smaller, etc. The five intermediate bearings are cast in aluminium; they are horizontally split, assembled by screws, and located in the camcase by large grubscrews entered from the side. The front bearing of each shaft is a one-piece cylindrical bush of aluminium: the oil supply enters the camshaft by this bush, as described on page 38. The rear bearing is of special pattern, as illustrated in Fig. 81. It consists of two phosphor bronze shells, lined with white metal, and is mounted between two flanges machined on the shaft, so as to take the thrust.



A and A1—oil holes in plate and washer, to be registered with oil duct A2 in bush.

Fig. 81.

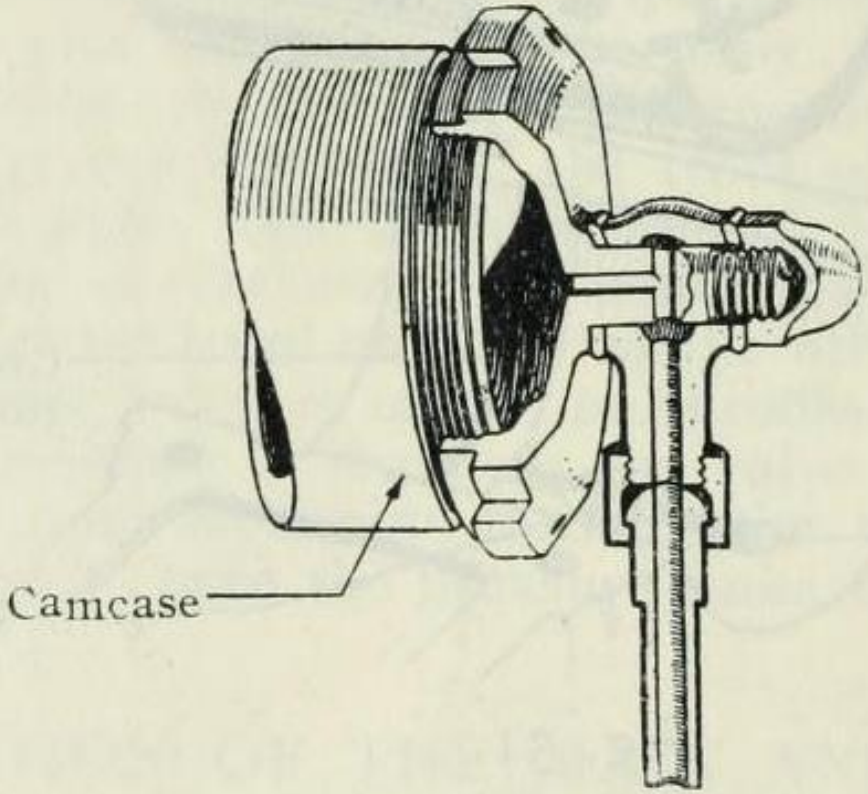


Fig. 32. (p. 38)
Oil Connection to Camshaft.

A camcase is illustrated in Fig. 20. It is an aluminium alloy casting, of tubular section between each pair of cylinders, and widening into approximately rectangular compartments with detachable lids over each cylinder head. It is secured to each cylinder head by a couple of studs.

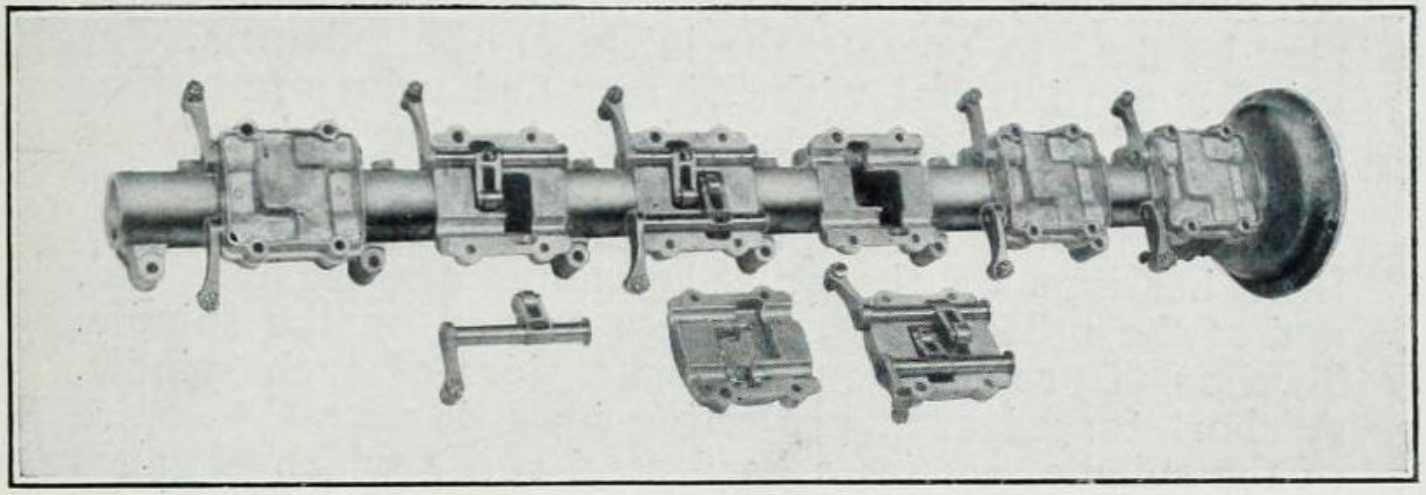


Fig. 20.

Camcase.

The inlet and exhaust rockers are machined from steel forgings, different in shape for the right- and left-hand sides of the cylinders, though either shape may be used to operate the inlets or the exhausts. The spindles are integral with the cam and valve arms. The lower half of each rocker spindle bearing is machined in the camcase, and the upper half in one of the removable lids. The spindles are located endways in their bearings by the valve-actuating arm at one end, and at the other end by a flange turned on the spindle. Two arms project from opposite sides of each spindle. A short forked arm, projecting inwards near the centre of the spindle, carries a hard steel roller which engages the cam. A longer arm, projecting from the end of the spindle, carries an adjustable bolt which actuates the valve. The bolt has a square on it, which is a loose fit in a square hole at the outer end of the arm: the bolt is packed to the height required for correct valve clearance by means of shim washers, and is then locked by a castellated nut and split pin. The engines are delivered with three shims of different thicknesses threaded on each bolt.

DISTRIBUTION GEAR.

Fig. 22 is a diagram of the general layout of the distribution gears. The main bevel on the crankshaft drives upper and lower vertical shafts. The upper vertical shaft drives the two inclined shafts which form the camshaft drives; and its splined extension drives the low tension generator. The lower vertical shaft drives the horizontal water pump shaft through bevel gearing, and its splined extension drives the oil pumps. These transmissions are next described in closer detail.

The mesh of the main crankshaft bevel can be adjusted by means of shims threaded over the bolts by which it is secured to the flange on the crankshaft.

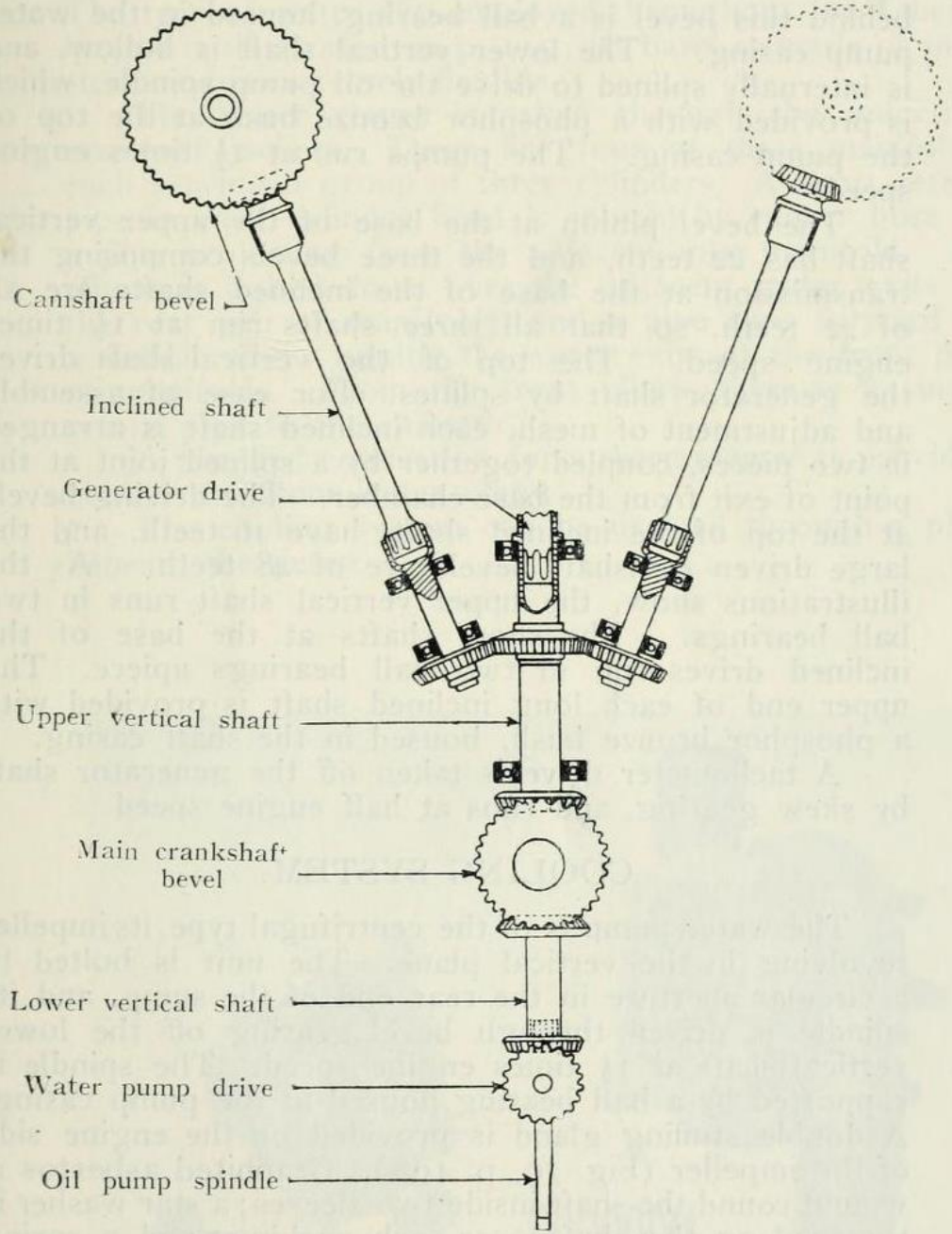


Fig. 22.
Diagram of Distribution Gear.

The lower arc of the main crankshaft bevel (33 teeth) meshes with the upper bevel (22 teeth) of the lower vertical shaft. This lower shaft is made in one piece with its top and bottom bevels, and runs in a split phosphor bronze bush, held in aluminium housings, which are mounted in a cylindrical lug cast in the base-chamber. Provision is made for oil to drain down through this bearing. The bottom bevel (21 teeth) of the lower vertical shaft drives another bevel (21 teeth) on the front end of the horizontal water pump shaft: behind this bevel is a ball bearing, housed in the water pump casing. The lower vertical shaft is hollow, and is internally splined to drive the oil pump spindle, which is provided with a phosphor bronze bush at the top of the pump casing. The pumps run at $1\frac{1}{2}$ times engine speed.

The bevel pinion at the base of the upper vertical shaft has 22 teeth, and the three bevels composing the transmission at the base of the inclined shafts are all of 22 teeth, so that all three shafts run at 1½ times engine speed. The top of the vertical shaft drives the generator shaft by splines. For ease of assembly and adjustment of mesh, each inclined shaft is arranged in two pieces, coupled together by a splined joint at the point of exit from the base chamber. The driving bevels at the top of the inclined shafts have 16 teeth, and the large driven camshaft bevels are of 48 teeth. As the illustrations show, the upper vertical shaft runs in two ball bearings. The short shafts at the base of the inclined drives run in two ball bearings apiece. The upper end of each long inclined shaft is provided with a phosphor bronze bush, housed in the shaft casing.

A tachometer drive is taken off the generator shaft by skew gearing, and runs at half engine speed.

COOLING SYSTEM.

The water pump is of the centrifugal type, its impeller revolving in the vertical plane. The unit is bolted to a circular aperture in the rear end of the sump, and its spindle is driven through bevel gearing off the lower vertical shaft at 1½ times engine speed. The spindle is supported by a ball bearing housed in the pump casing. A double stuffing gland is provided on the engine side of the impeller (Fig. 79, p. 108). Graphited asbestos is wound round the shaft inside two sleeves; a star washer is threaded on the shaft over each packing, and a spring between the washers keeps the packings compressed; the projections of the washers engage slots in the sleeves.

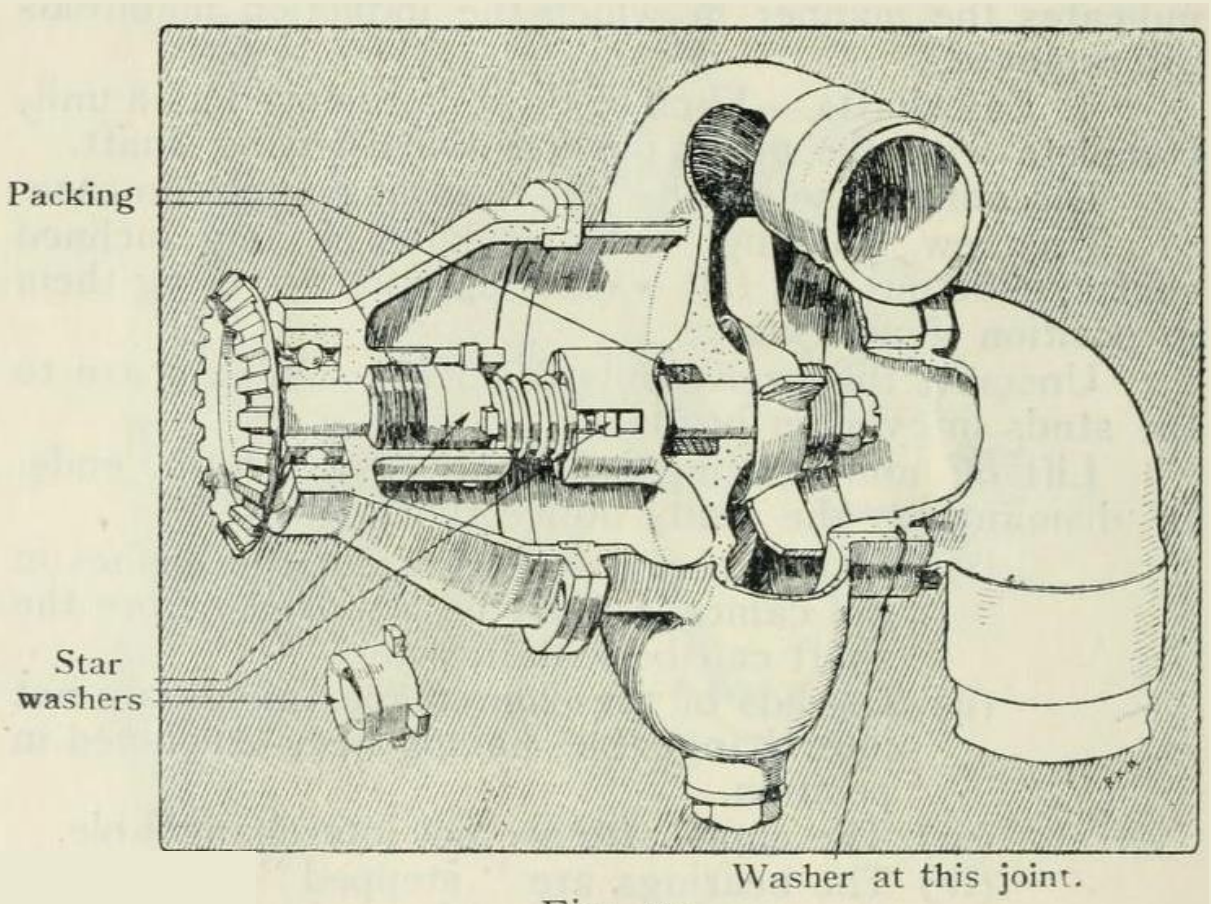


Fig. 79.
Water Pump Unit.

Supply pipes run from the two delivery ports of the water pump towards the right- and left-hand sides of the base-chamber respectively, and are coupled by rubber connections to long water manifolds, lying along each side of the engine below the cylinder base level. The main pipes of these manifolds are tapered towards the front of the engine; short branch pipes project upwards, and are jointed to rubber connections by stub pipes curving downwards from the base of each cylinder jacket. The type of water clip employed throughout the Liberty engine is illustrated on p. 119: its band is made of mild steel, and is extremely flexible.

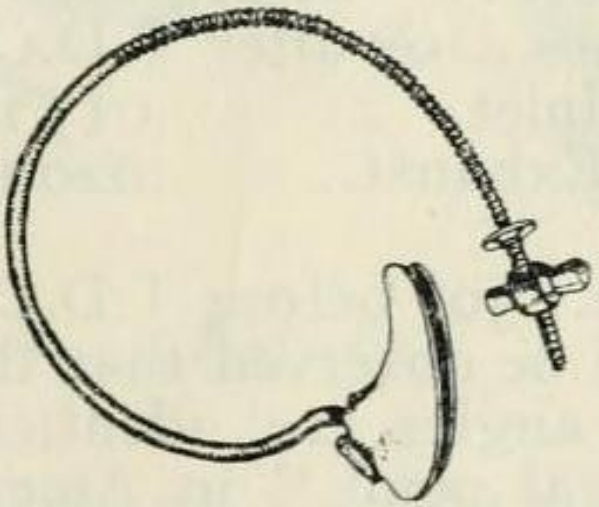


Fig. 89. (p. 119)
Water Joint Clip.

The water return is taken through the induction manifold jackets. There are four of these manifolds, each serving a group of three cylinders. A short return pipe in each cylinder head is jointed by rubber hose to a pipe projecting from the adjacent inlet manifold. An elbow is bolted down over the adjacent water exits of the rear pair of manifolds, and a pipe runs forward to a similar elbow uniting the water exits of the front pair of manifolds. From the front elbow there is a single return pipe to the radiator.

A plugged connection for a thermometer is provided behind the front water elbow.

The cooling system can be drained through a plug beneath the pump.

STARTER.

At the moment of going to press an electric starting motor has been adopted for the Liberty engine. A special handbook of instructions for its use and maintenance will be issued in due course.

Lubrication.

CHAPTER II.

The lubrication system is simple in outline, but demands somewhat lengthy description, as some of the individual units are complex. A large pump unit, consisting of a three-pinion duplex scavenge pump mounted above a pressure pump, is assembled in a casing bolted beneath the rear end of the sump. Both pumps are driven by a spindle which is jointed by splines to the lower vertical shaft. The supply pump forces oil under pressure along a manifold in the sump, which serves all the main bearings. A lead from the front main bearing conducts oil to a three-way branch at the front of the base chamber, whence three pipes are connected to the pressure gauge and the front ends of the two camshafts respectively. The oil drains back to the sump down the casings of the two inclined drives, lubricating the bearings and pinions of the distribution gears on its way. The pistons and gudgeon pins are lubricated by splash.

The double scavenging pump is located in the pump unit beneath the oil well at the rear end of the flat-bottomed sump, and is connected by a pipe in the sump to the oil well at the front end. Both oil wells are provided with filters, and their respective deliveries meet in a common return pipe to the tank.

A detailed description of the various components follows:—

OIL PUMPS.

It may be found difficult to grasp all the details of the pump until it has actually been dismantled; it is plentifully illustrated by sectioned and perspective drawings in Figs. 24-29. The diagram in Fig. 25 and the sectioned perspective in Fig. 24 are the simplest to study, when the actual pump is not available.

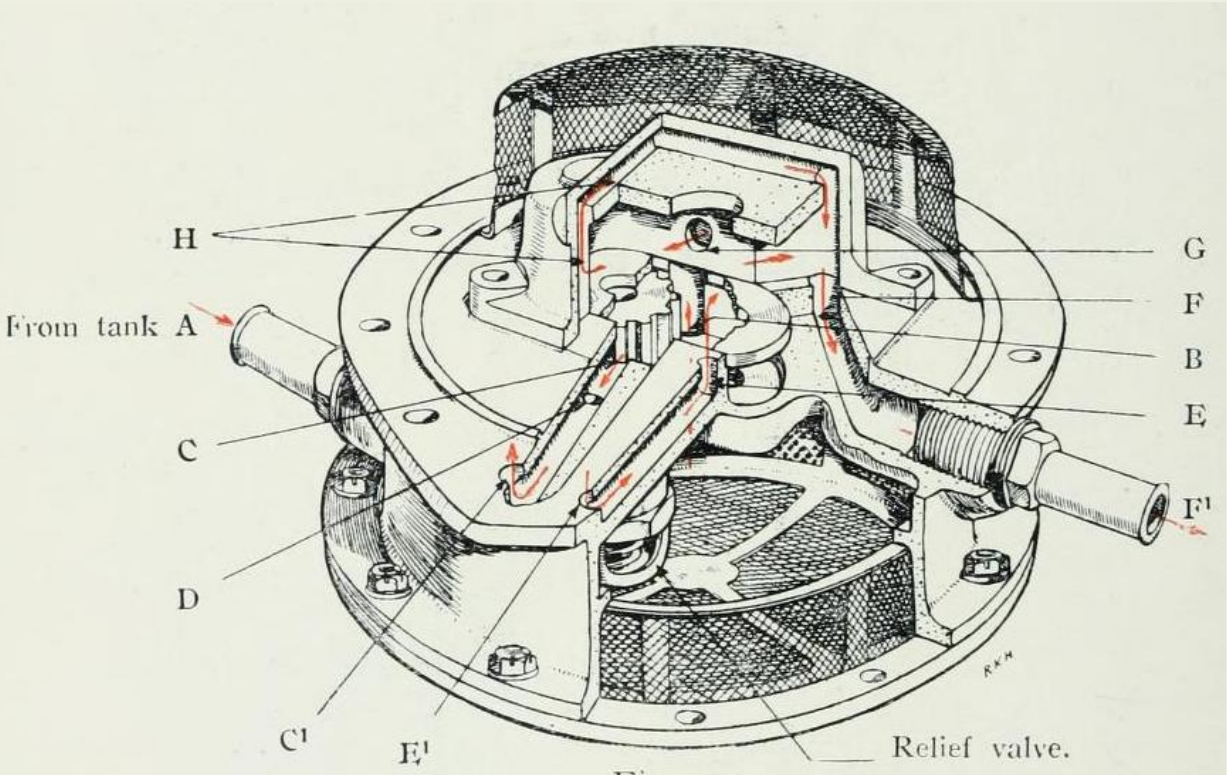


Fig. 24.

Broken View of Oil Pump Unit.

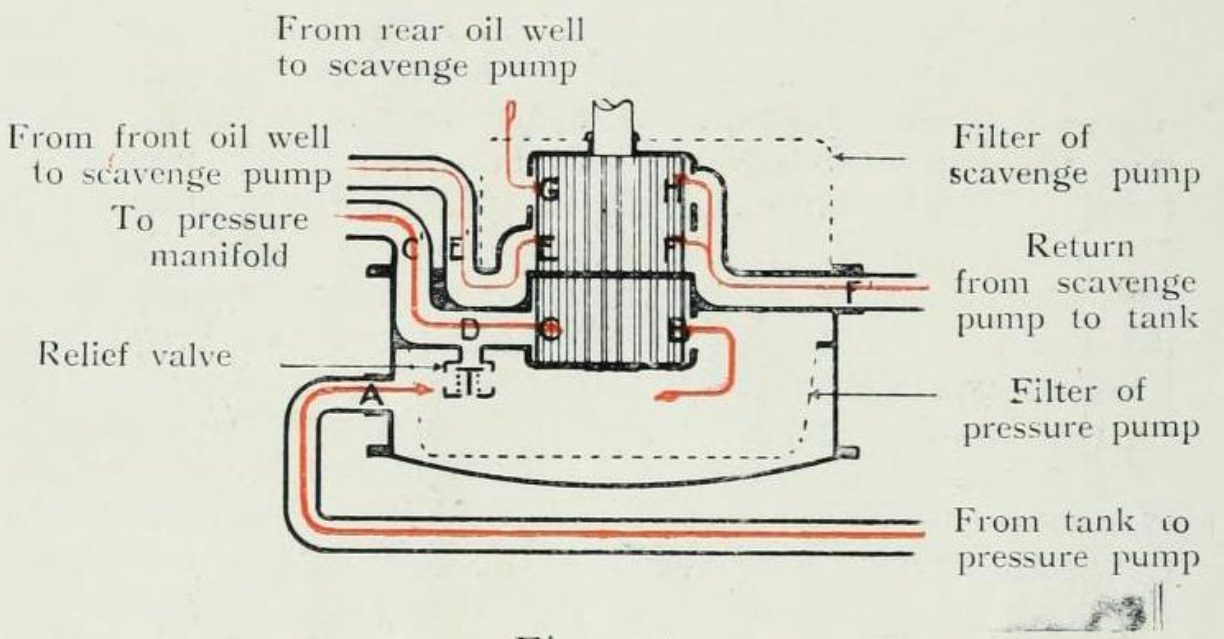


Fig. 25.

Diagram of Oil Pump unit, showing leads.

(N.B.—This sketch is purely diagrammatic.)

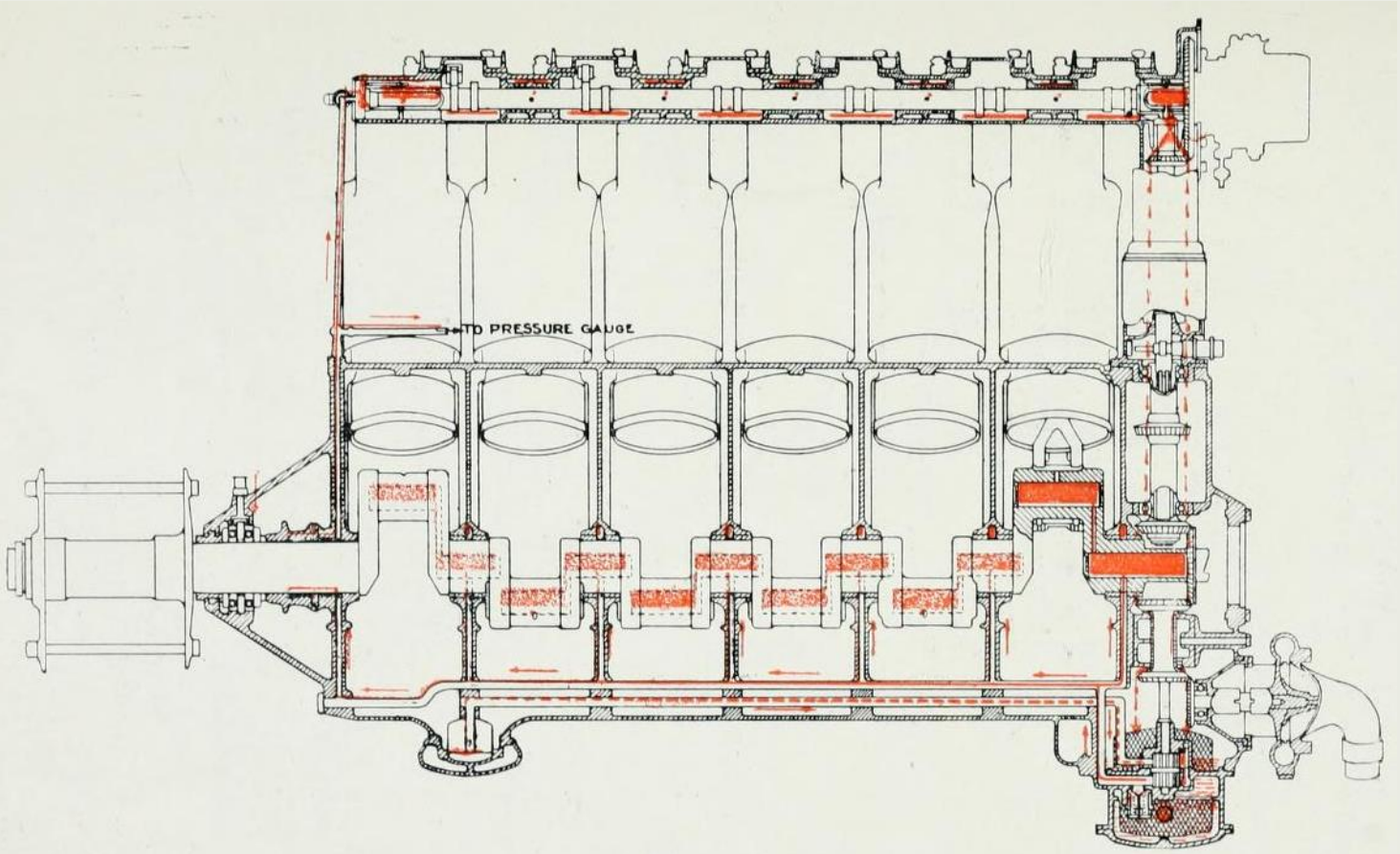


Fig. 26.
Diagram of Lubrication System. (Purely diagrammatic).

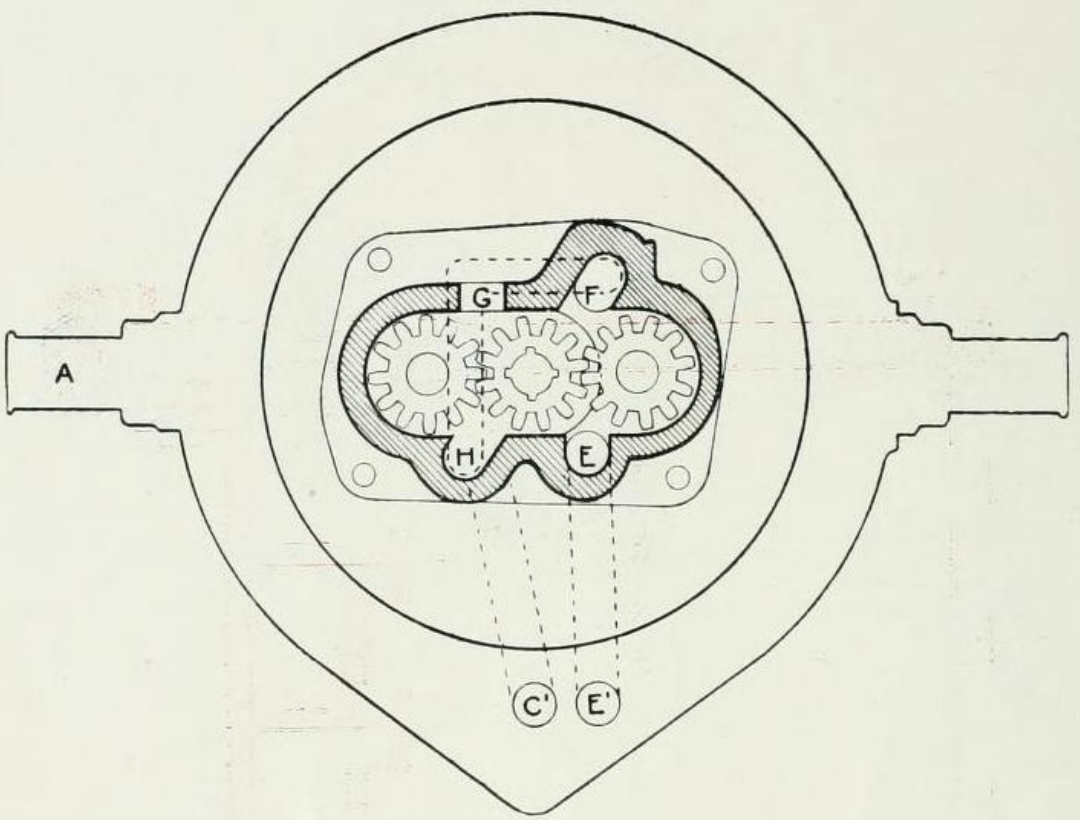


Fig. 27.

Plan View of Scavenge Pumps.

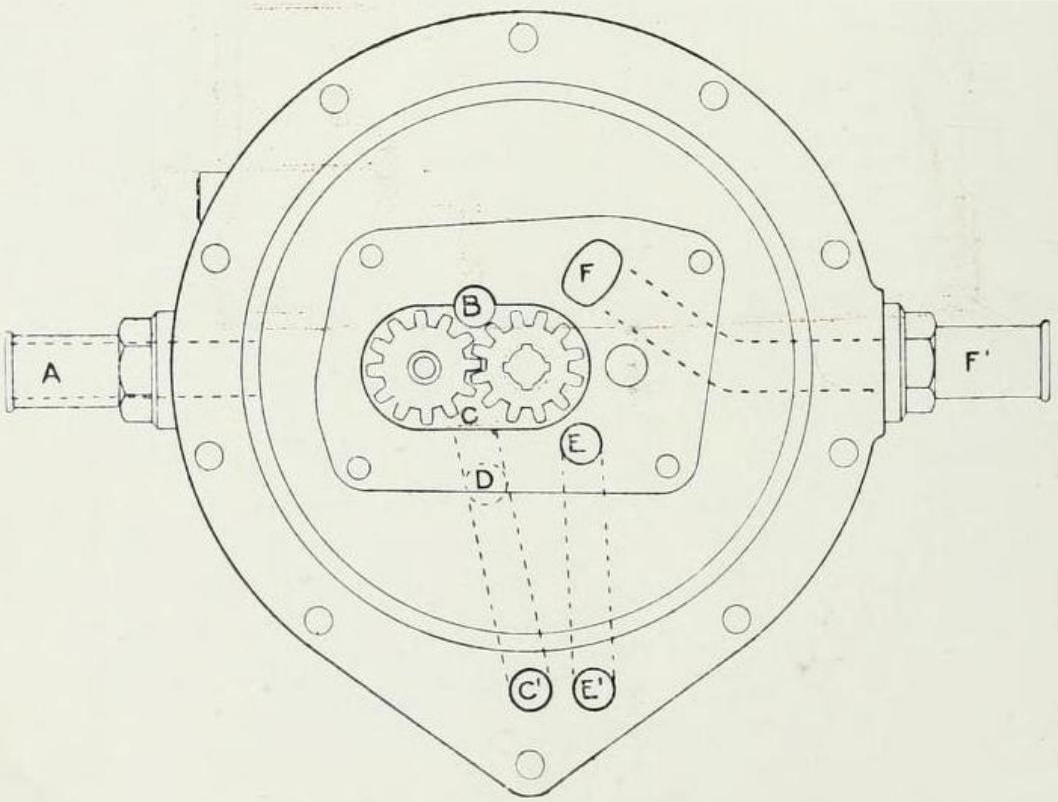


Fig. 28.

Plan View of Pressure Pump.

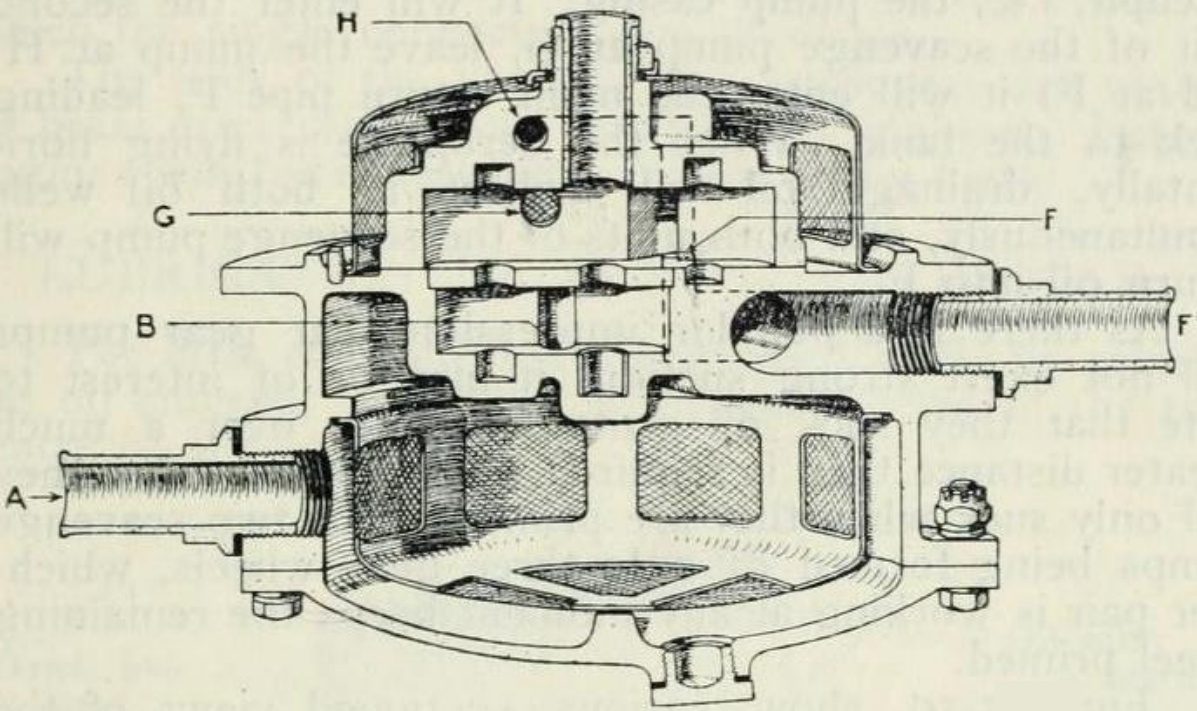


Fig. 29.

Cross Section of Pump Unit

(showing rear half).

As the section in Fig. 24 shows, the double scavenge pump and single pressure pump, together with the filters and relief valve, are accommodated in a casing, which is bolted beneath the rear end of the sump; the main pressure pipe and the return pipe from the front catchpit are connected to the pumps via ducts drilled in the pump casing. At the top of the unit is a phosphor bronze bush, in which the driving spindle runs. The spindle drives the centre pinion of the scavenging pump, and passes through a steel partition into the driven pinion of the lower or pressure pump. The loose gears are mounted on steel spindles fixed in the casing. The oil is filtered before entering either pump: the upper filter is locked in position by a nut and tab washer: the lower filter is secured by the bottom cover. The relief valve is situated immediately outside the delivery port of the pressure pump.

Fig. 25 is purely diagrammatic, and does not show the actual disposition of the various parts and leads. At A the supply pipe from the tank enters the filter chamber surrounding the lower or pressure pump, into which the oil passes at B. Oil under pressure emerges from the pump at C, and enters the sump pressure manifold at C1, passing on its way the relief valve D.

Turning to the scavenge pump, it must be remembered that the sump is flat-bottomed, and that when the aeroplane is diving or climbing, the drainage oil will run exclusively into the front or rear oil well. The scavenge pump consists of three pinions, driven by the centre gear. It is therefore the equivalent of two separate pumps, each composed of two gears: as its gears have deeper teeth than the gears of the pressure pump, each of its units is singly more powerful than the supply pump.

If the aeroplane is diving, the drainage oil collecting in the front catchpit will be sucked along the pipe E1 (Fig. 25), and enter one unit of the upper or scavenging pump at E. The pump will deliver it into the main return pipe to the tank at F. On the other hand, if the aeroplane is climbing, the oil will drain into the rear catchpit, i.e., the pump casing. It will enter the second unit of the scavenge pump at G, leave the pump at H, and at F1 it will enter the main return pipe F, leading back to the tank. When the aeroplane is flying horizontally, drainage oil will collect in both oil wells simultaneously, and both units of the scavenge pump will return oil into F.

As there is a popular impression that gear pumps will not exert strong suction, it may be of interest to state that they suck oil quite efficiently over a much greater distance than is required in this engine: but they will only suck when they are primed. The two scavenge pumps being formed of only three gear wheels, whichever pair is working at any moment keeps the remaining wheel primed.

Figs. 27-30 show various sectioned views of the pump, indicating the details of the various components and ducts with accuracy. The only point requiring further mention is the lead between the delivery port of the pump unit scavenging the front oil well, and the main return pipe: this lead consists of a duct machined in the casing of the scavenge pump, crossing over the top of the pump from one side to the other.

The relief valve is of the mushroom type; when an excessive pressure is reached, the valve is forced from its seating, and oil drains through the valve box back into the casing, until the pressure sinks to the normal.

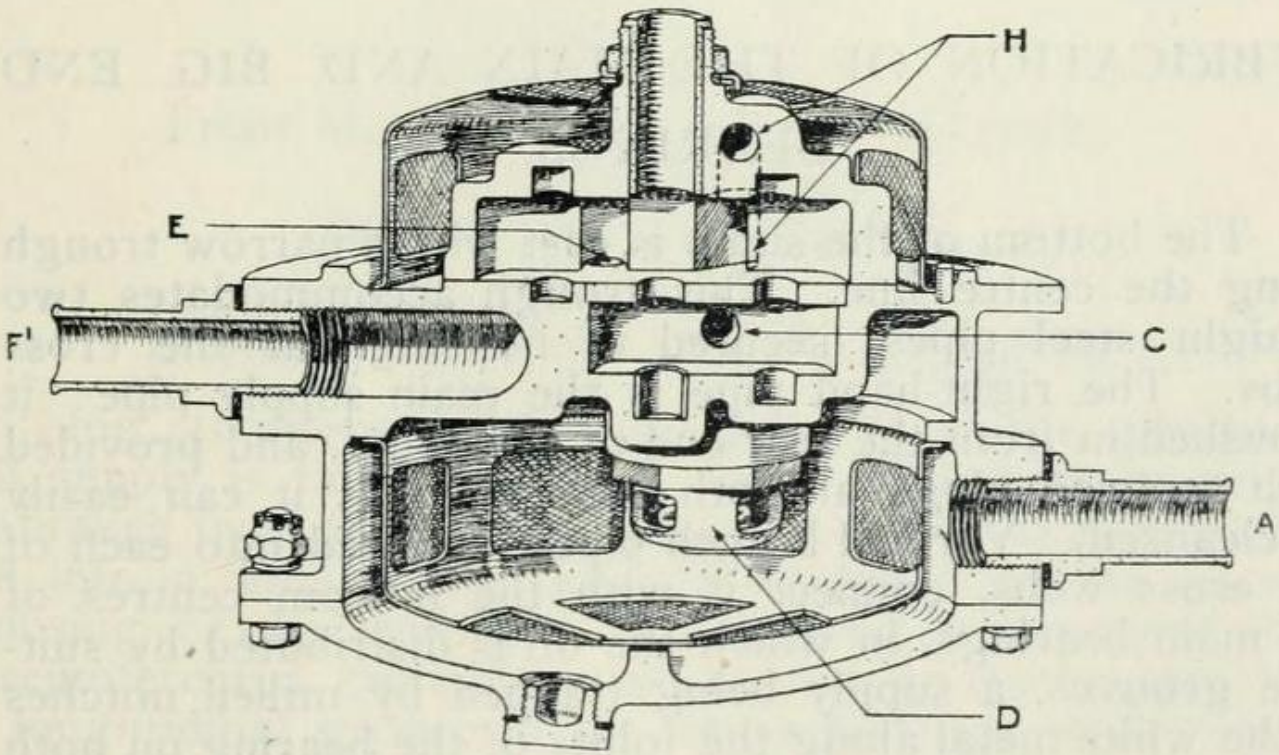


Fig. 30.

Cross Section of Oil Pump Unit

(showing front half).

LUBRICATION OF THE MAIN AND BIG END BEARINGS.

The bottom of the sump is cast with a narrow trough along the centre line. This trough accommodates two straight steel pipes, secured in housings at the cross webs. The right-hand pipe is the main supply pipe: it is pushed in from the rear end of the sump, and provided with screwed plugs at both ends, so that it can easily be cleansed. Vertical branch pipes, screwed into each of the cross webs, connect it with the bottom centres of the main bearings, in which the oil is distributed by suitable grooves, a supply being trapped by milled notches in the white metal along the joints of the bearing on both sides. At each bearing some of the oil enters the crankshaft through a suitable hole, travels up the rear web of the throw into the crank-pin, and is forced out of another hole into the big end bearing. Suitable grooves distribute oil over the crank-pin bearing, and four holes, spaced out at 90°, allow oil to penetrate to the centre of the outer circumference of the bush, on which the single connecting rod oscillates.

The ends of the journals and crank-pins are sealed by brass discs, tinned and sweated into position. Future engines will have steel plugs drawn up by bolts.

LUBRICATION OF THE GUDGEON PINS.

The little end bushes are lubricated solely by splash, the oil entering through a large hole drilled in the top centre of the little end.

LUBRICATION OF THE CAMSHAFTS.

Fig. 31 illustrates the manner in which the camshaft oil supply is taken from the front crankshaft bearing. A branch from the pressure manifold in the sump delivers oil into a longitudinal groove machined in the lower housing of the bearing. This groove is connected by circumferential grooves on both sides of the bearing to a longitudinal groove in the upper housing, which conducts the oil back to a vertical lead in the web of the base chamber. Through this lead the oil reaches a three-way connection on the top of the base chamber, from which pipes are led to a pressure gauge and to the front ends of the two camshafts respectively.

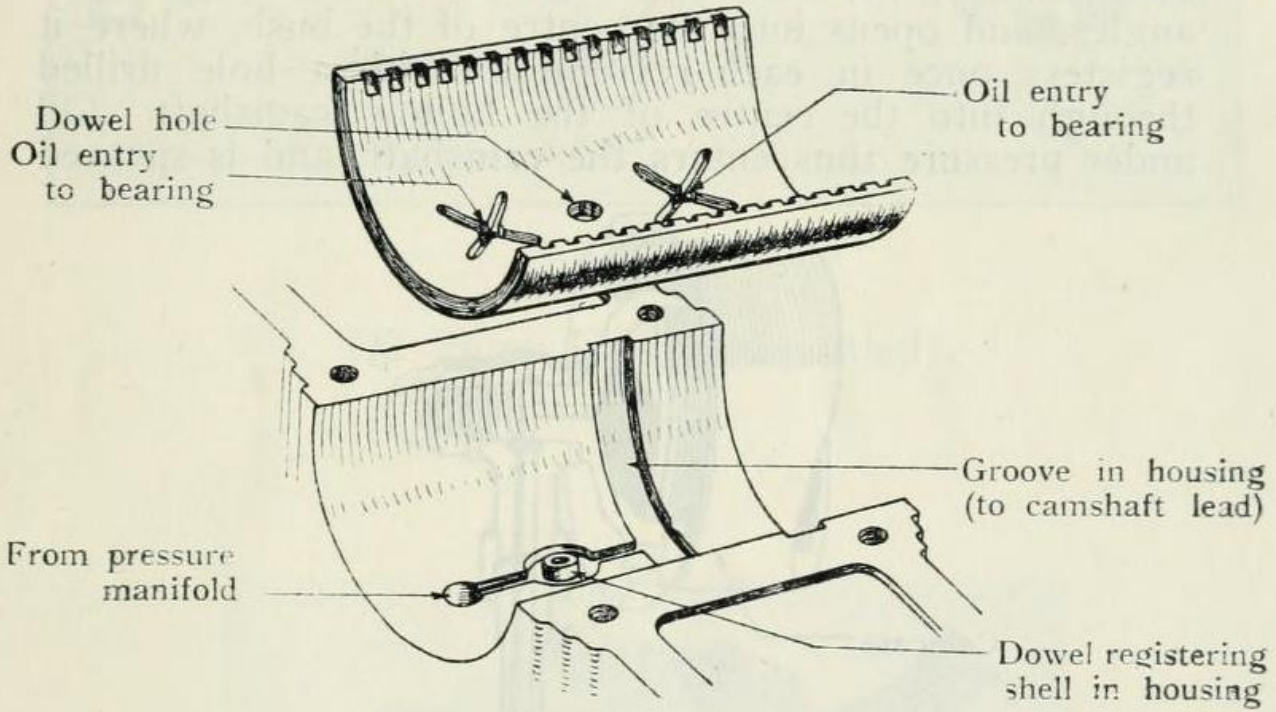


Fig. 31.

Front Main Bearing, showing oil leads.
Top: Bearing shell.
Bottom: Bearing housing.

Fig. 32 indicates how the oil supplies enter the camshafts.

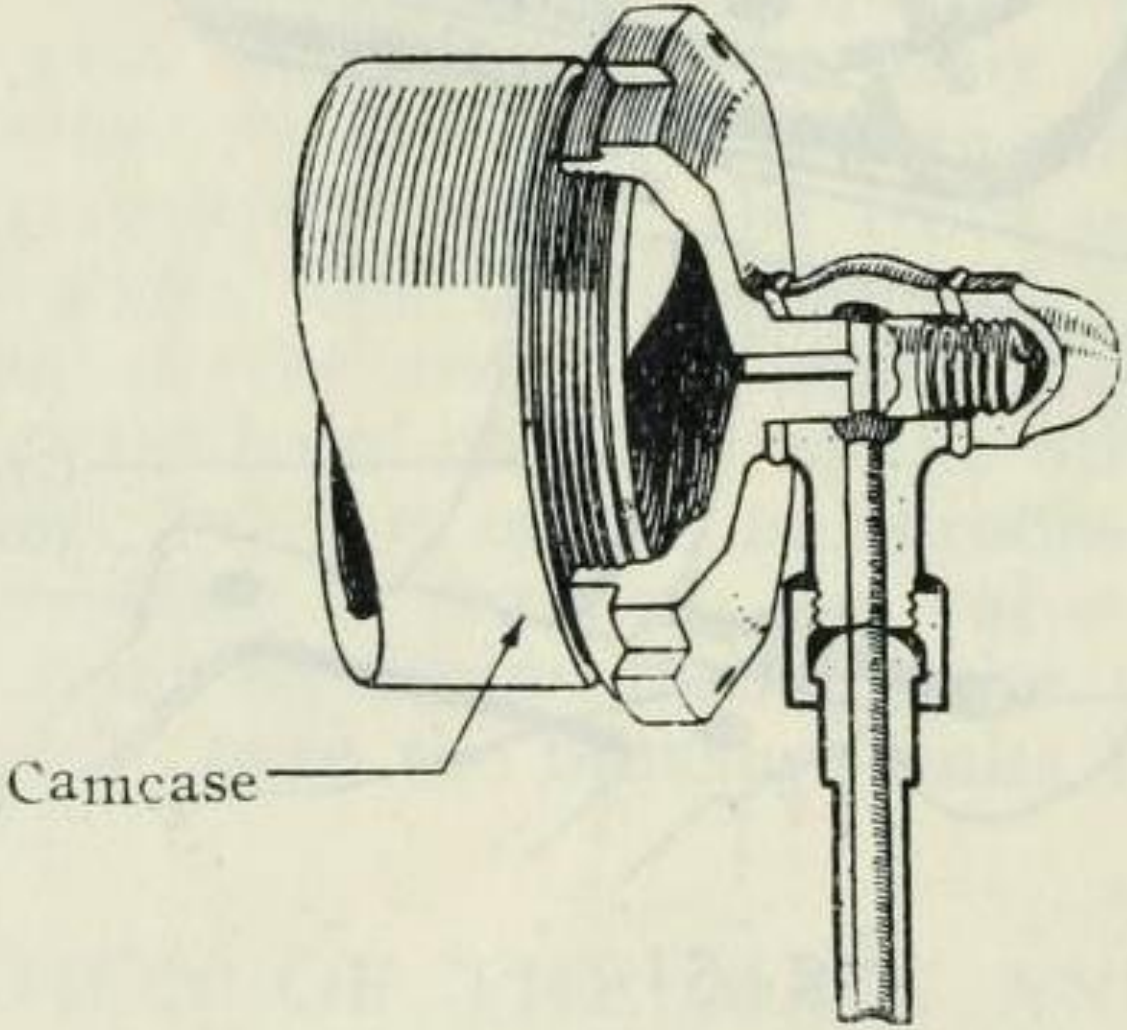
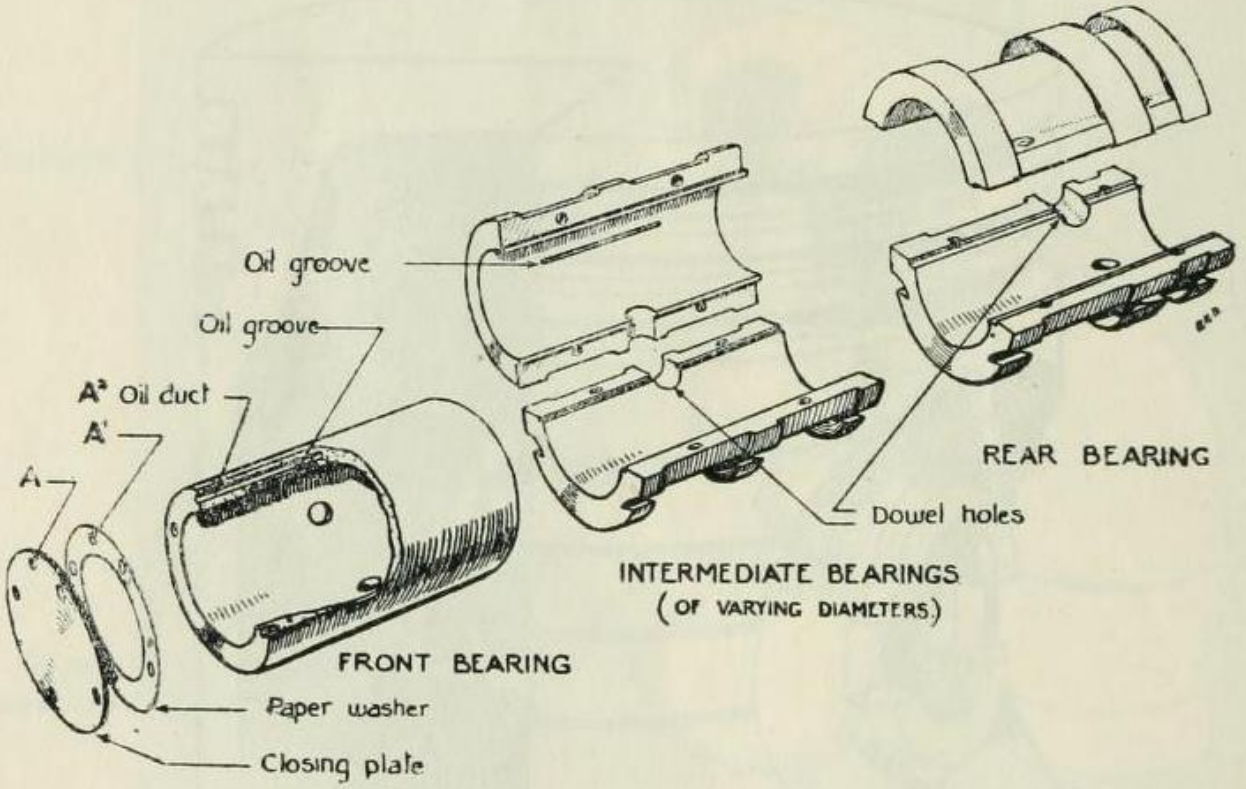


Fig. 32.

Oil Connection to Camshaft.

The front end of each camcase is sealed by a screwed cap, beneath which there is a C.A. washer: the oil pipe is connected to the centre of the cap. The front camshaft bearing is a cylindrical bush of aluminium: its front end is sealed by a metal plate, attached to the bush by four screws, and rendered oiltight by a paper washer. Thus an oil recess is formed between the metal plate and the screwed cap already mentioned. An oil duct is machined in the thickness of the cylindrical bush, parallel with its axis. The front end of this duct is open to the oil chamber; the rear end of the duct turns at right-angles, and opens into the centre of the bush, where it registers once in each revolution with a hole drilled through into the centre of the hollow camshaft. Oil under pressure thus enters the camshaft, and is sprayed out of holes positioned at the centres of the six remaining bearings, along which it is distributed by suitable grooves. There are no oil exits from the camshaft in the cam compartments, but an ample supply of oil leaks along the bearings into each compartment, and is splashed up by the cams. The rocking lever spindles are hollow, and drilled with one oil entry and three oil exits apiece, their ends being plugged with brass. The oil entry is above the point at which the roller arm joins the spindle · a small baffle cast on the under side of the camcase lid directs the oil splash into this hole, and it escapes into the spindle bearing through the oil exits above mentioned.

Deep grooves (Fig. 81, p. 110) are machined in the outer circumference of the lower half of each camshaft bush, so that the drainage oil can flow along the casing. It finally reaches the bevel gears at the rear ends of the camshafts, and drains down the casings of the inclined shafts, lubricating the bearings and bevels of the distribution gear on its way back to the sump.



A and A1—oil holes in plate and washer, to be registered with oil duct A2 in bush.

Fig. 81.

Camshaft Bearings.

As described in a previous chapter, the compartment in which the upper vertical shaft and lower inclined shafts are housed, is separated by webs from the main base chamber; the oiltrap shown in Fig. 87, p. 116, is the sole outlet for the drainage oil from this compartment. The construction of this trap produces an oil seal, which prevents condensed moisture in the main base chamber from reaching the ball bearings of the distribution shafts.

Provision is made for the oil to drain through the bearings of the various shafts, e.g., at the heads of the long and short inclined shafts and along the bush of the lower vertical shaft, which is illustrated in Fig. 88, p. 118.

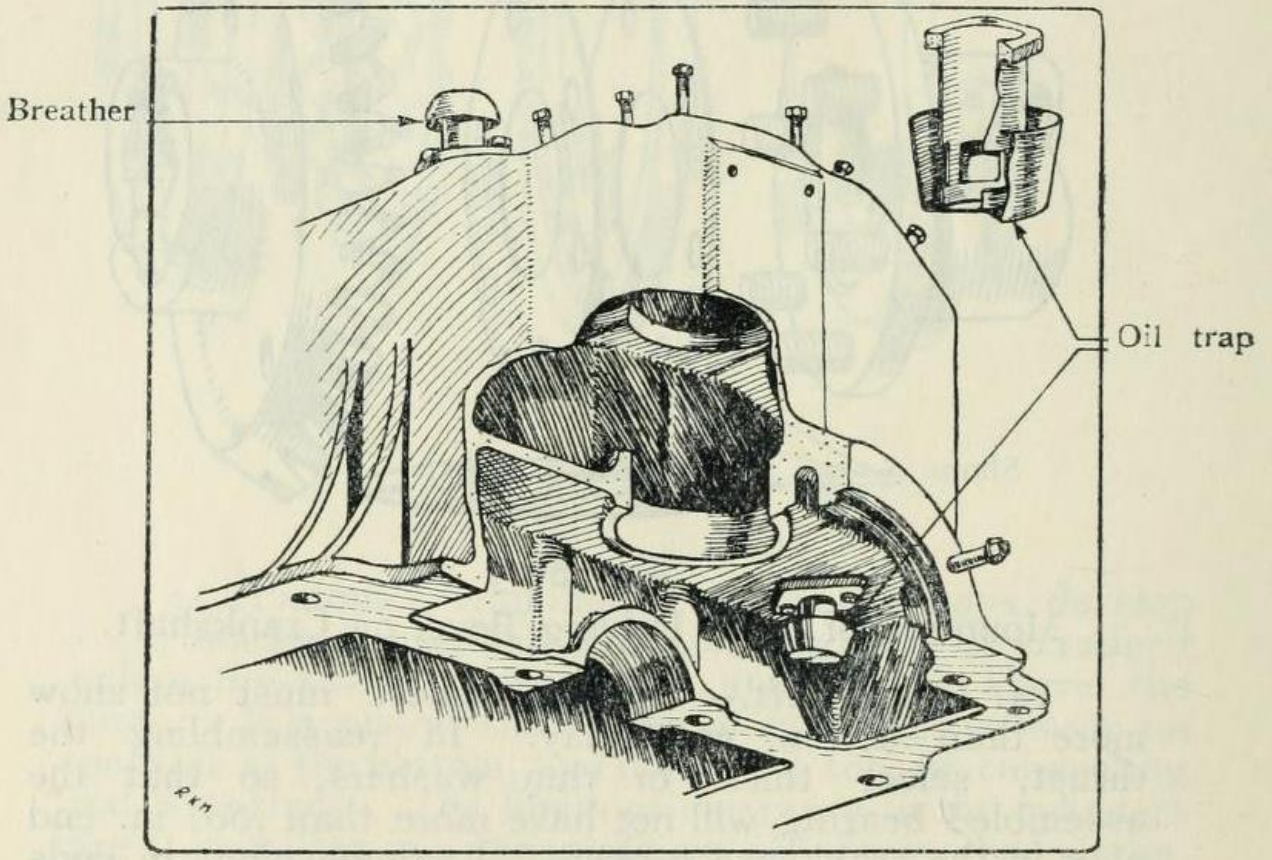


Fig. 87.
Upper Half of Crankcase (rear end), showing Oil Trap.

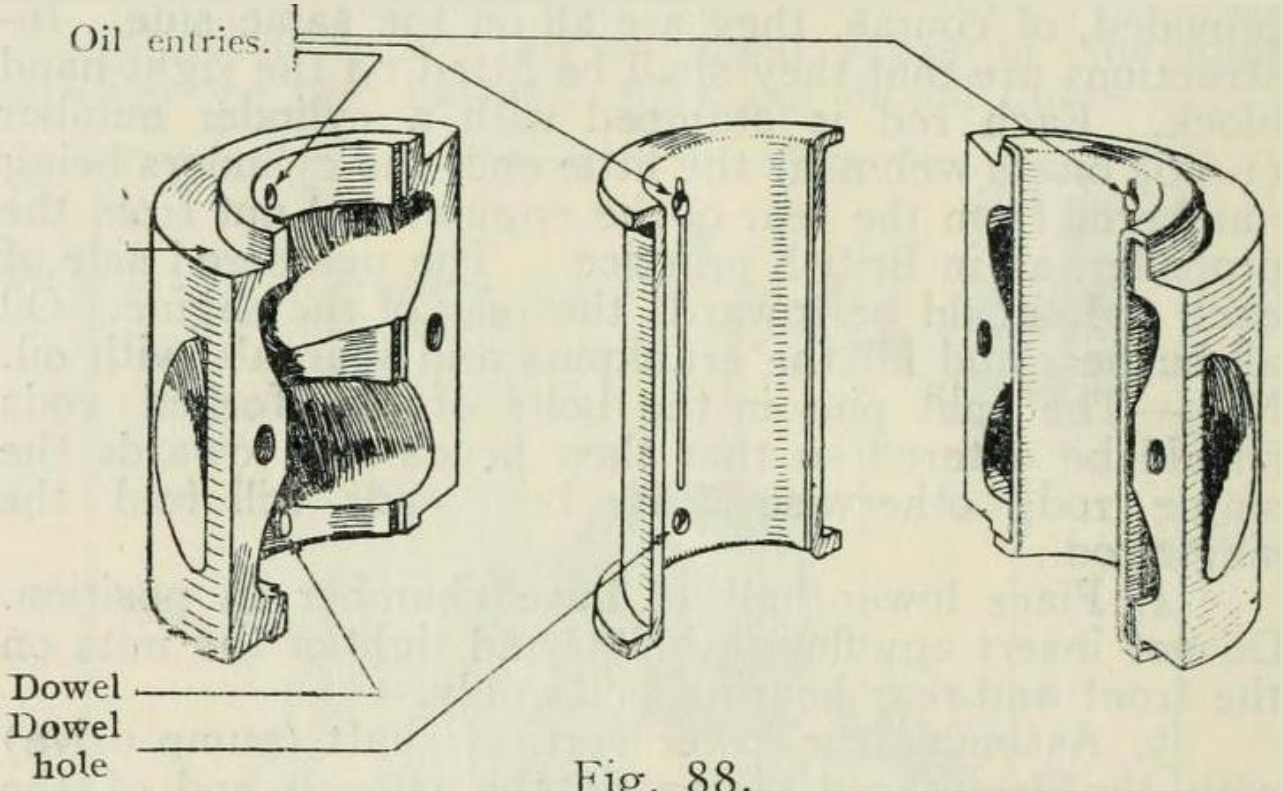


Fig. 88.
Housing and Bush of Lower Vertical Shaft.

LUBRICATION OF THE THRUST BEARING.

The main thrust bearing is lubricated by surplus oil from the front crankshaft bearing. A spring-lid lubricator is provided on the top of the nose piece, and the thrust housings in the nose piece are recessed to act as a reservoir. This reservoir should be replenished by hand before starting up an engine which has not been running for some time.

GENERATOR DRIVE BEARING.

It is recommended that the generator be removed after every ten hours running, and the ball bearing at the top of its drive, together with the shaft and splined coupling, be freely lubricated with Vacuum B.B. oil.

CHAPTER III.

Carburation.

Two duplex carburettors are bolted beneath the junctions of the forward and rear pairs of induction manifolds respectively, American Zeniths, type 52 D.F. being fitted to some engines, and Claudel-Hobsons type H.C.7. to others.

Zenith Carburettors.

Examination of these carburettors will show that they have been modified in this country as the altitude control originally fitted was not satisfactory. The general functioning of the carburettor has also been much improved.

Each carburettor is built up of three castings, viz., a throttle chamber, a main casting embodying duplex mixing chambers, together with a single float chamber, and an air intake. The latter is quickly detachable, being secured by spring clips to a couple of studs on the sides of the main casting. The throttle chamber contains a pair of butterfly throttle valves.

The maintenance of an approximately constant petrol-air ratio at all engine speeds is attained by the familiar Zenith device of a compensating jet. If petrol is supplied by a single jet located in the centre of a choke tube, high engine speeds will result in an excessive flow of petrol, due partly to the inertia of the column of petrol, and partly to the increased depression or suction. Conversely, there will be a deficiency of petrol at low speeds, owing to the weakness of the depression round the jet, and the low momentum of the stream of petrol between the float chamber and the jet. The compensating jet corrects these faults, because it possesses exactly opposite tendencies, supplying an excess of petrol at low speeds, and a reduced quantity of petrol at high speeds. Consequently, if the main and compensating jets are properly balanced, they co-operate to furnish a correct flow at all speeds.

Fig. 37 is a diagrammatic sketch of the Zenith principle in a simple form. G is the main jet, drawing petrol from the float chamber in the usual way. I is the compensator, or compensating jet, which controls the flow of petrol from the float chamber into the well J. The well J supplies petrol to a secondary spraying tube H parallel to the main jet G. It is clear that the flow of petrol from H will depend upon the height of the column of petrol in J, and this depends solely on the amount of petrol which can pass the compensating orifice I in a given time. The hole at I, namely the orifice of the compensating jet, is much smaller than the bore of the passage which supplies petrol to the main jet G. When the engine is not working, petrol rises in J, and a maximum flow is ensured from H for starting purposes. When the engine is running slowly, a maximum supply is obtainable from H, which balances the minimum supply drawn from G by the depression. When the engine is running at full speed, a minimum supply will reach H, whereas the increase in the depression is drawing a maximum supply from G. The action of the two jets is therefore mutually opposed: and if the orifices at I and G are accurately calibrated, a predetermined petrol-air ratio can be ensured at all engine speeds.

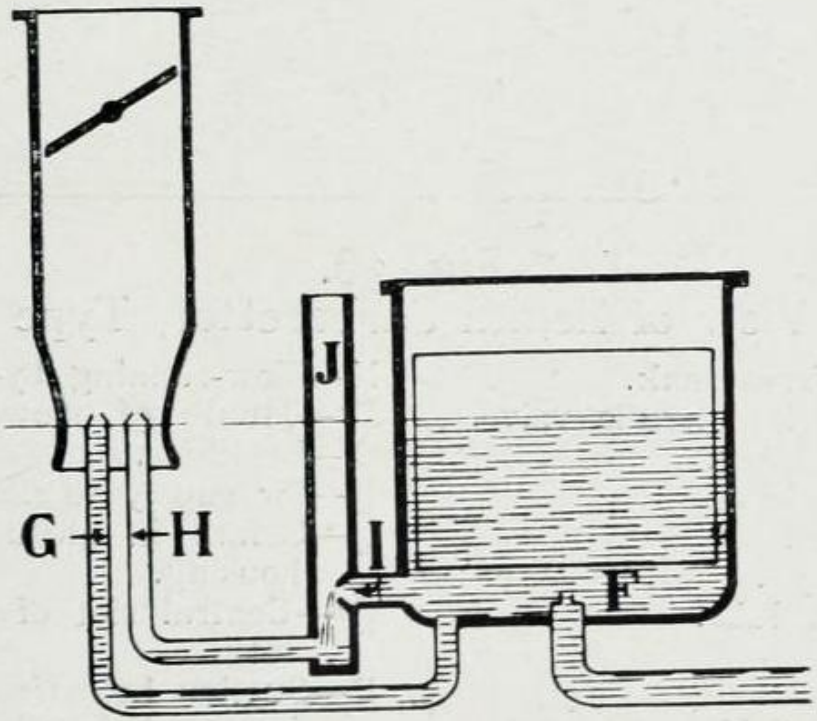


Fig. 37.

Diagram illustrating the working principle of Zenith carburettors.

Fig. 38 gives a sectioned view of the application of this principle employed in the American Zenith carburettor, type 52 D.F., as fitted to some of the Liberty engines.

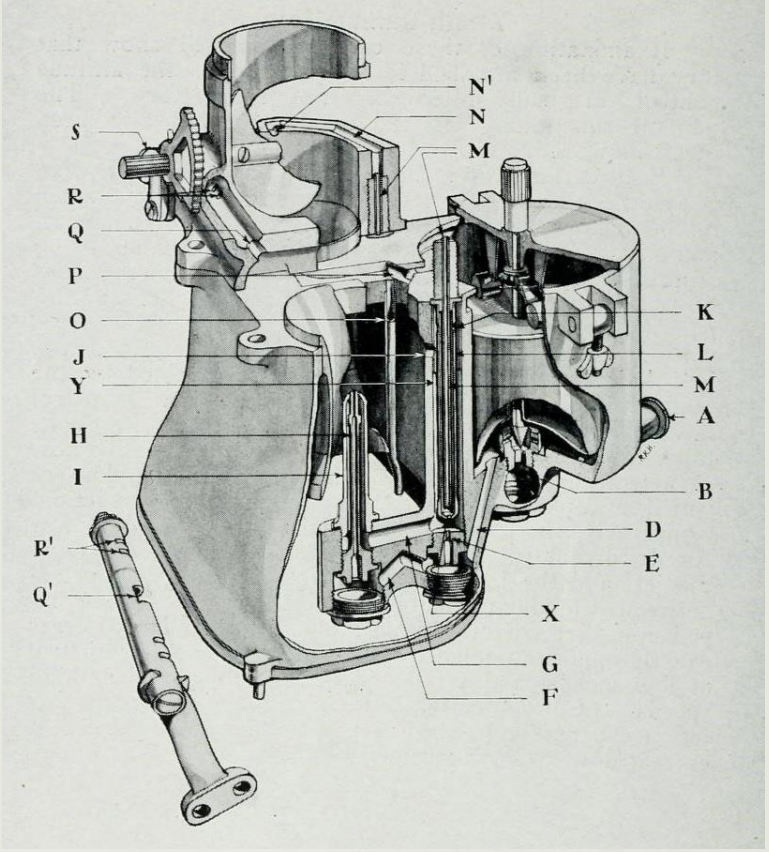


Fig. 38.
Broken View of Zenith Carburettor, Type 52 D.F.

A—Petrol supply from tank.
B—Petrol recess below needle valve.
C—Needle valve seating.
D—Petrol duct to jets.
E—Compensator jet.
F—Duct to main jet.
G—Duct to shroud tube.
H—Main jet.
I—Shroud tube.
J—Air supply to well Y.
K—Air holes in dipping tube L.
L—Dipping tube (slow-running device.
MM—Restrictions at head of dipping tubes.
N—Slow-running by-pass.
N1—Mouth of slow-running by-pass.
O—Leakhole.
P—Air supply to float chamber.
Q—Orifice in altitude control cock housing.
Q1—Central slot of altitude control cock.
R—Suction hole (from choke tube into cock housing).
R1—Holes in altitude cock registering with R.
S—Throttle stop.
X—Orifice in base of dipping tube.
Y—Well.

H is the main jet. Its petrol supply is received direct from the float chamber via the ducts D and F, and is mainly conditioned by the depression in the mixing chamber. The jet H delivers its minimum flow of petrol at low engine speeds, and its maximum flow at full throttle openings.

The main jet H is balanced by the outer or "shroud" tube I, which surrcunds H concentrically. The tube I receives its supply of petrol from the well Y, which in turn is supplied via the compensating orifice or jet in the plug E. Thus the sùpply of petrol to the tube I is not conditioned by the depression in the mixing chamber, but by the calibrated orifice in the plug E (i.e., the compensating jet). When the engine is running slcwly, the petrol flowing through the compensator E will build up to a comparatively high level in the well Y: as the engine is accelerated, the petrol level in Y will sink. Consequently, a maximum flow of petrol is drawn from the tube I at low engine speeds, and a minimum flow at high speeds. Thus its actiɔn is directly opposed to that of the main jet H; the main jet and compensator balance each other, and co-operate to supply an approximately constant petrol: air ratio at all engine speeds.

The slow-running device is in duplicate. Each consists of a tube M dipping at its lower end into the petrol in the well Y and connected at its upper end by the small duct N to the throttle chamber, into which it opens on a level with the lower edge of the butterfly throttle, when the latter is almost shut. With the throttle in its minimum position, the depression is insufficient to bring the jets H and I into action, but is concentrated upon the mouth of the slow-running by-pass at N^1. Petrol is drawn up the dipping tube through the pilot jet at X and mixed with air inhaled at K.

No adjustments to the main spraying devices are possible or necessary, the choke tubes, the main jets H and the compensators I, being standard calibrated sizes for all Liberty engines.

A throttle stop, controlling the quantity adjustment for slow running, is located beneath the throttle control spindle. (See pp. 142—3 for important note on adjusting the carburettor controls.)

Both throttles are operated by a single lever through a pair of toothed quadrants.

ADJUSTING CONTROLS OF ZENITH CARBURETTOR.

Each duplex carburettor is fitted with two butterfly throttle valves, and it may occasionally be found that the pair are not accurately synchronised (see dotted throttle positions shown in Fig. 98). No adjustment is provided, and in such cases the butterfly must be very carefully "set" so that the closing points agree.

It is further necessary to synchronise the throttles of the fore and aft carburettors in coupling up the connecting rod, and this should be done as closely as is compatible with taking up the backlash and torque in the connecting rod. This is done by means of the screw adjustment "X" in Fig. 99. If it is impossible to synchronise both carburettors, and also to set the connecting rod perfectly by one and the same adjustment, a slight variation in the throttle closing points is preferable to a sloppy setting of the rod. In this case the throttles of the front carburettor should close very slightly in advance of the rear throttles.

Finally the throttle stop screws ("Z" in Fig. 99) must be set so that they relieve the butterfly valve of excessive pressure when the control lever is slammed back.

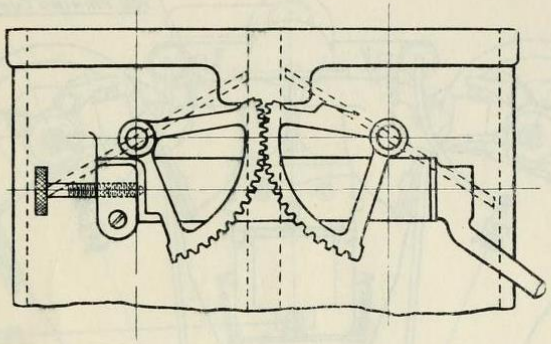


Fig. 98.

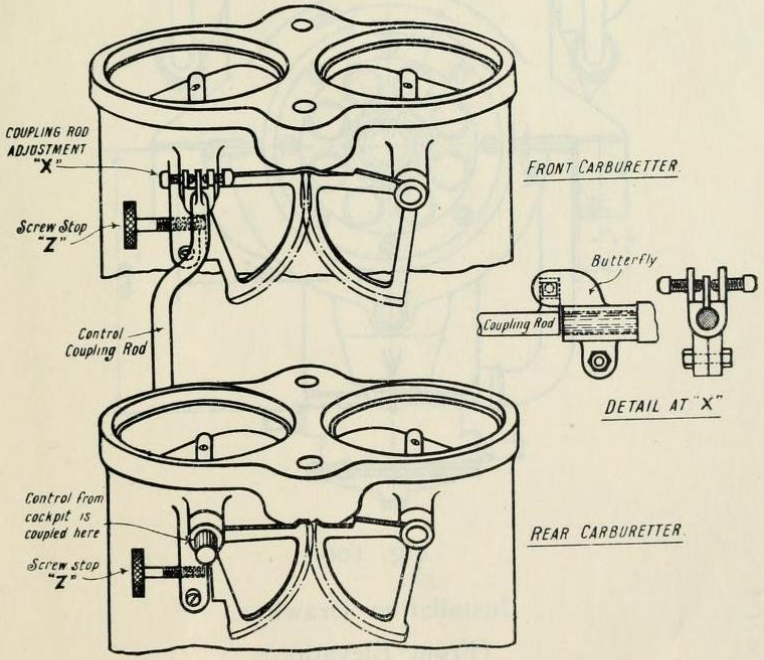

COUPLING ROD ADJUSTMENT "X"
Screw Stop "Z"
Control Coupling Rod
FRONT CARBURETTER
Butterfly
Coupling Rod
DETAIL AT "X"
Control from cockpit is coupled here
Screw Stop "Z"
REAR CARBURETTER

Fig. 99.

The official Zenith jets for the Liberty engine are:—

Choke Tube	...	...	36 mm.
Main Jet ...	...	...	280 cc.
Compensator	...	...	340 cc.
Shroud Tube	...	...	3.9 mm. diameter.

THE ALTITUDE CONTROL.

The density of the air decreases rapidly within the altitudes now reached by aeroplanes. The deficiency of oxygen then results in an over rich mixture, which is corrected by reducing the flow of petrol in proportion to altitude. This correction is effected by the pilot at his discretion by means of a separate control lever. On the carburettor under notice the "vacuum" system is employed. The flow of petrol from the float chamber to the main jet depends upon a difference between the pressure ruling in the float and mixing chambers respectively. Whereas the float chamber is subject to atmospheric pressure, the mixing chamber is governed by a "depression," which may alternatively be described as a partial vacuum, due to the descent of the pistons in the cylinders of the engine. Thus, if the petrol in the carburettor be regarded as a U-shaped column, there is atmospheric pressure at the float chamber tip of the U, and a depression at the mixing chamber tip of the U. The flow of petrol depends upon the difference between these two pressures. It is thus a simple matter to cut down the supply of petrol at high altitudes by reducing the pressure in the float chamber. Under the vacuum system of altitude control, the float chamber is fitted with an airtight lid, and is supplied with air at ground level and at moderate altitudes through a small hole communicating with the atmosphere and termed a "leak hole." So long as the leak hole alone is in action, atmospheric pressure governs the float chamber, and the maximum supply of petrol is assured. As the aeroplane gains altitude, and the petrol supply becomes excessive, the control cock is operated to connect up a "suction hole" with the float chamber. This suction hole draws air to the depression area at the narrowest diameter of the choke tube: the pressure in the float chamber is proportionately reduced, and the petrol supply is cut down.

The details of the control on this type of Zenith carburettor have been modified for the British Services, and are shown in Figs. 38 and 42. The bridge piece between the choke tubes contains a hollow chamber, connected as follows:—

i. By the hole P to the float chamber.

ii. By the pipe O to the main air intake. This pipe O is the "leakhole."

iii. By the duct Q to the housing of the altitude control cock, from which the "suction holes" R open into the mixing chamber.

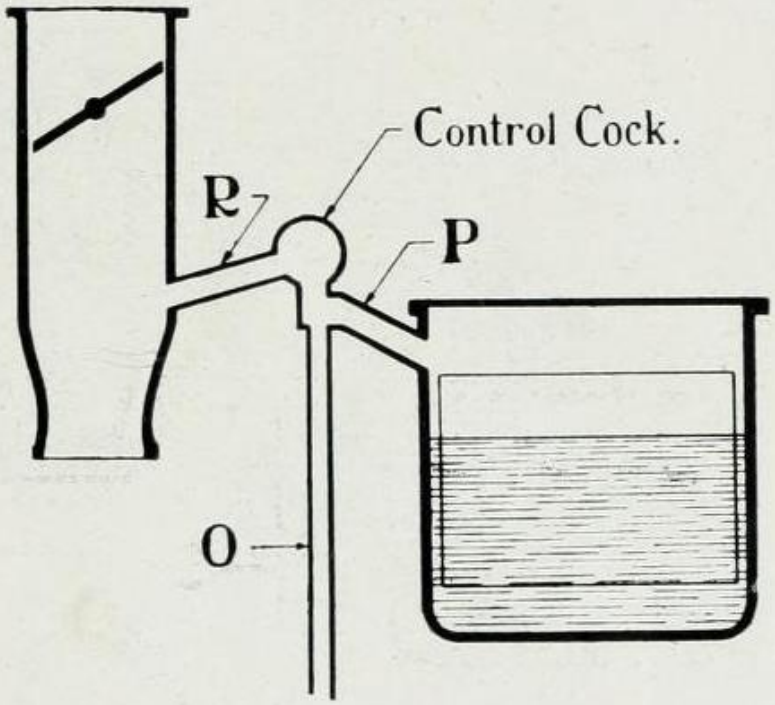


Fig. 42.

Diagram illustrating Zenith Altitude Control.

O—Leakhole.

P—Lead to float chamber.

R—Suction hole.

The pipe or leakhole O is permanently open. So long as the suction holes R are closed by the altitude control cock, O forms the sole air supply to the float chamber, and the flow of petrol to the main jet is at its maximum. As the control cock is progressively operated to open up the suction holes R, the pressure in the float chamber is weakened, and the flow of petrol to the jet is reduced.

Claudel-Hobson Carburettor,

Type H.C. 7.

This carburettor aims at providing a predetermined petrol-air ratio over the full range of engine speeds by a principle quite different to that employed in the Zenith. in outline the system is as follows:—

(a) Throttle shut to slow-running position. The petrol supply is restricted by a calibrated pilot jet: the air supply is automatically restricted by the slow speed of the engine: indeed, the velocity of the air would be too low to pick up petrol if the air were not drawn through narrow passages, e.g., a strangling slot in the throttle barrel, and a small bore by-pass: these narrow passages increase the velocity of the air stream.

(b) Full throttle opening. The petrol supply is determined by a calibrated main jet of the submerged type, mounted at the base of a "diffuser" in the mixing chamber. The volume and velocity of the air stream are conditioned by the diameter of the choke tube, etc.

(c) Intermediate throttle openings. As explained on page 43, the tendency of a crude carburettor is to supply an excess of petrol when the depression or suction reaches a maximum at high engine speeds. This tendency is counteracted in the H.C. 7 by the calibrated main jet; its maximum delivery is correct for high engine speeds. Such a system introduces a fresh difficulty. If the petrol supply is correct at full speed, it is likely to be deficient at quarter, half, and three-quarter throttle openings, when the depression is less. This difficulty is overcome by employing a varying petrol level in the diffuser tube. At intermediate speeds the main jet passes slightly more petrol than can be atomised. This small surplus of spirit forms a reserve in the diffuser, and the amount of the reserve will vary in proportion to the engine speed. As the diffuser is formed from tubes of small diameter, the level of the petrol in the diffuser will also vary. As the level falls, the main jet is progressively relieved of suction by air entering through the holes in the diffuser tube.

Consequently, as the engine is accelerated from its minimum towards its maximum speed, the petrol level is gradually and automatically lowered by the depletion of the reserve in the diffuser tubes; and, contrariwise, as the engine is slowed down, the reserve is built up again, and the level rises. Thus the tendency of an increasing depression to enrich the mixture is counteracted, and vice versâ.

The diffuser tube also serves a further purpose. In carburettors fitted with a simple jet, a stream of pure petrol issues from the top of the jet, and is not mixed with air until it enters the choke tube. With a diffuser type of jet, a small quantity of air is drawn at high velocity through the jet, and is mixed with the petrol before the latter issues into the choke tube. (The quantity of air depends upon the number of air holes in the diffuser tube uncovered by the falling petrol level.) Thus, instead of delivering pure petrol, the diffuser sprays out an "emulsion" of mingled petrol vapour and air into the stream of air drawn up from the main intake. This emulsion impinges into the main air stream at high speed, and at a sharp angle; atomisation is consequently thorough.

The sectional drawing, Fig. 44, and the photograph, Fig. 43, illustrate the construction of the carburettor, and its appearance. The throttle is shown in Fig. 45; the slot in the barrel closes round the top of the slow-running position when the throttle is closed, and acts as an air strangler, concentrating the depression round the head of the tube. The slow-running mixture is drawn into the engine partly via the by-pass shown in Fig. 44, and partly through the V in the back of the throttle.

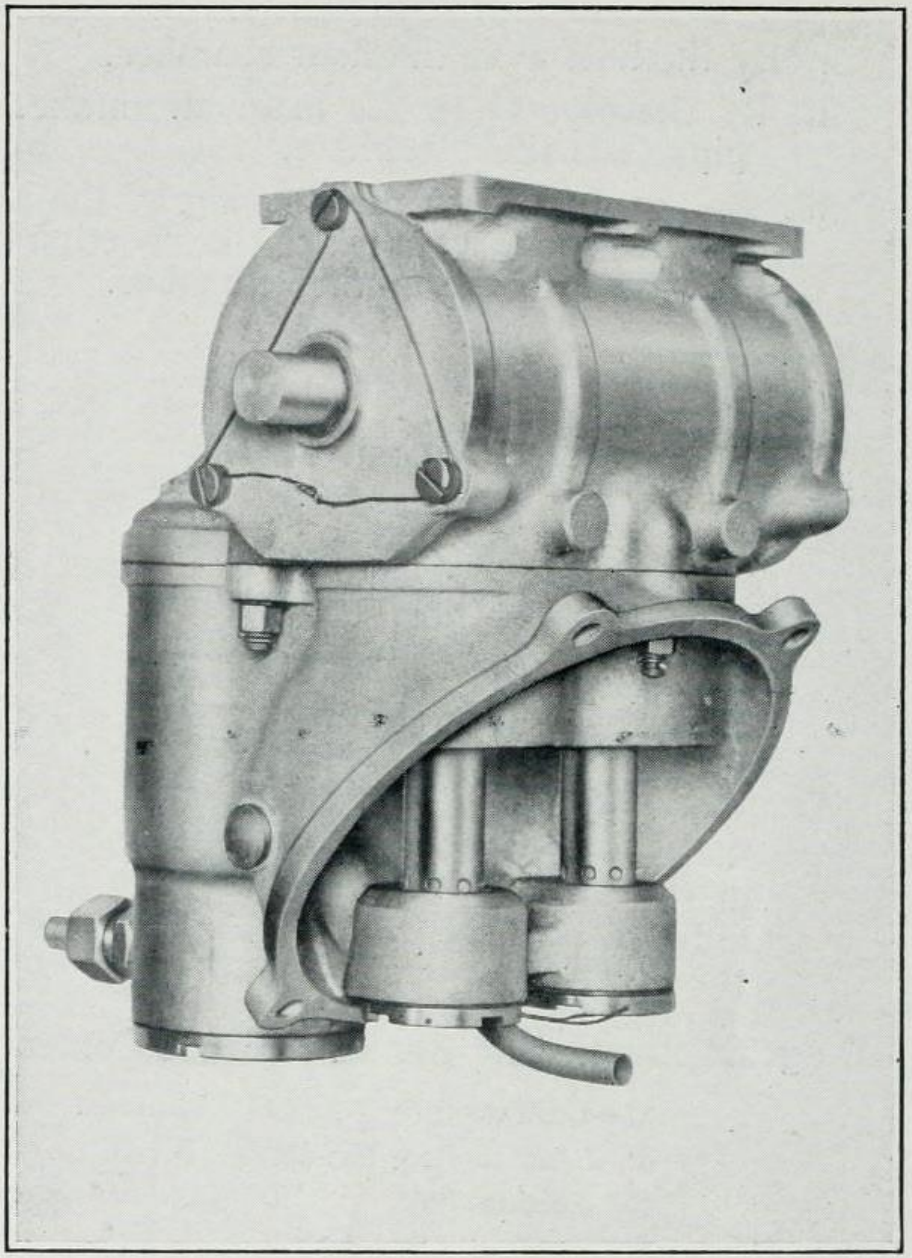


Fig. 43.
H.C. 7 Duplex Carburettor.

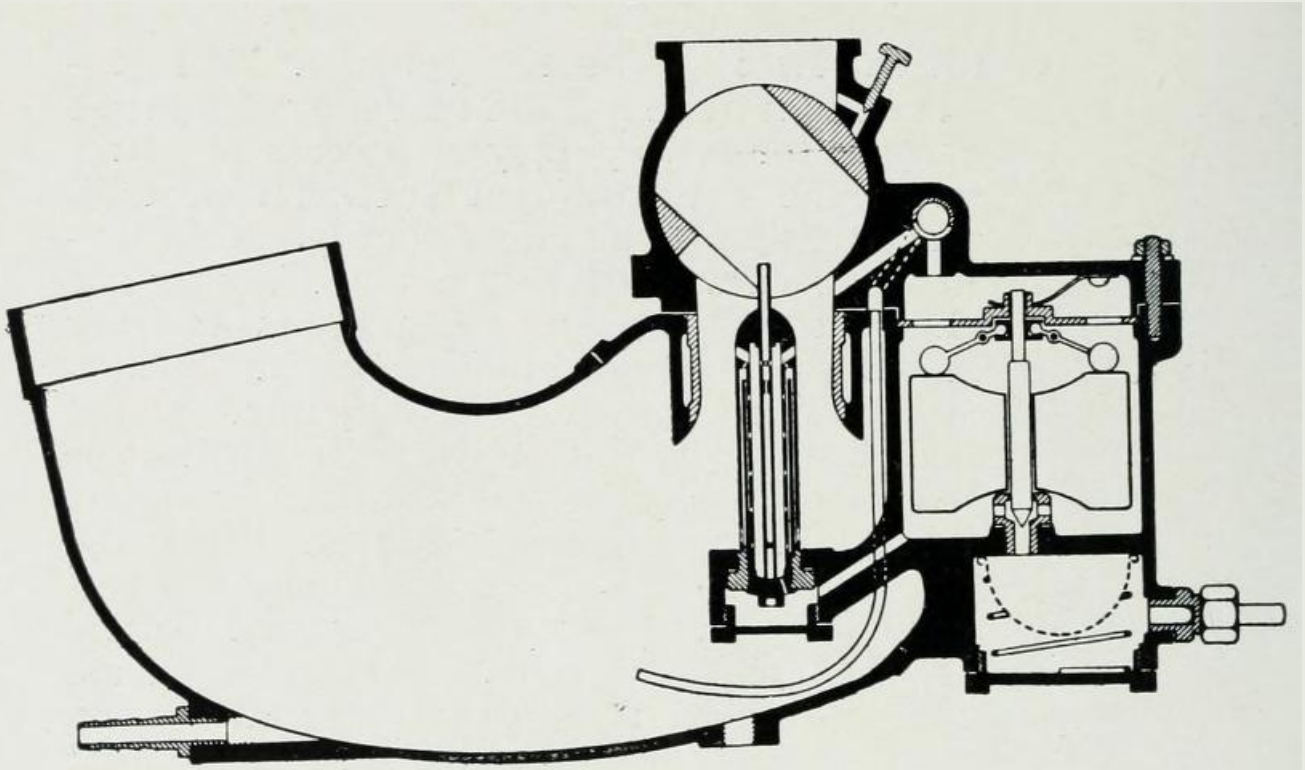


Fig. 44.

Section of H.C. 7 Carburettor.

The diffuser is illustrated in Figs. 46, 47. Petrol passes through the main jet A into the base of the diffuser: the main jet A determines the rate of the petrol supply, and its effective diameter must on no acccunt be tampered with, e.g., by cleaning with a broach. The petrol then fills the three concentric tubes B, N and M to a maximum height, determined by the adjustment of the float needle. This maximum height will be set at 8 mm. below the lip of the "guard" tube M; other considerations, as is explained below, affect the level while the engine is running. The action of these tubes will now be described in detail.

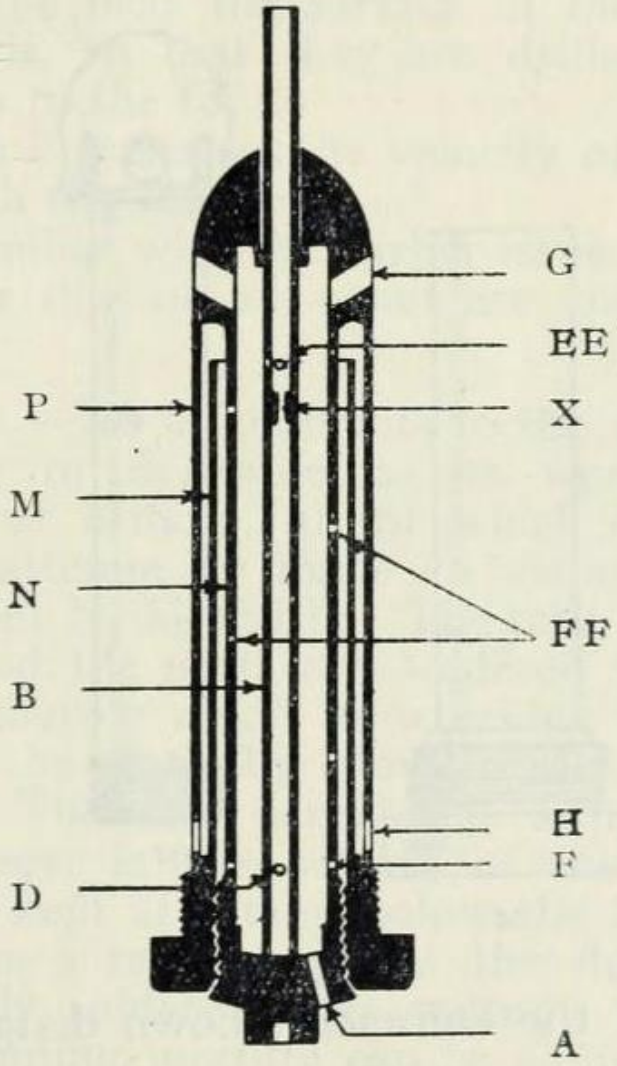


Fig. 46.

Section of the H.C. 7 Diffuser.

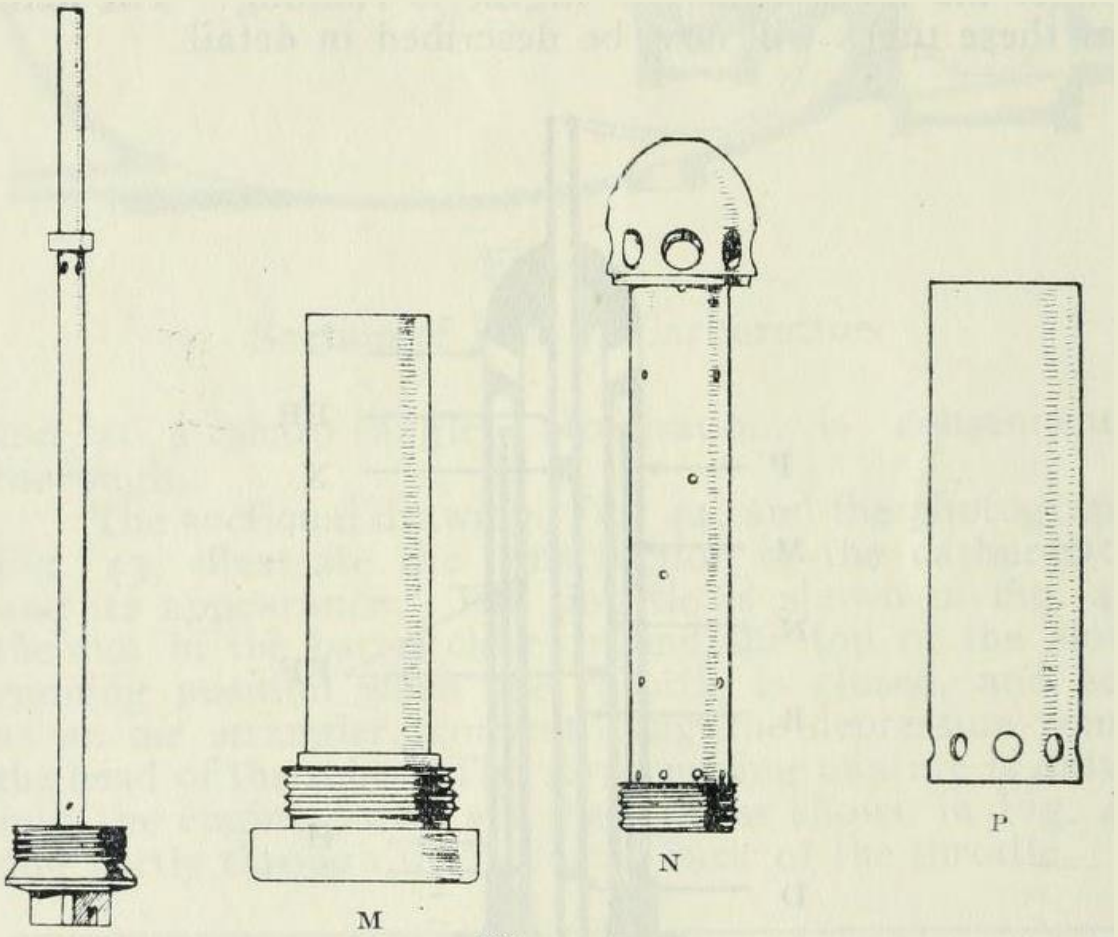


Fig. 47.
Parts of the Diffuser (shown dismantled).

The Slow-Running Tube B.—The slow-running tube B is mounted in series with the main jet A, i.e., it receives its petrol supply via A and D, instead of through a separate duct: the method of supply makes for fuel economy, as B tends to go out of action when the throttle is opened. A constriction in the inner diameter of B at the point X forms the pilot jet. There are two separate air supplies for slow-running purposes. Air from the main intake enters the "air" tube P through the holes H, passes up P, over the lip of the "guard" tube M, and through the depression holes F F into the "diffuser" tube N. From N the air passes into the slow-running tube B via the holes E E, immediately above the pilot jet X. This air is mixed with petrol before it emerges from the head of tube B. A second air supply is drawn up through the main air intake, its velocity being greatly increased by the strangler slot in the throttle barrel, which slides down round the top of B in the closed position of the throttle. The slow-running mixture passes towards the engine through the by-pass shown in Fig. 44, which is adjustable by means of a screw.

The main jet A passes more petrol than can be atomised through the tube B. Consequently, while the engine is running slowly, the tubes N and M fill up with petrol to the fixed maximum level, in readiness for the liberal supply of petrol required for acceleration.

The Depression Tube N.—On the throttle being opened, the depression immediately begins to act upon the depression tube N through the emulsion holes G G. Petrol is drawn out through G G, and is already mixed with air drawn thrugh the diffuser holes F F, over the lip of the guard tube M, out of the air tube P. This air and petrol are already mixed together when they emerge from G G, and impinge upon the stream of air drawn up outside the diffuser from the main intake.

As the engine speed rises there would be a tendency for an excessive amount of petrol to be atomised, if the level in the diffuser remained constant. But the main jet A is not large enough to maintain the maximum level of petrol in the tubes M, N, and B permanently; so the mixture remains constant.

If the engine is throttled right down again, the slow-running tube B comes into action afresh, and a reserve of petrol again accumulates in M and N.

The guard tube M is obviously provided to retain petrol in the depression tube N, whilst allowing air to enter N at the holes F F: it is essential that some of the holes F F shall be near the surface of the petrol at all its varying levels, so that they are drilled at intervals from the bottom to the top.

The air tube P increases the velocity of the air which is drawn through the diffuser.

(Readers familiar with the earlier issues of the H.C. 7 type should note that no air cones are now fitted round the diffuser.)

Adjustments.—No adjustments to the diffuser assembly are possible or desirable, as its working depends upon a variety of orifices, all of which are calibrated. Nor must any attempt be made to dismantle the unit consisting of tubes N, M and P. The tube N is expanded into position, and the parts are soldered together: any tampering will merely result in wrecking the assembly. Cleaning should be done by blowing through, and not with broaches. The sole permissible adjustment which affects the diffuser, is the setting of the petrol level, which should be kept at 8 mm. below the lip of the tube M: the collar is a tapping fit on the float needle, to which it is lightly soldered after setting.

The slow-running mixture can be adjusted for quantity by setting the adjusting screw of the by-pass (Fig. 44); and for quality, by setting the adjustable throttle stop screw. It might appear that the latter would only affect the quantity of the mixture; but it governs the strangling effect of the throttle slot round the head of tube B, and so varies the quality.

These adjustments will usually repay trouble after an engine has been overhauled, as the sum total of the air leaks at the various joints in the induction system must inevitably vary. The adjustment should be made with the engine warm, as its purpose is not so much to secure the best starting adjustment, as to obtain an economical setting on which an engine can be trusted not to choke when throttled down during flight. The procedure is therefore as follows:—

i. Warm up the engine.

ii. Set the throttle stop, till the engine just keeps running, and no more.

iii. Unscrew the by-pass adjustment a little, so that the engine runs a shade faster.

iv. Slow the engine down a little by resetting the throttle stop.

By the above method, the desired minimum engine speed is attained, plus a little extra strangling of the air, which will facilitate starting.

The standard Claudel jet sizes for the Liberty engine are:—

Main	...	...	...	...	490 cc.
Pilot	...	...	...	...	200 cc.

FITTING NOTES.

If a light carburettor is bolted up to an untrue induction pipe flange, the carburettor body may be distorted, and the throttle will bind. It is therefore essential to ensure a true jointing face on the induction manifold. This is peculiarly difficult with the Liberty engine, on which one carburettor face beds against ports in two separate induction manifolds: and the need for extreme care in erecting the cylinders and their manifolds is indicated.

Thin fibre washers are exclusively used for jointing, except at the joint between the two halves of the carburettor, where a thin (.01 in. maximum) paper washer is employed.

The main jet must make a petrol tight joint with its seating, or the calibration of the jet becomes futile.

The movement of the altitude control lever is short, owing to the limited travel of the small cock; the leverage should therefore be multiplied in linking this lever to the cock it controls.

Care must be taken to synchronise the controls, so that movements of the cockpit levers affect both carburettors identically: this, of course, applies to the altitude controls as well as to the throttles. Spare vacuum cocks are interchangeable, in the event of wear or damage. Under no circumstances must the holes or slots be tampered with in squadrons.

If the petrol is pressure-fed, the relief valve must act at 3 lbs. per square inch (absolute maximum). If fuel is fed by gravity, the head must not be less than two feet.

POSSIBLE CAUSES OF TROUBLE.

I. Absence or Shortage of Petrol.

1. Choked jets. Clear by blowing; the use of broaches is forbidden.
2. Dirt in tanks, supply piping, or filter.
3. Air lock in supply piping.
4. Needle valve stuck.
5. Toggle levers jambed.
6. Empty tanks.
7. Excessive heat, producing vapour lock in supply pipe.

II. Excess of Petrol: "Flooding."

1. Damaged, bent, worn, or eccentric needle.
2. Faulty needle seating (removable without dismantling carburettor).
3. Damaged washers on jet or needle seatings.
4. Other forms of leak at main jet seating.
5. Petrol level too high.
6. Toggle levers jambed.
7. Excessive pressure in tank.
8. Punctured float.

III. Defective Altitude Control.—When this is in order, opening the cocks fully should reduce the engine speed from 1,400 r.p.m. to about 1,200 r.p.m. at ground level. Needless to say, this test should only be made with the machine chocked and stationary, and the test should be barely long enough for the tachometer needle to record the drop. Such a test will not be made in flight; and if the altitude control should be held open for more than a few seconds in a ground level test, the engine might catch fire.

No trouble can arise with the altitude control except as the result of wear, dirt, careless adjustment of the control linkage, or unwarranted interferences with the parts.

THE ALTITUDE CONTROL.

As explained on p. 48, a carburettor setting which is correct at ground level will be far too rich at altitude unless special precautions are taken. The vacuum system is adopted in the H.C. 7 carburettor.

The petrol supply from the float to the jet depends on differences of pressure, as explained on page 48. The rate of supply can thus be slowed down by reducing the pressure in the float chamber. This is easily arranged. The cover of the float chamber is provided with an air-tight joint, and air is supplied to the float chamber through a permanent "leak hole" of small diameter, opening into the atmosphere. In addition, the air space in the float chamber is coupled to the depression area in the mixing chamber by means of a duct known as a "suction hole"; this duct is controlled by a cock and lever. At ground level the suction hole is shut: the float chamber receives air at atmospheric pressure through the leak hole: the maximum contrast exists between the air pressures in the float and mixing chambers, respectively: and the full petrol supply is obtained. As the aeroplane climbs, and a reduction in the petrol supply becomes essential, the suction hole is progressively opened by means of the cock. The pressure in the float chamber is proportionately reduced; and the petrol supply is correspondingly cut down. Figs. 48-50 illustrate the manner in which this system is applied to the H.C. 7.

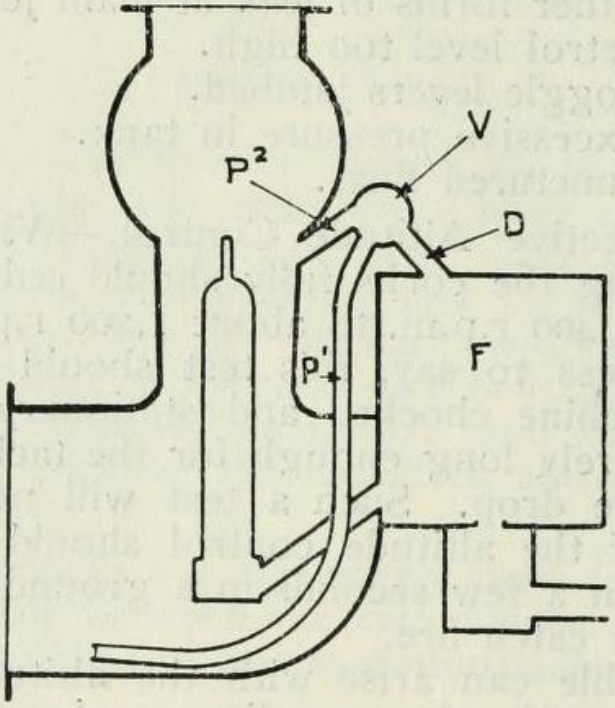


Fig. 48.

Diagram of the H.C. 7 Altitude Control.

F—Float chamber.
V—Control cock.
D—Air lead to float chamber.
P1—Leak hole.
P2—Suction hole.

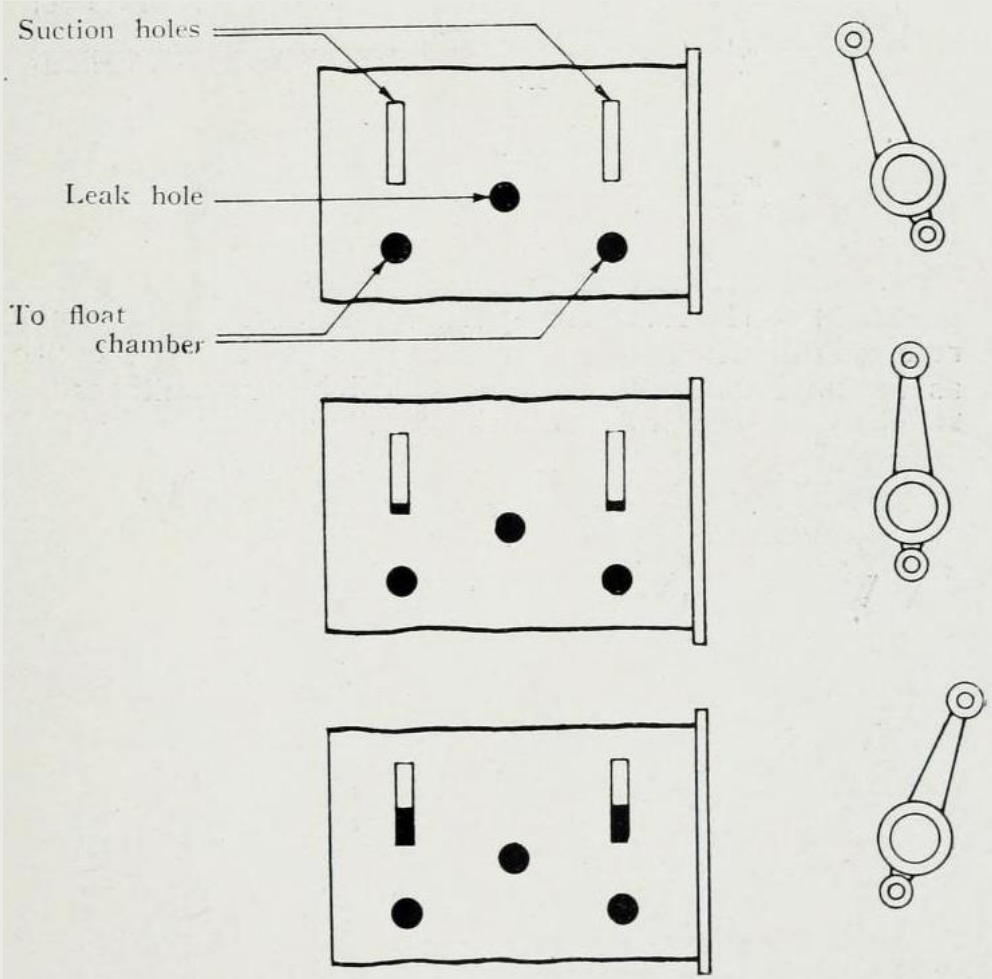


Fig. 49.

Diagram illustrating three positions of H.C. 7 Altitude Control Cock.

Top: Suction holes shut.
Centre: Suction holes just opening.
Bottom: Suction holes at maximum opening.

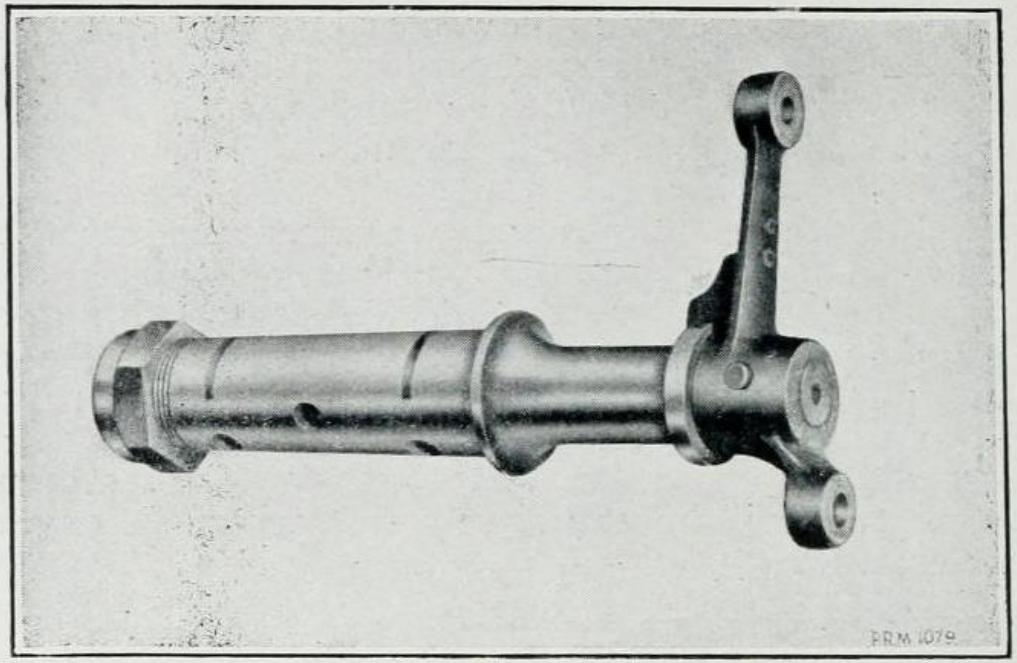


Fig. 50.

Photograph of H.C. 7 Altitude Control Cock.

THE USE OF THE VACUUM CONTROL.

The cock should always be kept closed at ground level: otherwise the weak mixture will overheat the engine, and, in addition, there is real danger of fire if the cock is opened wide for more than a few seconds.

Judicious use of the control will begin to make an appreciable difference in power and revolutions when a height of 10,000 feet is exceeded. At lower altitudes the control will effect real fuel economies, even if its use is not reflected on the tachometer dial.

The control, if already open, is automatically returned to the shut position whenever the throttle is closed. There is therefore no longer any risk of the engine being starved through the control being open when the pilot flattens out after a long dive. On the other hand, pilots should remember to reopen the control after a dive which terminates at a high altitude, e.g., after descending from 20,000 feet to 15,000 feet; otherwise, the mixture will be excessively rich when the engine is accelerated.

It is obviously impossible to recommend definite positions of the lever for specific altitudes. As a general rule, pilots will make a practice of opening the control as far as is possible without sacrificing revolutions.

CHAPTER IV.

IGNITION.

The ignition system is a highly developed form of battery-coil ignition, designed as an integral part of the engine. Owing to the angle between the two banks of cylinders being 45°, it is not possible to use a conventional type of 12-cylinder magneto, and although various schemes for the use of magnetos were considered, the present arrangement was finally adopted as providing the best compromise and being capable of rapid production.

The general lay-out comprises a direct current dynamo-generator, gear driven from the engine, and charging an 8-volt accumulator battery: current is supplied by the generator or battery to two complete ignition units which are mounted on the rear ends of the two camshafts. The necessary switches and instruments are made up into a neat switch-board, and carried in the pilot's cockpit. Each ignition unit consists of a contact breaker for the low tension primary current, an induction coil in which high tension current is induced at the moment of "break," and a distributor which passes the H.T. current to the plugs in their proper sequence.

Each ignition unit is complete in itself as regards the contact breaker mechanism, the coil, and the distributor, and each unit fires a plug in each cylinder. So far as this portion of the system goes, there is absolute duplication, with a further duplication of the main contact breaker levers—as described in detail later.

Current for ignition is supplied at starting, or when running with only one unit switched on, by the battery. As soon as the engine has run up to about 650 r.p.m. the generator takes up the ignition load, and on a further increase of speed begins to charge the battery, which is thus kept in good condition and well charged. In the event of a breakdown of the battery, the generator will run the ignition service, but the engine cannot then be restarted after a stop.

THE GENERATOR.

The generator, Fig. 51, is of the 4-pole, totally enclosed type, shunt wound for a maximum output of about 15 amperes at 10 volts, the normal output being considerably lower, or about 5 amperes. In constructional details the generator is quite simple; the tubular steel yoke A is held between cast aluminium end shields or housings B-C, which are bolted up with four long screws, of which the heads are locked by a simple ring of steel wire D. The armature runs in a ball bearing in the upper or brush-gear end shield, but the driving end is merely steadied by a plain bush containing a felt oil retaining washer. The driving end shield B is provided with three lugs by which the generator is studded down to the crankcase between the cylinders, and is extended to accommodate a pair of spiral gears which serve to drive the revolution indicator. The armature is built up of the usual laminations upon a steel spindle, the driving end of the latter being splined to fit a corresponding socket on the driving gear shaft, which runs in ball bearings mounted in the crankcase. No unusual precautions are required when mounting or dismounting the generator, but care should be taken to see that the splined spindle end is not burred or damaged before assembly. The revolution indicator drive gear E must be unscrewed complete before the armature can be withdrawn.

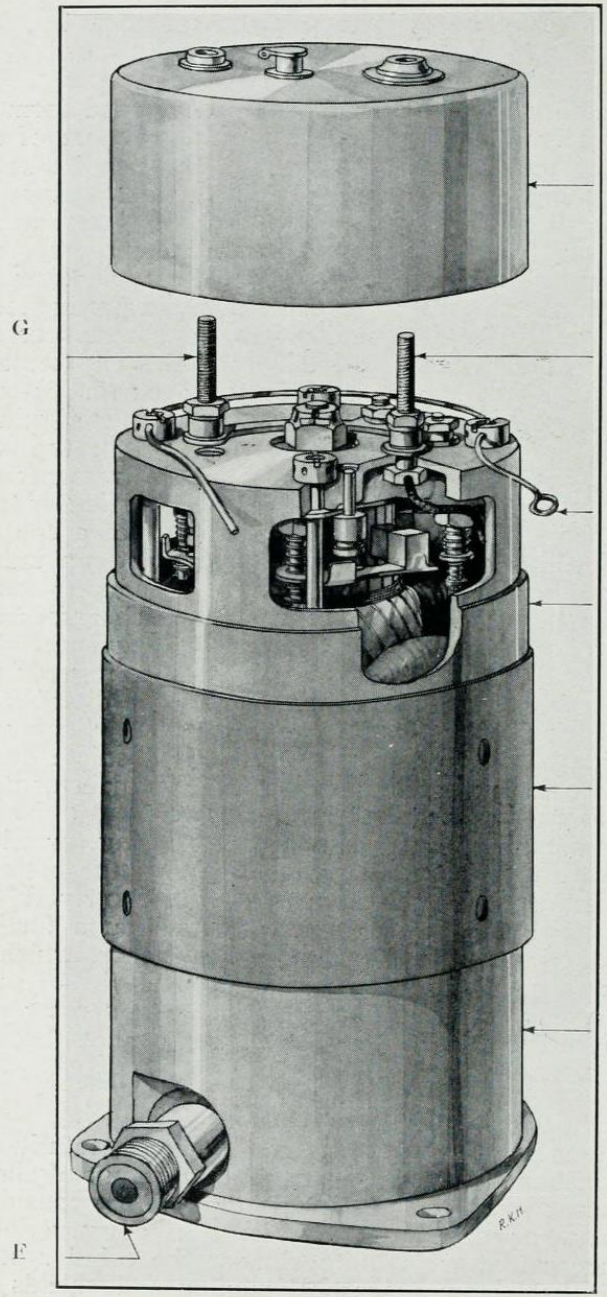


Fig. 51.
The Generator.

The armature is wound with 21 coils in series, the conductors being double-cotton-covered copper, with 20 wires per slot total. The commutator has 21 sections, and is $1\frac{1}{4}$ in. in diameter. The four field coils each consist of 145 turns of single-cotton-covered copper, the resistance being approximately $\frac{3}{4}$ ohm per coil at 60° F.

Two of the carbon brushes are insulated, but the other two are earthed: the whole system is connected up with one side insulated and the other earthed, a method which results in a considerable simplification of wiring and detail work. The details of the brush gear are extremely simple, the brushes being held up to their work by helical springs, which should maintain a practically constant pressure throughout the life of the brushes, the correct load being from 1 to $1\frac{1}{4}$ lb. per brush. The brush gear is enclosed by a light pressed aluminium cover F, through which the two cable terminal studs project: one of these, G, is connected to the insulated brushes, and is marked "GEN. ARM"; the other, H, takes the field current, and is marked "GEN. FIELD." The end of the cover is lined with insulating sheet, but some early models have a couple of loose fibre caps to protect the brush gear stud ends, instead of a complete lining.

Practically the only attention required by the generator should be cleaning of the commutator, and an occasional drop or two of thick oil to the ball bearing at the upper end of the spindle. At intervals corresponding to the stripping of the engine, the brush gear should be carefully looked over, and any necessary adjustments made; the windings should be well dusted by the use of bellows or an air jet; and the revolution indicator drive repacked with grease. The commutator must be watched for signs of scoring or unevenness of the bars; it should be trued up in the lathe before being allowed to become really bad. Should the insulating material between the copper bars tend to stand proud of the surface, it should be carefully scraped down by the use of a keen hooked scraper tool, which may conveniently be made from a hacksaw blade. The commutator and brushes should become nicely glazed, and this condition is not to be interefered with. New brushes must be fitted by rubbing them down on a strip of fine glass paper wrapped round the commutator, so as to bring them to the proper section. To do this, one of the four long assembly screws should be removed, when a brush arm may be lifted well clear of the commutator.

In the field no attempt should be made to effect any actual repairs to the generator in the shape of re-winding and so on; such work is for experts at base depôts only.

THE VOLTAGE REGULATOR.

No provision is made in the generatcr itself to effect any regulation of the voltage or current output under varying conditions of load or speed, but an automatic device is emplcyed to regulate the voltage, and consequently the current, by intermittently breaking the direct earth connection of the field winding, thereby weakening the field and keeping the voltage down to the desired value.

The regulator, Fig. 52, is mounted within a cast aluminium cup A, which normally is fixed behind the switchboard. It consists of a soft iron core wound with three windings of differing natures, magnetisation of the core due to the flow of current in these windings serving to pull down an "armature" blade B, and so break the direct path to earth for the field current. When the generator is not running, or when its voltage is below that to which the regulator is set—say 10 volts, the pair of contacts C are closed, and the field current can pass to earth across them. As the voltage rises, however, the pull of the core opposes, and eventually overcomes that of the spring D, resulting in the opening of the contacts at C. The alternative path for the field current is through two of the coils wound upon the core, one of these being of 115 ohms resistance, and the other—wound non-inductively—of 44 ohms. There is, therefore, a resistance of 159 ohms inserted into the field circuit by the opening of the contacts, the result naturally being an immediate fall in the current flowing in the circuit, and a corresponding weakening of the field.

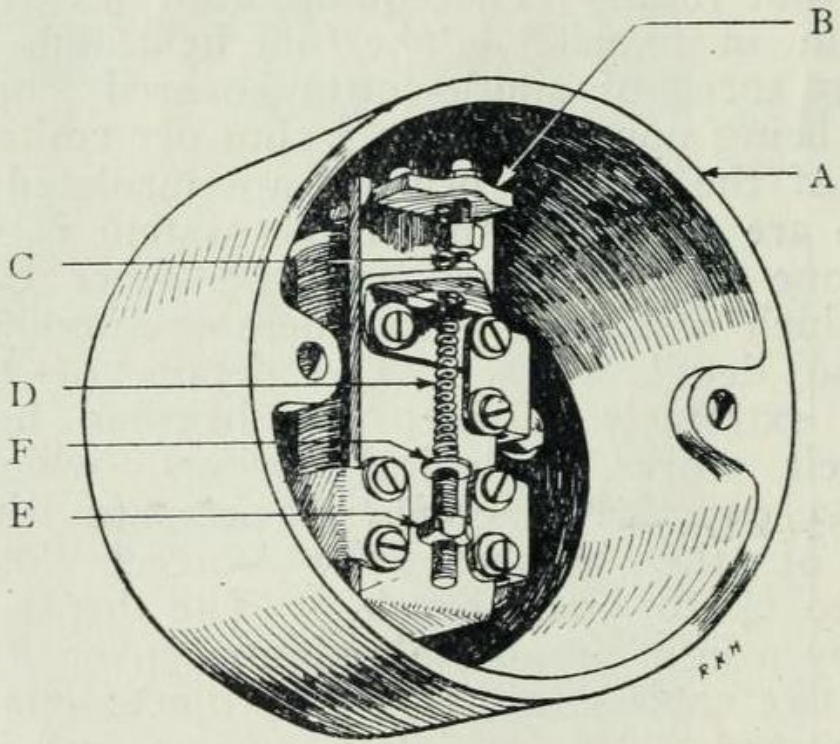


Fig. 52.
Voltage Regulator.

Adjustment of the regulator to maintain any line voltage within limits is made by changing the tension on the spring D; tightening up the nut E raises, and slackening it off reduces, the voltage. In making the adjustment, only the nut is to be turned upon the screw, the latter being held by the knurled head F while the nut is turned. The correct gap of the contact points C is from .005 to .007 in. when the armature blade B is pulled down upon the stop pin; the pin projects from .043 to .045 in. beyond the end of the core. It is important to maintain the correct setting of the gaps, as successful operation will depend largely upon the air gap in the magnetic circuit when the contacts are closed. In action, the armature blade is in a state of continual movement, the contacts opening and closing rapidly—just like those of a trembler coil or a bell. The adjustable contact screw is locked by a spot of solder, and requires touching only at quite long intervals.

The sole attention the regulator should need is periodic cleaning and adjustment of the contacts, and light lubrication of the bearing on which the armature oscillates.

As the regulator is very inaccessible when fitted behind the switchboard, a large opening must be cut in the wood board on which the two are mounted, as indicated by the dotted line A of Fig. 55, so at to permit of access to the contacts after the switchboard has been removed. To remove the switchboard it is necessary to take off the nuts on the two studs at B. The regulator and switchboard are delivered assembled on a piece of $\frac{3}{8}$ in. wood, which represents the instrument board or special base upon which they are to be permanently mounted in the aircraft. When fixing the regulator, the fanged washers C provided are to be fitted as indicated, the lugs being turned up against flats on the nuts after the latter have pulled the fangs into the wood.

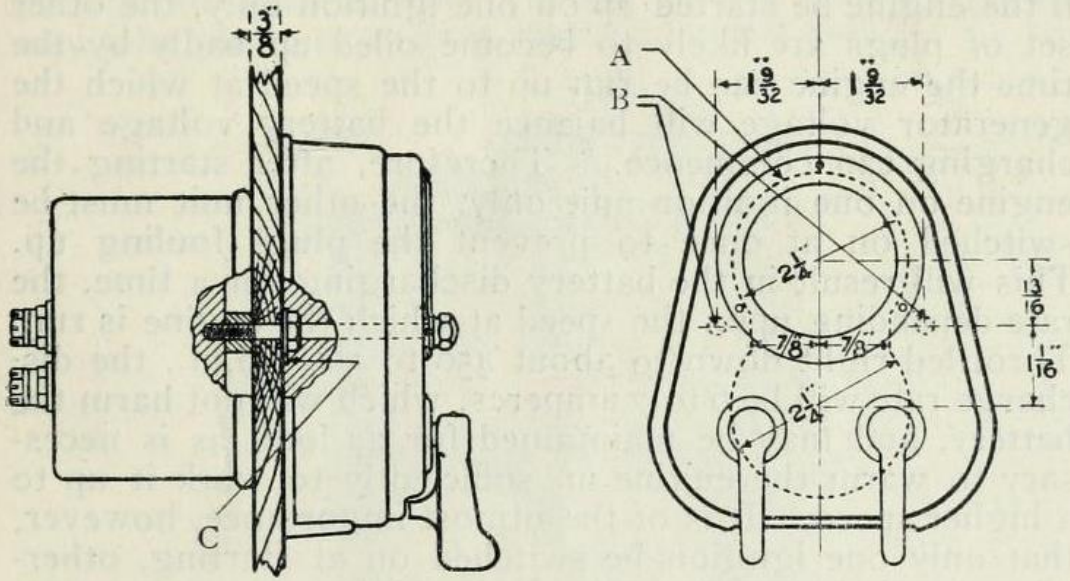


Fig. 55
Mounting of Switchboard and Voltage Regulator.

A—Cut hole in wood as shown by dotted line.
B—Two bolt holes, $\frac{7}{32}$ in. diameter.
C—When permanently fixed, bend up one ear of tab-washer against nut.

THE SWITCHBOARD.

The switchboard, of which front and back views are shown in Figs. 53 and 54, consists of a metal pressing and a moulding of insulating material held together by the two long studs which fix the regulator, and by a screw set between the switch handles. The two switches control the two ignition units, and serve at the same time to connect the generator to the battery for charging; the generator-to-battery circuit being completed only when both switches are in the "on" position together. Above the switches, and permanently connected up by metal strips, is a central-zero Weston ammeter reading to 20 amperes, charge and discharge.

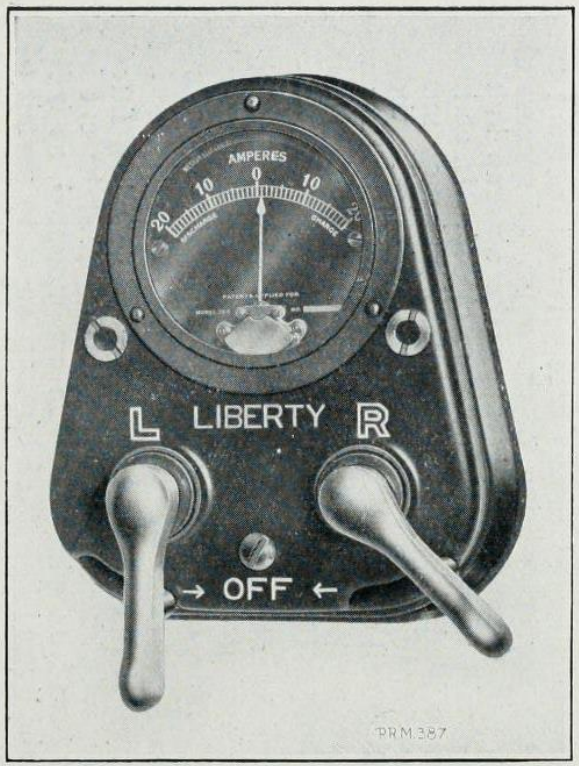


Fig. 53
Front of Switchboard.
A—To positive terminal battery (use heavy cable).
C—To right-hand ignition unit.
D—To left-hand ignition unit.

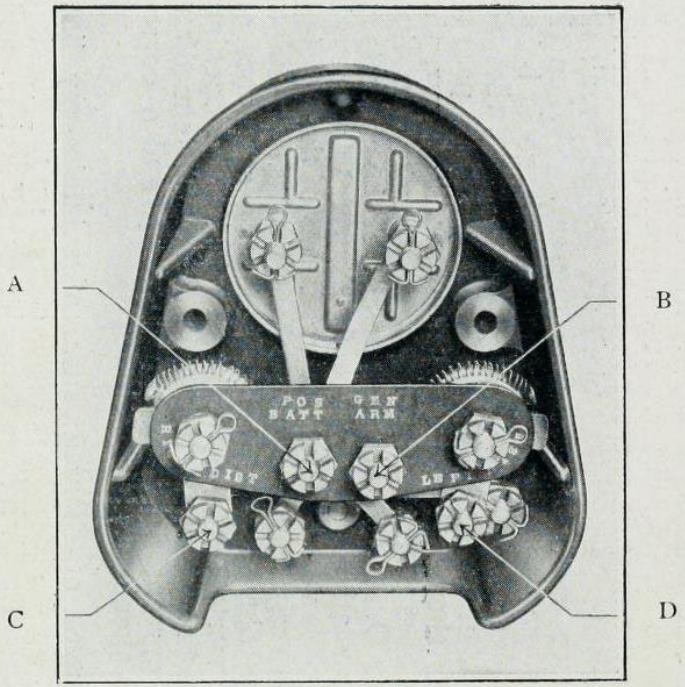


Fig. 54.
Back of Switchboard.
B—To terminal marked "GEN. ARM." on voltage regulator, and thence to generator (use heavy cable).

The ammeter shows the net current passing to or from the battery: when it indicates zero with the engine running and both switches on, the generator will actually be supplying about 3 amperes to the two ignition systems, and 3 amperes must be added to all "charge" readings to get the true value of the generator output. If both switches be put to "on" before the engine has run up to about 650 r.p.m., the battery will discharge through the generator, as the voltage of the latter will be lower than that of the battery. The difficulty arises, however, that if the engine be started up on one ignition only, the other set of plugs are likely to become oiled up badly by the time the engine can be run up to the speed at which the generator voltage will balance the battery voltage and charging can commence. Therefore, after starting the engine on one ignition unit only, the other unit must be switched on at once to prevent the plugs fouling up. This will result in the battery discharging for a time, the rate depending upon the speed at which the engine is run. Throttled right down to about 450 to 500 r.p.m., the discharge rate will be 6 to 7 amperes, which will not harm the battery, and may be maintained for as long as is necessary to warm the engine up sufficiently to work it up tc a higher speed. It is of the utmost importance, however, that only one ignition be switched on at starting, otherwise the discharge rate may be as high as 30 amperes or more, which will not only run the battery down very quickly, but may actually do harm to the generator and coils.

The switches are of a very simple pattern, and consist of four-armed spiders riding over metal contact studs set in the base moulding. There are two small resistance units, consisting of nickel-chrome wire wound upon grooved porcelain discs, mounted behind the switches; the function of these is to keep down the current passing through the ignition coils when the latter are switched on with the engine standing. As the resistance of the ignition coils is very low—about $\frac{1}{2}$ ohm—the current would be very high without these 1 ohm steadying resistances, which keep the initial current down to about 5 amperes per set. Should a switch be left on with the engine standing, there will be no discharge unless the contact breaker points are closed, but if the circuit be completed the ammeter will read about 5 amperes, gradually falling to about 3 amperes as the resistance warms up. Should both switches be left on, the discharge will be 30 amperes or so, and the battery will be totally discharged in a few minutes.

The terminals for wiring up the switch are plainly marked, and the connections are indicated in the figure, as well as in the general wiring diagram. Once in every month the switches should be exposed and cleaned, and a little grease smeared on the track over which the contacts move. At the same time, the two resistances should be examined: if they have been overheated the coils may have become unevenly spaced, or even come into contact in places. If they cannot be neatly opened out to even spacing, new coils must be fitted at once, as any fault here may have serious consequences. Should a resistance burn out or break, it will cut off that ignition; should several of the coils touch, the resistance may be so reduced that burning of the contact breaker points may take place, or even a burn-out in the coil.

THE BATTERY.

The standard 8-volt Liberty battery of Willard or Exide make consists of four cells in a one-piece ebonite box, measuring approximately $5\frac{1}{2}$ in. long by $3\frac{3}{4}$ in. wide by $6\frac{3}{4}$ in. high to top of terminals. The battery is of the so-called "unspillable" type, but is not absolutely so: it is quite sufficiently so for all practical purposes, however. Fig. 56 shows a section through an end cell of a Willard battery with the cable terminal and vent plug in place. The ebonite box A is moulded with ribs, upon which the plates B-C rest, with a fair amount of sludge space below them; it is provided with a main lid D, and a baffle plate E, sealed in with the usual compound at F. The baffle plate has a standpipe vent at G, and a small acid drain hole at H; the filler vent plug I screws down on a rubber joint ring, and is sufficiently long to stand above the electrolyte if the battery is turned upside down until all the acid has drained from the main compartment in which the plates are. The normal acid level is just below the baffle plate, and one cannot judge by mere inspection whether there is plenty of acid or a considerable shortage.

THE IGNITION UNITS.

In Fig. 60 is shown an ignition unit in its place upon the engine, the distributor head having been removed to expose the contact breakers. A detailed description follows, the like parts having like reference letters in the several figures.

At the rear end of each camshaft housing there is a flange with six bolts to take the corresponding flanged base A of the contact breaker shown in detail in Fig. 61.

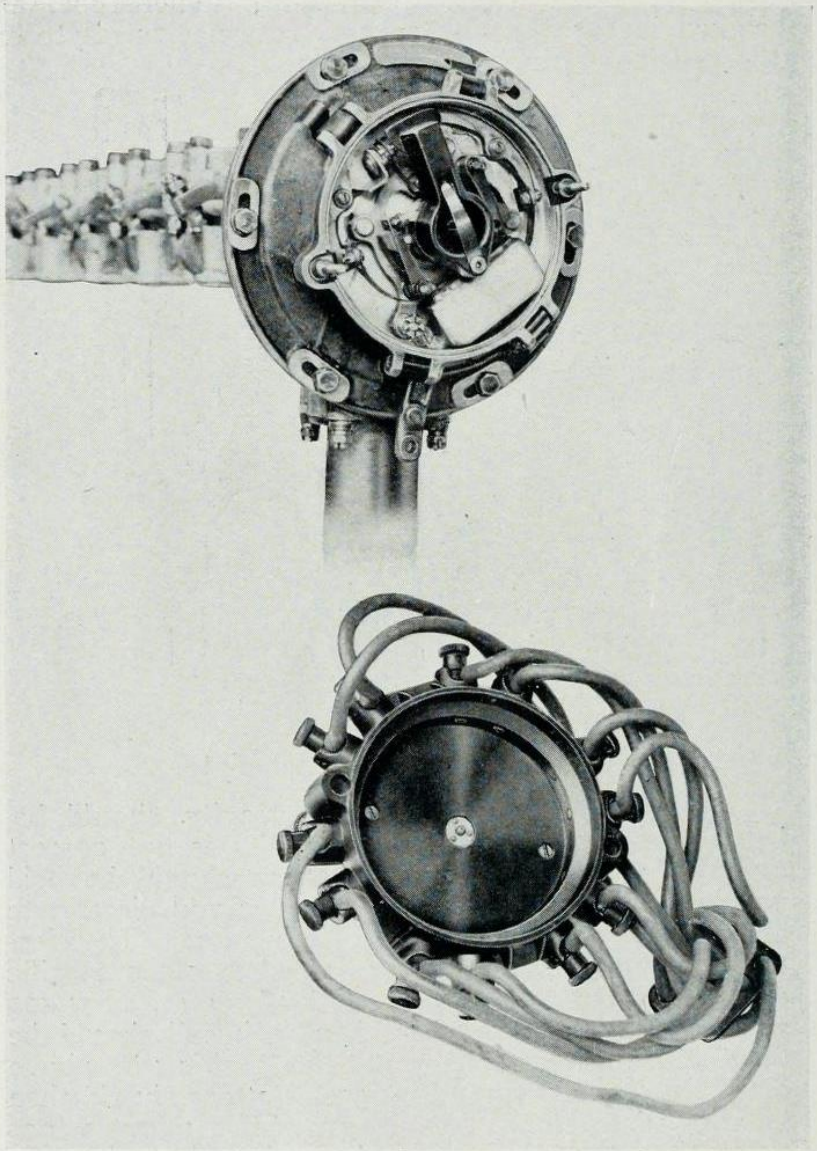


Fig. 60.

An Ignition Unit.

(Distributor head and cables removed to expose the contact breakers, condenser, and H.T. rotor.)

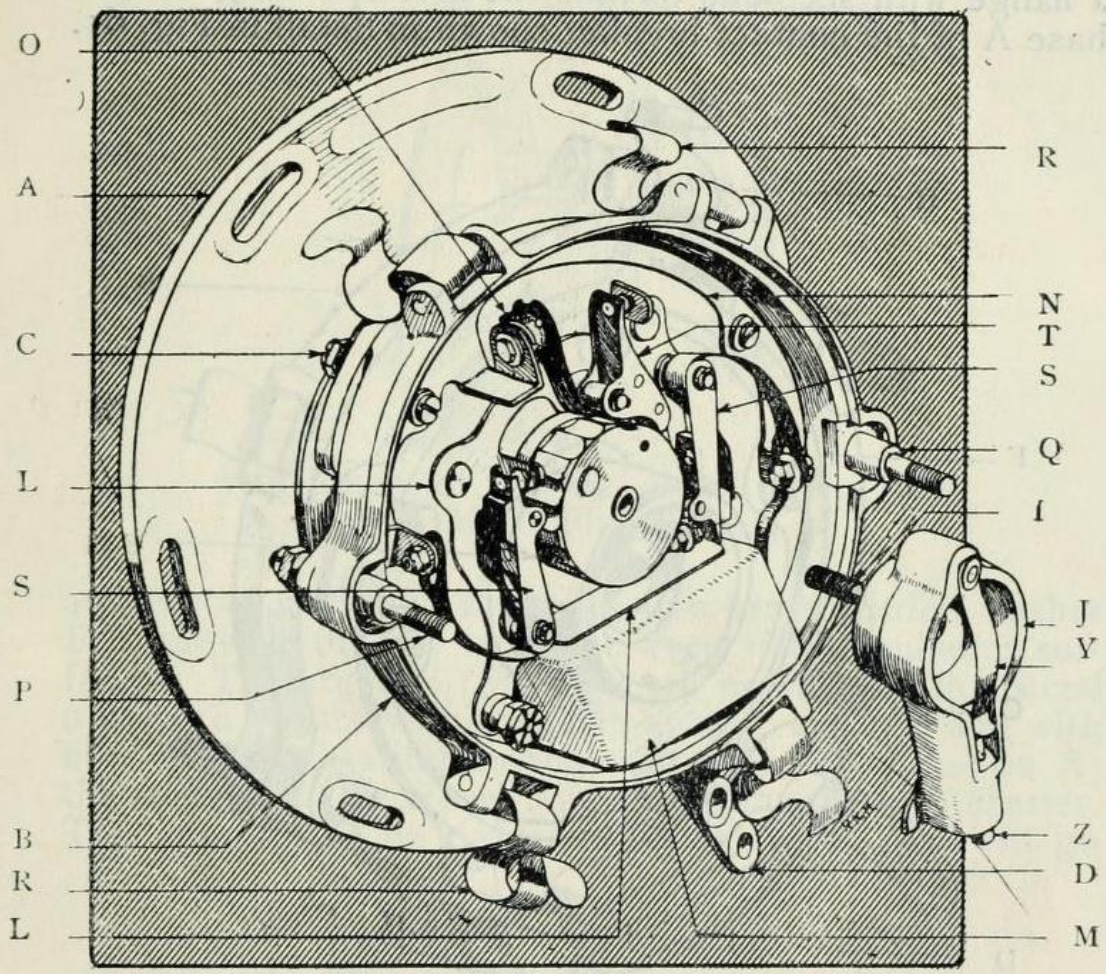


Fig. 61.
The Contact Breaker
(showing H.T. Rotor).

The six bolt holes are slotted to permit of the base plate A being adjusted 10° relatively to the camshaft casing, so providing for fine setting of the ignition timing. Mounted upon the base plate A is the base B of the contact breaker proper: the back of B is shown in Fig. 62, with four studs C which pass through slotted holes in lugs cast on A. The slots are long enough to permit a timing control movement of 20°, equal to 40° on the crankshaft, and the movement is effected by the usual control lever coupled up to the arm D, which may be reversed for use on either right- or left-hand units. The base B has a brass-sleeved boss E, which registers A and B concentrically; there is a thin brass friction washer F to prevent the rub being between two aluminium surfaces. The studs C (Fig. 63) are provided with special nuts with collars which pull up against springs, and with fibre washers bearing on the back of the lugs cast on A; the studs limit the travel, and the springs absorb chatter. The nuts should be tightened up as far as they will go without causing binding of the control gear.

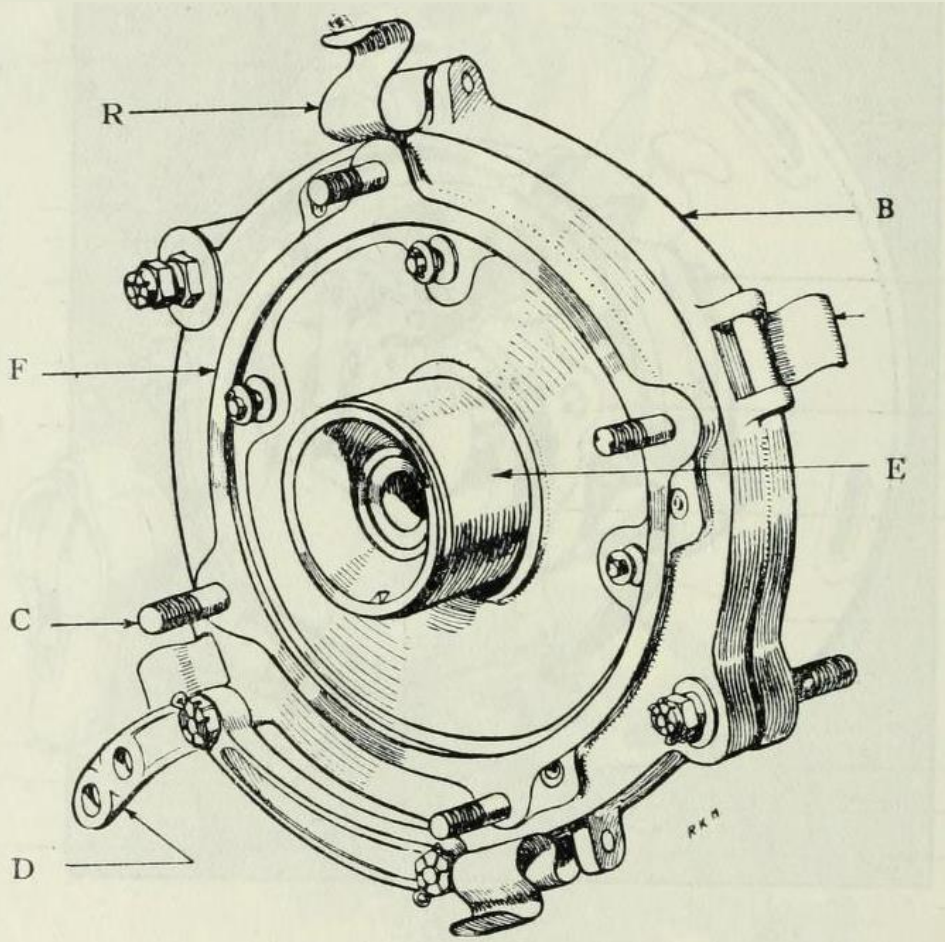


Fig. 62.

Contact Breaker Base Plate
(back view).

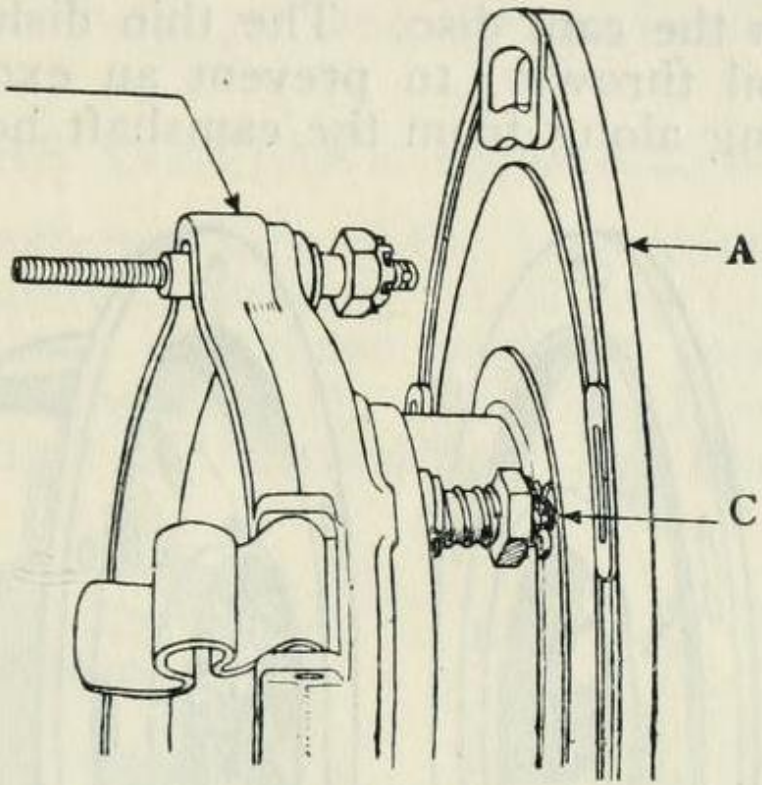


Fig. 63.
Attachment of Contact Breaker Base (B) to Main Flange (A).

Mounted in the base B are two annular ball bearings provided with grease-retaining felt washers, and in these bearings the cam spindle runs. In Fig. 64 the 12-lobed cam G is seen apart from the spindle H, to which it is keyed and secured by the screw I (Fig. 61); the screw also retains the high tension distributor rotor J (Fig. 61) in place, the rotor being driven by a shallow stud projecting from the cam disc. The thin dished flange K is merely an oil thrower, to prevent an excessive amount of oil working along from the camshaft housing into the contact breaker. In early models, the cam spindle was driven by a laminated spring coupling engaging with slots in the camshaft end (Fig. 65), with a dowel peg to take the drive in the event of the springs breaking. In later models, the spring drive is dispensed with, and a plain solid dowel peg engages a notch in a steel flange nipped under the seven nuts which bolt up the driven bevel wheel to the camshaft (Fig. 66).

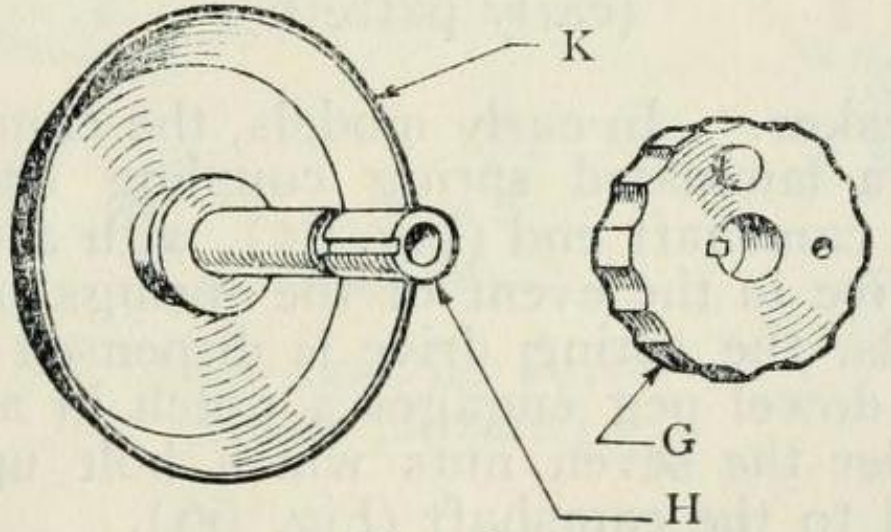


Fig. 64.
The Cam and Cam Spindle.

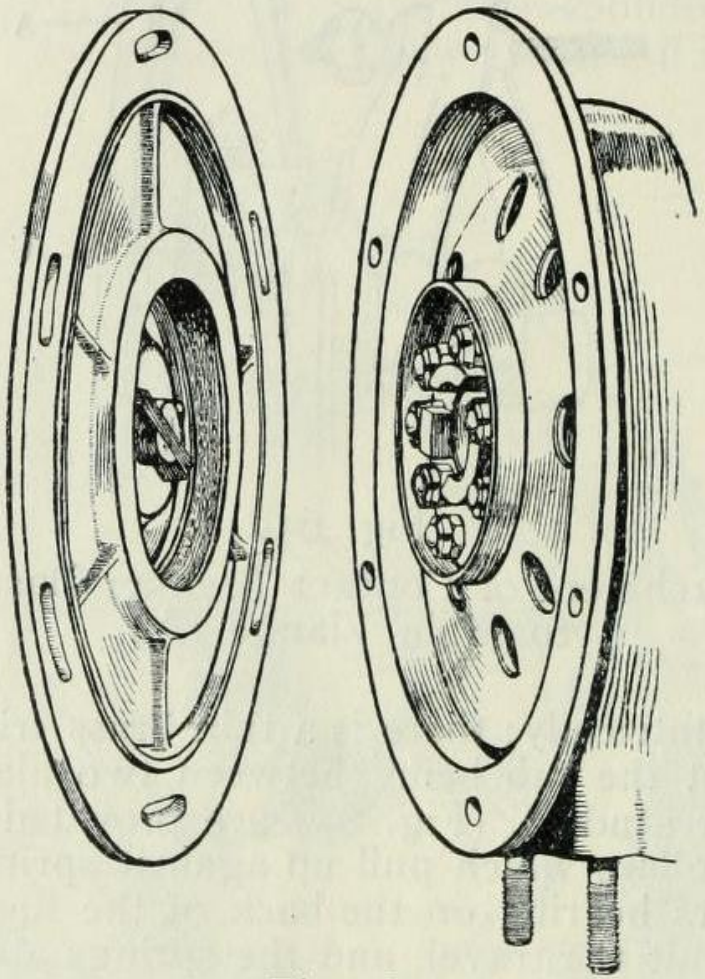


Fig. 65.
Cam Spindle Drive
(early pattern).

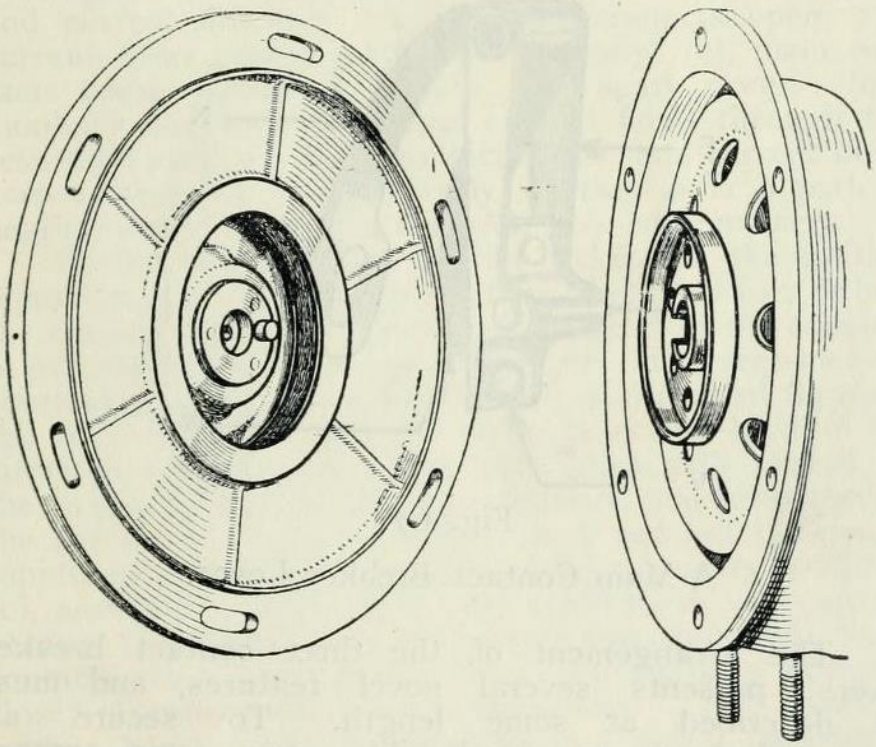


Fig. 66.

Cam Spindle Drive
(later pattern).

The body of the cam is hollowed out from the back and filled in with a felt oil pad, held in place by a light pressed steel plate. In the face of the cam there is a hole through which the felt may be oiled, and six tiny holes, drilled radially through the broad noses of the cam, feed oil to the fibre striker pads of the contact breaker levers. As the merest trace of oiliness is sufficient for these, care should be taken not to overdo the oiling here: it may be found that no special provision was necessary after all. The cam has six broad and six narrow noses or lobes, corresponding to the angular intervals between firing points—namely, 75° and 45° successively.

THE CONTACT BREAKERS.

On the external face of the base plate B (Fig. 61) there is mounted a pressed steel ring L carrying the earthed contacts, the three insulated contact breaker levers, and the condenser M. The ring L is pivotted on a stud to the right of the condenser, and has three other holes which are slotted for two plain studs and a screwed stud; the screwed stud is to the left of the condenser, and has a nut and split pin. The ring can, therefore, be moved slightly in relation to the cam in order to correct the setting of the contact breakers. There is also an insulated half-ring N, carrying the ends of the three spring blades controlling the levers, and the small resistance coil O. One end of the half-ring N is connected to the insulated stud P, and primary current from the generator or battery (after passing the coil) goes to earth via this connection, the springs, and the levers and contacts. At Q there is another insulated stud to which the primary lead from the switch is connected, and which, with its fellow P, serves to secure the distributor, and at the same time makes the primary circuit complete through the coil. The distributor cap is held in place by four spring-clips R in addition to these two studs, but the knurled-headed socket nuts of the studs P-Q must be pulled down very tight to make a good electrical circuit, apart from the mere holding of the distributor.

The arrangement of the three contact breaker levers presents several novel features, and must be described at some length. To secure an increased measure of reliability, two main contact breaker levers S-S (Fig. 61), are provided, either one of which will operate the ignition in the event of a failure of the other. Probably the most likely lever of the three to break down is the small auxiliary one T, and if this fail the other two may become useless, depending upon the nature of the fault. Should it remain permanently closed, the main levers cannot break the circuit, but if the auxiliary lever should open and remain open, the operation of the main levers will not be interfered with. In any case should one of the main levers, or the auxiliary lever, break down, it may be removed, and the engine run on one main lever only.

A main contact breaker lever S is shown apart in Fig. 67; the fibre striker pad U, the rivetted-in tungsten contact V, and the vulcanised-in rubber buffer pad W upon which the end of the spring X rests, are all clearly seen. The auxiliary lever T (Fig. 61) is generally similar, but cranked instead of straight, and the spring is connected to a small resistance coil O of about 8 ohms, instead of direct to the half-ring N already described. This auxiliary lever is timed about 5° in advance of the main levers, both for opening and closing.

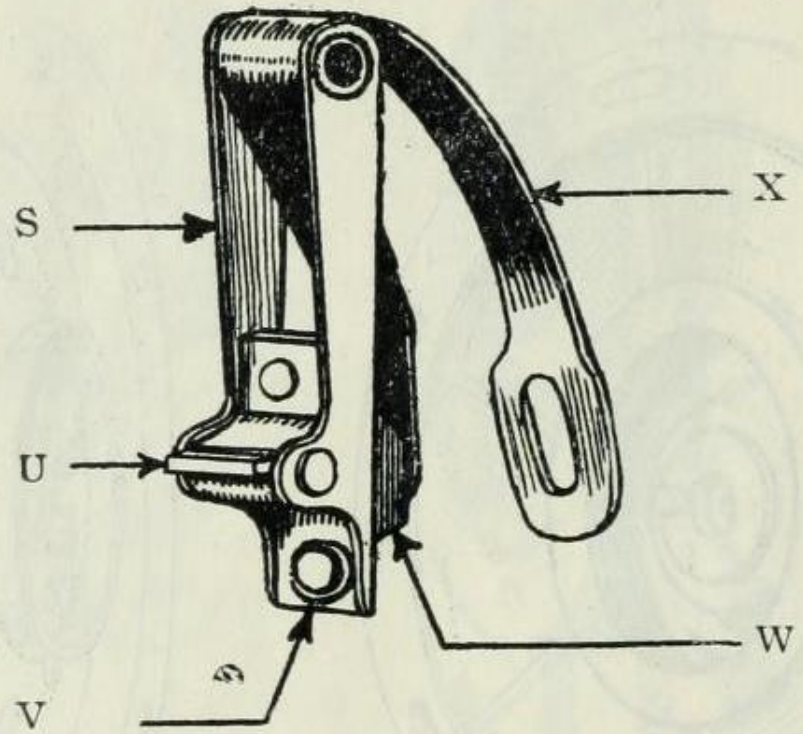


Fig. 67.

A Main Contact Breaker Lever.

When running normally in the forward direction (which is clockwise as viewed from the face of the unit), the sequence of operation is thus: (a), all contacts closed and current flowing; (b), auxiliary contacts open, and current flows across main contacts only; (c), main contacts open, circuit is broken, and spark occurs; (d), auxiliary contacts close, and current flows through the resistance coil; (e), main contacts close, and current flows across these almost exclusively, as they offer a path of negligible resistance; (f), the cycle now recommences.

Should the engine try to run backwards, the ignition is not actually cut out, but the flow of current (or, rather, the change of rate of flow) at each break of the contacts is so reduced that no spark can occur. The sequence on reversal is:—(a), all contacts closed, and current flowing; (b), main contacts open, but no spark occurs because the circuit is closed through the alternative path offered by the auxiliary contacts and the resistance, and consequently the current in the coil winding, does not fall sufficiently rapidly to induce a high voltage in the secondary winding; (c), auxiliary contacts open, and again there is no spark, because the current flow is at a very low value; (d), main contacts close, and current flows; (e), auxiliary contacts close; (f), the cycle now recommences. The auxiliary contact breaker fills its function as a safety back-firing device perfectly, with the qualification that it cannot prevent a single back-fire if the circuit is broken when the crank is in advance of top dead centre.

THE HIGH TENSION DISTRIBUTOR.

The distributor head (Figs. 68 and 69) is an extremely fine piece of moulding in the insulating material known as Bakelite, a ring of different composition being moulded in to form the rubbing track for the carbon brush Z of the rotor J (seen in Fig. 61). The distributor head has a spigot edge fitting into a bored register on the contact breaker base (B, Fig. 61); it is firmly held in place by four spring clips (R, Fig. 61), and two insulated knurled headed socket nuts which screw down on to the insulated studs P and Q (Fig. 61).

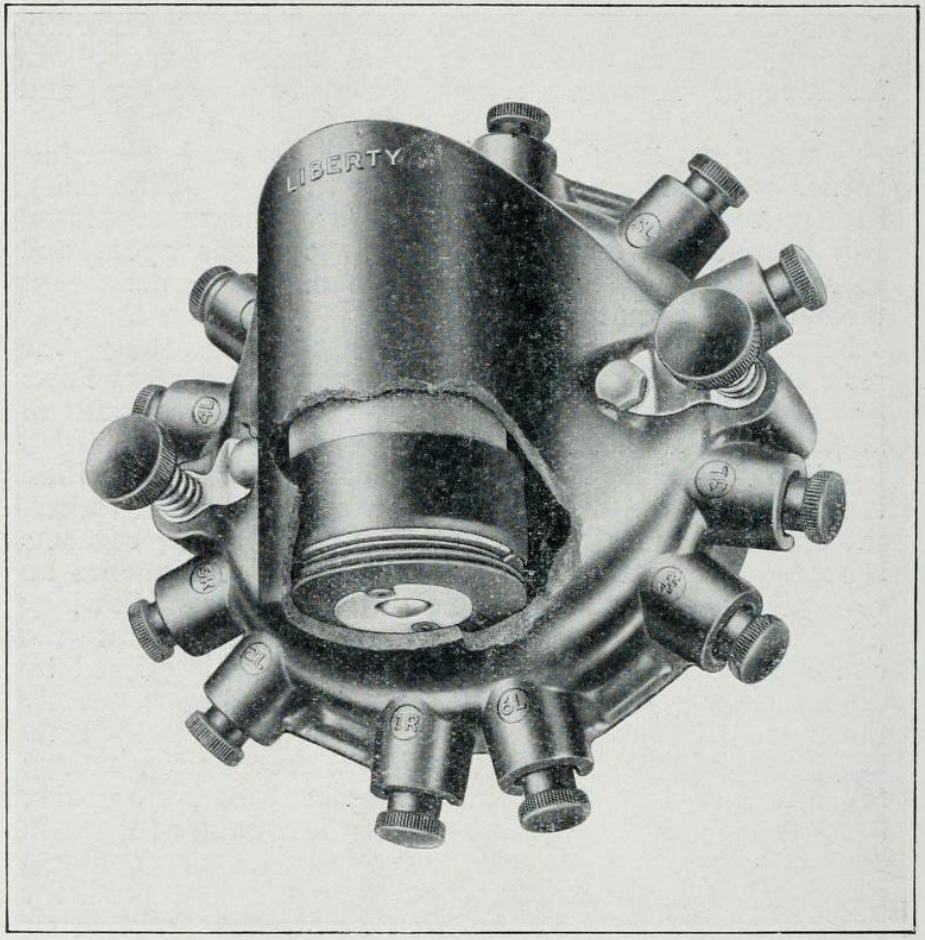


Fig. 68.
The Distributor Head
(exterior).

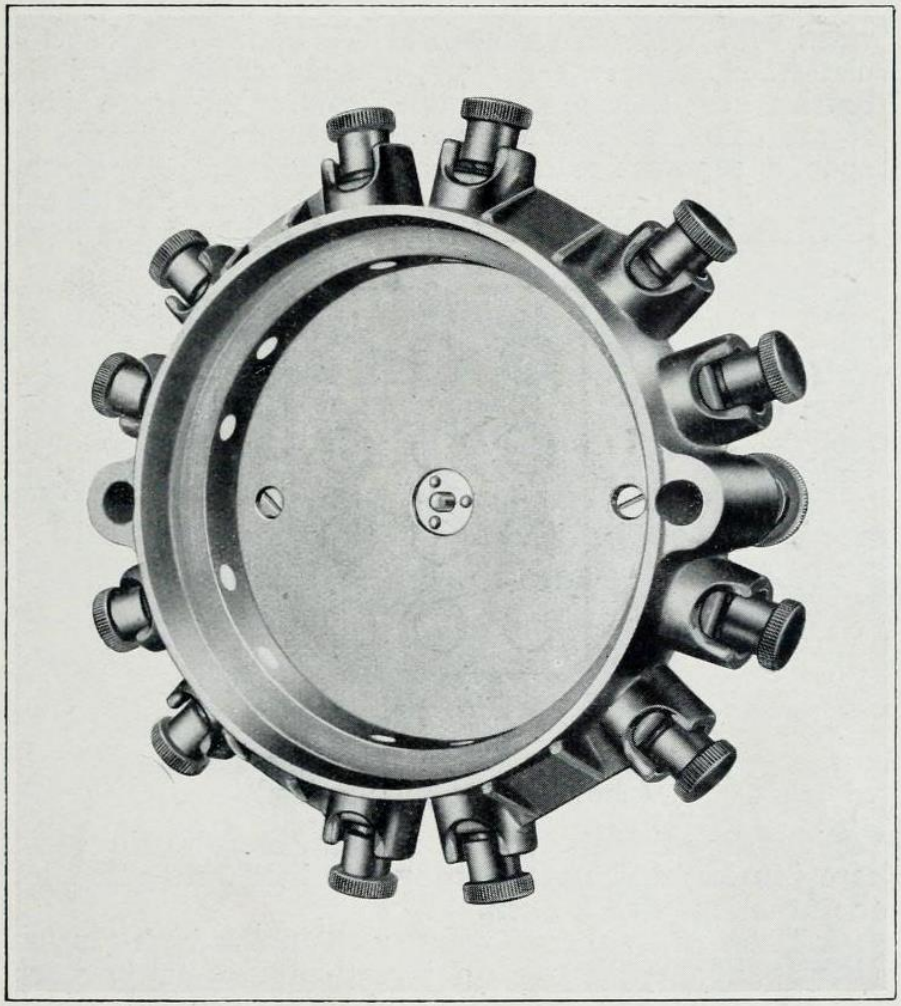


Fig. 69.
The Distributor Head
(interior).

Fitting snugly into the domed head is the induction coil, one end of which can be seen in Fig. 68. The coil is built up, as usual, with two windings of insulated copper wire upon a core of soft iron: the two ends of the primary winding are electrically connected to the metal portions of the knurled nuts fixing the head. As the battery lead is connected to the terminal stud Q, and the terminal stud P is in connection with the contact breakers, it follows that the primary winding of the coil forms part of the complete circuit, and that current will flow in the coil when either or all of the contact breakers are closed and the switch is on. One end of the secondary winding of many turns of fine wire is connected to the primary winding, but the high potential end is connected to a fixed carbon brush projecting slightly from the centre of a disc of insulating sheet, which closes the inside of the distributor head and hides the coil.

This brush, when the unit is assembled, presses upon a light bowed steel spring blade Y (Fig. 61), carried on the rotor J; as the free end of the spring blade touches upon a brass liner into which the carbon brush Z fits, the brush is brought into connection with the secondary winding of the coil. Moulded into the brush track in the distributor head there are twelve circular studs or "segments," each in connection with a screwed terminal knob, by which the corresponding high tension sparking plug cable is fixed. The bosses into which the insulated terminal knobs are sunk are notched on one side to clear the cables, and on the other side are very clearly marked with the numbers of the plugs; each terminal is provided with a spring washer. It will be noticed that the distributor segments are not placed equally round the brush track; they are at angles corresponding to those of the cams, so that the rotor brush must always be upon a segment when the cams open the circuit by breaking the contacts apart. The edge of the brush track is bevelled, so that the head may be the more readily slipped on over the carbon rotor brush; great care is necessary when putting the head into place, or the brush may be broken.

There is no special safetv gap in the high tension circuit, but there is an air gap of about 14 mm. between the spring blade Y and the head of the screw I, which fixes the rotor and cam to the cam spindle, and in the event of excess potential in the coil winding (due, for example, to a lead having come off a plug), a spark may pass here and save the coil from a breakdown.

HIGH TENSION CABLES.

The twelve high tension cables for each distributor go respectively to one plug in each cylinder, the left-hand unit firing the forward set of plugs and the right-hand unit firing the after set. The leads are of the usual pattern of 7 to $7\frac{1}{2}$ mm. rubber insulated flexible cable, fitted with spring clip terminals to take ball knobs on the plug electrodes. Carried by six steel clips or brackets fixed under the heads of screws securing the water pipe flanges to the induction manifolds, there is a "U" shaped aluminium conduit tube with a large opening at the base of the "U" by which the 24 leads enter, and a series of small holes by which single leads issue near their respective plugs. Between each distributor and the conduit tube the leads are passed through a pair of ebonite plates (Fig. 70), moulded with numbers corresponding to the numbers of the distributor terminals and plugs to which the leads are connected. The firing order of the cylinders, as indicated by Fig. 71, and by the metal name-plate on each engine, starting at the ignition gear end of the engine, is on left-hand side, 1, 9, 5, 11, 3, 7, and on right-hand side, 8, 4, 12, 6, 10, 2. The sequence through the whole engine is 1L, 6R, 5L, 2R, 3L, 4R, 6L, 1R, 2L, 5R, 4L, 3R.

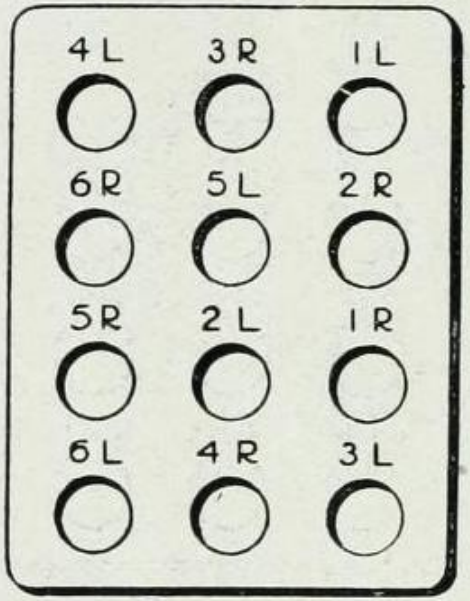


Fig. 70.

High Tension Cable Carrying Plate (showing the numbering).

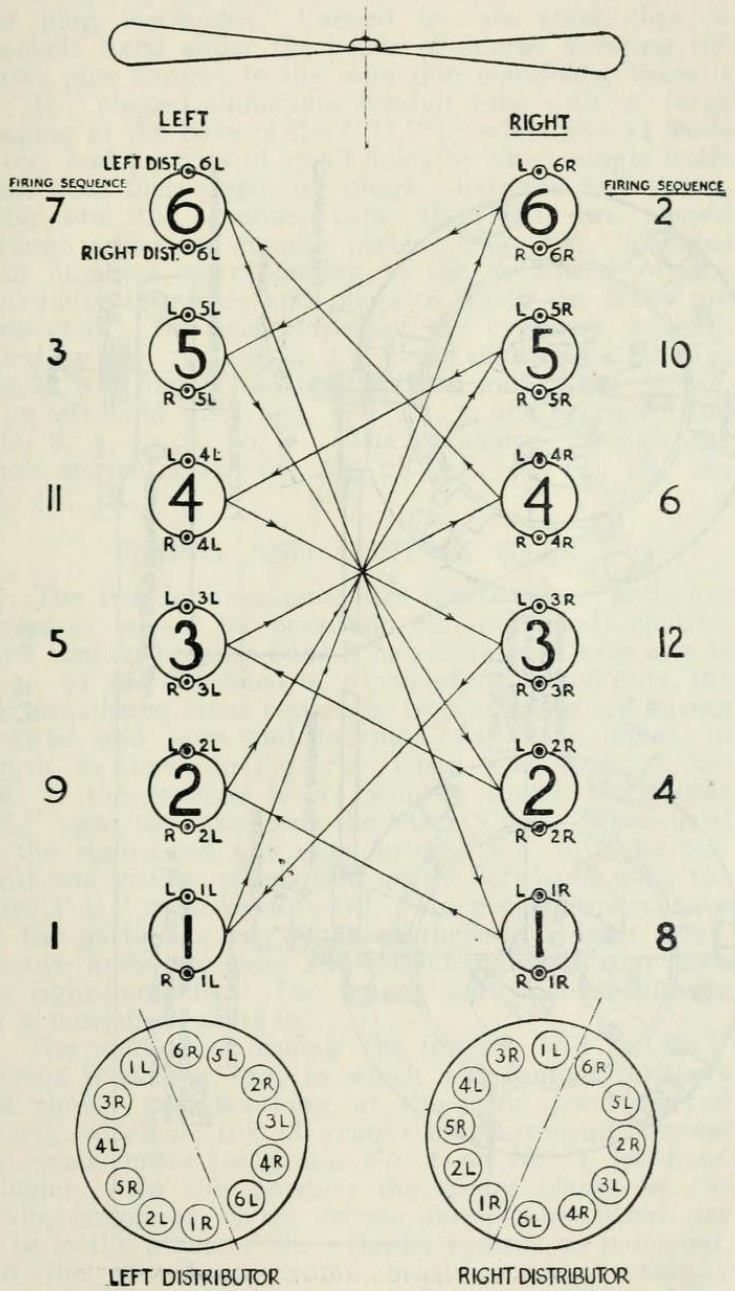


Fig. 71.
Diagram indicating Sequence of Firing and Distributor Connections.

TIMING AND CONTROL GEAR.

The two ignition units are timed alike, and are moved in unison by operation of the hand control. Each contact breaker base B has a cranked lever arm D (Figs. 61 and 62) fixed by a pair of studs and nuts, the two arms being cross connected by a coupling rod having screwed end jaws and locknuts for adjustment to length, as shown in Fig. 72. Upon one side of the web of the cranked levers will be found the letter "R," upon the other side the letter "L." When used on the right-hand unit, the letter "R" is to be outward and visible; when used on the left-hand unit, the letter "L" must be outward. In every respect, save for the particular way of fixing these little lever arms, the two units are alike and interchangeable, and both run right-handedly. The timing control must provide for a movement of $1\frac{5}{8}$ in.

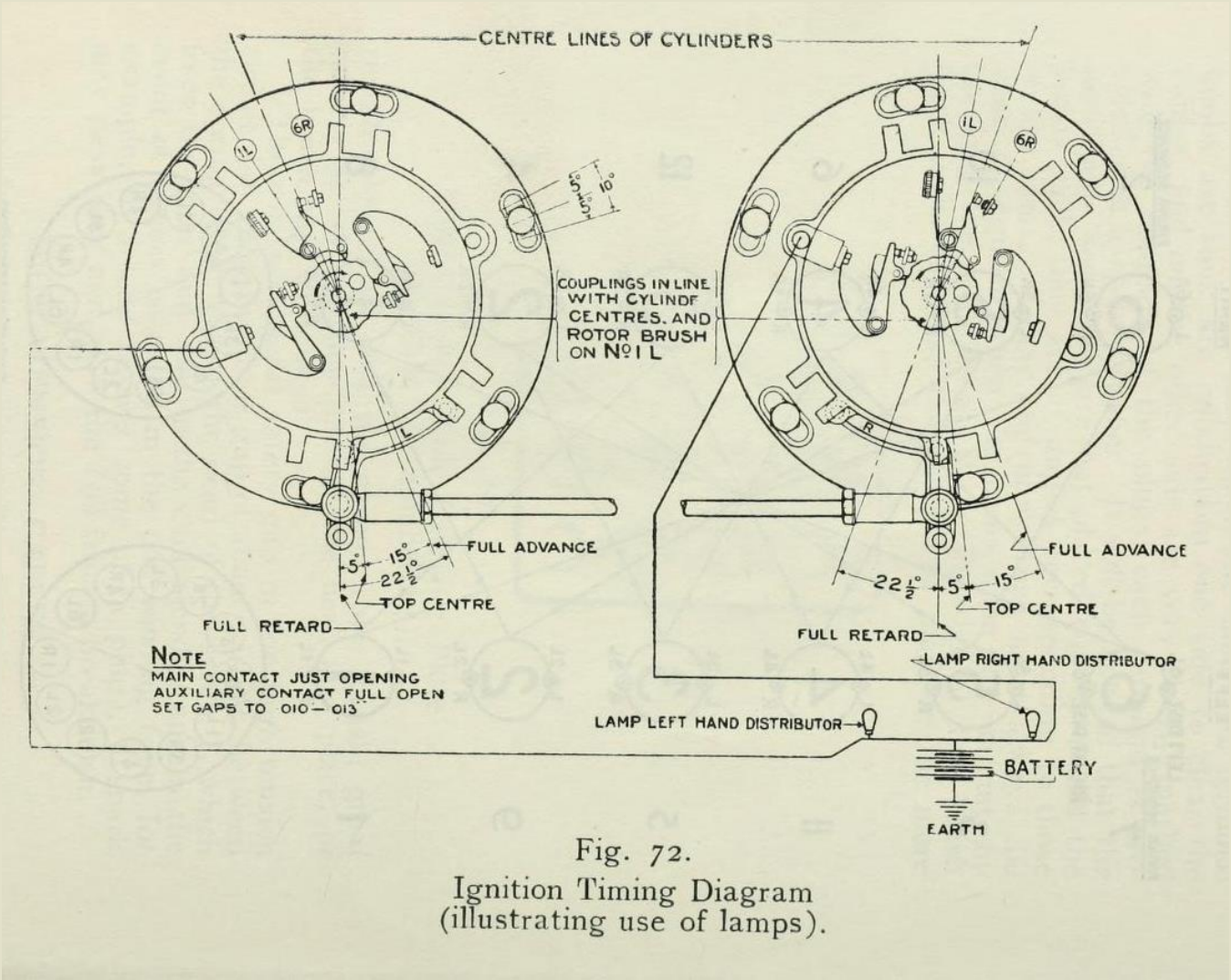


Fig. 72.
Ignition Timing Diagram
(illustrating use of lamps).

The method of timing the ignition will be fairly obvious from Fig. 72, in which the contact breakers are shown just breaking at the firing point on full retard, which is 10° of crankshaft movement beyond top dead centre for crank No. 1 on No. 1 left-hand cylinder. In this position the spring blades of the driving couplings, or the driving dowels when fitted, are to be in the plane of the cylinder centres as indicated, and the distributor rotor brush pointing midway between the auxiliary contact breaker points and the little resistance coil, thus coming on No. 1L distributor segment.

The exact firing point may be regulated by slackening off the six bolts securing each ignition unit base flange to its respective camshaft housing, and turning the unit in the required direction. The total range so obtainable is 10° on the unit, or 20° on the crankshaft, which is not only ample to cover any accumulated errors in machining, but will enable the timing of the ignition to be varied from the standard setting if required. The regular setting is to fire at 30° of crankshaft angle before top dead centre at full advance, and 10° after at full retard, and this setting should not be departed from without proper authority. When correctly set a notch is cut in the two main flanges, so that there can be no doubt of the position when reassembling.

To check the timing electrically two means are available, and either will give the required result. One way is to assemble the distributor head, turn the engine forward slowly by hand, and watch the ammeter to show when the circuit is broken and the firing point reached; this must be done on only one unit at a time, unless a lead is first removed from the generator terminal marked "GEN. ARM," as otherwise the battery would discharge through the generator (*vide* page 68). The alternative method is to wire up a couple of lamps or bells as indicated in Fig. 72. While either contact breaker is closed the current will flow in the corresponding circuit; but when all three contact breakers of the unit have opened, the circuit will be broken, and the lamp or bell will be dead. If, then, one unit be timed correctly in reference to the crankshaft, the other may be synchronised exactly by moving the base plate until the circuit is broken, when the six bolts may be locked up. The coupling rod should be disconnected when timing up for the first time, and both control levers set to full retard; the coupling rod can be adjusted to length and coupled up after the units have been set independently. Finally, the timing should be checked electrically for synchronism at full advance, and if necessary any slight adjustment can be made on the coupling rod to bring the two units dead together. It must be remembered that, as the ignition gear runs at camshaft speed, all angles as measured on the contact breaker and distributor will be doubled on the crankshaft. Hence the 15° of advance on the contact breaker, shown in Fig. 72, corresponds to 30° on the crankshaft, and the 5° of retard to 10° on the crank.

The correct setting of the contact breaker gaps is 0.012 in. at full lift, but the gaps of the two main breakers of either unit may be set between the limits of 0.010 to 0.013 in. if it should be necessary to bring the timing of the pair closer together. In any case, the spark occurs when the later of the two main breakers opens, and there should be no more than $1\frac{1}{2}^{\circ}$ between them. The fibre striker pad of the auxiliary contact breaker should be central on a narrow nose of the cam when the main breakers are just opening on two other narrow cams. To correct the relative settings of a pair of main breakers, take out the split pin and slacken the nut of the stud which secures the ring L (Fig. 61). The ring may then be slewed about the stud at the other end of the condenser, and by resetting the contacts a close adjustment may be obtained before re-locking the fixing nut.

The correct pressure between the contacts of the contact breaker levers is from 26 to 30 oz. The pressure may be adjusted by altering the effective lengths of the respective springs, which, as may be noted from Fig. 67, have slotted fixing holes.

DAILY ROUTINE.

1. Take the voltage of the battery before each day's flying. On open circuit—that is to say, with both ignitions switched off—the voltage should not be less than 8 volts; with one ignition switched on, and the ammeter showing a discharge of from 4 to 5 amperes, the reading should be not less than $7\frac{1}{2}$ volts. Should the voltages be lower, a freshly charged battery should be fitted.

2. Remove and clean the plugs, and set their gaps to 0.015 in., renewing any plugs that appear to be of doubtful soundness.

3. Remove the distributor heads and examine the contact breakers. The gap should be between the limits of 0.010 and 0.013 in., and the points should meet squarely.

4. Clean the carbon brush tracks of the distributors with petrol on a piece of cloth. Do not use any abrasive material.

5. Run over all leads, especially those on the engine, examine for deterioration from oil or burning, and see that all terminals are tight.

6. Before starting the engine, switch on each ignition system separately, and note the ammeter readings, which should be approximately equal. It may be necessary to turn the engine a few degrees *backward*, in order to bring the main contact breakers to the closed position before the full current can flow. Should one system show no discharge reading, there is a break in the circuit, probably due to a loose terminal or very dirty contacts. Should one show an excessively high discharge, there is a partial short circuit somewhere. To detect a short in a coil as distinct from the wiring, change over the primary leads to the distributor heads.

7. Immediately the engine stops, put both ignition switches to the OFF position.

WEEKLY ROUTINE.

1. Flush the battery as already detailed, and correct the acid density if necessary. Wipe the battery dry and clean from acid, and smear a little vaseline on the terminals before replacing it. Wipe out the battery box.

2. Remove the dust cover from the generator brush gear, dust the commutator, etc., and, if necessary, clean with petrol. See that the brushes are in order, and put a few drops of thick oil on the ball bearing at the top of the armature spindle.

3. Clean out the contact breakers, and put a drop or two of oil on the pivot bearing of each lever. Check and readjust the points if required. The amount of slack in the driving coupling should not allow of more than about $\frac{1}{16}$ in. of play at the end of the distributor rotor.

MONTHLY ROUTINE.

1. Let the weekly clean-up and inspection be, if possible, more thorough than usual.

2. Open out the switch, clean all contacts, and put a little vaseline on the track. Inspect the resistance coils.

3. Inspect and clean the voltage regulator. The gap between the contacts should be from 0.005 to 0.007 in. when the blade is pressed down upon the stop-pin. Work a drop of oil into the pivot bearing.

CHAPTER V.

Running Instructions.

MAXIMUM R.P.M.

The army type of Liberty engine has a high compression ratio, for the purpose of obtaining a high power output at altitude: it must never be run all out near the ground. Pilots and mechanics should carefully note the following r.p.m. limits:—

Maximum speed "running up" on the ground, 1,400 r.p.m.

Maximum permissible speed flying at ground level, 1,500 r.p.m.

Normal full speed at or above 6,000 ft.—1,650 r.p.m.

Maximum permissible speed at or above 6,000 feet.—1,750 r.p.m.

If a suitable propeller is fitted, it is practically impossible to exceed 1,400 r.p.m. in ground tests.

The naval model has a lower compression ratio, so that its maximum speed, irrespective of height, is 1,750 r.p.m.

PRECAUTIONS WITH A NEW ENGINE.

It is highly inadvisable to run a new engine at all hot, as there is a considerable risk of "baking" the rings into their grooves with burnt oil, a mishap which can only be remedied by dismantling the engine completely. For this reason it is inadvisable to run on a weak mixture—e.g., by testing the altitude control for more than a few seconds at ground level.

FILLING WITH OIL.

The recommended oil is Vacuum Mobiloil B B, the average consumption being eight to twelve pints per hour. A safety allowance of three gallons over and above the calculated consumption for an intended flight must be provided. When the engine is stopped after a flight, about a gallon of oil will slowly drain down into the sump. The scavenge pumps have a greater capacity than the pressure pump, and this gallon will quickly be returned to the tank when the engine is next started. It is therefore necessary to allow ample clearance in the tank when replenishing. As allowance must further be made for frothing and expansion, clearance should be left in the tank for about 1½ gallons of oil, whenever the sump has not been drained.

In winter the tank should be replenished with heated oil, unless facilities are available for keeping the engine warm whilst in the hangar.

The main thrust bearing must be filled with oil by means of an oil can before each flight. Mechanics should realise that the thrust housing will hold a good deal of oil, and that the race cannot run dry during a long flight if the housing is filled.

COOLING SYSTEM.

A plug beneath the lower delivery connection on the pump permits all the water to be drained in frosty weather. In refilling the cooling system, it is advisable to raise the tail of the aeroplane, so that the system will fill from the bottom upwards. Otherwise air may be trapped, when the circulation will be imperfect, and the machine will start on its flight with less than the full complement of water.

OIL PRESSURE.

After first starting up, therefore, if the pressure begins to fall, and finally becomes constant at about 25-30 lbs. at 1,650 r.p.m., when the oil has warmed up, the circulation is almost certainly correct.

In very cold weather the safest method of warming up the oil is to run the engine for several spells of two or three minutes each, switching off between spells, so that heat can reach the base chamber by conduction. The camshaft is remote from the pump, and may be the last component to receive proper lubrication, when the circulation is very sluggish. Under such conditions one of the lids may be removed from the camcase, and hot oil poured in.

When the engine is accelerated towards its maximum r.p.m., the pressure gauge should register not less than 25-30 lbs.

A WARNING ABOUT THE SWITCHES.

The Liberty engine is liable to be started accidentally, when it is warm or has just been doped, ready for starting. The type of ignition employed affords a very good spark: any rapid switching on and off produces a crude form of make and break, and may lead to sparking at the plugs. Special care should therefore be taken to see that nobody is within reach of the propeller when the switches are operated.

One switch only must be on contact at starting; if both switches are "on" during starting or slow-running, the heavy rate of discharge will run down, and will injure the battery. Needless to say, both switches must be kept in the off position when the engine is out of use, or the battery will run down. (See pp. 68 and 93.)

STARTING THE ENGINE.

Owing to the excellence of the spark at low speeds, the engine is easy to start, despite its size. It is doped via the compression cocks above the inlet manifolds or by means of the doping pump in the cockpit.

ONE distributor switch is then put on contact, the ignition being fully retarded, the throttle lever in the be drawn off by either of two methods, viz.:—
minimum position, and the altitude control shut. On the propeller being swung or the starter (if any) being operated, the engine should start. (The Americans usually pull the propeller over compression by means of three mechanics who link hands in line, the left-hand man pulling the propeller with his left hand, the centre man pulling on the right-hand of the man at the propeller, etc.) As soon as the engine fires, the ignition should be fully advanced, and the second distributor head switch put to "contact." The engine cannot fire backwards, as auxiliary contact-breakers cut out the ignition when a backfire occurs.

AFTER STARTING UP.

Warning is given above against accelerating before the oil is sufficiently fluid to circulate properly. The larger the quantity of oil in the tank, the longer will be the delay. A satisfactory oil temperature is 40° Centigrade, and this may not be attained for ten minutes in cold weather, if a supply of five gallons is carried. When the oil is circulating properly, the engine may be acceler-rated for a revolution test up to 1,400 r.p.m. Make a revolution test on each ignition set separately.

Should a test of the altitude control be made, the tachometer should register a drop of approximately 200 r.p.m. if the altitude control is fully opened for a few seconds with the engine running at 1,400 r.p.m. The altitude control must not be kept open for more than a few seconds at ground level, or the slow-burning mixture may cause the engine to catch fire.

SMOKY EXHAUST ON WIDE THROTTLE OPENINGS.

A smoky exhaust is noticeable at or near full throttle opening in the case of engines equipped with the H.C.7 carburettor. This effect passes off as the machine climbs into a less dense atmosphere, and is apparently due to "cracking" of the oil and petrol vapour, due to the high compression ratio of the engine, the volumetric efficiency of the H.C.7, and local causes peculiar to individual cylinders (e.g., overheated valves or pistons, carbon deposit, or uneven mixture).

The matter is not serious, as the exhaust will become clear, owing to decreased cylinder pressure, before reaching 10,000 feet. The smoke may be decreased by slightly retarding the ignition. In any case, the ignition, in flight, should be set to the point at which the engine runs best from the point of view of revolutions; and it should be noted that with its special form of ignition the Liberty engine is sensitive to its ignition control to a greater extent than occurs where magnetos are used.

This paragraph is included to prevent mechanics from ascribing the smoky exhaust tc over-large jets. The standard Claudel jets (main 490 cc., pilot 200 cc.) are the smallest compatible with full r.p.m. at ground level.

AFTER THE PRELIMINARY RUN.

If circumstances permit, switch off the engine after its preliminary run and acceleration tests, and carry out the following inspections:—

i. The sump and camshafts should be warm.
ii. The cylinders, water pipes, and radiators should be hot.
iii. See that the water pump is not excessively hot, indicating that the stuffing glands are too tightly packed.
iv. There must be no oil, petrol or water leaks.

AFTER A FLIGHT.

Take whatever precautions are locally authorised to facilitate the next start, e.g., inject a little paraffin into the compression cocks, and on to the valve stems, giving the engine one or two turns.

Refill the oil tank, unless this job is postponed in order to use warm oil immediately prior to restarting.

Test, and, if necessary, reset the tappet clearances.

Overhaul all nuts.

Fill the main thrust with oil.

Clean the petrol filter, and, if ordered, all three oil filters.

Examine, and, if necessary, clean or renew the sparking plugs.

Inspect all ignition connections.

In winter, take precautions aganst frost: in summer, replenish with water.

Verify the condition of the ignition, especially the accumulator. Test the firing on each distributor separately. As this ignition is of a type unfamiliar in the British Services, Chapter IV. should be carefully studied.

Refill the petrol tanks.

PERIODIC ATTENTIONS

Cleanse the oil and petrol filters.

Overhaul and test the ignition. (See Chapter IV.)

Examine the high tension cables for worn or perished insulation.

Remove and clean all the sparking plugs.

Cleanse the carburettors.

Examine the stuffing glands of the water pump.

Oil the joints of all the engine controls.

Standard Fits and Clearances.

(Expressed in fractions of an inch.)

	Minimum.	Maximum.	Desired
Crankshaft.			
Diametrical Clearance	.0025	.00325	
End Play	.0575	0775	
Connecting Rods.			
Forked End—			
Diametrical Clearance	.003	.004	
End Play	.008	.020	
Plain End—			
Diametrical Clearance	.005	.0065	
End Play	.004	.008	
Gudgeon Pin.			
Fit in Rod	.00025	00125	Select for .001 Clearance
Fit in Piston	.00025 tight	.00075 tight	Select for light drive fit
Piston Rings.			
Fit in Grooves	.00125	.003,	Top .003 Mid. & Bot. .002
Gap	.021	,041	.030
Piston.			
Fit in Cylinder	.018	.022	Select for .020 Clearance
Camshaft.			
Diametrical Clearance	001	.003	
End Play	.000	.004	Min. .002
Camshaft Upper Drive Shaft.			
Diametrical Clearance—			
Large Bushing	.0005	.0025	Min. .0015
Small Bushing	.0005	.0025	Min. .0015
End Play	.002	.008	Min. .004

Standard Fits and Clearances.—*continued.*

	Minimum.	Maximum.	Desired.
Rocker Levers.			
Diametrical Clearance	.00025	.00175	Min. .001
End Play	.005	.010	.0075
Valves.			
Fit of Stems in Guides.			
Diametrical Clearances—			
Exhaust Valves	.004	.0065	.005
Inlet Valves	.002	.0045	.003
Water Pump Shaft.			
Diametrical Clearance	.0015	.0035	Min. .0025
End Play	.006	.010	.010
Water Pump Bevel Driver.			
Diametrical Clearance	.001	.0025	
End Play	.005	.008	
Oil Pump.			
Fit of Gears in Housing.			
Diametrical Clearance	.001	.005	Select for .004 Clearance
End Play	.002	.007	Select for .003 Clearance
Tappet Gap.			
Exhaust Valves	.019	.021	
Inlet Valves	.014	.016	
Contact Breaker Gap	.010	.013	
Sparking Plug Gap	.015	.018	.015
Regulator.			
Contact Gap	.005	.007	
Height of Pin	.043	.045	

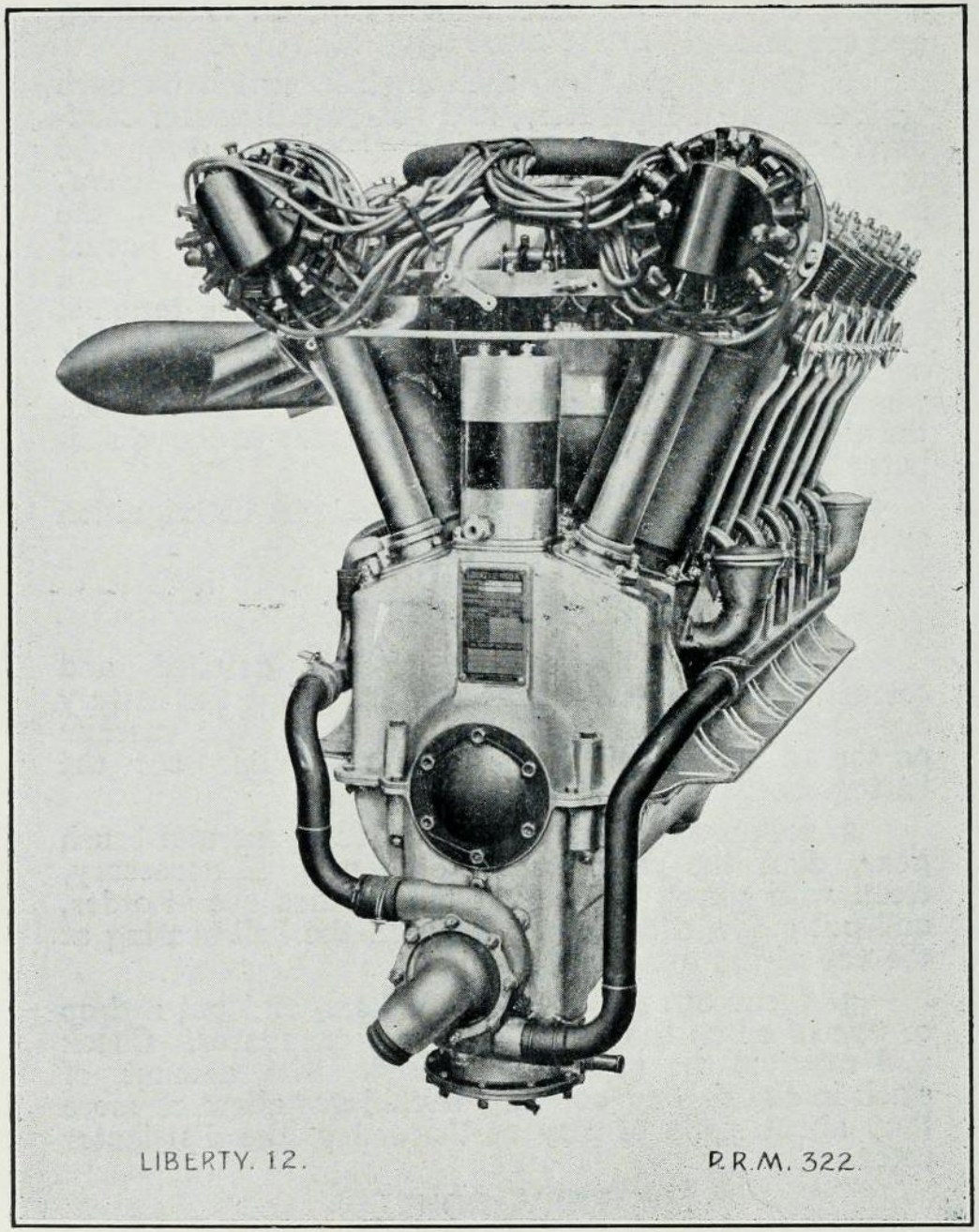


Fig. 74. Rear View of Engine, showing Distributors and Generator.

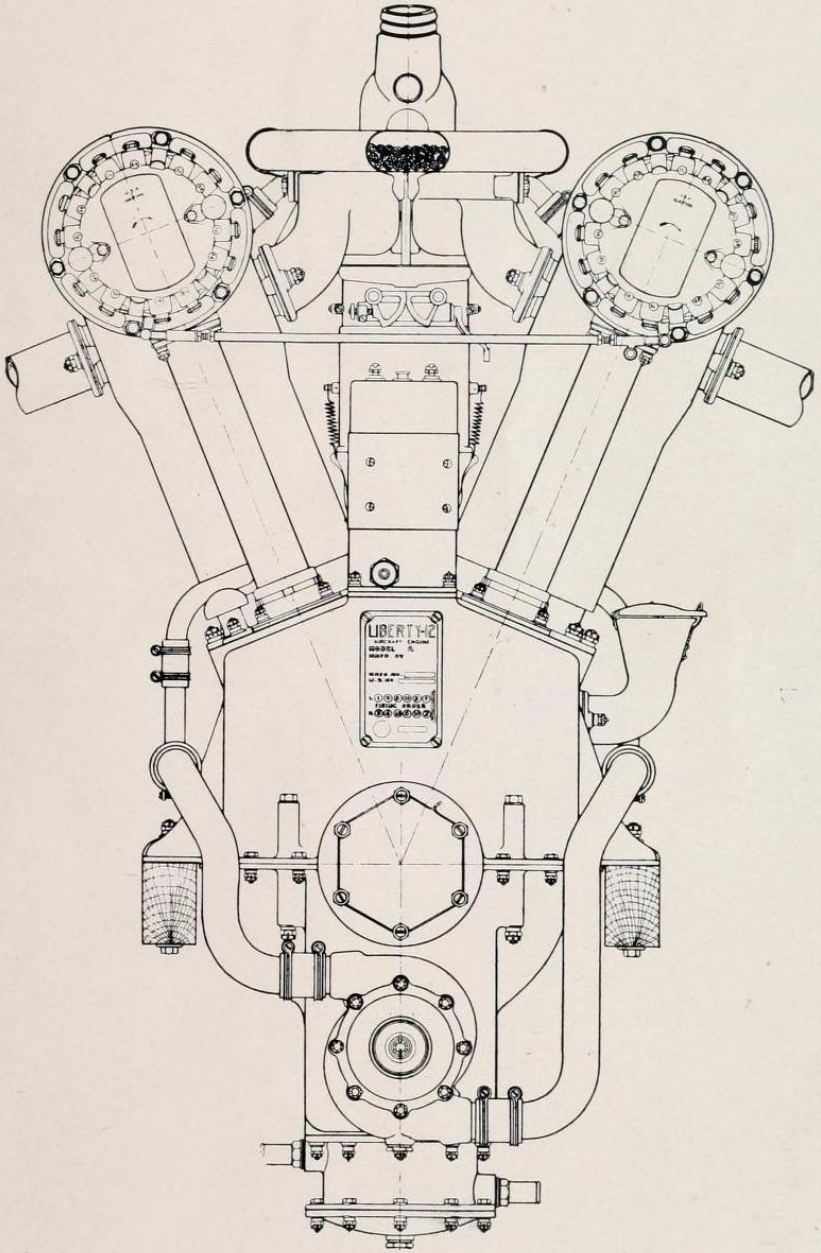


Fig. 104.

Rear Elevation.

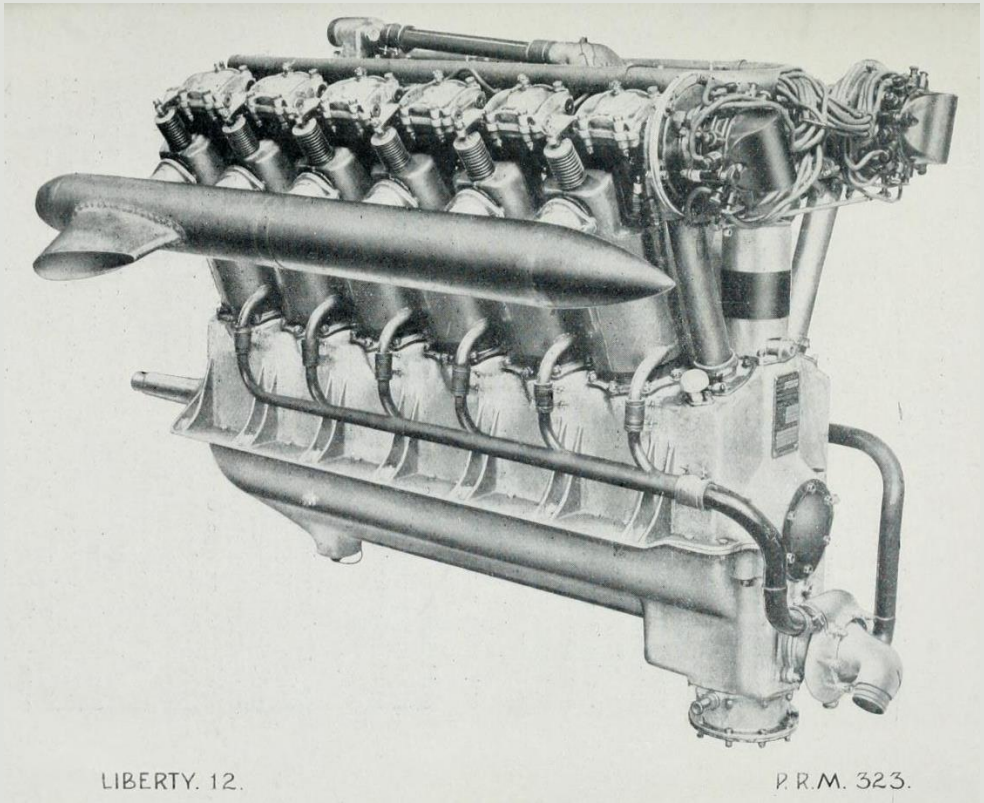


Fig. 75.
Three-quarter Side View of Engine.

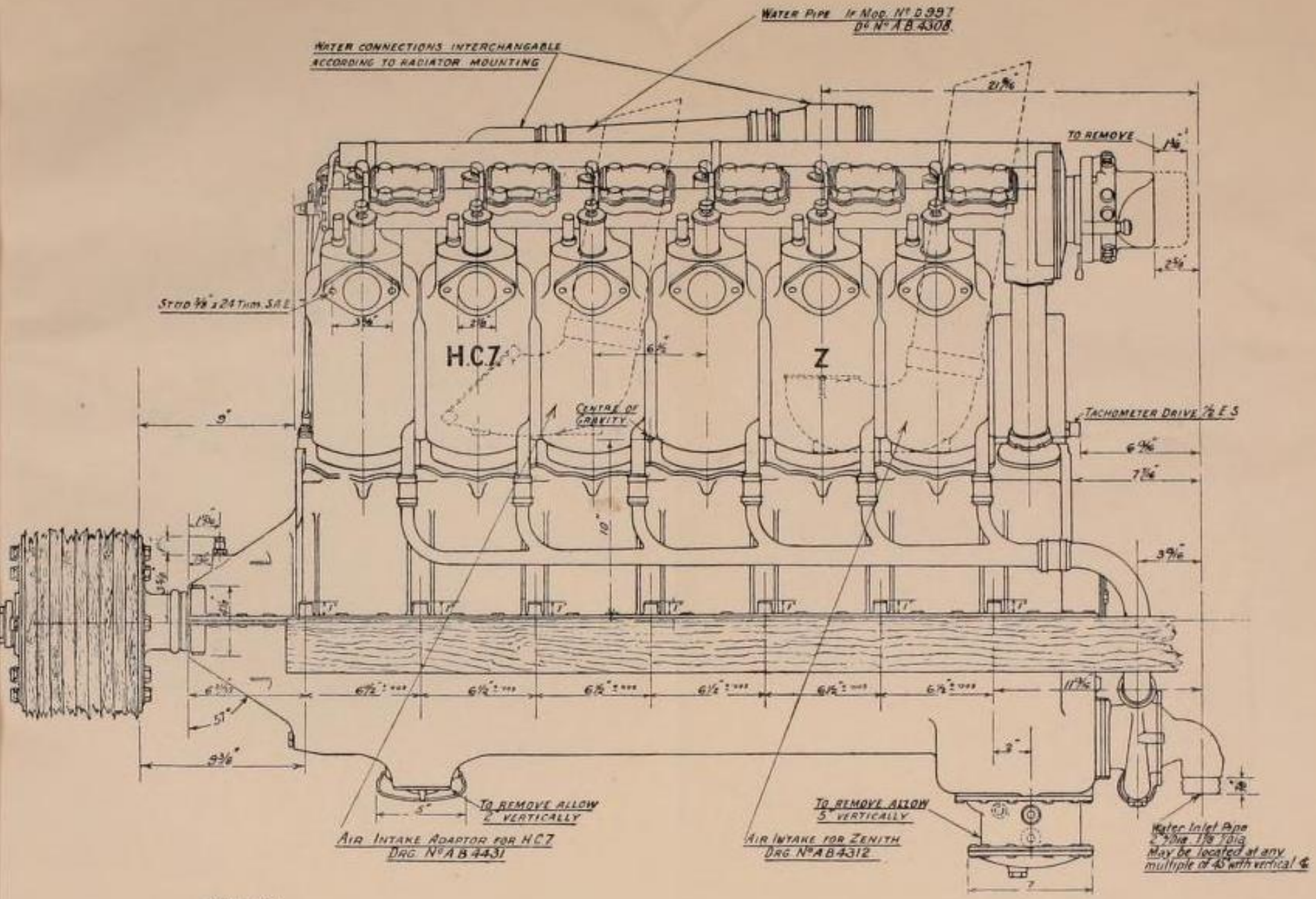


Fig. 102
Installation Drawing.
(Side Elevation).

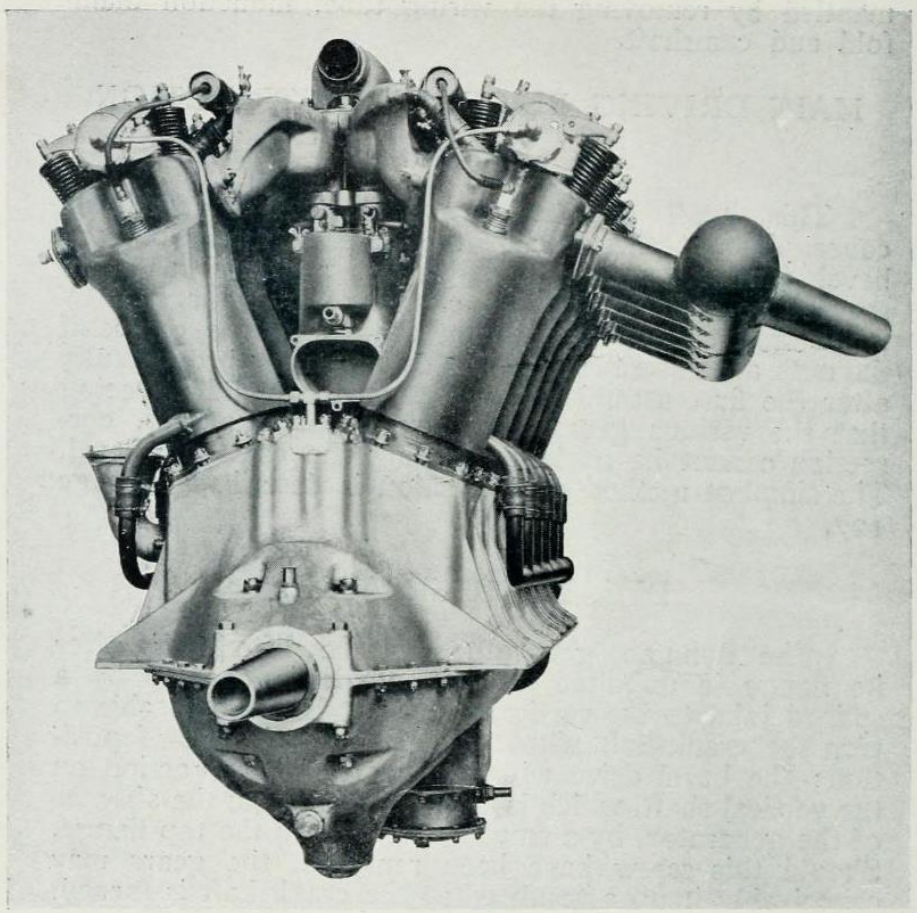


Fig. 76.
Front End View of Engine.

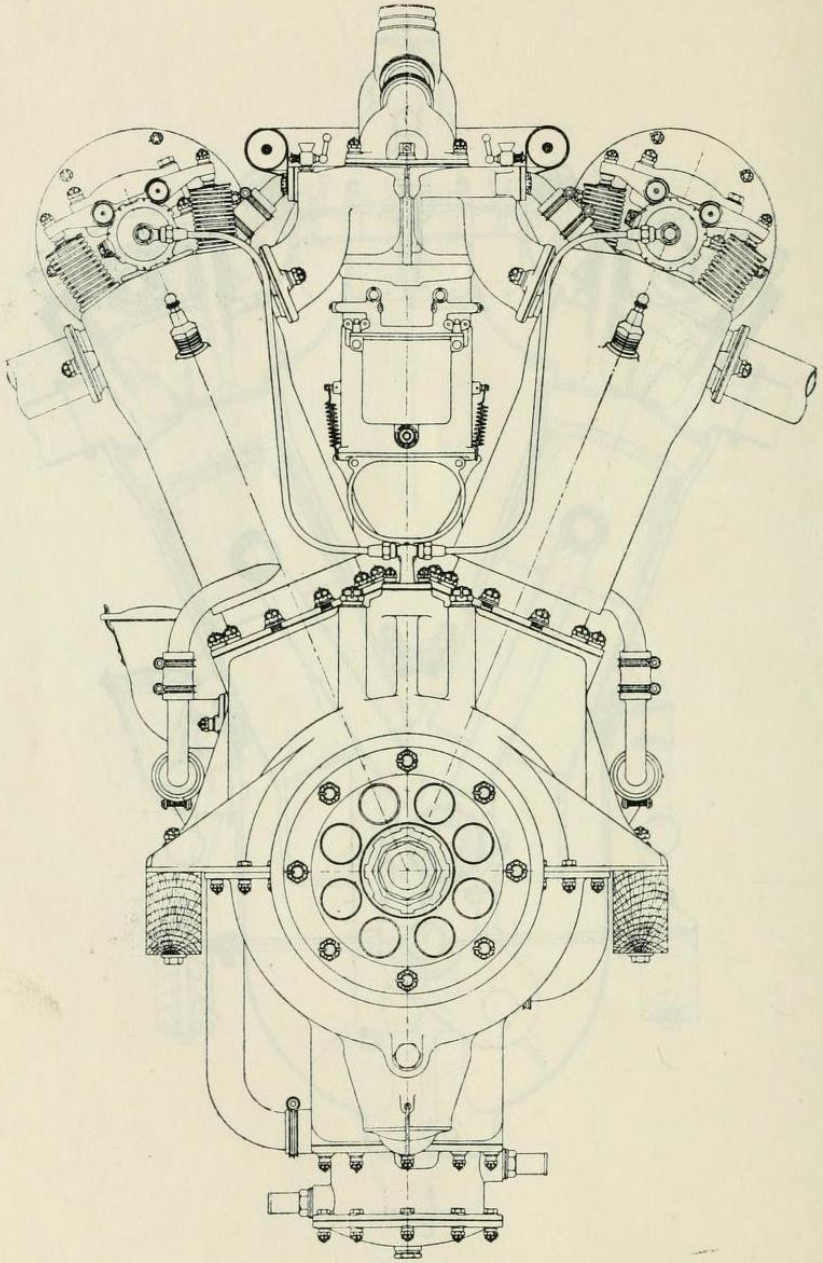


Fig. 106.

Front Elevation.

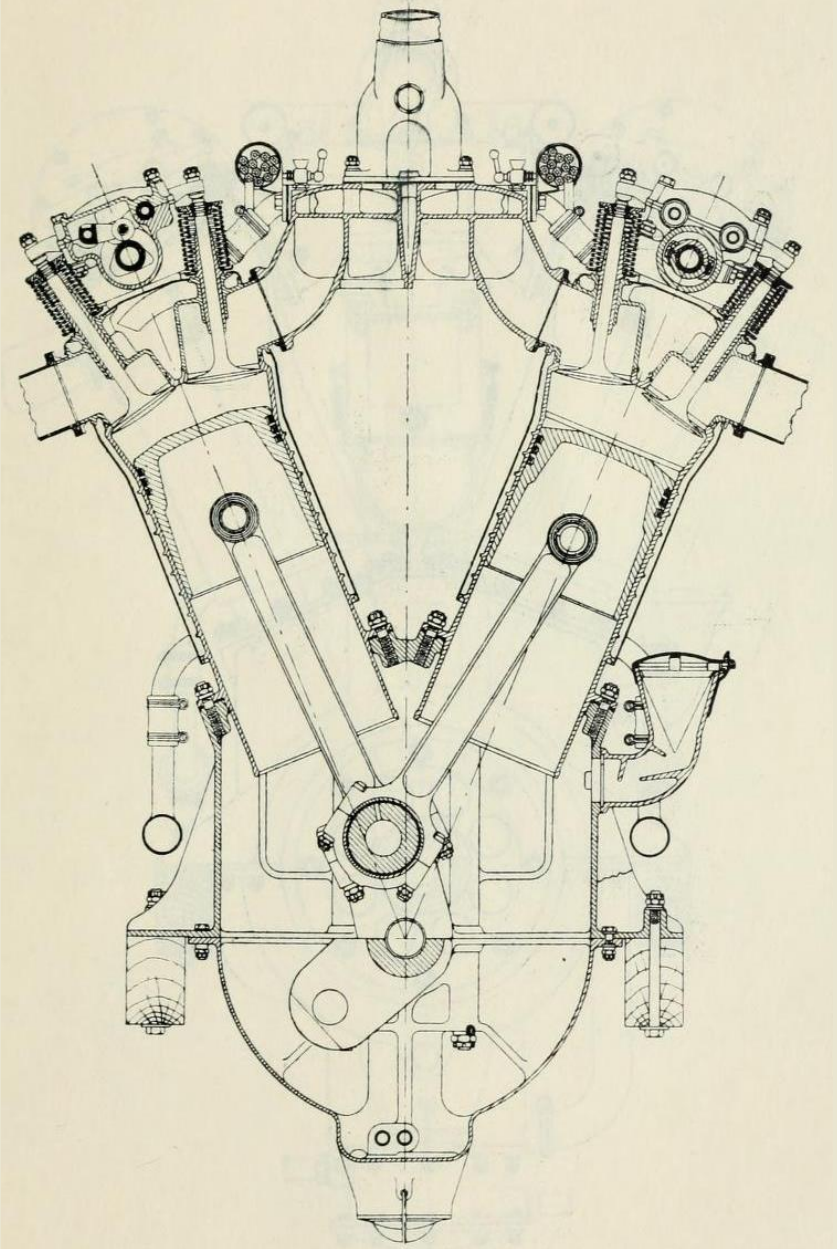
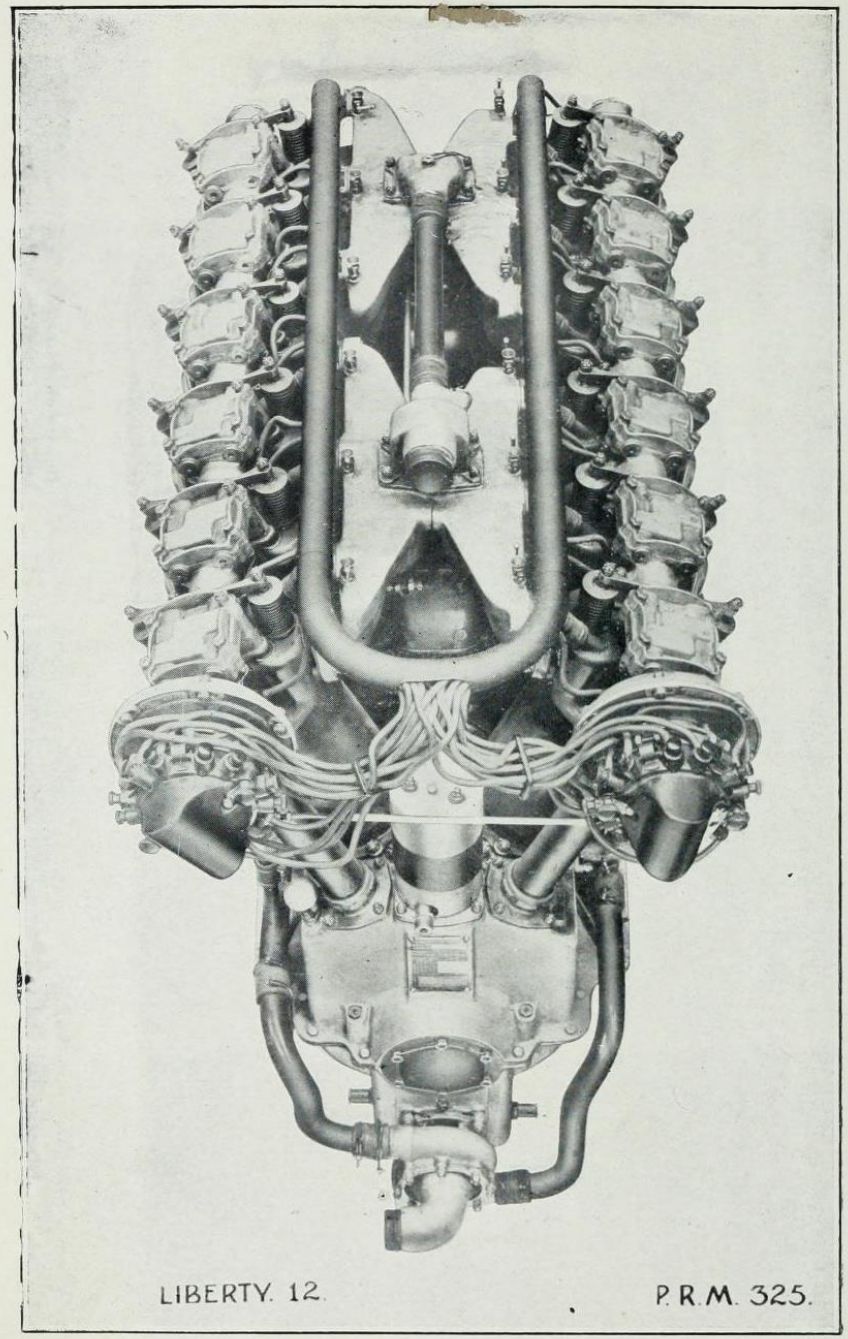
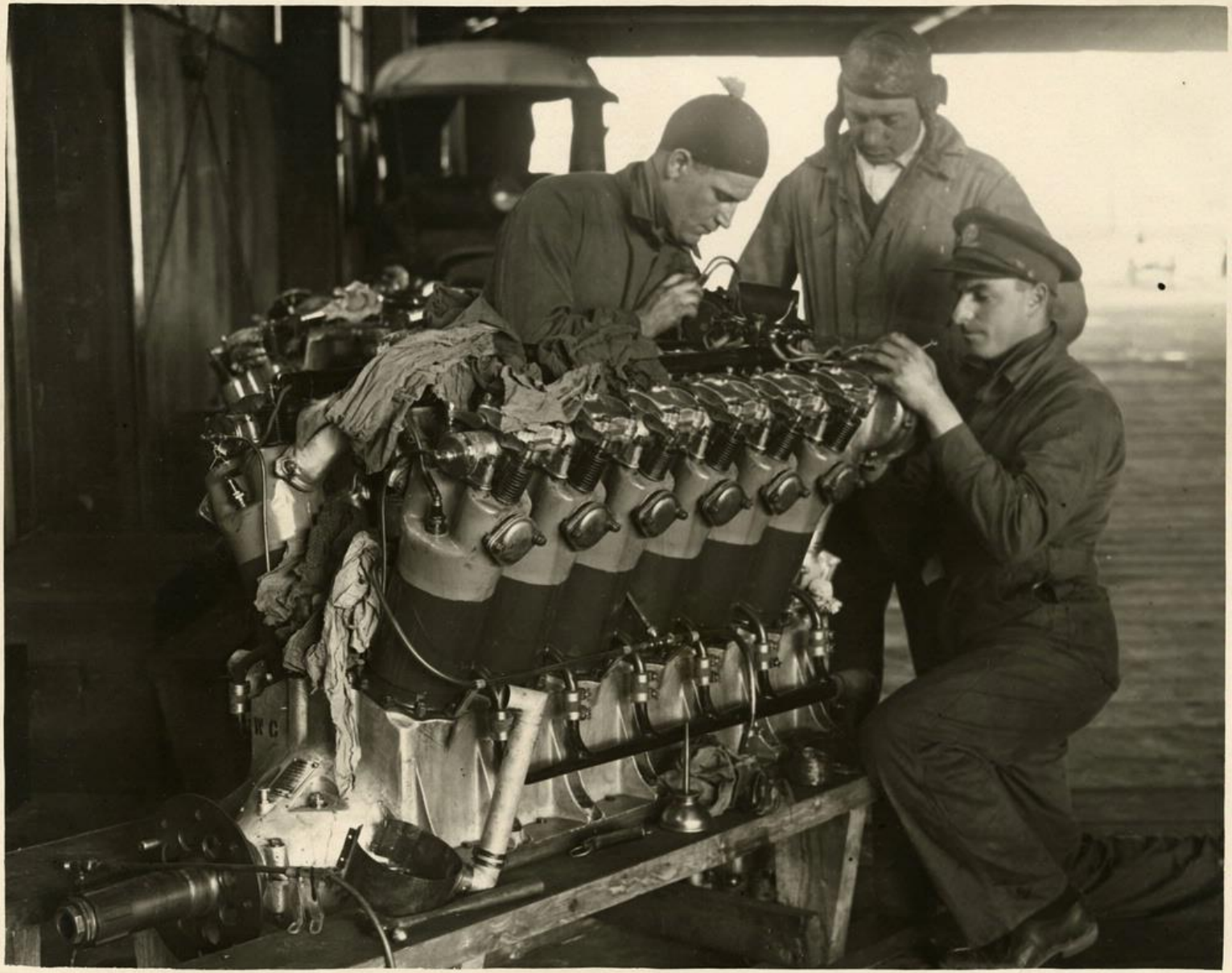


Fig. 105.

Transverse Section through Cylinders.



The Liberty Engine.



Part 7

The Two R's



The Hon. C. S. Rolls.



Sir Henry Royce, O.B.E.

A Commemorative History of Rolls-Royce Aero-Engines

***FLIGHT,* May 7, 1954**

RE: introduction to an article written by *H.F. King* entitled: "The Two R's . . ."

TWO men, with the agreeably alliterative names of Rolls and Royce and with notions and ideals even more happily matched, met in Manchester fifty years ago this month. Rolls - the Hon. Charles Stewart Rolls - possessed wealth, an Eton-and-Cambridge education, a degree in mathematics and applied science and a fine record as a motorist. He was a sportsman, as distinct from what we should nowadays call a playboy and he had consistently displayed a manly daring at the wheel and a determined approach to the technical problems of motoring.

In 1894, at the age of 17, he was taken by his father, Lord Llangattock, to France, where the great game and business of motoring was flourishing uninhibited. Having shipped home a 3-3/4 h.p. Peugeot, he drove it to Cambridge in excess of the speed limit - at 44 m.p.h. - and in 1896, when the man-with-the-red-flag was put out-of-business, he turned to racing and records.

It was not in his sporting ventures alone that fortune favoured him, but in the business of C.S. Rolls and Co., which he established with Claude Johnson in 1902. In 1903 he set a world speed record of 93 m.p.h.; but the car was a 70 h.p. Mors and by the following year, when his books showed orders for a hundred fine Continental cars, he could still not find a British product which measured up to his standards.

Henry Royce - the second party to the meeting - had known in his youth none of the luxuries and pleasures which birth had bestowed upon Rolls. At ten years of age he started work as a telegraph boy, later attending a technical college and serving a few years in the Great Northern locomotive shops at Peterborough. Then, after a spell in an engineering works at Leeds, he set-up a business in Manchester, making arc lamps and dynamos. The slump after the Boer War caused him to turn his ambition to cars. Disappointed with a foreign model which he acquired, he decided to put his own ideas into practice and in 1903 he completed a two-cylinder car of 10 h.p., having handled much of the precision work himself.

One of his first three cars went to Henry Edmunds, a pioneer motorist who had lately become a Director of the firm of Royce, Ltd.; and it was he – “the godfather of Rolls-Royce” - who arranged the meeting in Manchester. The two men took to each other immediately and having tried-out Royce’s car, young Rolls undertook to sell its maker’s entire output. But he was looking much farther ahead than 10 h.p. and two cylinders; he saw before him the golden market of Edwardian England and the engineering perfection that was to link his name with that of Rolls in a monogrammatic symbol of excellence. So he began to ply his partner with suggestions and demands.

The “two R’s” were first officially linked in business association at Christmas 1904 by a working agreement between the two firms; and thenceforth the Rolls-Royce car began the ascent to its long-held pinnacle of fame.

By 1906 Royce’s production was large enough to allow Rolls to stop his sales of other makes of car and Rolls-Royce, Ltd. was founded. Royce’s old partner, A.E. Claremont, became Chairman; Rolls was Technical Managing Director; Johnson became Commercial Managing Director and Royce was nominated Chief Engineer and Works Director.

While Rolls had been winning the T.T. race and another at the Empire City track, New York, Royce had been busy with a 40/50 h.p. six-cylinder car for the Motor Show of 1906. This became the *Silver Ghost.*

Rolls, who had become a member of the Aeronautical Society in 1901, was already a keen balloonist; then, having met the Wright brothers, he turned to heavier-than-air craft. He was awarded his pilot’s certificate (No. 2) on March 8th, 1910 - the very same day that Lord Brabazon received his No. 1. On the Wright biplane he made the first heavier-than-air crossing of the Channel by an Englishman and the first double crossing by any aeroplane in history; but soon afterwards - on July 12th, 1910 - he crashed to his death at the Bournemouth flying meeting. He was the first Englishman to die in an accident to a powered, heavier-than-air machine.

“Although only 33 years of age,” said *FLIGHT*, “Mr. Rolls had already done what it has fallen to the lot of very few men to do and what only a very small percentage of men are capable of doing, whatever may be their opportunities.”

The technical achievements of Royce in aero-engineering are outlined hereafter; the more personal aspects of his career, and that of Rolls, have already been told at length - especially in Harold Nockolds’ book *The Magic of a Name, in Rolls - Man of Speed,* by Laurence Meynell, and in the monograph *Frederick Henry Royce,* by our late Managing Editor G. Geoffrey Smith.

In 1910 Royce became seriously ill and thereafter was absent for long periods from his new factory at Derby. He worked on in the south of France and on the south coast of England.

Following the British Schneider victory of 1929 - made possible by that masterpiece, the “R” engine - a baronetcy was conferred upon him and he heard from his bed how an improved engine of this type sent a Supermarine S.6B to final victory in the Schneider Race of 1931. He died on April 22nd, 1933.

Royce shunned publicity (“I am only a mechanic,” he would say); but the ensuing record of his company’s achievements in aero-engineering alone is some measure of his greatness.

The Eagle

A truly historic engine, the Eagle was designed by Henry Royce in collaboration with his Chief Assistant, A.G. Elliott (now joint Managing Director and Chief Engineer). It set the pattern for the smaller Falcon and the larger Condor and in improved forms, continued in service from 1917 until the 1930s.

Though designed for only 200 h.p., the first example was run in October 1915 (less than six months after work on the drawings had been started at Derby) at a brake horsepower of 225; and it may be noted that the present style and title of a certain mechanic who was then in attendance is Lord Hives of Duffield, Chairman and joint Managing Director, Rolls-Royce, Ltd.

By March 1916 the new engine was delivering 266 b.h.p.; by July 284 h.p. and by December 322 h.p. By September 1917 the figure had risen to 350 h.p.; in Februrary 1918 it had reached 360 h.p. An official Rolls-Royce instruction book dated December 1917 ascribes the following outputs (at normal r.p.m.) to the various series: Eagle I, 225 b.h.p.; Eagle II, 266; Eagle III, 284; Eagle IV, 284; Eagle V, 322; Eagle VI, 322; Eagle VII, 322; and Eagle VIII, 350. These variants differed in the type and number of carburetors, in jet size, in the pattern of inlet pipes and pistons and other details.

By far the most famous among them was the Eagle VIII, which powered such fine aircraft as the Phoenix Cork, Felixstowe F.3 and F.5, the D.H.4, 9A, 9B, 10B and 10C, the Fairey IIIC and IIID, the Handley Page 0/400 and V/1500, the Short Shirl and the Vickers Vimy and Vernon. Other military installations were made in the Wight seaplane, F.E.2D, F.E.4, R.E.7, Porte Baby, F.2, Felixstowe Fury (F.4), D.H.10, Fairey F.16 and F.17 Campania, Handley Page 0/100 and Vickers Vim. Civil applications included the D.H.16 and Handley Page W.8b.

Irrespective of series number, the Eagle was a twelve-cylinder, water-cooled, 60-deg. vee of 20.32 litres capacity. Each cylinder, with its water-jacket, formed a separate unit; the barrel, machined from a steel forging, was retained by a base flange and studs. Inlet and exhaust ports were machined from solid forgings, welded-in at opposite sides of the head and the water-jacket was fabricated from steel pressings, welded in-place. There was one inlet and one exhaust valve for each cylinder and a single camshaft, carried in a casing along each bank of cylinders, operated both. There were two sparking plugs per-cylinder served, on the earlier engines, by four six-cylinder magnetos and on the later series by two twelve-cylinder magnetos.

A contemporary Rolls-Royce description continues: “The oil consumption sh-ould be taken as 1 gallon-per-hour . . . The lubrication system is of the type in which one oil pump supplies pressure oil to the main bearings and other parts, while one scavenger pump evacuates the accumulation of oil in the crankcase to the oil tank . . . The quantity of water carried in the Rolls-Royce carburetors are fitted with a control so that the delivery of petrol may be adjusted from the pilot’s seat. This not only serves as a means of correcting the effects of decreasing atmospheric pressure with increasing altitude, but can also be used to obtain extremely economical running and also to obtain a rich mixture for starting . . . All controls, e.g., throttle, altitude and magneto are brought to one common location on the engine to facilitate connection to the plane . . . The carburetor throttles are fitted with springs, which, in the event of a breakage of the control, are intended to open the throttles to the full extent.”

A special feature of the Eagle was the epicyclic reduction gear for which the advantage was claimed that it imposed far less strain on the crankcase than would spur gearing. The gear was of fixed sunwheel-type in which an annulus, or internally toothed gearwheel, on the crankshaft meshed with three small spur gearwheels on the extremities of three arms formed integrally with the airscrew shaft.

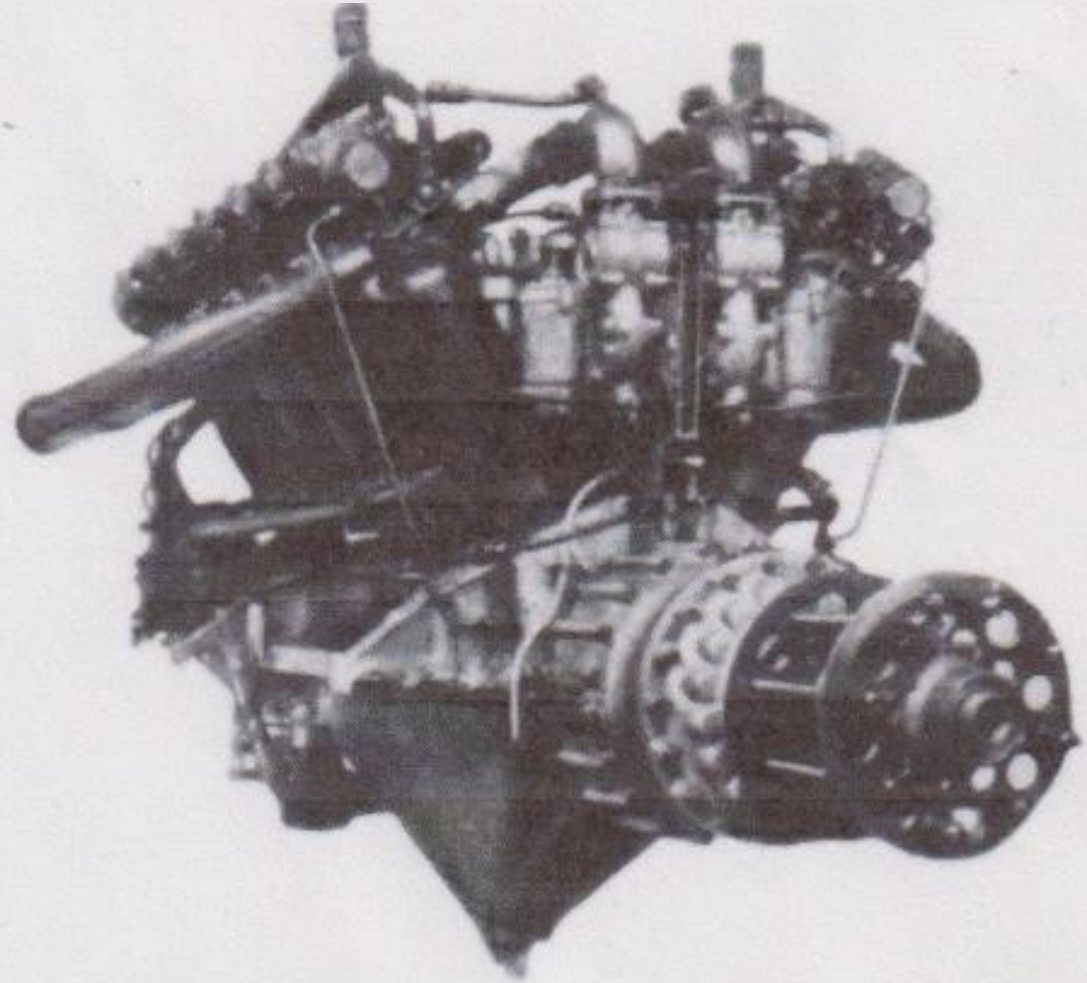
The three small gears were connected to three pinions which meshed with the fixed sunwheel, and the air- screw shaft was bolted to the three-armed spider which carried the planet pinion cage. An Oldham coupling provided the anch-orage of the sunwheel to the gear casing and allowed the gears to be perfectly aligned.

Late in 1922 *FLIGHT* reported: “A recent model introduced by Rolls-Royce, Ltd., is the Eagle IX, which is generally similar to the famous Eagle VIII but differs from that type in certain details. The new model has been designed to be equally suitable for peace and war purposes and to that end, the following improve-ments have been effected: Two carburetors are fitted instead of four so that tuning is considerably facilitated. The placing of the carburetors low-down all-ows of using direct-gravity feed; the float feeds have been redesigned. The engine will now function satisfactorily with a ‘head’ of only 8 in. above the cen-tre-line of the crankshaft. In view of the tendency in modern commercial aircraft of employing direct-gravity petrol feed from the main tanks in order to avoid pumps, piping, etc., this should be a great advantage and should help to ensure for the Eagle IX as great popularity as that enjoyed by the previous model.”

In the Eagle XV the epicyclic gear was further modified by the insertion of an additional friction clutch and gearwheel in the train, making the existing friction anchorage into a manually controllable clutch and converting the gear from a single-speed to a two-speed type. In the absence of a variable-pitch airscrew this arrangement gave a considerable advantage.

The following data for the Eagle VIII are taken from *Rolls-Royce Aero Engine Instruction Book, Eagle Series I - VIII and Falcon Series I, II and III. Air Board Technical Department Book No. 244, December 1917*: Dry weight, 847 lbs; normal r.p.m., 1,800; max. permissible r.p.m. (5 min. only), 2,000; gear ratio, 0.60; b.h.p. at normal r.p.m., 350; petrol consumption in gal/hr at sea-level, normal r.p.m. and normal b.h.p., 23; carburetors, four R.R. C.H. (Rolls-Royce, Claudel Hobson), 42 mm; magnetos, four Watford; pistons, high compression, four rings (one at bottom).

In 1925 a little-known Eagle development - the 16-cylinder, 500 h.p. Mk.XVI - made its appearance. It had a stroke of 4-1/4 in. instead of 4-3/4 in. The Mk.XX was a projected scaled-up version, but was never built.



Eagle VIII.

The Hawk

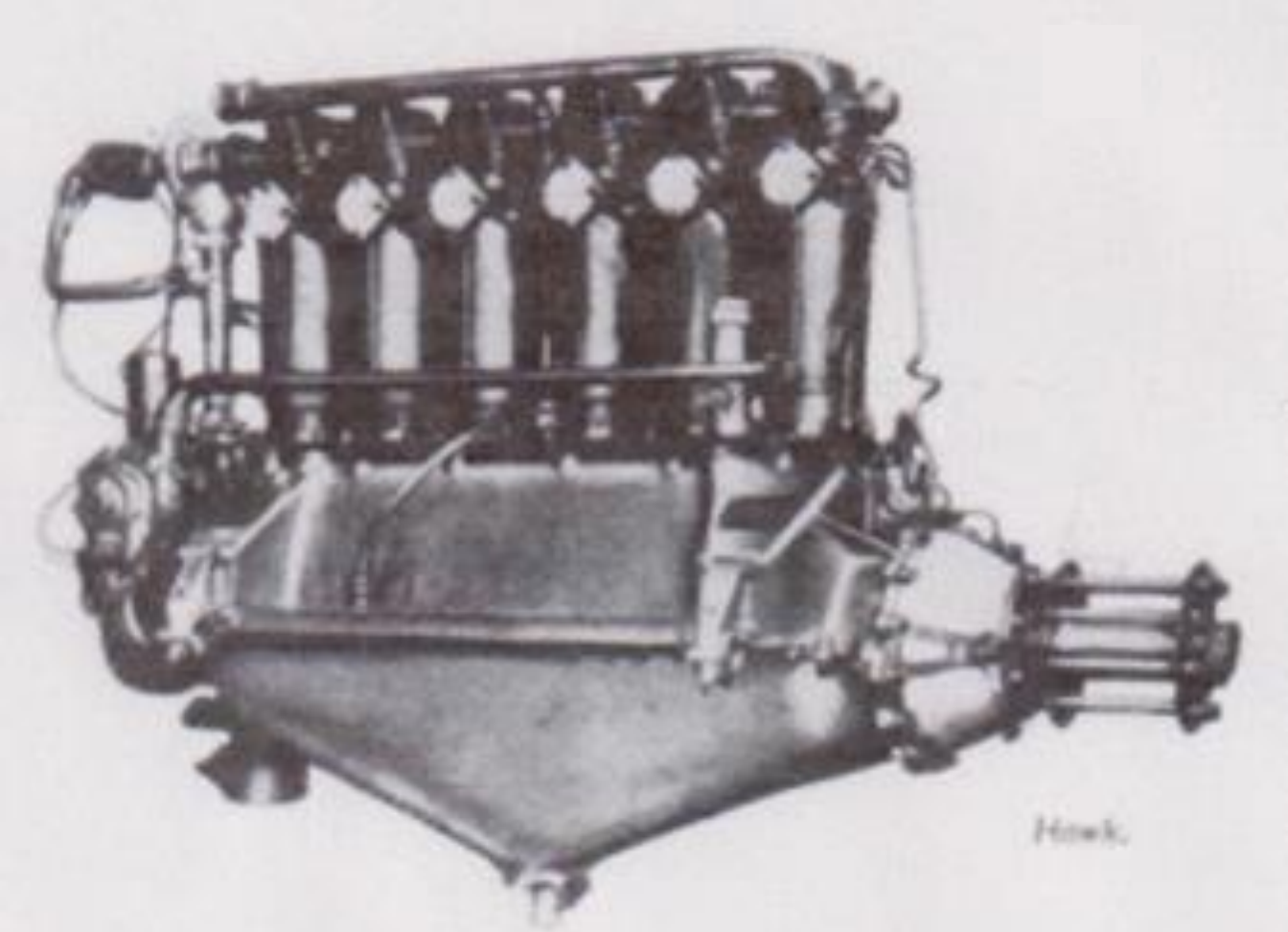
Originally intended for use in training aircraft, this little engine became far better known as the power-plant of Naval airships. It was designed, in 1915, for an output of 75 h.p. at 1,350 r.p.m., but ratings soon increased. Thus, in February 1916, it was giving 91 h.p.; in October 1918, 94 h.p. and later in the same month - at 1,500 r.p.m. - 105 h.p.

Rarely does an official service handbook pay tribute to a proprietary article, but in the R.N.A.S. volume dealing with the S.S. Zero airship one reads: “The Rolls-Royce Hawk type engine of 75 h.p. was adopted as possessing a degree of reliability and other properties of particular suitability higher than other makes available.”

Of 55,700 hours flown by British airships, 36,000 were put in by Hawk-engined craft. In August 1918, a flight of 50 hr. 55 min. duration was recorded and patrols of 23-30 hrs. were not uncommon. Heavier-than-air machines fitted with the Hawk included the Sage trainer Type III, a few B.E.2Es and Avro 504Fs.

A six-cylinder, ungeared, vertical water-cooled unit, the Hawk had one magneto and one carburetor. Oil consumption was half-a-gallon-an-hour. An official Rolls-Royce description ran: “It is usual, when starting this small engine, to turn it by means of the propeller for filling the cylinders after the induction pipes have been primed. The operation of the hand magneto (supplied by Messrs. Rolls-Royce) then starts the engine. The Rolls-Royce Patented Device is supplied for priming. This is a light and simple apparatus, embodying a hand pump, which can be fixed in any convenient position near the pilot’s seat, or as desired. One priming device may serve two or more engines with the use of a change-over cock. When required, a starting handle can be supplied, arranged in-line with the crankshaft at the timing gearcase end of engine and connected thereto by a reduction gear. This apparatus is specially suitable for airship installations.”

Data for the Hawk with a nominal output of 100 h.p. at 1,500 r.p.m. were: max. permissible r.p.m., 1,700; fuel consumption at normal power, 6.5 gal./hr.; weight, 405 ibs.



1044

The Falcon

In April 1916 came the Falcon - virtually a scaled-down Eagle. Again ratings increased by leaps and bounds. Thus, in April 1916 the figure was 205 h.p.; in May, 228 h.p.; in February 1917, 247 h.p.; and in April 1917, 262 h.p.- all the foregoing at 1,800 r.p.m. By November 1917, the output had risen to 278 h.p. and by July 1918, to 285 h.p. - in both instances at 2,000 r.p.m. Official data for the Falcon I were: weight, 650 lbs.; b.h.p. at normal r.p.m., 228; fuel consumption (gal./hr.), 16.6. Corresponding figures for the Falcon II were: 665, 255, 18.25, and for the Falcon III (by far the most famous member of the family) 660, 270 and 18.75.

Constructional particulars already given for the Eagle VIII apply generally to the Falcon III. The best-known application of the Falcon was to the Bristol Fighter F.2B, wherein the Series III engine became standard and remained in service until the 1930s. Other British military installations were made in the Martinsyde F.1, F.3 and F.4, R.E. 6 and 7, Armstrong Whitworth F.K.12, Avro 523C and 529 Pike, Blackburn S.P. and G.P. seaplanes, Kangaroo and Sprat, D.H.4, Fairey F.2, Sopwith tractor triplane, Parnall Perch, improved Short 184 and Vickers Vendace.

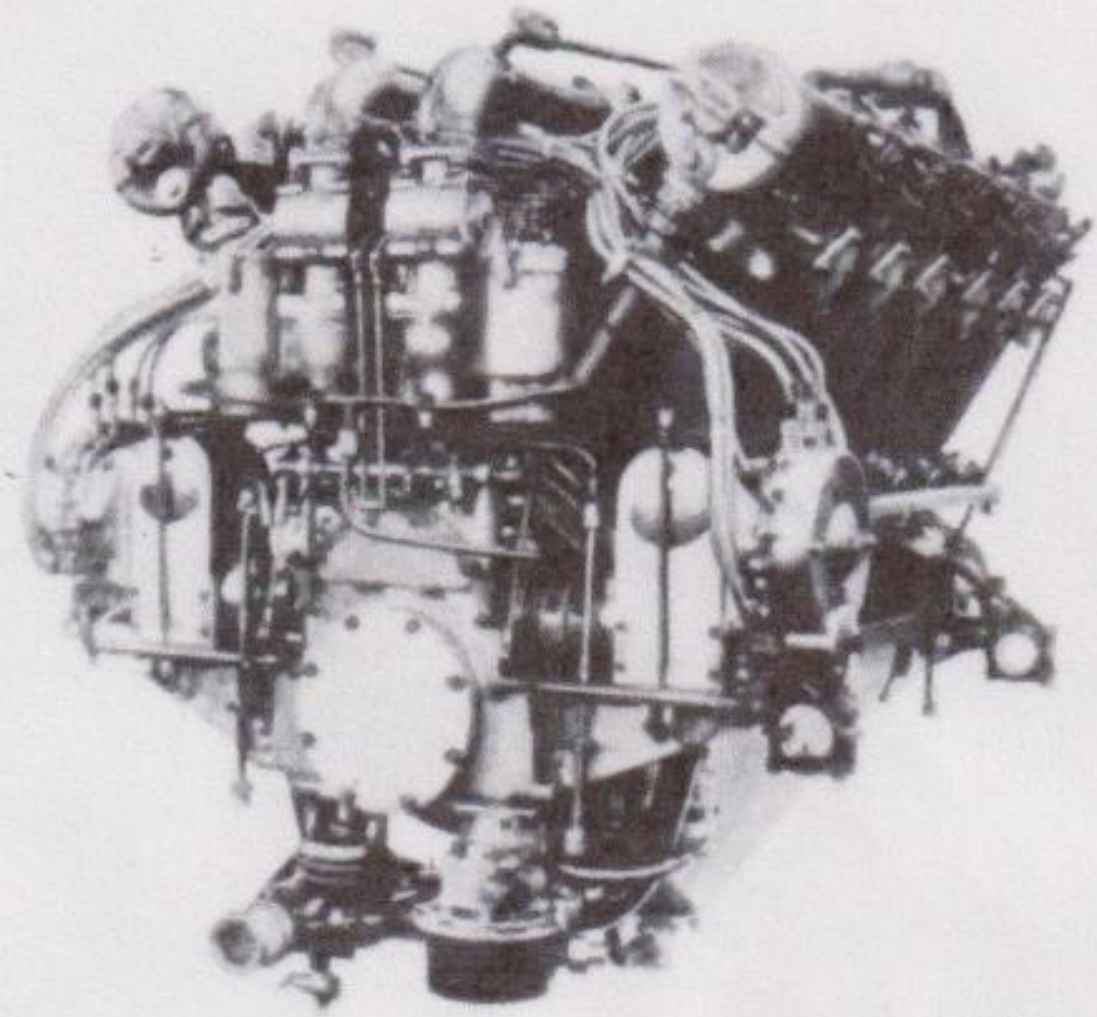
In tribute to the Falcon and the “Brisfit” we reprint these verses from “The Ballad of the Bristol Fighter:”

There are half a dozen buses
On which I’ve had a whack,
From the R.E.8 to the two-ton weight
Of the lumbering old Nine Ack.

But few of them know the secret
Of making my heart rejoice,
Like a well-rigged Bristol Fighter
With a two-six-five Rolls-Royce.

Is there a sweeter music,
Or a more contented sound,
Than the purring clop of her broad curved prop.,
As it gently ticks around?

Hold her down to a hundred,
Then up in a climbing turn
Till we catch our breath in the air, up high.
I wouldn’t exchange my seat, not I,
For a thousand pounds to burn.



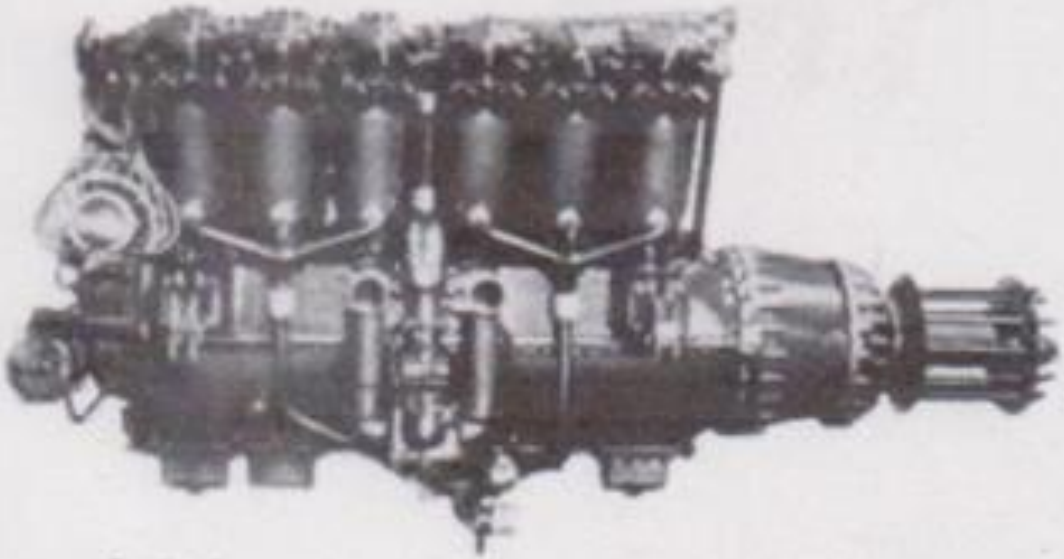
Falcon III.

The Condor

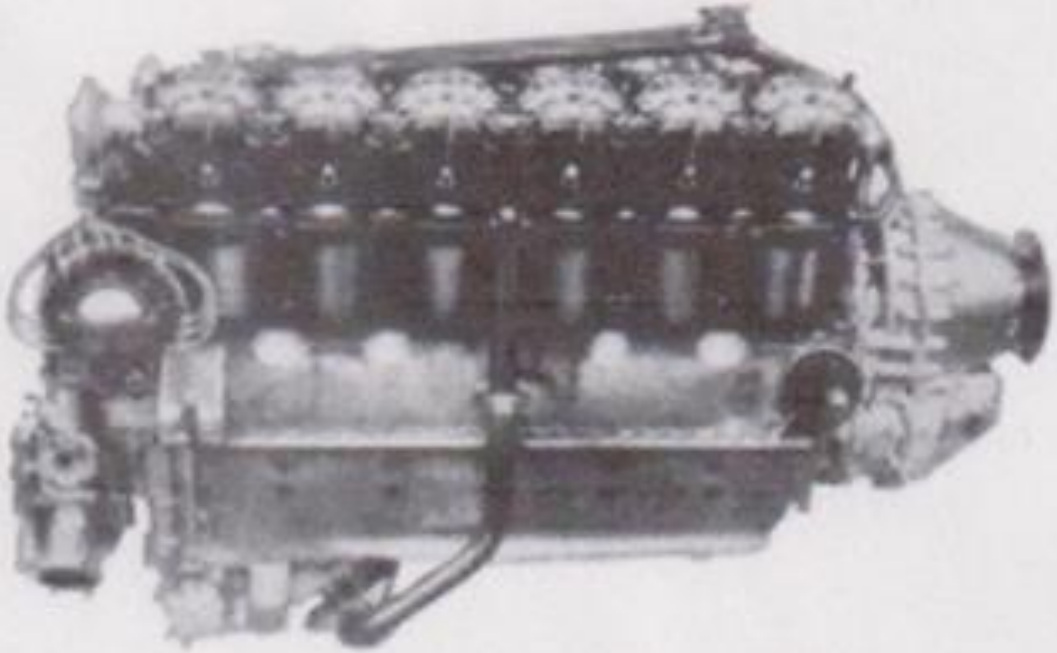
When it first appeared, in August 1918, the Condor followed very closely the pattern of the Falcon and Eagle, though it was of larger (35 litres) capacity. The Condor Series I was designed for 550/600 h.p. and the larger cylinders necessitated four valves per-cylinder instead of two. The valves on each bank were operated by a single camshaft. There were only two carburetors and these were mounted low-down on each side of the crankcase in line with the centre bearing. The water pump was transferred to the centre of the engine and an electric starter could be provided.

In succession to the Series I came the IA, wherein the normal output was raised to 650 h.p. at 1,900 r.p.m. There is no record of the Condor II but the Series III, which differed considerably from its predecessors, became very well-known indeed and like the IA, developed 650 h.p. at 1,900 r.p.m., though it weighed nearly 300 lbs. less.

A notable feature of the Series III was the fitting of a single-spur reduction gear, carried in a housing bolted to the front-end of the crankcase. This, as the photograph shows, greatly changed the outline of the engine and made for improved cowling lines.



Condor I.



Condor III.

The makers nevertheless recognized that higher stresses were set-up in the crankcase than with the old epicyclic type. In the new gear a flange was formed on the front-end of the camshaft and to this was bolted an internally toothed ring, the teeth of which engaged with similar teeth on the end of a short hollow shaft. The opposite end of the shaft was formed with splines to transmit the torque to a hollow pinion mounted in roller bearings. Thus, any transverse loads were prevented from being transmitted to the crankshaft from the gearing. The pinion engaged with a toothed wheel mounted on, and keyed to, the airscrew shaft which was supported on roller bearings and was fitted with a ball-and-thrust bearing to take the thrust of the airscrew. The engine was cleared to use a metal airscrew and an efficient diameter was about 16 ft.

Another point-of-difference between the Condor and the earlier Rolls-Royce engines was in the design of the connecting rod assembly: whereas in the former engines articulated rods had been used, the Condor had forked rods.

Engines of the Condor III series varied from one another in certain respects, but an Air Ministry description in a publication of 1926 remarks that the various pumps serving the engine had been built into a single unit bolted beneath the crankcase lower half. This unit comprised three oil pumps, a water pump and a petrol pump, the last-named being a unit not previously fitted to any Rolls-Royce engine as a standard component.

The description went on: “The carburetor has been redesigned and the altitude control valve is of an entirely new design. Owing to the desire to reduce weight, no hand starting device has been provided, but provision has been made for starting by means of the Bristol gas starter. To this end, a gas distributor is provided and is driven from the mechanism contained in the wheelcase.”

The Condor IV was a direct-drive engine intended for fighters and was extensively flown in the Hawker Hornbill, the fastest fighter of its day. The absence of the reduction gearing saved about 80 Ibs. in weight. Normal output was 650 h.p. at 1,900 r.p.m., and dry weight, 1,250 Ibs.

An experimental Condor was fitted with a turbo-supercharger running at 26,000 r.p.m. and giving an induction pipe pressure of 13.5 Ibs./sq. in. at a height of 2,000 ft. It was never flight-tested. The Series VIII, specially designed for internal installation in a projected Supermarine fiying boat, was another development which was not air-tested.

Flight-testing has made a vast contribution to Rolls-Royce successes. Depicted in this "Flight" photograph are a Fairey Battle (Merlin), Hawker High Speed Fury (Goshawk), and Heinkel He 70A (Kestrel).



During 1932, it was announced that a compression-ignition version of the Condor had passed the Air Ministry's civil-engine type-test of 50 hrs. and that flight trials were then underway at in a Hawker Horsley. The C.I. Condor gave 500 h.p. and weighed, with spares and accessories, 1,504 lbs. Conversion was initiated by the Air Ministry and the engine was developed at the Royal Aircraft Establishment with the cooperation of Rolls-Royce, Ltd.

British aircraft powered with the Condor included the Beardmore Inflexible, Avro Aldershot, Ava and Andover, Blackburn Iris I, II and III, D.H. Derby, Fairey Atalanta, Titania and Fremantle, Handley Page Handcross, Hawker Horsley, Saunders-Roe Valkyrie, Short Cromarty and Singapore, Vickers Vixen and Vanguard and Westland Yeovil.

The Kestrel

The year 1925 saw the beginnings of a new engine which differed radically from its forebears in having each of the two banks of six cylinders formed from a single aluminum-alloy block. Of 21.24 litres capacity, it was of extremely compact design and first appeared, under the designation F.10, as a direct-drive unit. During June 1927, *FLIGHT* was able to announce that the F.10 had completed its official 100 hr. type-test at the first attempt and had been granted a Certificate of Airworthiness. The maximum b.h.p. was 490 at 2,350 r.p.m. and the fuel consumption, at normal power and speed, 30 gal./hr. Dry weight was 760 lbs.

In May of the following year *FLIGHT* again reported on the development of the "F" series, introducing the F.12 and describing it as "in a general way the geared version of the F.10." Later, fuller designations and characteristics of the "F" series were made known; thus the F.XIA, F.XIB, F.XIIA and F.XIIB differed with regard to gear ratio and compression ratio; the FXI engines had a gear ratio of 0.632:1 and the F.XII a ratio of 0.552:1. The letters A and B indicated compression ratios of 6:1 and 7:1 respectively. Subsequently, the F.XIVA and F.XIVB were added to the series; the F.XIV had a gear ratio of 0.475:1.

During 1930, the “F” type engine was named the Kestrel and yet another system of designation was introduced. The name was followed by the series number I, II or III, indicating 0.632, 0.552 and 0.475 reduction gear ratios respectively; then followed the letters A, B, MS or S, indicating 6:1 compression, 7:1 compression, medium supercharger or full supercharger.

As we have said, the most notable design feature of the Kestrel was the adoption of the monobloc principle and this resulted in a very light and rigid engine. The blocks were set at an angle of 60 deg., the cylinder heads, with the necessary inlet and exhaust passages, being cast integrally with the walls forming the water-jackets. Renewable valve-seating rings were screwed into the heads and the valve-guide bushes were of cast-iron. The flanged joint between the upper-end of the carbon-steel cylinder liner and the head was made gas-tight by a soft aluminum ring and near the lower-end of the liner, a sliding watertight joint was formed by means of a rubber ring fitted into a groove in the liner. Just below this joint a flange formed on the liner abutted on the crankcase and the whole assembly was held in position by long bolts. Where these bolts passed through the water space between the liners they were enclosed in aluminum tubes, swaged at the ends to make a watertight joint with the jacket casting. The two inlet and two exhaust valves per-cylinder were operated by an overhead camshaft, through a separate rocker for each valve.

The three oil pumps were of the gear type and were driven by spur gearing from the vertical shaft which drove the water pump. Lubrication was on the dry-sump principle.

The engine was fitted with hand-starting gear, comprising a worm wheel incorporating a multi-plate clutch mounted on the sleeve carrying the main bevel wheel for the auxiliary drive; the clutch was set to slip when a predetermined torque was exceeded. In the event of backfire, also the clutch would slip, thus saving the gears from damage.

In Kestrel engines of the types A and B, two Rolls-Royce Duplex carburetors were mounted between the cylinder blocks. The two throttles of each carburetor were connected by a pair of toothed quadrants and one quadrant of each pair was mounted on the end of a longitudinal shaft so that all four throttles were opened and closed simultaneously and to the same extent. The carburetors were fitted with a device by which the flow of petrol from the float chamber to the jet was automatically regulated in accordance with altitude.

The supercharger consisted of a high-speed centrifugal fan mounted co-axially with the crankshaft at the rear of the engine and drawing air through the carburetors. The aluminum-alloy impeller, with radial blades, was driven through a speed-multiplying gear comprising a system of three planets.

These were frictionally driven from a pinion on the crankshaft by means of slippers, held in engagement with the insides of the gear rims by light springs. As the speed of rotation of the crankshaft - and therefore of the slippers - increased, the radial pressure of these springs was augmented by centrifugal force and, consequently, the torque which the planets could transmit increased as the square of the speed. As the torque required to drive the impeller increased at a like rate, the gear was capable of driving the impeller with a predetermined margin of torque above that causing slip, which was constant throughout the working range of speed.

The object of this special friction drive was to protect the gearing against damage on sudden acceleration or deceleration of the crankshaft due to the inertia of the impeller. The impeller inertia, however, in combination with the friction drive, served to damp-out torsional oscillations of the shaft which drove the camshaft and auxiliaries, including the supercharger itself.

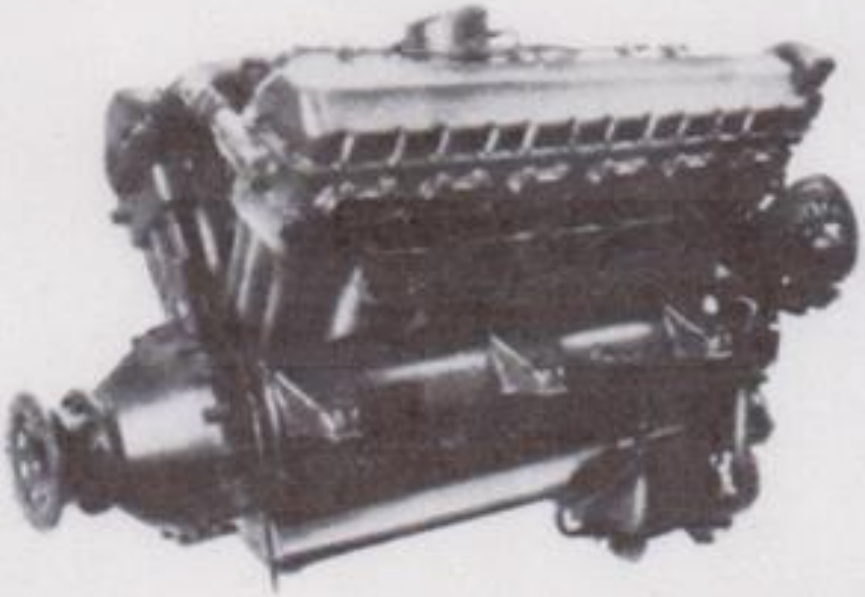
For all the varieties of Kestrel so far mentioned, the normal crankshaft speed was 2,250 r.p.m. and at this speed the un-supercharged low-compression engine developed 490 h.p. at sea-level. The unblown high-compression types gave 480 h.p. up to 3,000 ft., the medium-supercharged models 525 h.p. at sea-level and 500 h.p. at 3,000 ft., 480 h.p. at 11,400 ft.

The next series of Kestrels bore the series numbers IV, V, VI, VII, VIII, IX, X, XI and XII. Of these the IV, V and VI were fully supercharged, with 0.632, 0.553 or 0.477 reduction gear; the VII, VIII and IX were medium supercharged, with the same sequence of gear ratios; and the X, XI and XII were un-supercharged, with a compression ratio of 7:1. The fully supercharged engines were rated at 600 h.p. at 11,000 ft. and the medium supercharged and un-supercharged versions at 630 h.p. at 3,000 ft. and 575 h.p. at sea-level respectively.

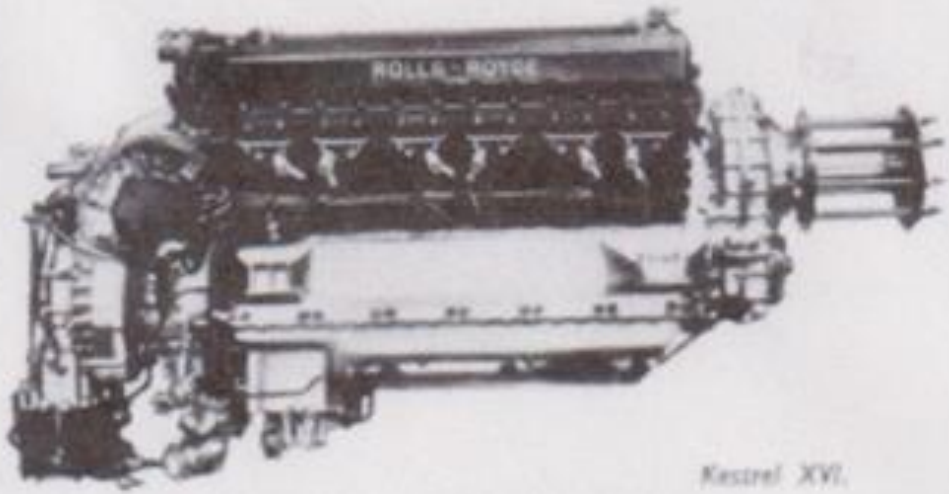
The ultimate in Kestrel development were the Series XIV, XV and XVI, fully supercharged, but more highly rated than the IV, V and VI. The supercharger ran at 9.4 times the crankshaft speed, whereas on the IV, V and VI it ran at 8.8 times that speed. The rating was 690 h.p. at 2,600 r.p.m. (an increase of 100 r.p.m. over the earlier engines) at 11,000 ft. and at 3,000 r.p.m. the output was 745 h.p. at 14,500 ft. The weight was 975 lbs.

The Kestrel XXX was a later development for training aircraft and had a rated power of 535 h.p. at 12,500 ft.

Kestrels were installed in numerous types of British and foreign aircraft - military and civil. British military applications included the Avro Antelope, Blackburn Nautilus and Sydney, Fairey Fox I, II, III and IV, IIIF, Firefly II and III, Fleetwing, Hendon II and S.9/30, Gloster C.16/28 and Gnatsnapper III, Handley Page Heyford, Hawker Hart, Demon, Fury, Osprey, Nimrod, Audax, High-Speed Fury, Hardy, Hartebeeste and Hind, Miles Master, Parnall Pipit, Saunders-Roe A.10, Short Singapore II and III and Gurnard, Supermarine Southampton, Vickers 141, B.19/27 and 163 and Westland Wizard.



F.10 (later Kestrel).



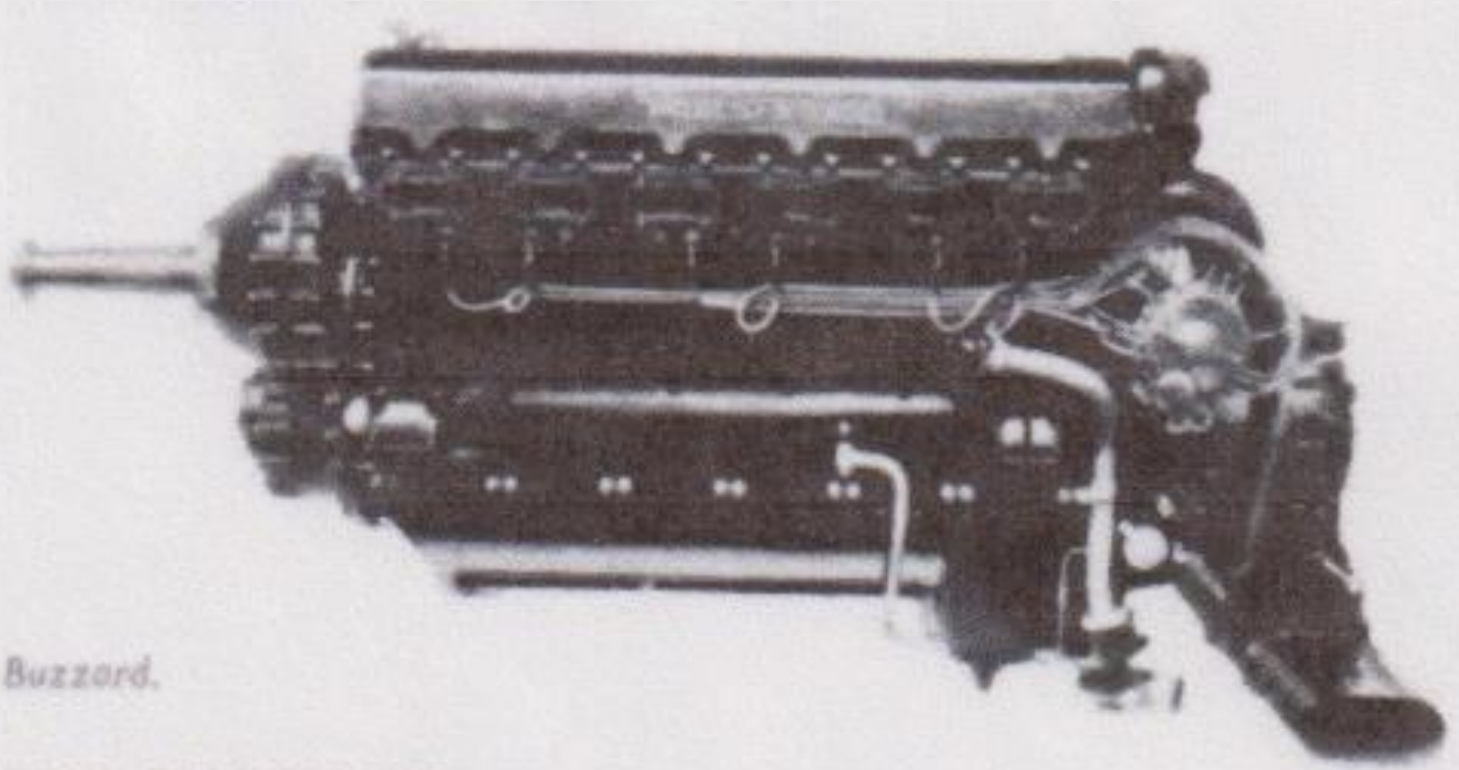
Kestrel XVI.

The Buzzard

Originally known as the “H” engine, the Buzzard was larger and more powerful than the Kestrel, but very similar in design. In fact, it bore the same relationship to the Kestrel as did the Eagle to the Falcon. The bore and stroke were 6 in. x 6.6 in. and the engine was supplied as standard with a medium supercharger capable of being used to its fullest extent on the ground, so as to give the maximum possible take-off power.

The Series I, II and III engines had reduction gear ratios of 0.632, 0.553 and 0.477 respectively and the normal power was 825 h.p. at 2,000 r.p.m. at sea-level. At 2,300 r.p.m., 955 h.p. was available at sea-level. The dry weight was 1,540 lbs.

Buzzards were installed in the Blackburn Iris V and VI (Perth), M.1/30 and M.1/30A, Handley Page H.P.46 (M.1/30), Hawker Horsley, Short Singapore I, K.F.I and Sarafand and Vickers M.1/30.



Buzzard.

THE BUZZARD

The “R” Engine

This special racing engine, first developed for the Supermarine S.6s participating in the Schneider Trophy Contest of 1929, epitomized Rolls-Royce excellence and remains a lofty monument on the road of British aero-engine progress. A development of the Buzzard and having most moving parts in common with that engine, it differed considerably in appearance, as the picture shows. External modifications - made in order to allow better streamlining - affected the valve covers, cylinder blocks, bottom cover and bearer feet. Auxiliaries were redisposed to reduce the depth and the length of the reduction-gear housing was increased in order to fine-down the cowling lines. The gear itself was of 6:1 ratio. A major factor in achieving the output of 1,900 h.p. at 2,900 r.p.m. was an entirely new supercharger.

Notable as was the 1929 model, that produced for the 1931 contest was even more remarkable, for it gave 2,300 h.p. at 3,200 r.p.m. for a weight of only 1,630 lbs. This meant that the power had increased 21 per cent for a weight increase of only 6-1/2 per cent - an advance obtained largely by increasing the engine speed, the supercharger gear ratio and the size of the air intake.

With typical caution Rolls-Royce decided that a one-hour run at full power should be the first mark to be passed before the 1931 “R” engines could be delivered as airworthy.

By the end of April the early specimens were usually lasting about 20 min before some kind of failure. By the middle of July they would still only do about half-an-hour non-stop; but on August 3rd a run of 58 min. was accomplished at 2,360 h.p. and on August 12th, one-hour non-stop was completed at 2,350 h.p.

As part of the re-design of the 1931 engine, an entirely new type of connecting rod was developed and very considerable modifications were effected in the crankshaft and crankcase to withstand the terrific loads. “Some idea of the magnitude of the crank-chamber stresses,” *FLIGHT* remarked, “may be gained from the fact that the load on the centre main-bearing due to centrifugal and inertia forces was no less than nine-tons. Alternative bearing metals were tried, but white metal was finally made to stand-up. An obscure trouble experienced at one time was side-lashing of the big-end bearings against the webs, which caused failure of the white metal on either side of the big ends.”

Considerable trouble occurred with valve springs - rather more so than was expected considering that the speed was raised by only 300 r.p.m.; in fact, at one time two or three would be found broken after a ten-minute run. Extensive tests were run on a valve-spring rig consisting of one cylinder block. and all aspects of design and material were thoroughly reviewed. The springs finally arrived at were somewhat reactionary, but no further failures at all were experienced on the engines after fitting them.

“The oil consumption,” *FLIGHT* reported, “rose to terrific figures at the 1931 speeds and powers, partly owing to great quantities lost through the breathers. On one 25-min run the oil consumption was at the rate of 112 gallons-an-hour; the test house was a sight after it! By weeks of work on combinations of scraper rings and crankcase breathers, by modification of the scavenging system and by the final adoption of a deeper sump which filled all the available space in the machine, the consumption was reduced to about 14 gallons-an-hour for the final race engines. It also effected a considerable reduction in the oil temperature rise through the engine; oil entered the engine at about 80 deg. C and came out at about 140 deg. C. The oil used was pure castor.”

The fue! to be used was the subject of many tests, for a compromise had to be effected between power and specific consumption. Invaluable assistance was rendered by the Ethyl Export Corporation. The plugs used in both 1929 and 1931 were Lodge Type X170, which gave very little trouble indeed. During the course of development, incidentally, it was found that an actual engine-run was a more severe test of insulation and general performance than anything the plug-makers could impose themselves.

It was decided to give all plugs an endurance test in an engine before sending them to Calshot. After this run they were returned to the Lodge firm, who examined the inners, re-polished them and fitted new outer bodies, before despatching them to Calshot.

A few doubtful cases, which might have caused trouble in flight, were found in this way. Actually, no plug troubles of any description were experienced in the air and the same plugs could be used for warming-up and taxying as for full-throttle flying.

Both B.T.H. and Watford magnetos were used on the race engines. Some trouble was experienced with these on the test-bed due to the vibration to which they were subjected; consequently every nut on them had to be split-pinned, and certain parts had to be stiffened-up.

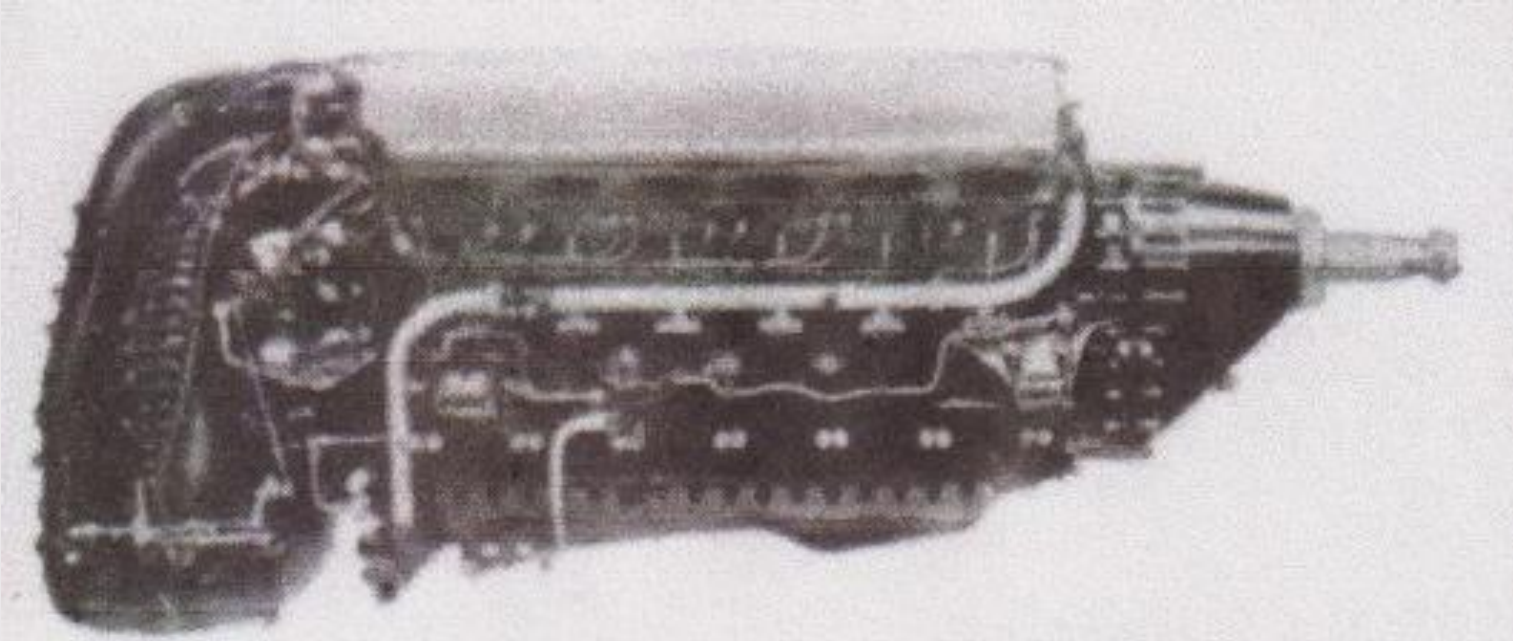
Before despatch the engines were tested in a hangar with an airscrew fitted. The tick-over speed was set at 475 r.p.m. and the engines were remarkable (as racing units) for their tick-over and flexibility. Once in the aircraft they were started by compressed-air or with a Bristol gas starter.

Hiduminium alloys (R.R. 5O series) were extensively used and, the life of the engines being short, aluminum-alloy forgings replaced bronze and steel in many parts. From the experience gained from many smashed-up engines, a “life of parts” list was drawn-up and pieces were scrapped after their allotted span, whether broken or not. This procedure was found to be cheaper and quicker than rebuilding smashed engines.

There was hardly a single component part in the engine which did not receive design attention and which was not improved in some way - from large units like the crankcase and cylinders down to individual nuts and bolts all over the engine. “It is no exaggeration to say,” *FLIGHT* observed, “that five years of normal development work would have been required to cover the same amount of gro-und.”

For short periods powers appreciably greater than 2,350 b.h.p. were obtained from the “R” and on September 9th, 1931, a power of 2,530 h.p. was taken from a “sprint” engine, enabling an S.6B to establish a world record of 407.5 m.p.h.

Engines of the “R” type were used not only in the S.6, S.6A and S.6B seaplanes, but for land-speed records in Bluebird, Speed of the Wind and Thunderbolt and for water-speed records in Miss England I and III and Bluebird II and III.

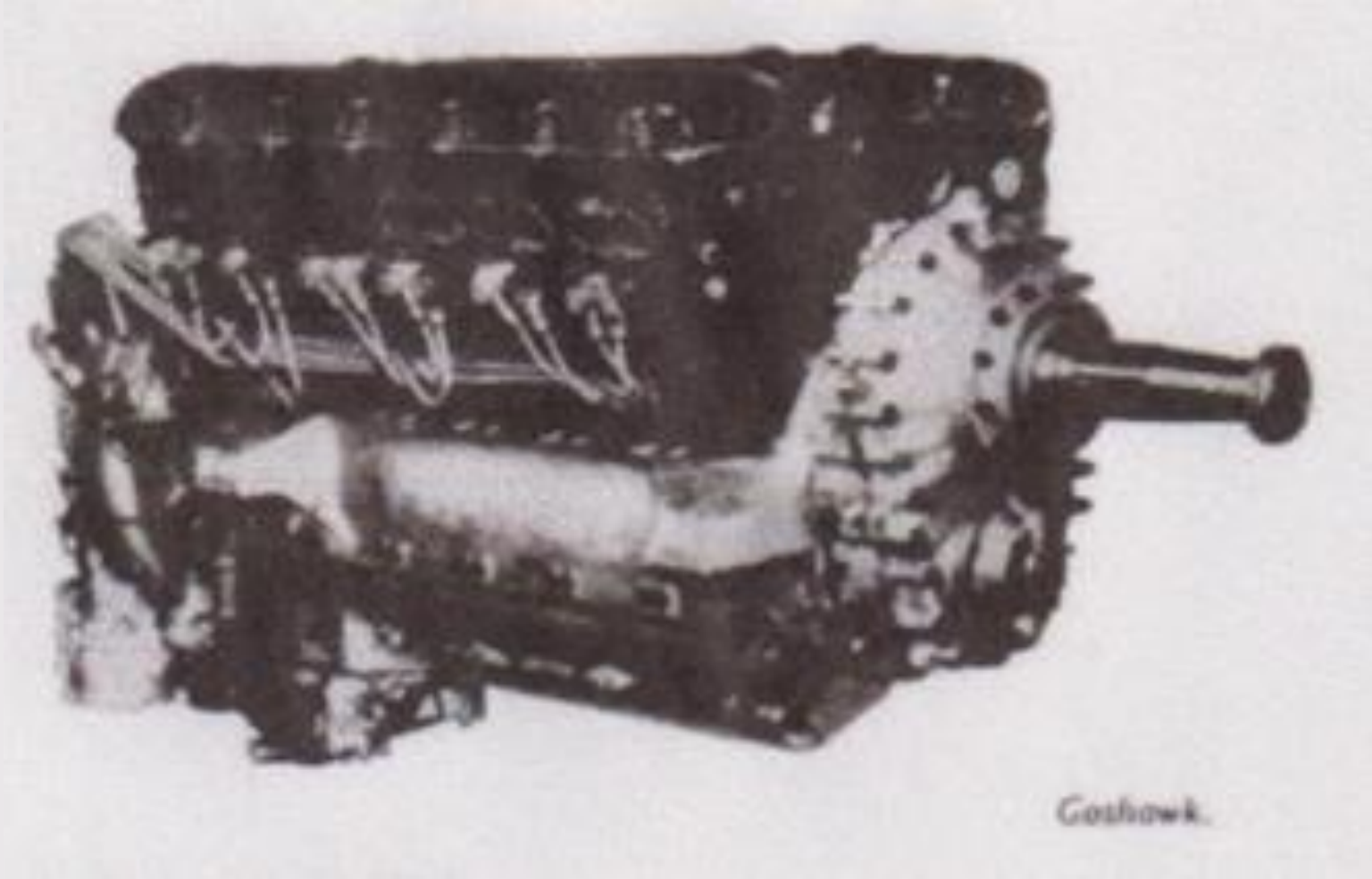


The "R" engine of 1931.

The Goshawk

First announced in 1934, and originally known as the P.V.G., this modified Kestrel paved the way for the development of the Merlin and was designed to be evaporatively cooled. Bore and stroke were the same as for the Kestrel, i.e., 127 mm x 140 mm. Goshawks I, II and III were fully supercharged and gave 600 h.p. at 2,600 r.p.m. at 12,000 ft. and 650 h.p. at 15,000 ft. The weight was 975 lbs. and the three marks had reduction-gear ratios, respectively, of 0.632, 0.533 and 0.477. Goshawks VI, VII and VIII were medium-supercharged units rated at 660 h.p. at 2,600 r.p.m. at 6,000 ft. and geared - successively - as the I, II and III.

Only a few Goshawks were built, but they were fitted in the Blackburn F.7/30, Bristol F.7/30, Gloster S.15/33, Hawker High Speed Fury II and P.V.3, Short R.24/31, Supermarine and Westland F.7/30, and Westland Pterodactyl V.


Goshawk.

The Merlin

Drawings for the P.V. 12 engine, as the Merlin was a called, were begun in January 1933. When the first example was run on October 15th, a number of weaknesses were revealed and it was not until July 1934 that a 100-hr type-test could be completed. This first unit gave 625 h.p. at 2,500 r.p.m. for take-off, 7 4 h.p. at 12,000 ft. Rated boost was plus 2 lbs. and weight 1,177 lbs.

In *The Magic of a Name,* Harold Nockolds relates how early bench tests resulted in persistent cracking of cylinder jackets and failures of the double-helical reduction gear. The substitution of straight spur-gears cured the reduction-gear trouble, but strengthening of the big integral cylinder blocks and top-half of the crankcase was not regarded as the complete answer to the cylinder-jacket defects. Experiments with different types of cylinder heads were made and the integral cylinder block and upper-half of the crankcase were replaced by separate castings for the two components.

The Rolls-Royce Engineers then justifiably felt that they were on the right road, but an attempt in 1935 to pass a 50-hr. civil type-test with the Merlin C (as the engine incorporating these changes was called) ended in failure and it was not untl December of that year that the test was completed. The rating was 955 b.h.p. at 2,600 r.p.m. at 11,000 ft. with a maximum output of 1,045 b.h.p. at 3,000 r.p.m. at 12,000 ft. and the engine (Merlin F) was put into production as the Merlin I.

In September 1937, *FLIGHT* published the first description of the Mks I and II, remarking that engines of this series had then flown for over 2,000 hrs. and that they had shown a marked superiority over the early Kestrels in respect of the rough treatment they would stand. It was disclosed that the chief difference between the Merlin I and II (formerly Merlin G) lay in the cylinder heads. Whereas in the Merlin I these were of the detachable “ramp” type, the Merlin II had blocks and heads cast in a unit, following earlier practice. Both models had four valves per-cylinder, each with two concentric return springs. There were two sodium-cooled exhaust valves on the outside of the head and two inlet valves on the inside. On the Merlin II all four were parallel to the centre-line of the block, but the two inlet valves in the detachable head of the Merlin I were inclined at about 45 deg. to the exhaust valves. In both engines the latter had phosphor-bronze guides and high-silicon-chrome steel seatings were screwed into the heads.

A fixed-datum automatic boost regulator maintained a constant induction-pipe pressure without continual reference to the boost gauge and throttle adjustment.

The hollow crankshafts were carried in seven special lead-bronze bearings, and the reduction gear was of 0.477:1 ratio. Half the casing for the gearing was cast integrally with the crankcase; in this respect the Merlin differed from the Kestrel. Oil pumps carried on the lower-half of the crankcase took their drive from the wheelcase through an idler gear. The dry-sump system was employed and two scavenge pumps drained the front and rear-ends of the crankcase. The pistons and the floating steel gudgeon-pins, which had phosphor-bronze bushes, were splash-lubricated; a baffle in the lower-half of the crankcase preventing excess oiling.

Sandwiched between the supercharger and the crankcase at the rear of the engine was a wheelcase from which a full complement of drives was taken. The Rolls-Royce/S.U. carburetor was of the twin-choke tube, updraught type, with a separate diffuser to each choke placed at right angles to the airstream. The semi-automatic, two-stage mixture-control device was operated by air intake pressure, boost and/or a cockpit lever.

International power of the Merlin I and II was 950/990 h.p. at 2,600 r.p.m. at 12,250 ft. and the maximum take-off output was 890 h.p. at 2,850 r.p.m.

When some of the first figures for the Merlin were published in *FLIGHT* during May 1937, a note was appended on the development by Rolls-Royce, Ltd., of compact “power-plant” assemblies, wherein the mounting was arranged to permit the radiator being carried close to the crankcase.

The Kestrel and Merlin: Some New Facts About Two Famous Liquid-cooled Units: A Historical Comparison

***FLIGHT,* May 20, 1937**

RE: introduction to an article entitled: "R-R's Latest"

"THIS being a period of recollection the results of a comparison recently made by Rolls-Royce between the Eagle I - the first Rolls-Royce engine to go into large-scale production - and one of their modern Kestrel series (concerning which the latest information is given hereafter) is of special interest…"
***FLIGHT,* May 20, 1937**

"…The Kestrel X has been chosen because, like the Eagle, it is rated at full throttle at sea-level, precluding the complications introduced into a direct comparison by supercharging…"

***FLIGHT,* May 20, 1937**

"…The power output per-unit of cylinder capacity has increased by 20 per cent., the b.m.e.p. by 59 per cent, the specific weight has been reduced by 52 per cent and the fuel consumption by 33 per cent. In spite of these advances, the normal running life between overhauls is 500 hours, compared with the 60 hours obtainable in 1915, indicating that the large increase in performance has been combined with corresponding gains in reliability. These improvements, of course, have been made possible by all-round development and improved materials and fuels…"

***FLIGHT,* May 20, 1937**

"…Comparison between the Eagle I and a modern Kestrel supercharged type like the XVI, which gives 745 h.p. at 14,500 ft., would show an even more striking contrast…"
***FLIGHT,* May 20, 1937**

Composite Cooling

"…All the Kestrel engines with exception of the unsuper-charged models are cleared for operation with two-position variable-pitch airscrews and have been tested for composite cooling, which implies that the system may be operated right up to its boiling point under a slight degree of pressure which permits the use of a smaller radiator than would be possible with a normal system of water-cooling…"

***FLIGHT,* May 20, 1937**

"…Since the radiator is inadequate to dissipate all the heat generated on the climb a slight degree of boiling occurs, but in level flight the engine operates as a straightforward water-cooled unit. By locating the radiator in a special cowl having an adjustable flap at its exit, the cooling can be controlled and the radiator drag at high speed reduced. Composite cooling, therefore, reduces the direct drag due to the size of the radiator and also the interference drag…"

***FLIGHT,* May 20, 1937**

THE ROLLS-ROYCE KESTREL ENGINES.

Type.	Series.	International Ratings.			Maximum Rating.			Rated Boost lb. sq. in.	Maximum Take-off.			Continuous Cruising.		Oil Cons. pts. hr.	Net Dry Weight lb.	Octane Rating Fuel.
		r.p.m.	h.p.	Alt.	r.p.m.	h.p.	Alt.		r.p.m.	h.p.	Boost.	Max. r.p.m.	Max. Boost lb. sq. in.			
S.	IV-VI V.P.	2,750	610	13,000	2,900	640	14,000	+1.5	2,750	700	+6	2,500	+1	4-8	985	87
MS.	VII-IX V.P.	2,750	715	4,250	2,900	730	5,950	+2.625	2,750	800	F.T.	2,500	+1½	4-8	985	87
R.	X-XII	2,500	585	S.L.	2,900	630	S.L.	—	2,500	585	F.T.	2,500	—	3-6	885	87
S.	XIV-XVI V.P.	2,750	715	12,250	3,000	745	14,500	+3.25	2,750	745	+6	2,600	+2½	4-10	985	87

"…All the Kestrel engines have completed the supplementary test for running at economical cruising consumption and for dive-bombing at speeds in excess of the maximum r.p.m. The main performance data relating to the current Kestrel series, which are available with a wide range of standard are given in the accompanying table…"

***FLIGHT,* May 20, 1937**

"…Some additional information on the Merlin has lately been released. This engine has a bore and stroke of 5.4 in. and 6 in. respectively, giving a total cylinder capacity of 1,647 cu. in. or 27 litres. This engine has been designed for high-temperature liquid-cooling, using ethylene glycol as the cooling medium. The international rated power is 990 hp at 12,000 ft., the maximum output being 1,050 hp on standard service fuel of 87 octane number. The net dry weight is 1,318.5 lbs…"

***FLIGHT,* May 20, 1937**

"…In addition to intensive engine development, the Rolls-Royce Company has concentrated recently on the development of engine installations possessing the combined advantages of reliability, low-drag and minimum weight…"
***FLIGHT,* May 20, 1937**

"…To these ends, the engine mounting has been arranged to permit the radiator being carried close to the crankcase and by mounting the header tank round the nose of the reduction gear the amount of piping in the system has been reduced to a minimum…"

***FLIGHT,* May 20, 1937**



"…Advantage of recent research in the reduction of cooling drag has been taken by enclosing the radiator in a low-drag cowl in which the cooling is done by air at relatively low velocity. The flow of cooling air is controlled to suit various flight conditions by an adjustable flap at the exit from the cowl…"

***FLIGHT,* May 20, 1937**



Two recent Merlin installations: above, in the Hawker P.4/34 light bomber, and, on the right, the Fairey to the same specification. Both radiators have a flap to suit cooling to varying flight conditions. (*Flight* photographs)

"…A great deal of work has also been done on exhaust systems and a type has now been evolved which combines good noise and flame-damping properties with low-weight and head resistance…"

***FLIGHT,* May 20, 1937**

"…The investigation of the complex problems affecting powerplants is carried out by Rolls-Royce's special experimental flight section, where all manner of questions are explored and teething troubles overcome…"

***FLIGHT,* May 20, 1937**

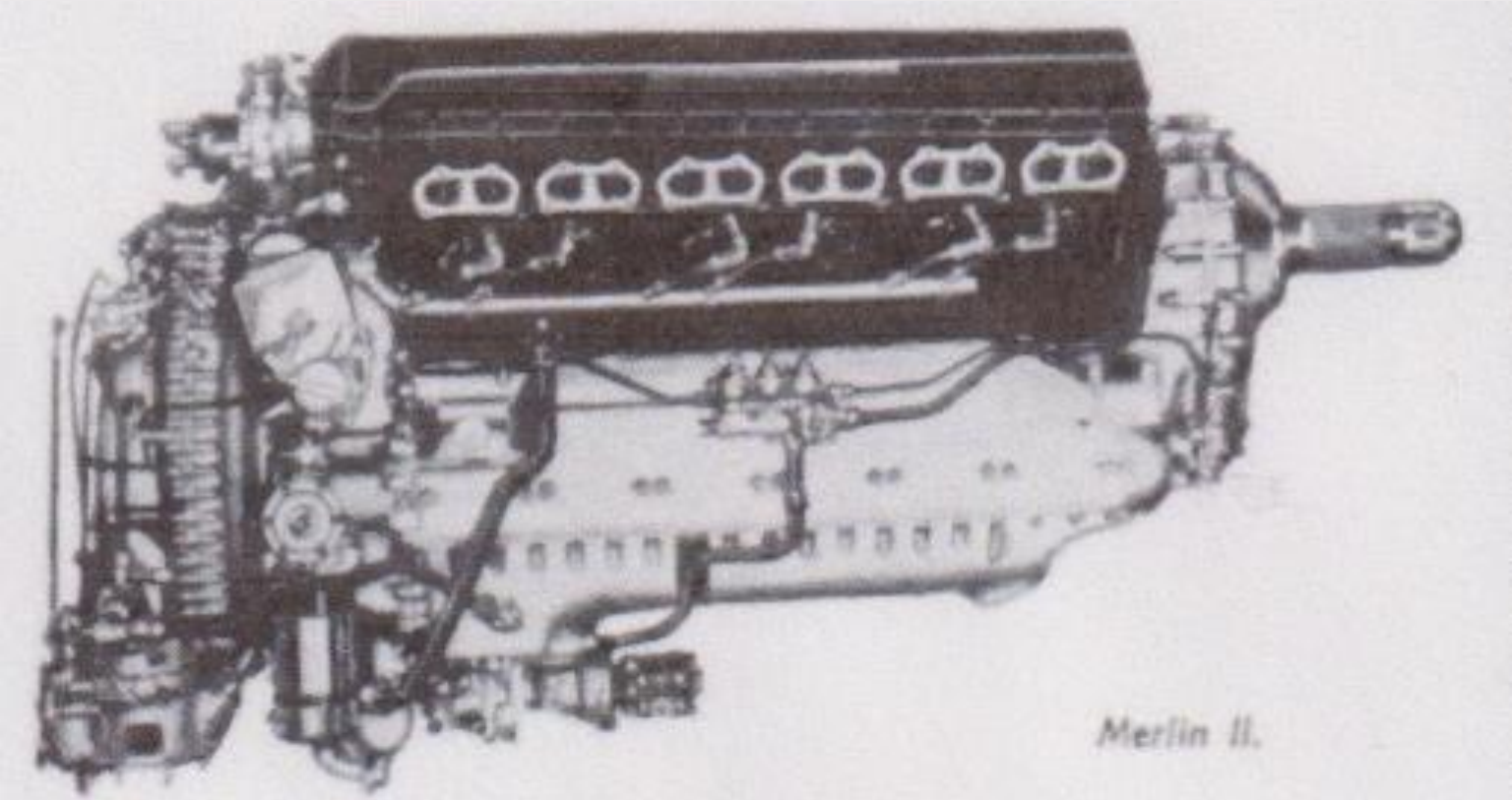
"…Valuable work in connection with the initial proof tests of new engines, the development of low-drag cooling systems, efficient exhaust systems and flight problems associated with the use of variable-pitch airscrews has already been done. It is thus possible to make recommendations based on practical results to aircraft requiring information on powerplant layout."

***FLIGHT,* May 20, 1937**

Moreover, by mounting the header tank round the nose of the reduction gear the amount of piping was reduced to a minimum. Advantage was taken of then-recent research in the reduction of cooling drag by enclosing the radiator in a low-drag cowling, wherein the cooling was done by air at relatively low velocity, and from which the flow through the matrix was controlled to suit various flight conditions by an adjustable flap at the exit.

A tribute was paid also to Rolls-Royce's special experimental flight at teed, ahem, on April 12th, 1935, a P.V. 12 engine had first been flown in a Hawker Hart (other early machines used at Hucknall were the High Speed Fury II, a Gloster Gnat-snapper, a Hawker Horsley, a Heinkel He 70A and a Fairey Battle). "Valuable work in connection with the initial proof tests of new engines, the development of low-drag cooling systems, efficient exhaust systems and flight problems associated with the use of variable-pitch airscrews has already been done," it was reported.

During June 1937 a Merlin II, mounted in a Horsley, began a 400-hr. flight endurance test at Farnborough and a specially rated "racing" engine was developed from it with a view to installation in the Special Spitfire, with which an attack on the world's speed record was contemplated.



Merlin II.

The engine used was a Merlin III, which differed from the Merlin II in having a standardized de Havilland/Rotol airscrew shaft and dual accessory-drive. It was taken from stock and was fitted with strengthened pistons, gudgeon-pins and connecting rods to withstand the extra load. “The power output of the standard engine,” writes Harold Nockolds, “was 1,030 b.h.p. at 3,000 r.p.m. at 10,250 ft. with plus 6-1/4 lb. boost. “Solely by opening the throttle, raising the super-charger pressure and using fuel of a higher octane,” he goes on, “the petrol normally used at that time was 87 octane. The engine was made to develop no less than 2,160 b.h.p. at 3,200 r.p.m. with the supercharger giving 27 lbs./sq. in. boost. This was a phenomenal performance for it meant that a power-to-weight ratio of 0.621 lbs. per-horsepower had been achieved - a considerable improve-ment on the 0.71 lbs. per-horsepower of the 1931 R engine.”

“This tremendous output, which was admittedly only attained for a short period, nevertheless gave ample proof of the inherent possibilities of the Merlin. But Elliott and Hives were perhaps even more satisfied with a 15-hr. endurance run at 1,800 b.h.p., 3,200 r.p.m. and 22 lbs. boost accomplished during the devel-opment period. After this they felt perfectly satisfied that the Merlin would be capable of meeting all the demands that might be made of it. How right they were!”

How right, indeed, for the story of Merlin development we now have to outline is one of the most inspiring in the history of British aero-engineering.

The Merlin II and III were installed in the Spitfire I, Defiant I, Hurricane I, Sea Hurricane I and Battle I and were - as will always be remembered - vital factors in the winning of the Battle of Britain. The Merlin IV had pressure-water cooling in place of the glycol cooling of the earlier models and was developed for installation in the Armstrong Whitworth Whitley IV bomber. The Mk.VIII, installed in the Fairey Fulmar I, was a medium-supercharged unit rated at 1,010 h.p. at 2,850 r.p.m. at 6,750ft and, using 100-octane fuel, delivered 1,080 h.p. at 3,000 r.p.m. for take-off.

The Merlin X - installed in the Halifax I, Wellington II and Whitley V and VII - represented a very important advance in that it had a two-speed supercharger to improve take-off, low-altitude performance during climb or level flight and fuel economy under cruising conditions. The speed change was effected through an oil-pressure system, the actual changeover under full power taking about a second. In low-gear, the Merlin X gave 1,145 h.p. at 5,250 ft. and in high-gear, 1,010 h.p. at 17,750ft.

The Merlin XII, driving a Rotol three-blade constant-speed airscrew, was installed in some Spitfire IIs; its maximum output was 1,150 h.p. at 3,000 r.p.m. at 14,000 ft. and it had a 0.477:1 reduction gear.

The next production-type engine was the Merlin XX, which, compared with the X, delivered a greatly increased power at height. The two units were, however, interchangeable. Describing the engine in great detail during 1942, *FLIGHT* remarked: “So far-seeing and gifted were the designers in evolving the original design that the successive types up to the latest and far more powerful Merlin XX remain substantially the same. Even the crankshaft and bearings, the pistons, cylinder blocks, crankcases are basically the same as in the original conception, though naturally innumerable detail improvements have been effected as constant study and experiment and metallurgical improvements have made possible.”

The two-speed supercharger of the Merlin XX was of improved design, incorporating a modified form of central entry which gave a freer flow of air to the blower. The low-gear ratio was 8.15:1 and the high gear 9.49:1. Amendments were also made to the rotating and fixed guide vanes and the improvements mentioned in conjunction with a larger, twin-choke, updraught S.U. carburetor (designed as a complete, separate unit) gave a marked increase in power.

Thus, using 100-octane fuel, the international rating in low-gear was 1,240 h.p. at 2,850 r.p.m. at 10,000 ft. and plus 9 Ibs./sq. in. boost; in high-gear the figure was 1,175 h.p. at 2,850 r.p.m. at 17,500 ft., again at plus 9 Ibs. boost. *FLIGHT* commented: “These figures represent an increase of nearly 250 h.p. over the Merlin II of identical cylinder dimensions and illustrate, in a convincing manner, the technical progress achieved by years of ‘toil, tears and sweat,’ to borrow a classical phrase from our worthy Prime Minister. Nor is the limit of attainment yet in sight.” It was further remarked that the achievement of extracting so much extra power from a given cubic capacity had increased the dry weight by only 75 Ibs. and that over 100 h.p. were being taken from each cylinder. The Merlin XX powered the Beaufighter II, Defiant II, Halifax II and V, Hurricane II and IV and Lancaster I and III.

Merlins 21, 22, 23, 24 and 25 were all essentially similar to the Merlin XX. The 21 was fitted in the Mosquito I, II, III, IV and VI; the 22 in the Lancaster I and II and the York I; the 23 in the Mosquito I, II, IV, VI, XII and XIII; the 24 in the Lancaster I and III and York I; and the 25 in the Mosquito VI and XIX. Take-off power of the 24 and 25 was 1,620 h.p.

The Merlin 28 was a Packard-built engine, installed in the Lancaster I and III and the Kittyhawk IT and known in America as the V-1650-1. When it was disclosed in Great Britain that this American-built engine would differ from its British equivalent in having detachable cylinder heads, it was explained that this form of construction had already been proved satisfactory by Rolls-Royce, Ltd., and would have been adopted by them two years or more previous to the Packard innovation had it not been for the fact that such an important modification would have delayed the attainment of maximum production.

The Merlin 29 was also Packard-built, but had a reduction gear ratio of 0.477:1 instead of 0.42:1 and was fitted with a splined airscrew shaft; it was fitted in Canadian-built Hurricanes and the Kittyhawk II. Changes from its predecessor were so small that the designation V-1650-1 was retained.

The Merlin 30 was a medium-supercharged engine, installed in the Barracuda I and Fulmar II, and giving 1,240 h.p. at 7,250 ft. and a take-off output of 1,300 h.p. The Merlin 31 was another Packard V-1650-1 and was mounted in the Canadian Mosquito XX, the Australian Mosquito 40 and the Kittyhawk IT. An increase in take-off output from 1,300 h.p. to 1,600 h.p. characterized the Merlin 32, which powered the Barracuda II and Seafire II. The Merlin 33 was yet another Packard-built version, installed in the Mosquito XX and 40 and the 38 (also by Packard) was fitted in the Lancaster I and III. Both the 33 and 38 gave 1,390 h.p. for take-off.

A variant which saw very extensive service was the Merlin 45, fitted in the Spitfire V, P.R.IV and VII and Seafire II; at 16,000 ft. and 2,850 r.p.m. its output was 1,200 h.p. The Merlin 45M was rated for duty at lower levels and delivered 1,585 h.p. at 2,750 ft.; it was fitted in the Spitfire L.F.V. The Merlin 46 and 47 were both high-altitude engines (1,115 h.p. at 19,000 ft.); the 46 powered the Spitfire V, P.R.IV and VII and Seafire I and the 47 (which had a cabin supercharger) found its application in the Spitfire VI. The Merlin 50 was similar to the 45 and was fitted in the Spitfire V; the 50M was almost identical with the 45M and powered the Spitfire L.F.V; the 55 was again like the Merlin 45 and was fitted in the Spitfire V and Seafire III and the 55M resembled the 45M and was the power unit of the Spitfire L.F.V and Seafire L.F.III.

In March 1940, Rolls-Royce had been asked by the Ministry of Aircraft Production to submit their proposals for increasing the high-altitude output of the Merlin to enable a pressurized development of the Wellington to operate at 40,000 ft. An output of 800 h.p. at 40,000 ft. was estimated to be required. To that end, the company set about experimenting with a two-stage supercharger and an engine with this fitment was bench-tested in April 1941. This became the Merlin 60, which, though installed in Wellington VIs, was soon declared obsolete. Adapted for fighter requirements, however, and designated Merlin 61. the new engine was installed in the Spitfire VII, VIII, IX and P.R.XI, and gave those fighters a decided “edge” over their German adversaries.

The key feature of the Merlin 61 was its two-speed, two-stage supercharger, with two rotors on a common shaft. The mixture was compressed by the first stage and was delivered to the inlet of the second stage, where it was further compressed before being delivered to the induction pipe. In order to reduce the mixture temperature to a normal figure, a box-like intercooler was interposed between the outlet of the second-stage supercharger and the rear of the cylinder blocks. In a typical Spitfire installation the intercooler radiator was mounted under the port wing in a duct, which also housed one of the main engine-cooling radiators.

The real significance of the Merlin 61 was that at 40,000 ft. it developed double the power given at a much lower altitude by the Merlin II of 1939/40. Even at 23,500 ft. its maximum power was 1,390 h.p. The weight had risen to 1,640 lbs. The Merlin 62 was used in the Wellington VI and the 63 (wherein the maximum output had risen to over 1,650 h.p.) appeared in the Spitfire VII, VIII, IX and P.R.XI. The 64 was similar to the 63 but had a cabin supercharger; it was mounted in the Spitfire VII. The 66 powered the Spitfire L.F.VIII and IX. The 67 had a reduction gear of 0.42:1 instead of 0.477:1, as had the 63, 64 and 66 and the 68 was a Packard-built model, designated V-1650-3 and installed in the Mustang III. Its take-off output was 1,400 h.p. In the Merlin 69 - another Packard-built variant, known in America as the V-1650-7 - 1,490 h.p. was available for take-off; this engine powered Mustang IIIs and IVs.

The Merlin 70 appeared in the Spitfire H.F.VIII and IX and P.R.XI and the 71 (with cabin blower) in the Spitfire H.F.VII. The Merlin 72 was applied to the Mosquito P.R.IX, XVI and 30 and the Westland Welkin I.

Some Mosquito XVIs and Welkin Is had Merlin 73s or 76s. The 76 was the same as the 72, but had a cabin supercharger. Yet another engine for the Mosquito XVI and Welkin I was the 77, with cabin supercharger. In the Merlin 85 the take-off output was increased to 1,635 h.p. This was a bomber engine and was installed in the Lancaster VI and Lincoln I. The Merlin 224 was built by Packard and was the same as the Merlin 24; it was fitted in the Lancaster I and III. The 225 was another Packard-built model used in the Mosquito 25 and 26 and identical with the Merlin 25. The Merlin 266 - again Packard-built - was the same as the Merlin 66 and was mounted in the Spitfire L.F.XVI.

The war being over and the exigencies of security less restrictive, particulars were released of the Merlin 113 and 114, which became well-known as the power-plants of Mosquitoes 34, 35 and 36. These engines delivered 1,430 h.p. at 27,250 ft. with a boost-pressure of plus 18 lbs. Even more notable were the Merlin 130 and 131, specially “tailored” for the de Havilland Hornet. The installation of these was amazingly clean and in this con-nection it may be observed that a steady increase in b.h.p./sq. ft. of frontal area had been achieved by Rolls-Royce since the days of the Eagle and Falcon.

Thus, every four years between the two World Wars an increment of roughly 25 b.h.p./sq. ft. was attained until 1936. With the advent of the Merlin there was a very decided improvement, amounting to 60 b.h.p./sq. ft., continuing until 1940. Between 1940 and 1944 the figure was 100 b.h.p. and in 1945, with the introduction of the Merlin “100” series, 340 b.h.p./sq. ft. was recorded.

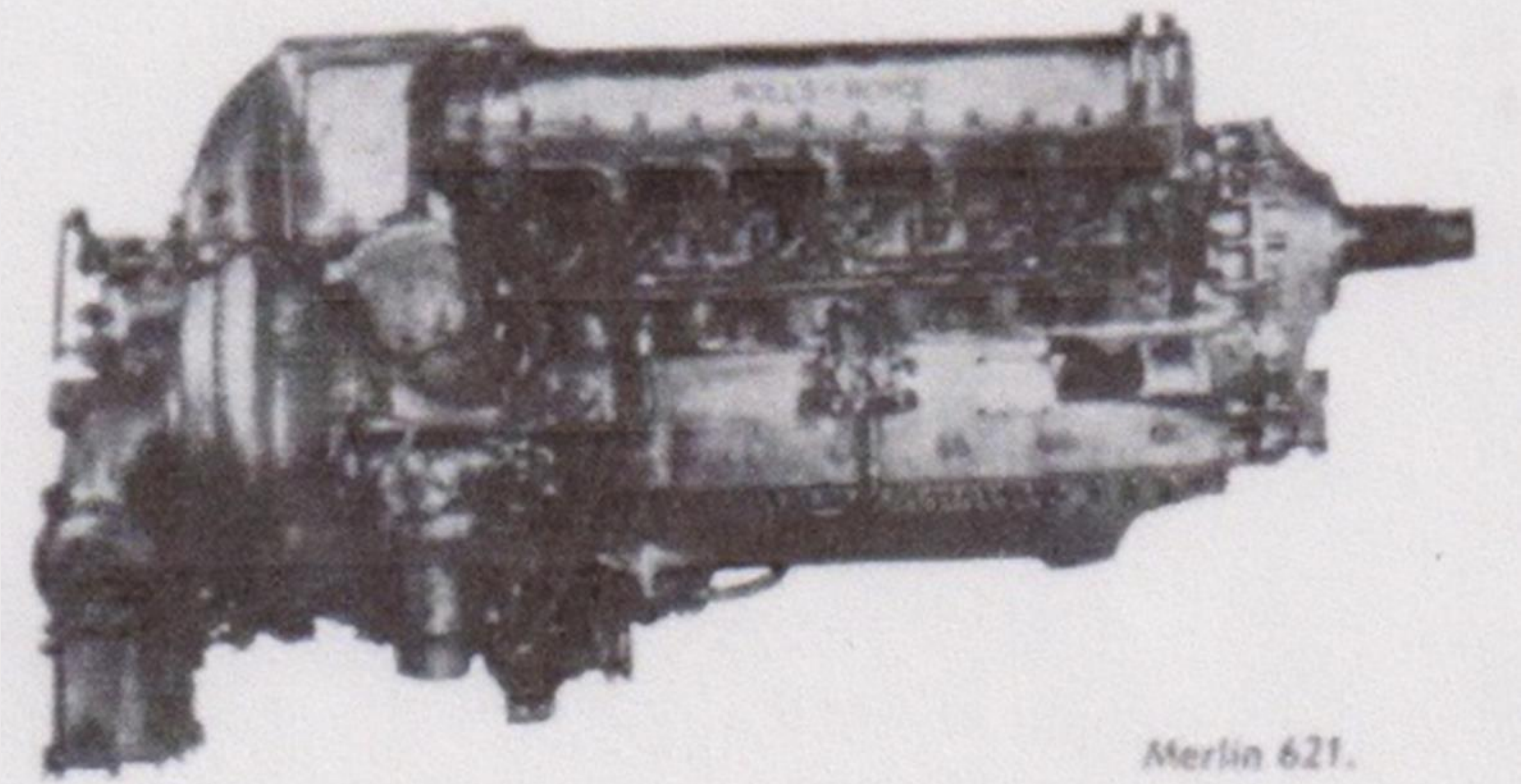
The Merlin 130 and 131 were the first of their family to incorporate downdraught carburetors; and, to eliminate the air scoop as used on the Mosquito, ducted air intakes were faired into the leading edges of the wing. The wartime Bendix/Stromberg carburetor was replaced by a low-pressure fuel-injection system, which delivered through a spray nozzle into the supercharger eye. The 130/131 differed, incidentally, only in being “handed” right and left respectively. The sum total of improvements incorporated in these remarkable engines raised the output to 2,030 h.p. at 1,250 ft. with a boost of plus 25 lbs./sq. in.

Another special military Merlin of the post-war years was the 140, developed for the Short Sturgeon and equipped to drive contra-rotating airscrews. Emergency maximum power was 1,650 h.p. at 16,750 ft.

As though the foregoing mass of engine designations were not sufficiently bewildering, we now have to record that the latest Merlin to go into service with the R.A.F. and Royal Navy is the 35, a trainer engine developed for the Avro Athena and Boulton Paul Balliol. It has a single-speed supercharger and a maximum take-off output of 1,280 h.p.

Although the Merlin engine will be remembered principally for its military applications, it has achieved in post-war years a remarkable record in the civil field.

The first of the civil Merlins, the 102, was the first to complete successfully the Air Registration Board's type-test requirements for civil aero-engines. There followed the 500 series (these were installed in Lancastrians and Yorks) with two-speed, single-stage supercharger and the 600 series, with two-speed, two-stage supercharger. The 620 was designed specifically for North Atlantic operation and went into service during 1947 in the Canadair North Star airliners of T.C.A. The 600, 620 and 621 series deliver a continuous cruising power of 1,160 h.p. at 23,500 ft. and 1,725 h.p. for take-off; the 622-626 units have a continuous cruising rating of 1,420 h.p. at 18,700 ft. and give 1,760 h.p. for take-off.



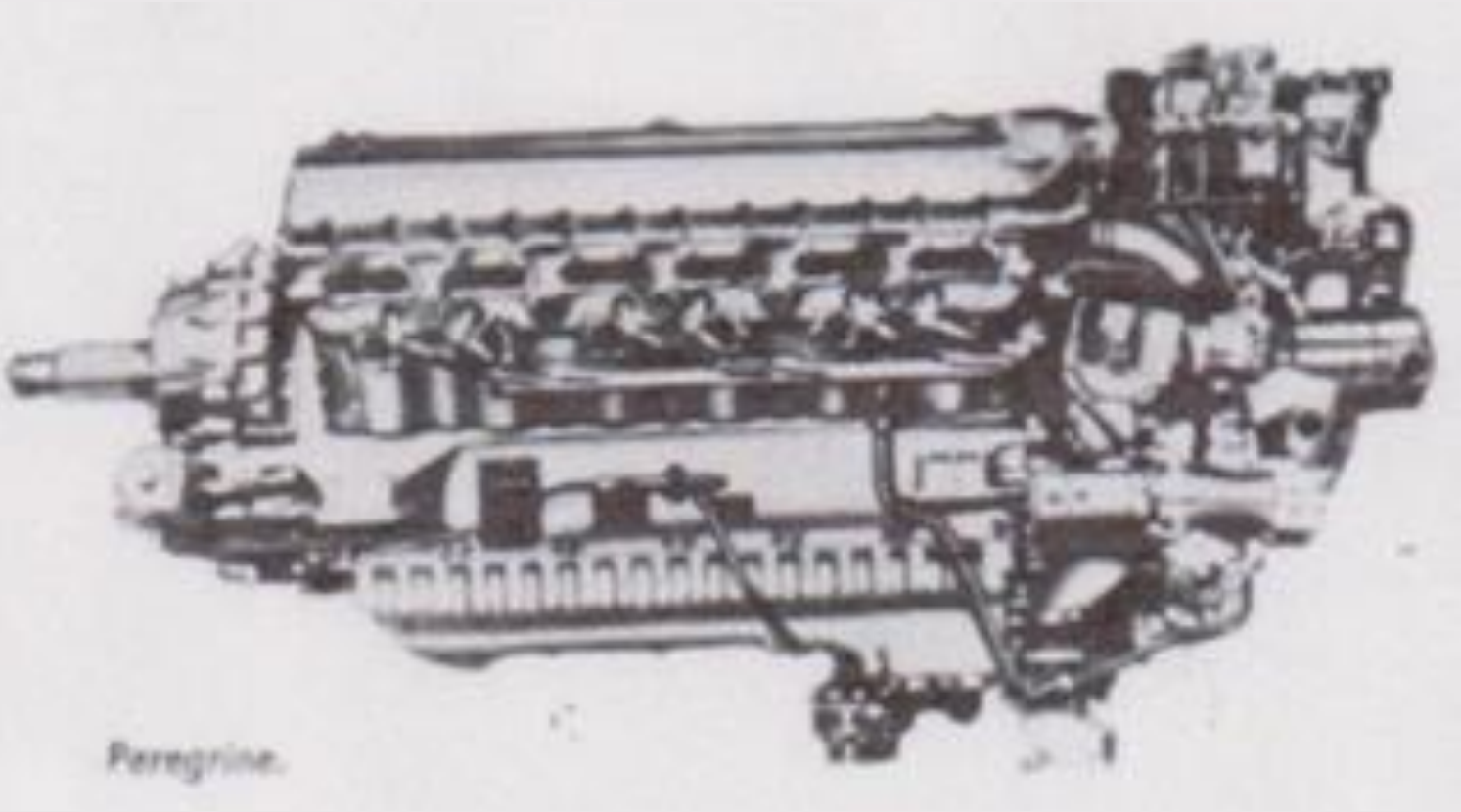
Merlin 621.

There are numerous variations between the civil Merlins; thus, the 621 has half intercooling and charge heating; the 722 either full or no intercooling; the 623 half intercooling and charge heating; and the 724 and 724-1C either full or no intercooling. Installations include: Merlin 621, Avro Tudor II and IV; 722, T.C.A. Canadair North Star; 623, Tudor IVB and V; 724, T.C.A. North Star; 724-1C, B.O.A.C. Argonaut (Canadair Four).

The Peregrine

The Peregrine was developed during 1939 from the Kestrel. Running on 87 octane fuel, it had an international rating of 860 h.p. at 2,850 r.p.m. at 13,500 ft. and a maximum output of 885 h.p. at 3,000 r.p.m. at 15,000 ft. A number of Merlin features were incorporated and provision was made for a wide-range of auxiliaries. External differences from the Kestrel included the fitting of a downdraught carburetor; this had progressive boost control in which the “dead” range of movement of the throttle lever was eliminated.

Peregrines were installed in the Westland Whirlwind and Gloster F.9/37.



Peregrine.

The Griffon

It is not perhaps generally realized that the Griffon 37.V.12 was originally developed to meet Fleet Air Arm requirements - specifically, to give high powers at low altitudes and thus to be suitable for installation in torpedo-bombers. The decision to go ahead with it was taken in December 1939 and it was recognized that the same basic engine should be suitable for installation in existing fighters, then powered with the Merlin. Dimensions and configuration were planned accordingly.

Relative frontal areas were 7.5 sq. ft. and 7.9 sq. ft. “It would seem well-nigh impossible,” *FLIGHT* remarked, when describing the Griffon for the first time, “that with such similarity of overall dimensions in two engines of the same basic type the swept volume of one should be 35.9 per cent larger than that of the other. Such, however, is the case. Piston area of the Griffon is 23 per cent greater than that of the Merlin, this having been achieved by increasing the cylinder bore to 6 in., a figure which is just about verging on the optimum limit.”

Though following Merlin lines, the Griffon differed very extensively in detail design. A prominent innovation was the taking of the camshaft and magneto drives from the front; this was decided upon in order to reduce torsional vibration in the camshaft drive.

By interpolating a semi-floating coupling between the crankshaft and the driving wheel of the reduction gearing, and, in addition, by taking the cam drives from the airscrew-driving gear angular variations in crankshaft speed were greatly reduced in their transmission to the camshafts.

“Perhaps the most novel feature of the crank assembly,” *FLIGHT* commented, “is that the main bearings and big ends are all lubricated from the hollow interior of the shaft. This scheme, though novel, is by no means new, Rolls having first tried it years ago; however, the Griffon is the first Rolls engine in which it has become practice.”

Early Griffons - the II, III and IV - had two-speed, single-stage blowers and gave a maximum power of 1,735 h.p. at 16,000 ft. and 1,495 h.p. at 14,500 ft. For take-off, 1,720 h.p. was available. These engines differed in reduction gear ratio; the II and III being geared 0.451:1 and the 4, 0.510:1. Until superseded by the Griffon XII, the series II engine was installed in the Firefly I and II; the Griffon III and IV were mounted in the clipped-wing Spitfire XII - specially developed to tackle the Fw-190 at low and medium levels. By increasing boost-pressure to 15 lbs./sq. in., the take-off power of the Griffon VI was raised to 1,815 h.p. - an increment of importance in that this engine powered the Seafire XV and XVII carrier-borne fighters. The Griffon XII resembled the VI except in supercharger and reduction gear ratios; it delivered 1,645 h.p. at 11,500 ft.

The system of designating the two-stage supercharged Merlins with series numbers beginning with 6 was also adopted for the Griffon range. For a weight increase of 290 lbs., accounted for by the new blower system, the Griffon 61 delivered 2,035 h.p. at 7,000 ft. and 1,820 h.p. at 21,000 ft.; its most famous application was in the Spitfire 21. Identical in all but reduction gear, the Griffon 65 powered the Spitfire XIV, and the Griffon 66 was again similar but had a cabin supercharger for P.R. work in the Spitfire XIX. Griffons 64 and 67 were derived, respectively, from the 61 and 64 and gave no less than 2,375 h.p. at 1,250 ft. and 2,145 h.p. at 15,500 ft; the 64 powered the Spitfire 21 and Seafire 46 and the 67 appeared in the Spitfire XIV.

Though early examples of the Vickers-Supermarine Spiteful had the Griffon 61, the production model had the Griffon 69, the maximum power of which exceeded that of the earlier two-stage Griffons by some 300 h.p. with no increase in weight. This meant that each cylinder was developing something approaching 200 b.h.p. Official maximum powers were 2,375 h.p. at 1,250 ft. in M.S. gear, and 2,130 h.p. at 15,500 ft. in F.S. gear. Boost-pressure was plus 25 lbs./sq. in., made possible by 150 grade fuel.

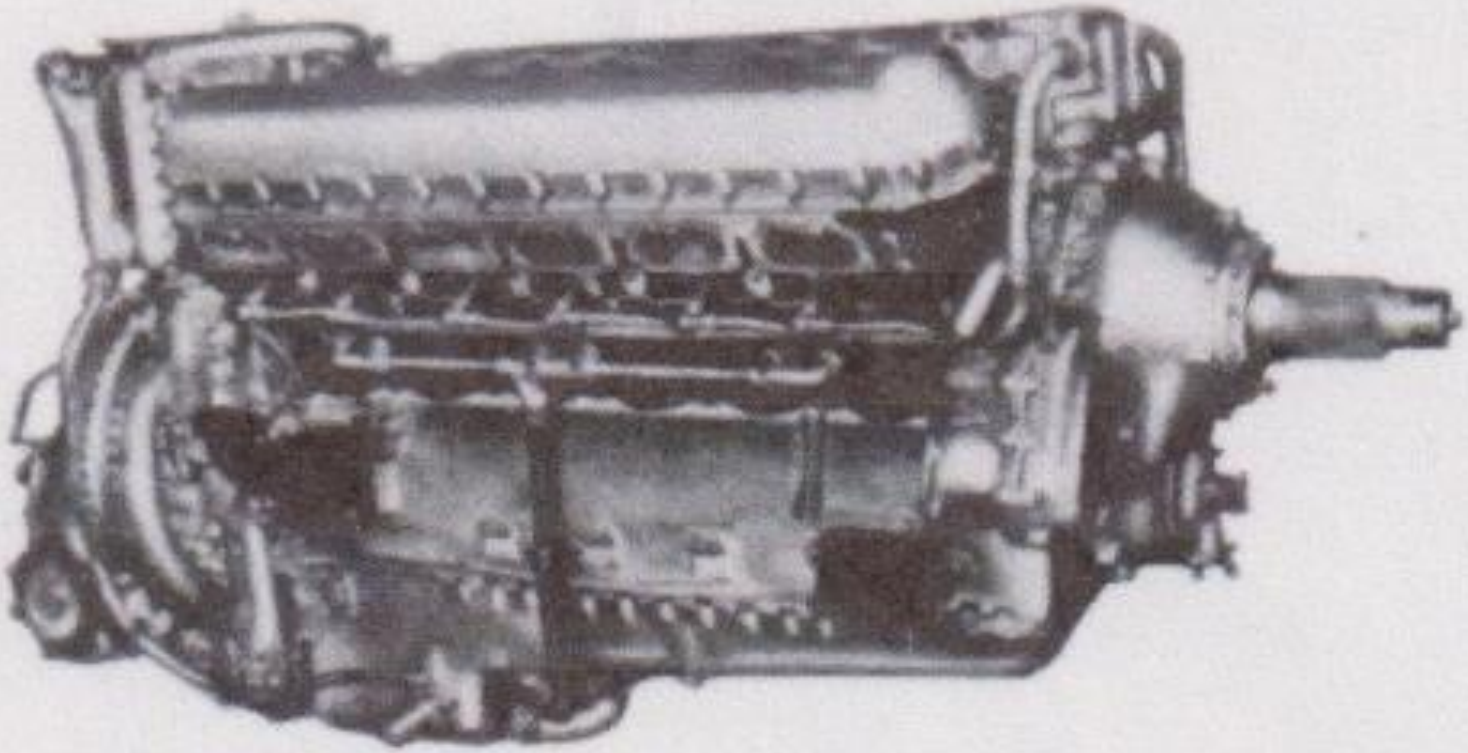
Griffons 72 and 74 were further developments of the 65 for the Fleet Air Arm; they delivered 2,245 h.p. at 9,250 ft. The 74 was distinguished from the 72 in having a Rolls-Royce injection pump instead of the Rolls-Royce Bendix/Stromberg carburetor. These engines were, respectively, the power-plants of the prototype Firefly IV and production Fireflies of the same mark.

An innovation of more than usual interest was the adoption, on the Griffon 85, of a drive for contra-rotating airscrews; this engine appeared in the Spitfire XIV, 21 and Seafire 45. The Griffon 87 was a further development; rated at 2,145 h.p. maximum at 15,500 ft. and the 88 differed only in having an injection pump. “Contraprop” Griffons of the 85, 87 and 88 series were mounted in the Spitfire XIV and 21 and Seafire 45 and 47.

For the Barracuda V, Rolls-Royce developed the Griffon 37, with a modified two-speed, single-stage blower maintaining 18 lbs./sq. in. boost in either gear. Though the Barracuda was thus provided with no less than 2,055 h.p. at 2,250 ft., only Merlin-powered machines of this type went into squadron service.

Perhaps the most impressive of all Griffon developments was the three-stage supercharger incorporated in the 101 series, together with Rolls-Royce fuel injection. The new blower made possible an output of over 2,000 h.p. up to 20,000 ft. - with no increase in dimensions. Weight rose by a mere 40 lbs.

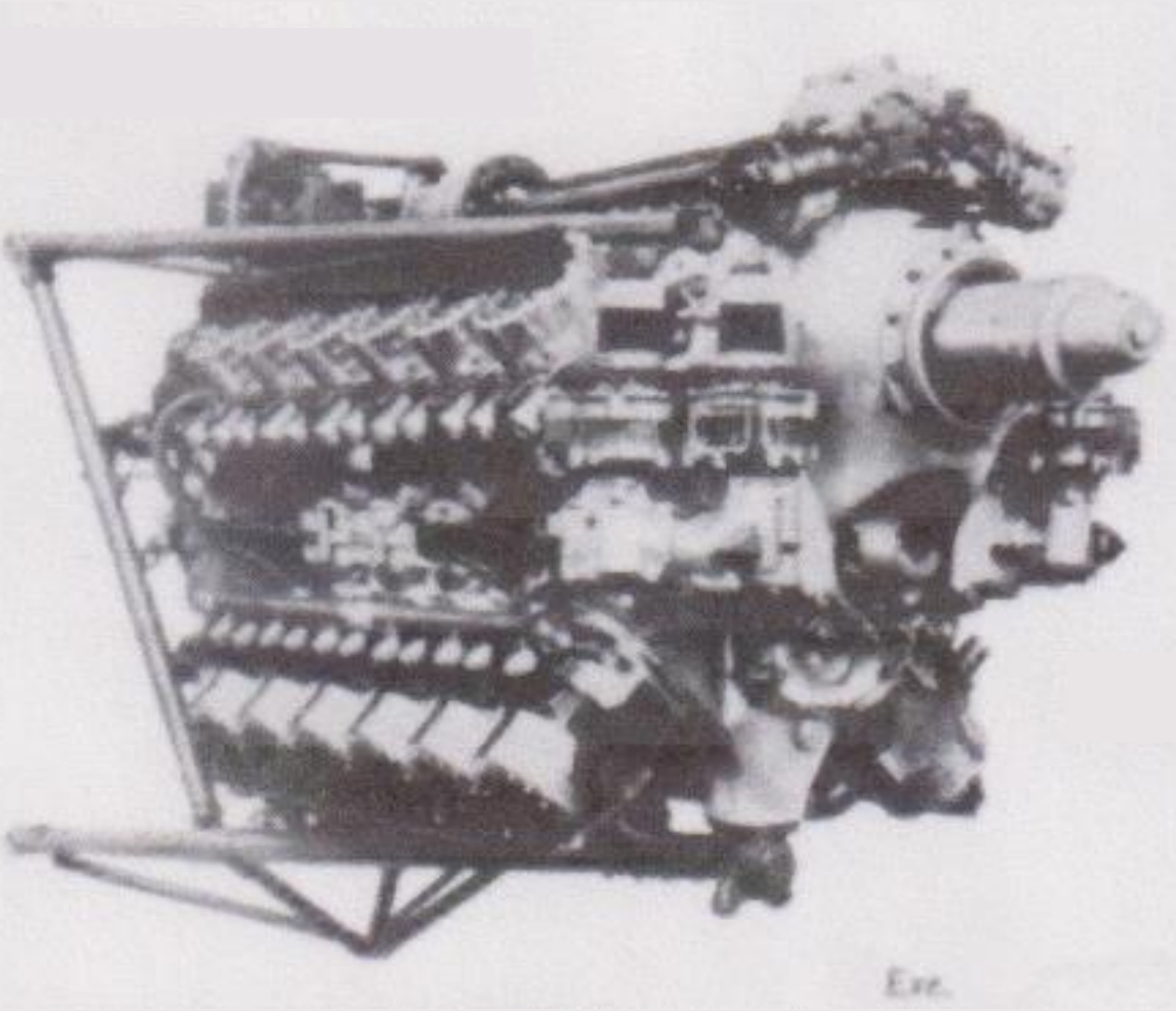
Notable among post-war developments is the Griffon 67; for use in long-range service aircraft and having provision for contra-rotating airscrews. On this engine water/methanol injection is automatically brought into play when the boost-pressure for the standard fuel approaches maximum value. The controlling unit works in conjunction with the boost-control and progressively increases the flow of water methanol with boost-pressures from 184 to 25 lbs./sq. in. Contraprop Griffons power the Avro Shackleton maritime-reconnaissance aircraft. Other variants of the Griffon are serving in the numerous marks of Fairey Firefly.



Griffon 130.

The EXE – and Others

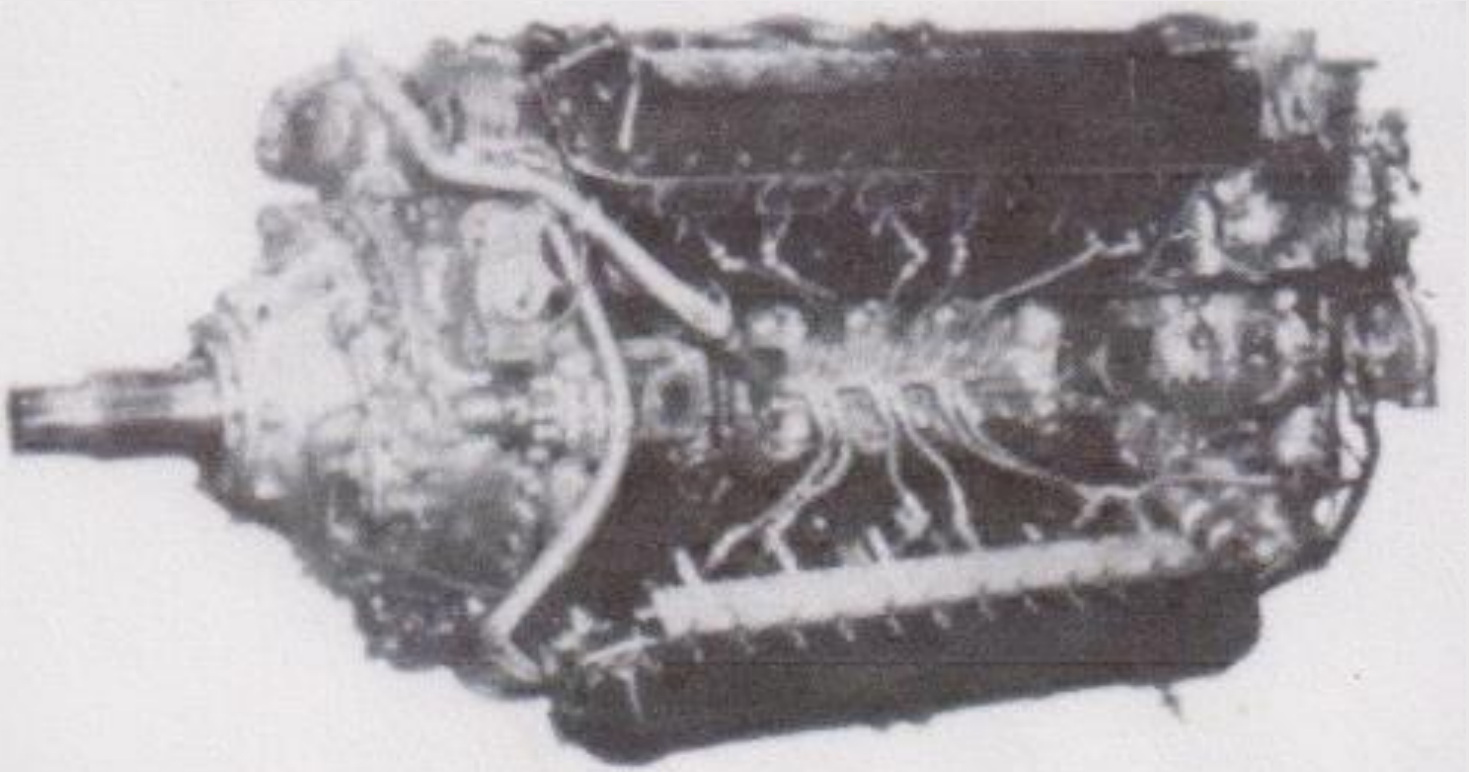
The first Rolls-Royce engine to be named after a river, as are the modern turbo-jets, was this experimental unit which was notable in having sleeve valves and pressure-air cooling. Its 24 cylinders were arranged in X form; in four banks of six and the capacity was 22 litres. Rated output was 1,200 h.p. at 4,000 ft. The Exe - a rare picture of which appears herewith - was test-flown in a Fairey Battle during 1938, but the project was shelved when it became clear that the company's main productive capacity must be devoted to the Merlin. Another experimental unit related to the Exe was the Pennine and it may be noted here that in the years preceding the war Rolls-Royce were experimenting with two-stroke as well as four-stroke engines and continued the compression-ignition experiments started with the Condor. The H-layout was also examined.



The Vulture

This liquid-cooled engine had its 24 cylinders arranged in four banks of six, again in the form of an X, and may be considered as two Kestrel-size units with a common crankshaft. It was test-flown in a modified Hawker Henley and was used on operations in Avro Manchester bombers, though various troubles and the desirability of concentrating on the Merlin and Griffon led to discontinuance of development (the basic Manchester airframe, with four Merlins in-place of two Vultures, of course, became the splendidly successful Lancaster). The Vulture was also installed in the Hawker Tornado fighter and Vickers-Armstrong's Warwick bomber.

Few details of the engine were ever released, but when it was first described in *FLIGHT*, in June 1942, it was noted that the capacity was 2,592 cu. in. Maximum power ratings were 1,845 h.p. at 3,000 r.p.m. at 5,000 ft. in low-gear and 1,710 h.p. at 3,000 r.p.m. at 15,000 ft. in high-gear. Detail construction followed previous practice in that light-alloy cylinder blocks, head and coolant jacket were employed, with "wet" cylinder liners of steel. The crankshaft was carried in seven bearings. Each cylinder had four valves, operated by overhead camshaft, and two sparking plugs; there were two independent screened magnetos. Variable-datum automatic boost-control, with two-position mixture-control, was used in conjunction with an S.U. twin-choke, downdraught carburetor and there were two vertical air intakes, coupled by a single entry. The two-speed supercharger delivered mixture to two trunk pipes, each feeding two blocks of cylinders.



Vulture.

Eagle the Second

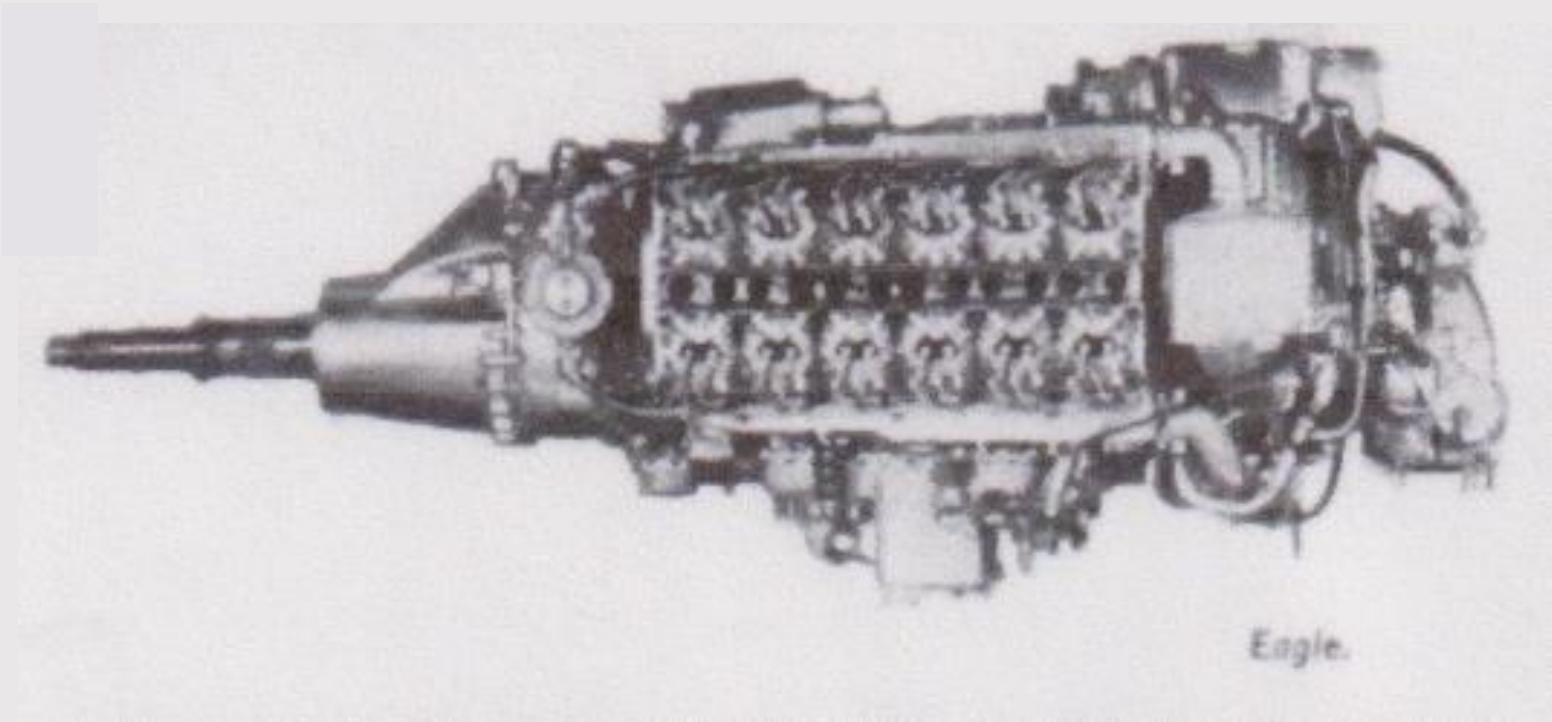
The illustrious and wholly fitting name of the first Rolls-Royce aero-engine was revived for this, the last of the great line of reciprocating, liquid-cooled units. Reviewing design factors that decided the form of this magnificent piece of engineering *FLIGHT* remarked: “The initial design project was conceived toward the end of 1942 as the necessity for a higher-powered engine was foreseen. Considerations of aspiration and flame travel set a more or less effective limit of about 6-inches to bore size and with cylinders of this order it has been established that 12 pistons-per-crankshaft is about the practical limit. Thus, a twin-crankshaft engine was necessary and the disposition of the cylinders in a flat-H followed, naturally, since far-and-away the best installation case is met by this layout.

“Sleeve valves were decided upon in view of the fact that they undoubtedly offer advantages over poppet valves from the aspect of maintenance and obviation of adjustment; and whilst no one would be so reckless as to suggest that the poppet valve has reached the ultimate peak of development, it is not far short of the summit and its limitations are very well known.”

Our description of the engine continued: “The case is split vertically into port and starboard halves of cast light alloy - and a beautiful piece of work it is - with seven bearings for each crankshaft carried in lateral webs axially stiffened by integral inter-costal bracing in each half . . .”

“The front-end of the crankcase is double-walled with approximately a 2 in cavity, the inner wall housing the No. 1 main bearings of each crankshaft and the front wall carrying the tail bearings for the timing gears uniting the crankshafts. Cylinder blocks are also very fine examples of sandcasting technique in light alloy; the upper and lower rows of cylinders on each side being formed in one casting. Each cylinder is ventilated with three inlet and two exhaust ports, the latter ports of each vertical pair of cylinders discharging to a common pair of ejector stacks. Sleeve drive is by a worm shaft on each side commonly serving top and bottom rows of sleeves, each shaft running in six split plain bearings…”

Early Eagles (I and II) drove a single airscrew, but the Eagle 22 was arranged for contraprops in view of its application to the Westland Wyvern T.F.1 deck-landing strike fighter. In M.S. gear the Eagle delivered 3,415 h.p. at 3,500 r.p.m. for take-off. The maximum power rating in M.S. gear was 3,500 h.p. at 3,250 ft, and in F.S. gear, 3,020 h.p. at 15,250 ft.



Eagle.

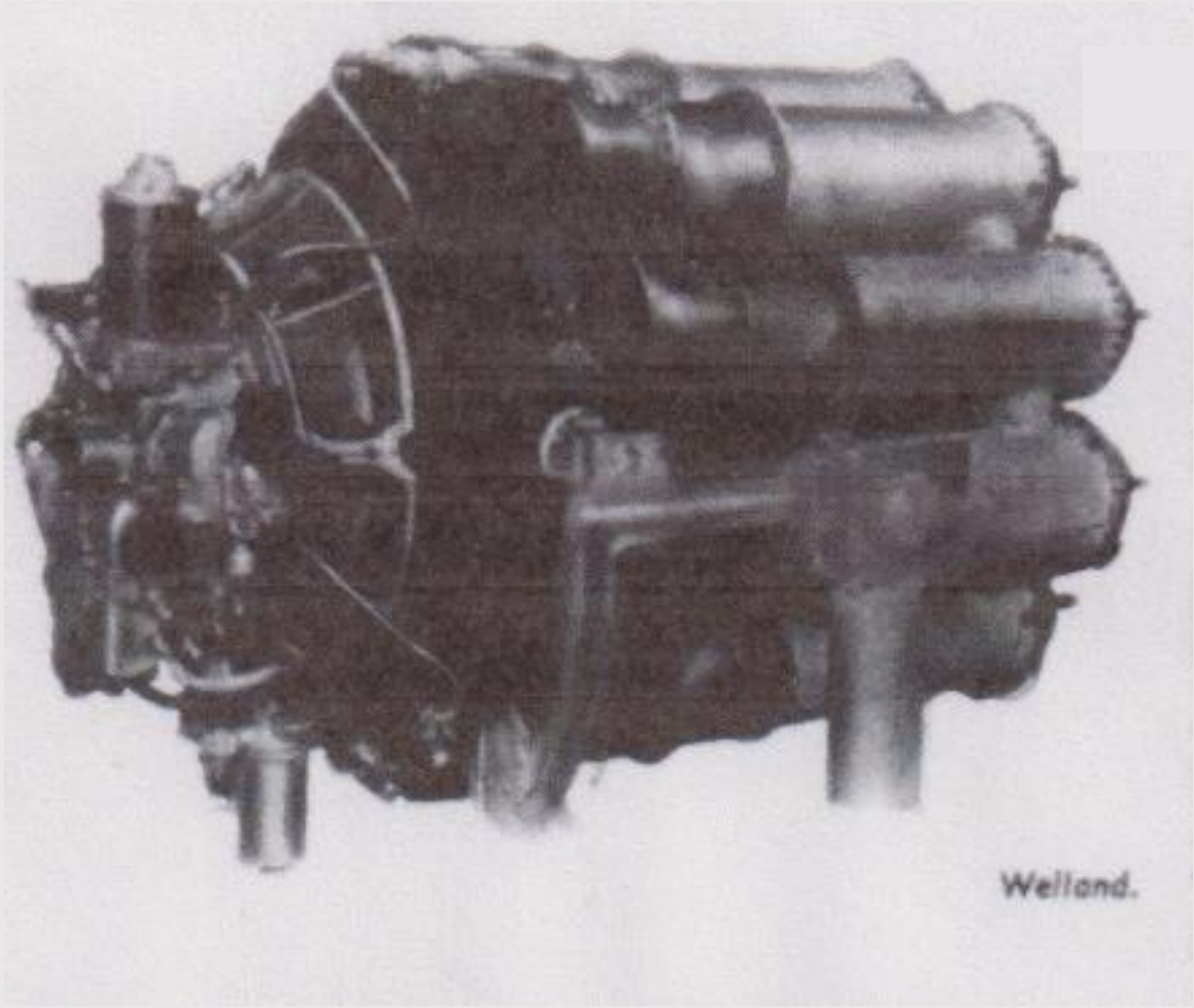
Active interest in jet propulsion was first shown by Rolls-Royce during 1938 when a department was established for the design of gas-turbines. In 1939 the first projects were put in-hand and by 1940, test rigs for components had been set-up. Towards the end of that year the company was making components for Whittle units on behalf of Power Jets, Ltd. and was undertaking the manufacture of turbine blades, casings, pumps and other components. During 1941 a special test plant was installed, with a Vulture to drive the compressors and at the end of that year, under instructions from the Ministry of Aircraft Production, the company undertook the development and manufacture of Whittle-type turbojets, in conjunction with Power Jets, Ltd. and the Rover Company.

The first Rolls-Royce turbojet, known as the WR1, measured 54 in. in diameter and was designed for a thrust of 2,000 lbs. Built primarily to demonstrate that the aircraft gas turbine could be made completely reliable, it ran for some 35 hrs. Two examples were built, but combustion trouble was experienced.

Early in 1943, Rolls-Royce took over research on the W2B/23 unit from the Rover Company whose Engineers had developed straight-through combustion; units of the type were installed in the Gloster E.28/39 experimental aircraft and in the tails of the Vickers-Armstrong Wellingtons.

The first Rolls-Royce/Whittle W2B/23 passed its 100-hr. type-test in April 1943 and was given the name *Welland* in June 1943. Two were fitted in the Gloster F.9/40 (prototype of the Meteor) and by May 1944, Wellands were being regularly delivered for R.A.F. Meteors.

The Welland had a reverse-flow combustion system, a maximum diameter of 43 in. and could develop 1,700 lbs., although for the F.9/40 it was at first derated to 1,450 lbs.


Welland.

The Derwent

While work on the Welland was in-hand, Rolls-Royce were already proceeding with a new design to utilize experience gained from their development work. The project was to be of the same maximum diameter in order that it might be installed in standard Meteor nacelles, but it was to develop 2,000 lbs. thrust. Drawings were started in April 1943 and by July the new unit was ready for test. In November of that year it passed its 100-hr. type-test at the full 2,000 lbs. rating and in April the following year it went through its first flight tests in a Meteor, with a Service rating of 1,800 lbs. and a weight of 920 lbs. It was known by its experimental designation B.37 or, in conformity with the “River” nomenclature, as the Derwent I. The Derwent II gave a thrust of 2,200 lbs. and the III was a special unit to provide suction for boundary-layer removal; the Derwent IV was rated at 2,400 lbs. thrust. The Derwent 5 was an entirely new engine - still of 43 in. diameter, but developing twice the thrust of the original Derwent I. It was, in effect, a scaled-down version of the Nene and its development was motivated by the promise shown by the Nene and the knowledge that the Meteor could utilize thrust greatly in excess of the original estimates.

The Derwent 5 was superseded by the Derwent 8 and 9. The 8 incorporated two outlets to feed compressor-air through piping to heater muffs on the exhaust unit; tappings were taken from these muffs to heat the cabin and the guns and/or camera.

The 9 used the same method of heating, but had in addition larger combustion chamber-inter-connectors and high-energy ignition to give more consistent re-lighting in flight as well as to increase the altitude at which re-lighting was possible.

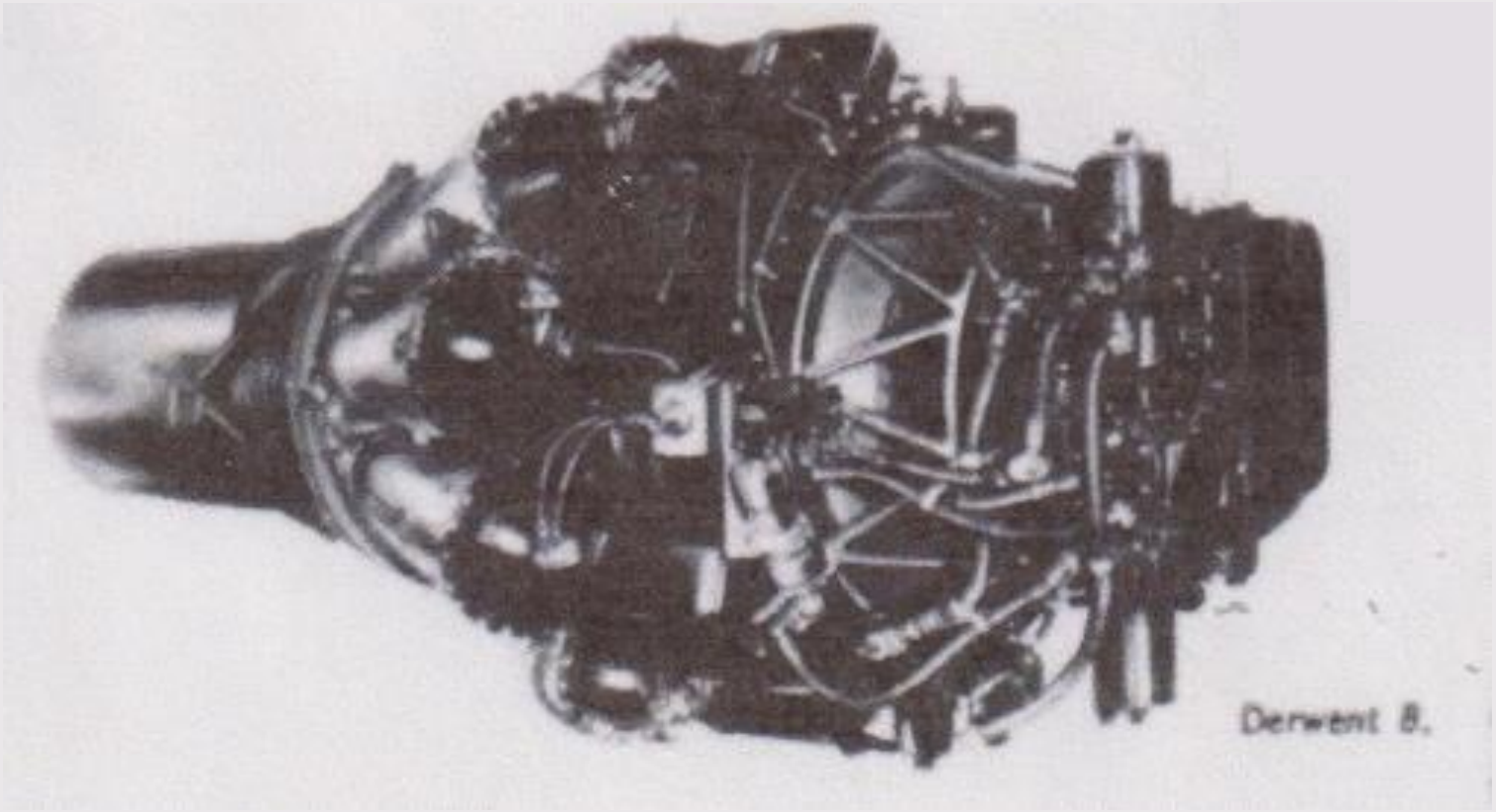
The body of a Derwent is built-up on the compressor rear casing which, though immensely strong, is very light and is considered by Rolls-Royce to be a fine example of their foundry technique. On the front face are the diffuser ring, the front casing and front air intake and the wheelcase. To the rear the main structure comprises the rear air intake, the cooling-air casing and the centre and rear bearing-housings, which successively lead to the combustion chambers and distributes it to the annulus of stationary nozzle-guide vanes; it also carries the auxiliary cooling air-ducts leading from the region of the turbine disc and rear-bearing housing.

Centrally runs the main rotating assembly and disposed round the engine, between the compressor casing outlet elbows and the nozzle-box, are the nine combustion chambers. So carefully balanced is the rotating assembly that as much as a minute-and-a-half elapses before it comes to rest after the engine is shut-down.

At maximum static thrust the characteristic double-sided impeller deals with 62 lbs. of air-per-second, with an efficiency of 81 per cent and a compression ratio of 4:1. For this task it needs about 8,000 h.p., which is transmitted from the turbine through the coupling. The impeller is 24 in. in diameter and has 29 vanes on each side. Guide vanes convert axial to radial flow.

Maximum thrust of the Derwent 8 is 3,600 lbs. at 14,700 r.p.m. and the specific fuel consumption is 1.01 lbs./hr./lb.

Experimental Derwents included the RD.9, which had a 15 per cent increase in mass flow and the RD.10 - a scaled-up version utilizing the rotating parts of the Nene. The RD.11 was another scaled-up development.


Derwent 8.

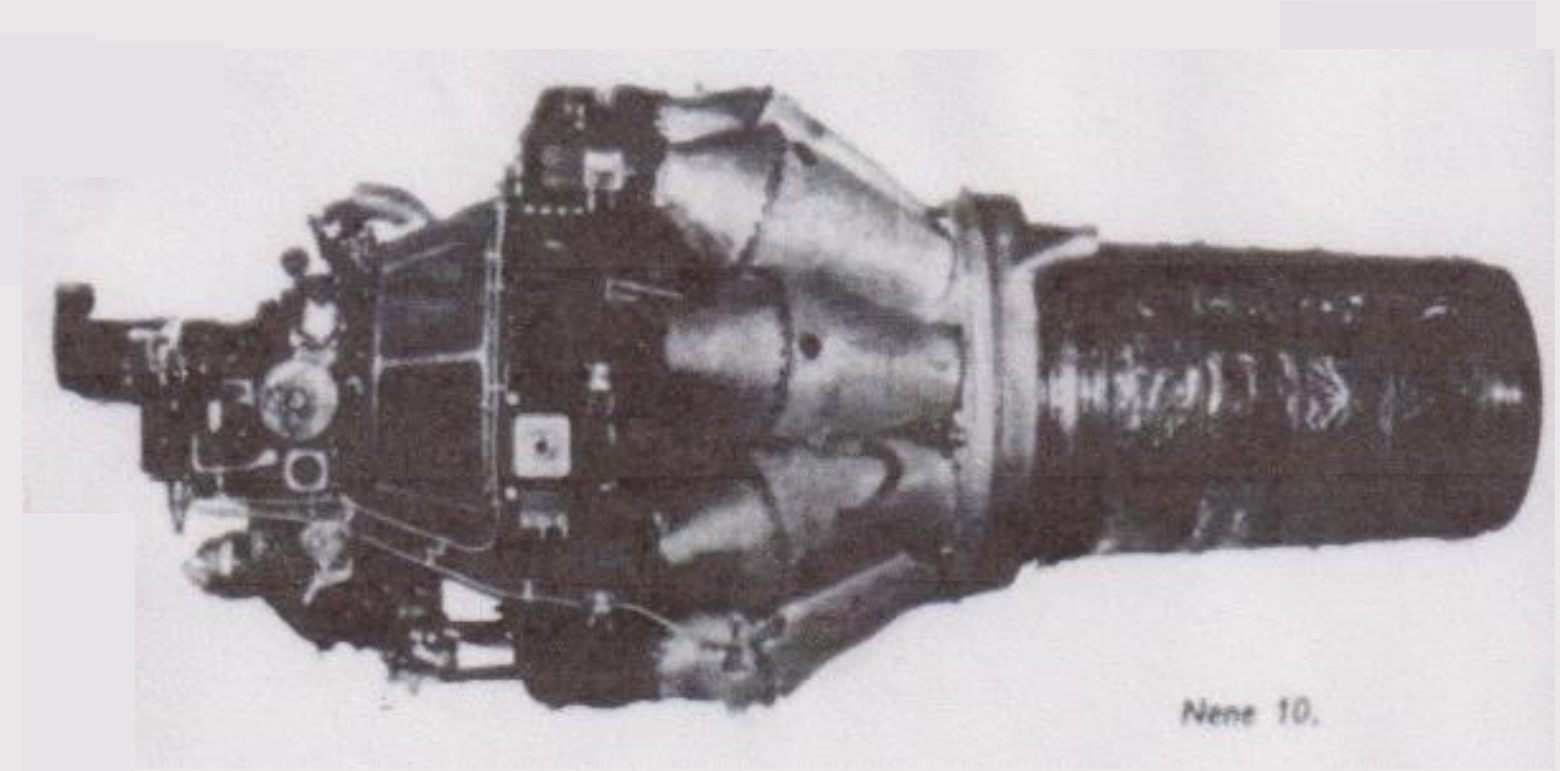
The Nene

Designed to a Ministry of Aircraft Production specification of 1944 calling for a turbojet having a maximum diameter of 55 in., a minimum static thrust of 4,000 lbs. and a weight not exceeding 2,200 lbs., the Nene, as has already been explained, is the “big brother” of the later Derwents. Consideration was given in the early project stage to the scaling-up of a Derwent to meet the specification, but as this would have entailed increasing the diameter to nearly 60 in., a new design was put in-hand and was completed in 5-1/2 months. In this the diameter was kept down to 4-1/2 in. and a thrust of 5,000 lbs. was attained.

The design of the nine combustion chambers follows Derwent practice. Each consists of a cast expansion chamber attached to an outer air-casing containing a flame tube. About 15 per cent of the air entering each chamber is directed by perforated baffles and swirl-vanes in the flame tube into the combustion zone around the burner head. In this zone, where the air is turbulent and moving slowly, the primary air-flow, together with a small reverse flow round the flame tube, mixes with the fuel sprayed from the burners and burns at a flame temperature 1,600-2,000 deg. C. To prevent distortion of the flame tube due to local overheating caused by impinging on the walls, a thin layer of air is admitted round the inside periphery of the tube through a circular “window piece.”

The remaining air flows between the flame tube and air casing and communicates with the combustion zone through rows of holes in the flame tube. This diluting air is consequently expanded and accelerated rearwards, but it also cools the products of combustion to the temperature required at the turbine inlet.

Current marks of Nene include the 3, with electric starter motor and two torch-igniter units (this powers the Supermarine Attacker F.1); the Mk.10, which is similar to the Mk.102 later mentioned but has a larger wheelcase of accessories (this is the engine of the Canadair Silver Star); the Mk.101, specially adapted for the Sea Hawk and having a horizontal gear-box drive, Piessey turbo-starter and divided jet-pipe; and the 102, which is interchangeable with the III but has various design changes including two high-energy igniters. This last powers the Supermarine Attacker F.B.2. Nenes have also been installed in the Gloster E.1/44, an experimental Lockheed Shooting Star and the Dassault Ouragan.

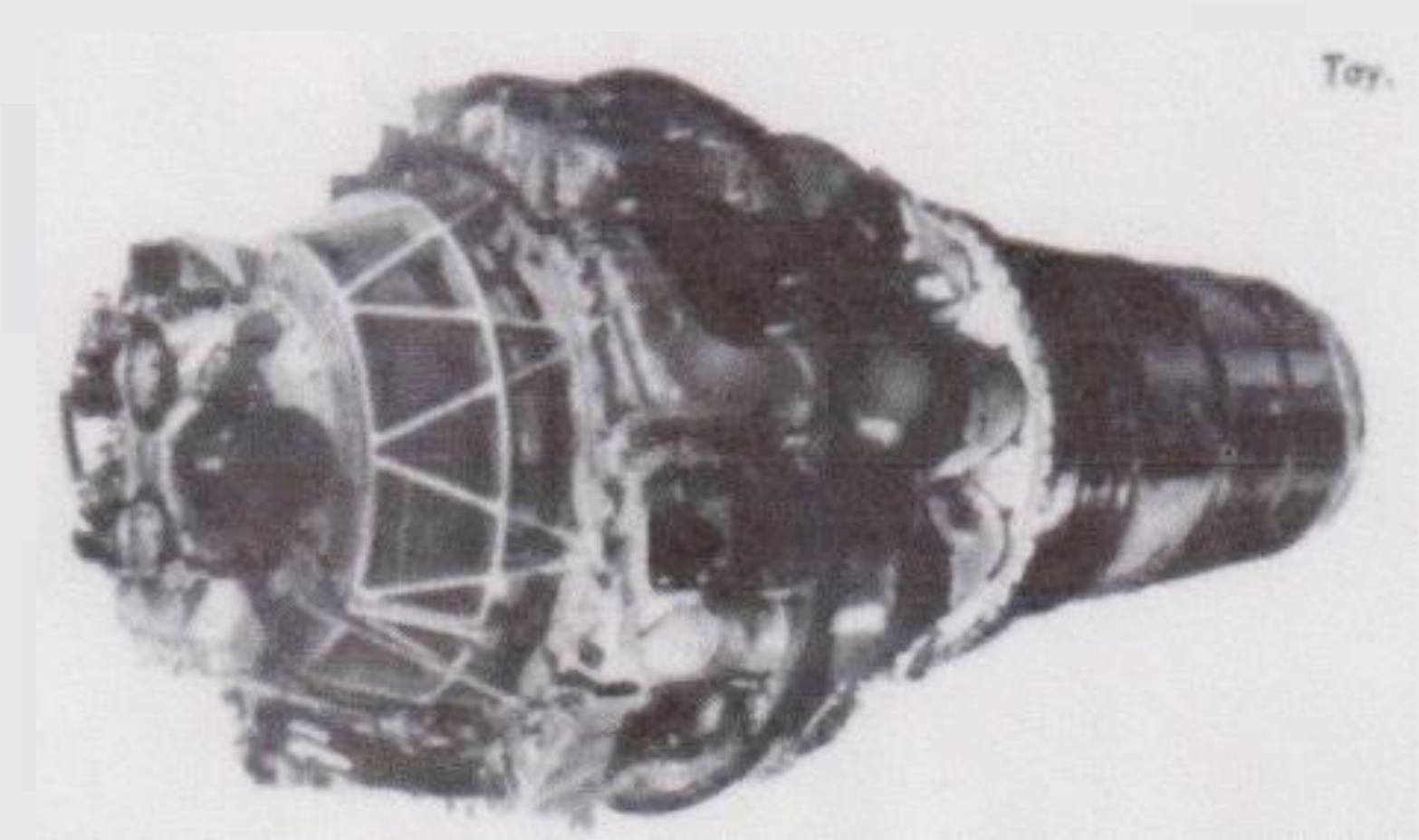


Nene 10.

The Tay

Little known in England (though two units of the were test-flown in a special Vickers Viscount), the Tay was developed in the first instance by Rolls-Royce from the basic Nene design. It has been further improved by the Pratt and Whitney and Hispano-Suiza concerns which, respectively, hold the American and French licenses. In America the engine is known as the J48 and its applications include the Lockheed F-94C Starfire, Grumman F9F-5 Panther and F9F-6 Cougar. Ratings of 6,250-7,000 Ibs. have been recorded without water injection, a power-boost system which increases thrust by about 1,000 Ibs.

Hispano-Suiza Tays have been installed in Dassault Mystére II, III and IV fighter and the production Tay 250 is for the Mystére IVA. A development of the Tay by the French company is called the Verdon (following the “River” nomenclature) and has a modified compressor with new guide-vanes, revised flame-tubes and combustion chambers and new turbine-blades and disc. A special afterburner has been developed for this engine which is to replace the Tay in the Mystére IVA (afterburning experiments with both the Derwent and Nene were made some years ago by the Rolls-Royce Company).


Tor.

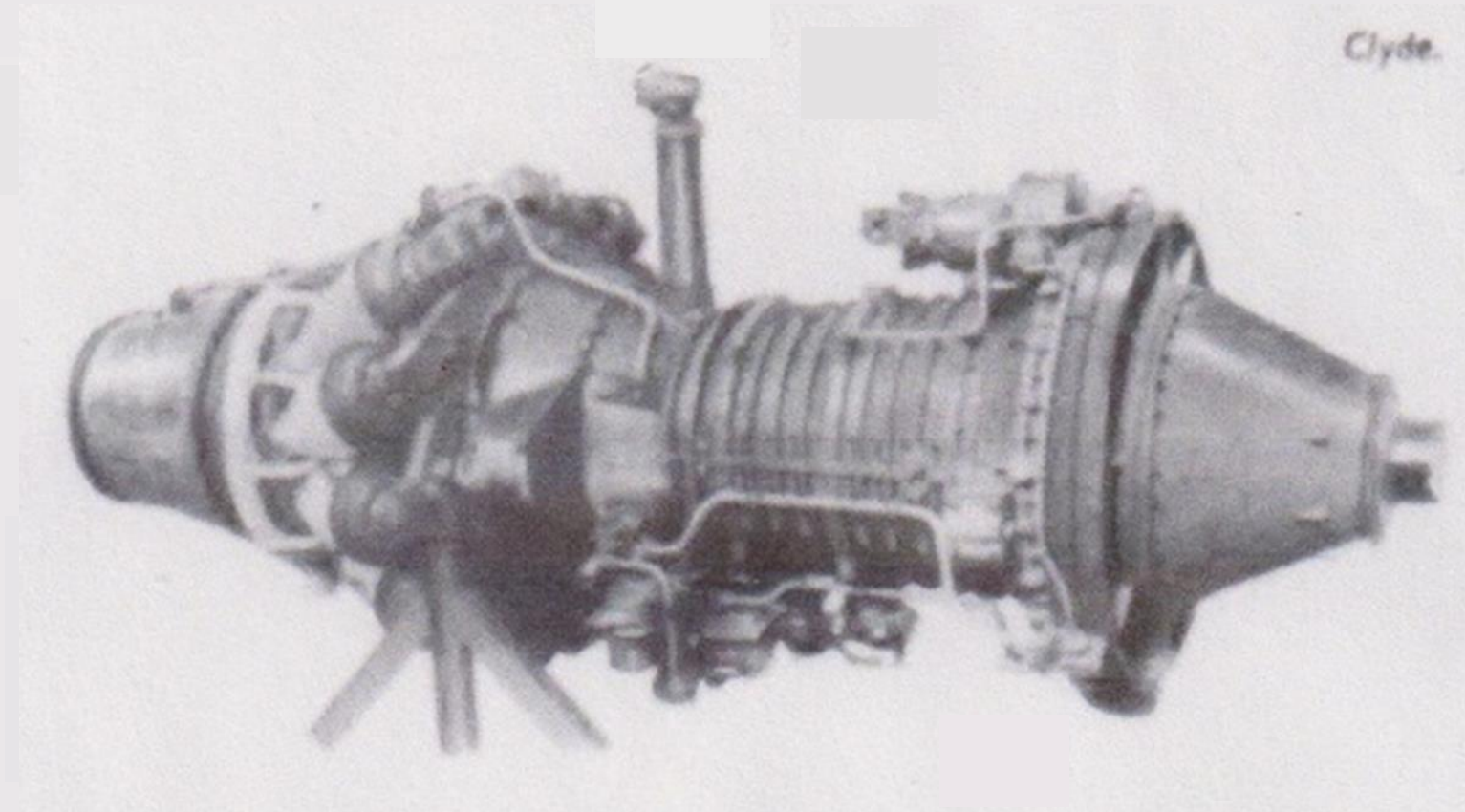
The Trent

This was Britain’s first turboprop and the first turboprop in the world to fly. It was on test as early as March 1945 and in September of the same year, two units were installed in a Meteor. Experimental work with the Trent (RB.50) actually dated back to May 1944, when a Welland was equipped with a spur-type reduction gear and tested for shaft-horsepower. The Trent was built solely to gain experience with a unit combining jet and airscrew propulsion and was merely an early Derwent with reduction gearing and a small-diameter, five-bladed airscrew.


Trent.

The Clyde

The RB.39 Clyde was a large designed before the end of the late war. It was remarkable in having a nine-stage axial compressor and a six-stage centrifugal compressor, in addition to two turbines. The forward (high-pressure) turbine drove the centrifugal blower and the rear (low-pressure) turbine the axial compressor and contra-rotating airscrews. The Clyde was the first turboprop to pass its full civil and military type-tests. Its first tests were run at 2,500 s.h.p. and this was later increased to 3,020 s.h.p. Subsequent ratings were 3,500 s.h.p., 4,200 s.h.p. and 4,500 s.h.p.; these last proved that the reduction gear was capable of standing greatly increased overloads. The Clyde was flown only in the Westland Wyvern strike fighter.


Clyde.

The Avon

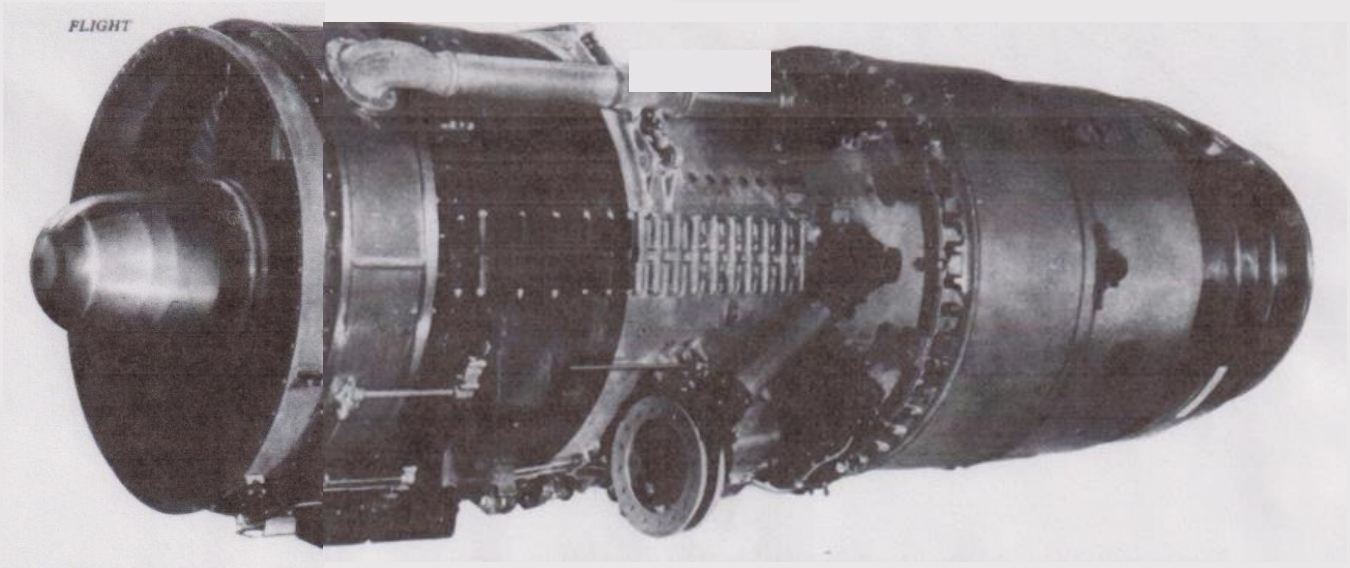
The Avon is, in effect, the modern Merlin and, like the Merlin, it had its early troubles; but it is now firmly established as one of the most reliable aero-engines of all-time.

Originally designated AJ65 (signifying an axial unit of 6,500 lbs. thrust), it went into production during 1950 for the English Electric Canberra bomber. For the historical record, the prototype RA.2 weighed 2,400 lbs. and gave 6,000 Ibs. thrust, while the production RA.3 was 125 lbs. lighter. The second basic type to be built in series was the RA.7, which, in 1952, became the progenitor of a 7,500-lb. thrust family of Avons. The first of the series with all-weather protection, the RA.7 had a power/weight ratio even better than that of the original production engines, notwithstanding the fact that it had been restressed to accept the loads imposed at transonic speeds. The RA.7R (the suffix “R” denotes that reheat, or afterburning, is fitted) delivers 9,500 lbs. static thrust at sea-level, and an offshoot of the same family is the civil 500 series, the 503 being the engine of the Comet 2.

The latest series of Avons is headed by the RA.14, which first ran in 1952. These newest Avons are considerably redesigned and, although no detailed description is permissible, it can be seen that RA.14 has a longer compressor than its forerunners, and that it also has a true annular combustion chamber - the latter, no doubt, in order to accept the tremendous mass flow without increasing “hoop” diameter.

The R.A.14 appears to be intended for installation in the wing (it is known that it powers the Vickers-Armstrong Valiant B.1) and every effort has been made to reduce depth to a minimum. A civil counterpart is the R.A.16 of 9,000 lbs. thrust, which was originally in to power Comet 3, though that aircraft is now intended to have a much later variant giving 10,000 Ibs. thrust.

Development flying was undertaken in an adapted Lancaster and a Meteor and Avons are now flying in the D.H.110, Hawker Hunter, Supermarine Swift, Supermarine 508/529, Saab Lansen, Dassaul Mystere IVB, English Electric Canberra, Short S.A.4, Vickers-Armstrong Valiant and de Havilland Comet 2.


FLIGHT

The Dart

This compact turboprop is quite unique, not only in its technical make-up, which we shall describe, but in being, at the time of writing, the only turboprop in regular service in the world. Although it has achieved renown as the power unit of the Vickers Viscount, it has also been flown on a limited scale in the Avro Athena and Boulton Paul Balliol advanced trainers.

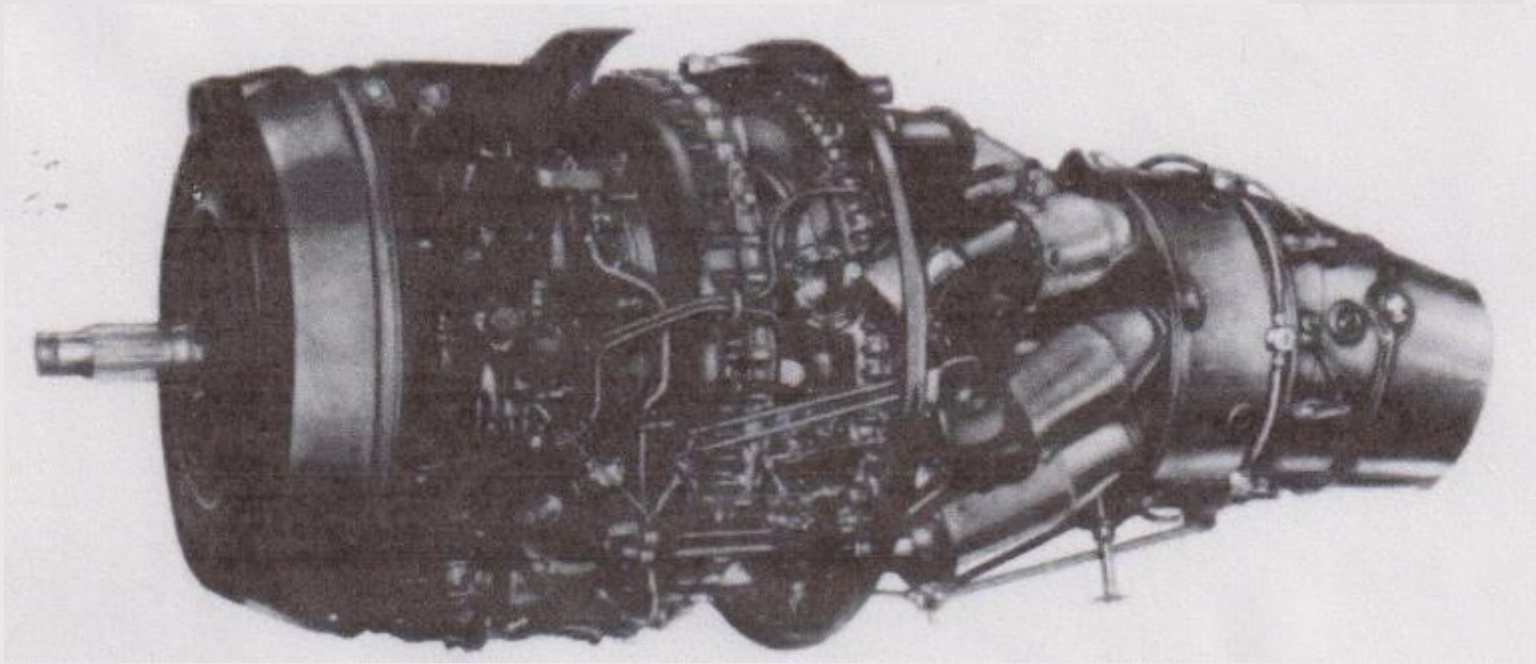
The Dart is characterized by a two-stage centrifugal compressor, handling ab-out 20 !bs of air-per-second, and a two-stage turbine. Steel guide vanes dir-ect the air between the 19 rotor blades from which it is impelled at high-speed. After passing through a diffuser the flow is directed through curved passages formed by the compressor casings and inter-stage guide vanes, into the second rotor.

The two stages of the turbine are locked together on a common shaft and the blades of the high and low-pressure stages have “fir tree” roots. Both discs are cooled on their front and rear faces and a steel-strip seal prevents gas leakage between the stages. There are seven combustion chambers.

Under tropical conditions lost take-off power is restored by water/met-hano! injection.

Now coming into production for Viscounts is the Dart RDa.6, which has a new reduction gear and other refinements, making possible a maximum rating of 1,500 h.p. Another new engine is the Rda.5 – almost completely new and designed for even greater powers. It is scheduled to power the Viscount 800 Series.

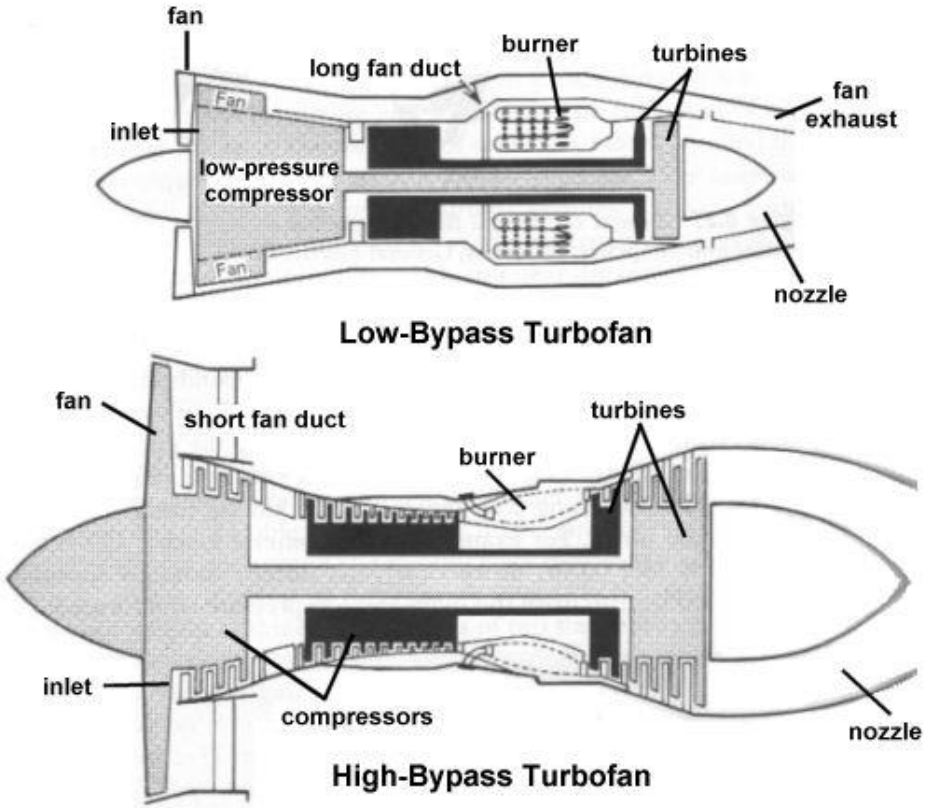
The following data apply to the Dart 505: diameter, 37.9 in.; length, 95.1 in.; dry weight. 1.030 lbs.; max. power, 1,400 s.h.p. plus 365 lbs. thrust; equivalent shaft horsepower, 1,515 at 14,500 r.p.m.; specific fuel consumption, 0.83 lbs./hr./c.s.h.p.



The Conway

Though it may be said that this is an engine of the “bypass” type, no illustrations or technical details may be published. In a bypass engine the excess air from an oversize low-pressure axial compressor is passed around the combustion chambers, so that a far greater mass flow results and at a lower mean velocity than in a simple turbojet burning fuel at the same rate.

A variation on the *turbojet* is the *turbofan*. Although most components remain the same, the turbofan introduces a fan section in front of the compressors. The fan, another rotating series of blades, is also driven by the turbine, but its primary purpose is to force a large volume of air through outer ducts that go around the engine core. Although this "bypassed" air-flow travels at much lower speeds, the large mass of air that is accelerated by the fan produces a significant thrust (in addition to that created by the turbojet core) without burning any additional fuel. Thus, the turbofan is much more fuel efficient than the turbojet. In addition, the low-speed air helps to cushion the noise of the jet core making the engine much quieter.



Turbofans are typically broken into one of two categories; *low-bypass ratio* and *high-bypass ratio,* as illustrated above. The *bypass ratio* refers to the ratio of incoming air that passes through the fan ducts compared to the incoming air passing through the jet core. In a *low-bypass turbofan* only a small amount of air passes through the fan ducts and the fan is of very small diameter. The fan in a *high-bypass turbofan* is much larger to force a large volume of air through the ducts. The low-bypass turbofan is more compact, but the high-bypass turbofan can produce much greater thrust, is more fuel efficient and is much quieter.

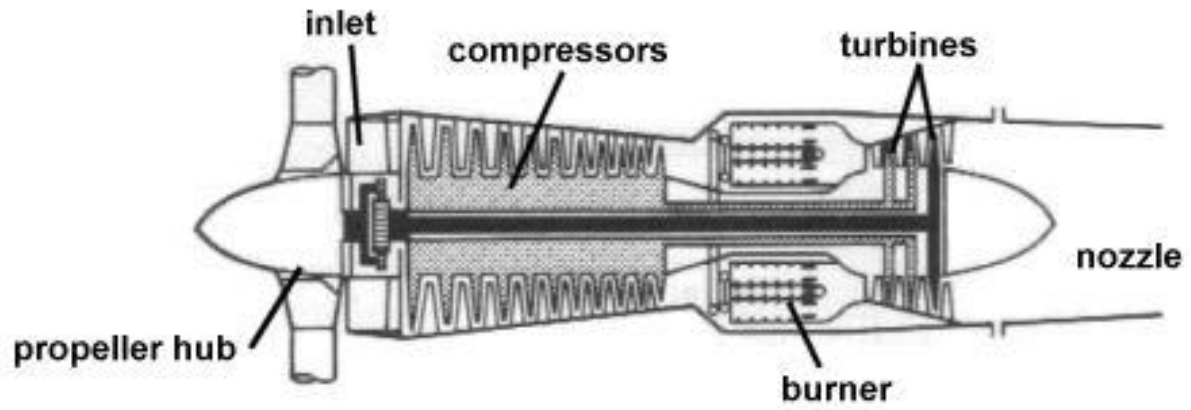


1165

JT3D (J57) low bypass, turbofan engines on a Boeing 707



High-bypass R-R turbofan engine



Turboprop

A concept similar to the turbofan is the *turboprop* (above). However, instead of the turbine driving a ducted fan, it drives a completely external propeller. Turboprops are commonly used on commuter aircraft and long-range planes that require great endurance (i.e., P-3 Orion). The turboprop is attractive in these applications because of its high fuel efficiency; even greater than the turbofan. However, the noise and vibration produced by the propeller is a significant drawback and the turboprop is limited to subsonic flight only. In a typical turbo-prop, the jet core produces about 15% of the thrust while the propeller generates the remaining 85%.



P-3 Orion

Unnamed Turboprop

Another new and semi-secret Rolls-Royce development is an extremely compact turboprop intended for civil use. Under development as a private venture, it will initially have a rating of about 2,500 s.h.p., but far greater powers should be forthcoming.

Production

Between 1915 and 1924 Rolls-Royce aero-engine Eagle, 4,674; Hawk, 200; Falcon, 2,185; Condor, 327.

The total production of Kestrel engines was 4,750, of Buzzards 100, and of “R” engines, 20.

More than 150,000 Merlins were built in Great Britain and the U.S.A. by the end of the war and Griffon production to date is over 6,000.

Frontal Area

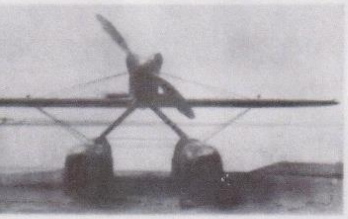


Bristol Fighter F.2B (Falcon III)



Vickers Vimy (two Eagle VIII)

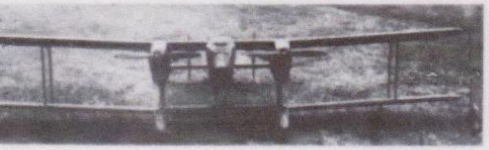
Without exception, the Rolls-Royce aero-engines have been notable for their small head resistance and their amenability to clean installation, though both these considerations – as this unique collection of head-on views emphasizes – are of a relative nature. Comparing, for instance the views of the Vimy of 1918 and the Valiant of today, one sees in the former two massive power-eggs housing a total of 750 h.p. while in the latter the presence of the equivalent of, perhaps, 70,000 h.p. is proclaimed only by the air-intakes and slight bulges in the wing surfaces. Likewise edifying are the views of the Supermarine S.6B racer and the Spitfire fighter. Not shown are modern single-jet fighters such as the Hawker Hunter and Supermarine Swift, wherein the Avon turbojet is completely submerged in the fuselage.



Supermarine S.6B ("R" engine).



Hawker Hart (Kestrel IB).



Handley Page Heyford (two Kestrel IIIS).



Supermarine Spitfire prototype (Merlin C).



Avro Lancaster prototype (four Merlin X).



Fairey Firefly I (Griffon XII).

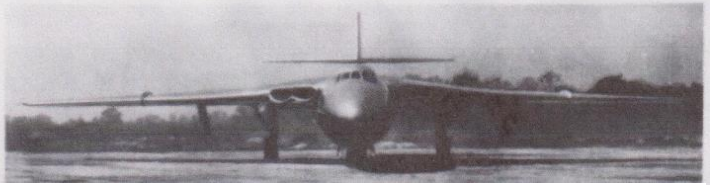


de Havilland Hornet F.1 (Merlins 130/131).



English Electric Canberra B.1 (two Avon).

Vickers-Armstrongs Valiant B.1 (four Avon RA.14).



Chronology of Rolls-Royce Aero-Engine Development

1914 Design of first Rolls-Royce aero engine—later named Eagle—started. Company making engines of official pattern at Derby.

1915 Eagle on test six months after design initiated. Hawk designed and developed. Falcon designed.

1918 Condor on test at 525 h.p.

1919 Alcock and Brown, in a Vickers Vimy (two Rolls-Royce Eagle VIIIs), made first direct crossing of North Atlantic: flying time, 16 hr 12 min. Ross Smith and Keith Smith, in an Eagle-Vimy, made first flight from England to Australia—11,130 miles in 124 hr flying time.

1920 Van Ryneveld and Quintin Brand, also in an Eagle-Vimy, made first flight from England to South Africa—6,281 miles in 92 hr 58 min flying time.

1925 Design of Rolls-Royce "F" series of engines (later called Kestrel) started.

1926 First "F" engine tested and delivered.

1927 The "H" engine—later the Buzzard—under development.

1929 Air Ministry decided in February to compete in Schneider Trophy Contest; Rolls-Royce asked to develop a racing engine. Within six months "R" engine was delivering 1,900 h.p. for a weight of 1,350 lb. Installed in Supermarine S.6, which won Schneider Contest at 328.63 m.p.h.

1931 Rolls-Royce again asked to develop a Schneider Trophy engine to help secure a third victory, which would gain Trophy outright for Gt. Britain. Outcome was improved "R" engine of 2,360 h.p., weighing 1,630 lb. Schneider Trophy won outright. Later "R" engine gave 2,530 h.p. and enabled world speed record to be raised to 407.5 m.p.h.

1932 Design of the P.V.12 engine (later called Merlin) started. (P.V. denoted private venture.)

1934 Merlin completed its first 100 hr run at 790 h.p.

1936 Merlin completed Service Type Test at 975 h.p.

1938 Building of Crewe factory started.

1939 First Merlin built at Crewe. Design and development work started on 37.V.12 engine, later named Griffon. Building of Glasgow factory begun in August.

1940 First Merlin built at Glasgow. First test run of Griffon.

1942 Quantity production of Griffon started.

1943 First Rolls-Royce turbojet—the Welland—passed its 100 hr type test: thrust, 1,700 lb, weight, 850 lb. Design of Derwent I started.

1944 Deliveries of Welland begun, for installation in Gloster Meteor. Design and development of Nene started.

1945 Meteor powered with Derwent Vs broke world air speed record at 606 m.p.h. In September a Meteor was flown with two Rolls-Royce Trent turboprops, being the first turboprop aircraft to fly. By this year power of Merlin had increased to over 2,000 h.p.

1946 World air speed record again broken by a Derwent-Meteor; speed 616 m.p.h.

1947 Pratt and Whitney signed licence agreement for manufacture of Rolls-Royce Nene and Tay. Nenes in production at Derby. Trans-Canada Airlines started operations with Merlin-powered Canadair North Stars.

1948 First public appearance of Avon turbojet at S.B.A.C. Display. Belgium signed licence agreement for manufacture of Derwents.

1949 Dart turboprop type-tested at 1,000 h.p. B.O.A.C. introduced Merlin-powered Argonauts (similar to North Stars).

1950 Australia signed licence agreement to build Nene and Avon. Hispano signed agreement to make Nene and Tay.

1951 English Electric Canberra, with two Rolls-Royce Avons, made first non-stop transatlantic crossing by a jet aircraft—the first of numerous record flights by Avon-Canberras.

1952 Sweden signed licence agreement to build Avon.

1953 Avon-Canberra flew from London Airport to Darwin, Northern Australia, in 22 hr 21 sec. Avon-powered Hawker Hunter established world air speed record of 726.6 m.p.h.; Avon-powered Supermarine Swift later raised record to 735.7 m.p.h. Ministry of Supply opened new factory at East Kilbride, Lanarkshire, to augment production of Avons for the R.A.F. (In addition, Avons were being made by the Bristol Aeroplane Co., Ltd., D. Napier and Son, Ltd., and the Standard Motor Company.)

1954 By May of this year British-built Rolls-Royce gas turbines had completed 2½ million flying hours; Merlins had completed over 5½ million flying hours in commercial service. By the end of the year over 185,000 Rolls-Royce piston and gas-turbine engines will have been built.

Part 8

Trends

Show of Excellence

Important Advances in All Types of Units at the Paris Salon: Britain's Usual Show of Excellence

***FLIGHT,* December 8, 1938**

RE: introduction to an article entitled: "Some Trends in Engine Design"

The Real Value

"THE real value of 'trends' which are often assumed to be indicated by exhibits in the Paris Salon is frequently questionable. Particularly is this true of the aero-engines..."

***FLIGHT,* December 8, 1938**

Putting on a Show

"…So many initially promising prototype powerplants appear in modified form year-after-year on the stands of their manufacturers, but never in actual aircraft and the number which achieve widespread adoption is very small, even compared with the number of prototype aircraft which find their way into general use…"

***FLIGHT,* December 8, 1938**

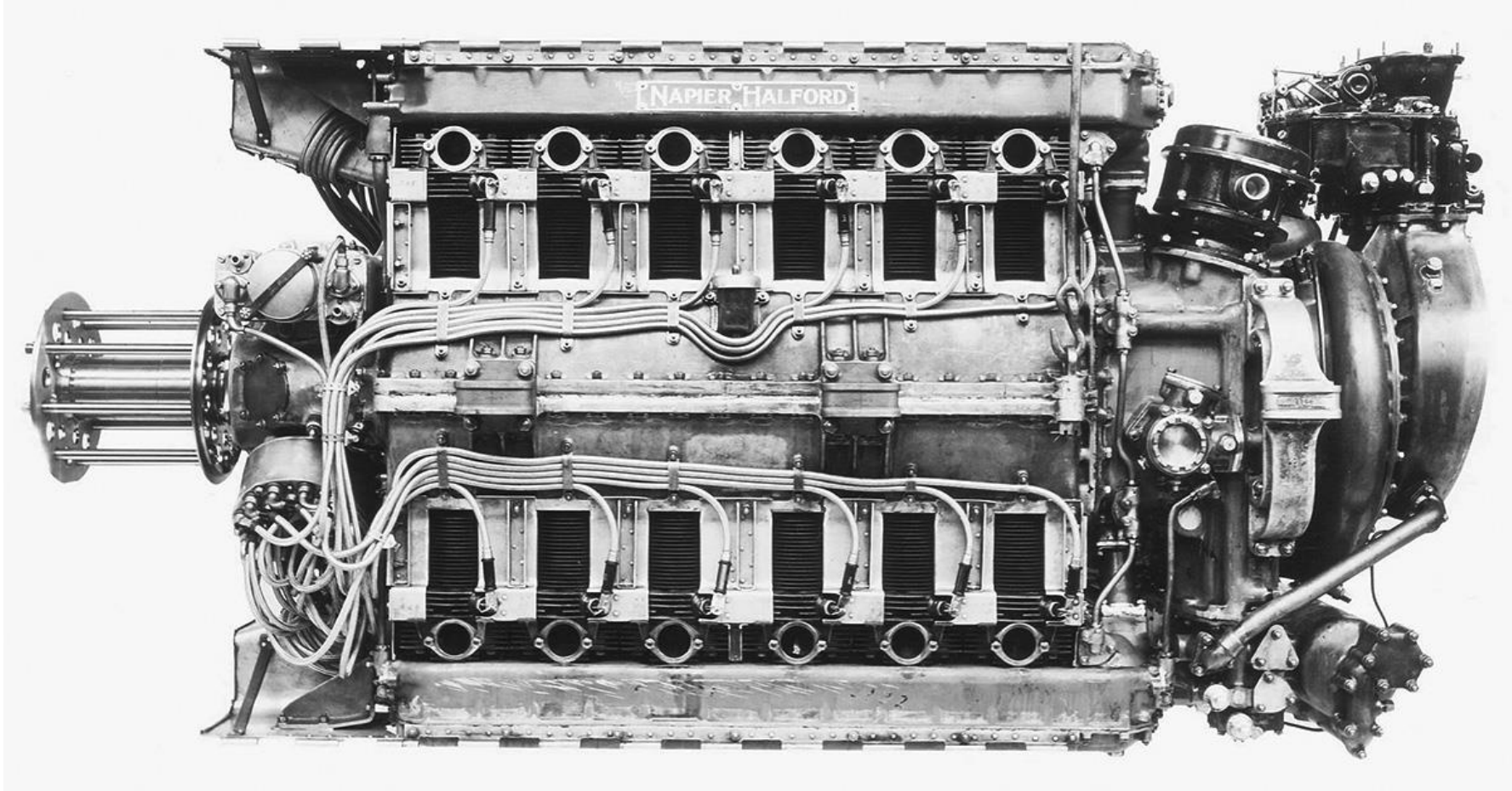
"…Nevertheless, we can ill afford to ignore any new unit, however unorthodox it may seem in comparison with established types, for engine development still runs in very diverse channels and a seemingly fantastic novelty may have a definite effect on future design…"

***FLIGHT,* December 8, 1938**

"…By way of example, the Napier-Halford Dagger with its twenty-four tiny cylinders in H formation and its high operational speed would have occasioned a good deal of cynicism when it was shown for the first time (even with the name of Napier behind it) had it not been developed to an advanced stage of refinement and reliability and subjected to official testing before being publicly announced…"

***FLIGHT,* December 8, 1938**

RE: in 1928, independent aircraft engine designer *Frank Bernard Halford* was contracted by D. Napier & Son to design aircraft engines with a displacement between 404.09 and 718.37 cu. in. Halford's first designs for Napier were the H-16 Rapier (Napier designation E93) of 1929 followed by the inverted I-6 Javelin (Napier designation E97) of 1931. Around 1932, Halford and Napier reached a new agreement and the design of engines larger than the 718.37 cu. in. limit were initiated. The first of these designs was a 24-cylinder development of the Rapier with an enlarged bore and elongated stroke. This engine was named the "Dagger" and carried the Napier designation "E98." The engine was also called the "Napier-Halford Dagger."



Like the Rapier, the air-cooled Dagger was a high-revving aero-engine with numerous small cylinders and minimal frontal area. Halford's belief was that a smaller engine running at higher speeds would produce the same power as a larger engine running at slower speeds.

<u>Caption</u>: "The Napier Dagger I air-cooled H-24 with its downdraft carburetor and propeller shaft in line with the engine's centerline. 'Napier Halford' can be seen on the upper camshaft housing. Note the two engine mounts on the side of the crankcase and third mount on the accessory housing."

Fresh Possibilities

"…This year, the only startling departure from conventional design among the bigger units is the 2,000-hp Hispano Suiza, though there are many units (notably British) which, although developed directly from types which have appeared before, are virtually new designs in that they open up fresh possibilities in aircraft development…"

***FLIGHT,* December 8, 1938**

"…The best examples this year are those engines equipped with two- or three-speed superchargers or developed for operation on 100-octane fuel…"

***FLIGHT,* December 8, 1938**

Holding its Own

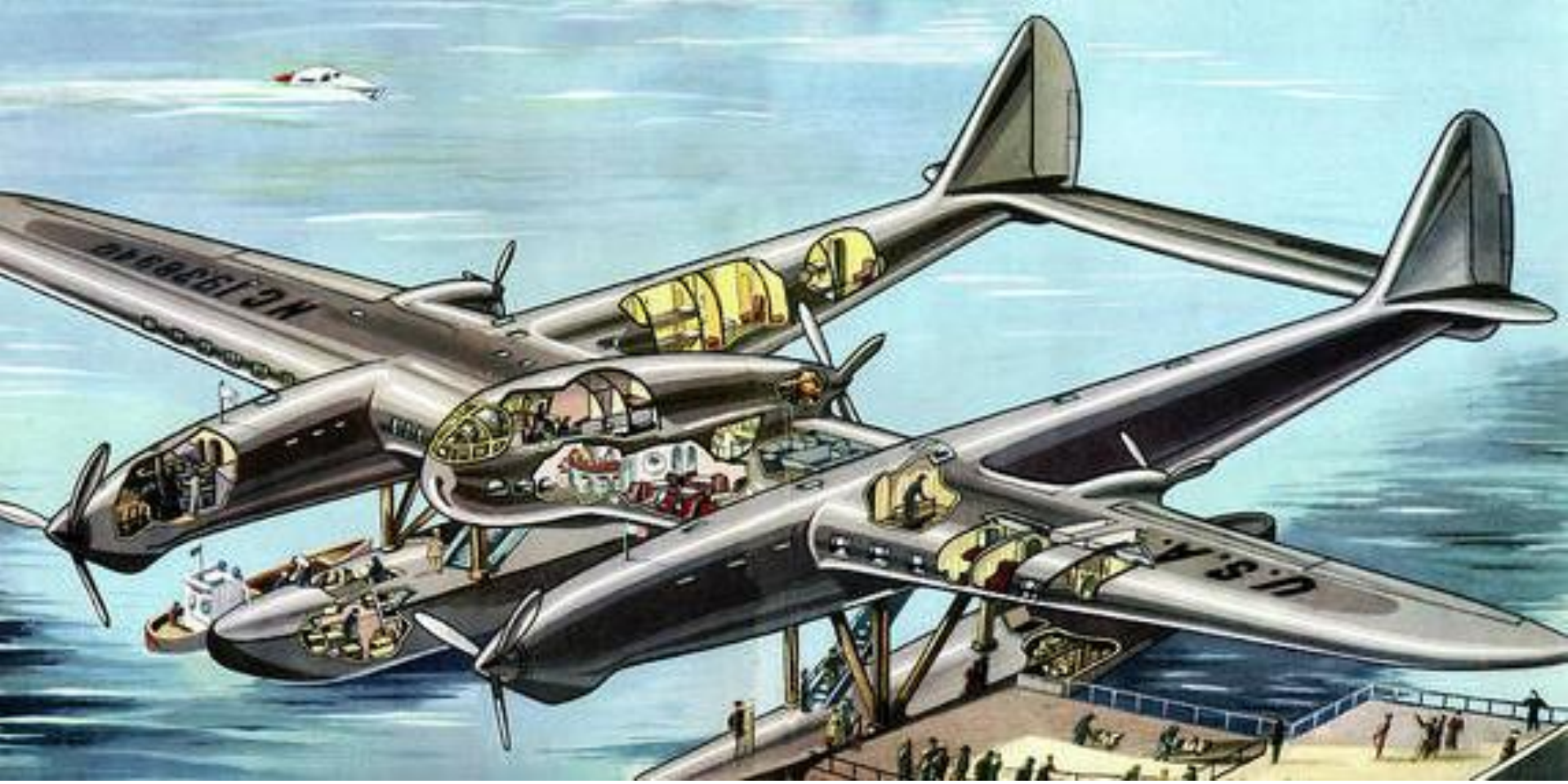
"…Despite the ingenuity displayed in the development of air-cooled units from the little four-in-line to the multi-bank types, the liquid-cooled camp is not only holding its own but making-up much of the leeway it has lost in certain directions during post-war years…"

***FLIGHT,* December 8, 1938**

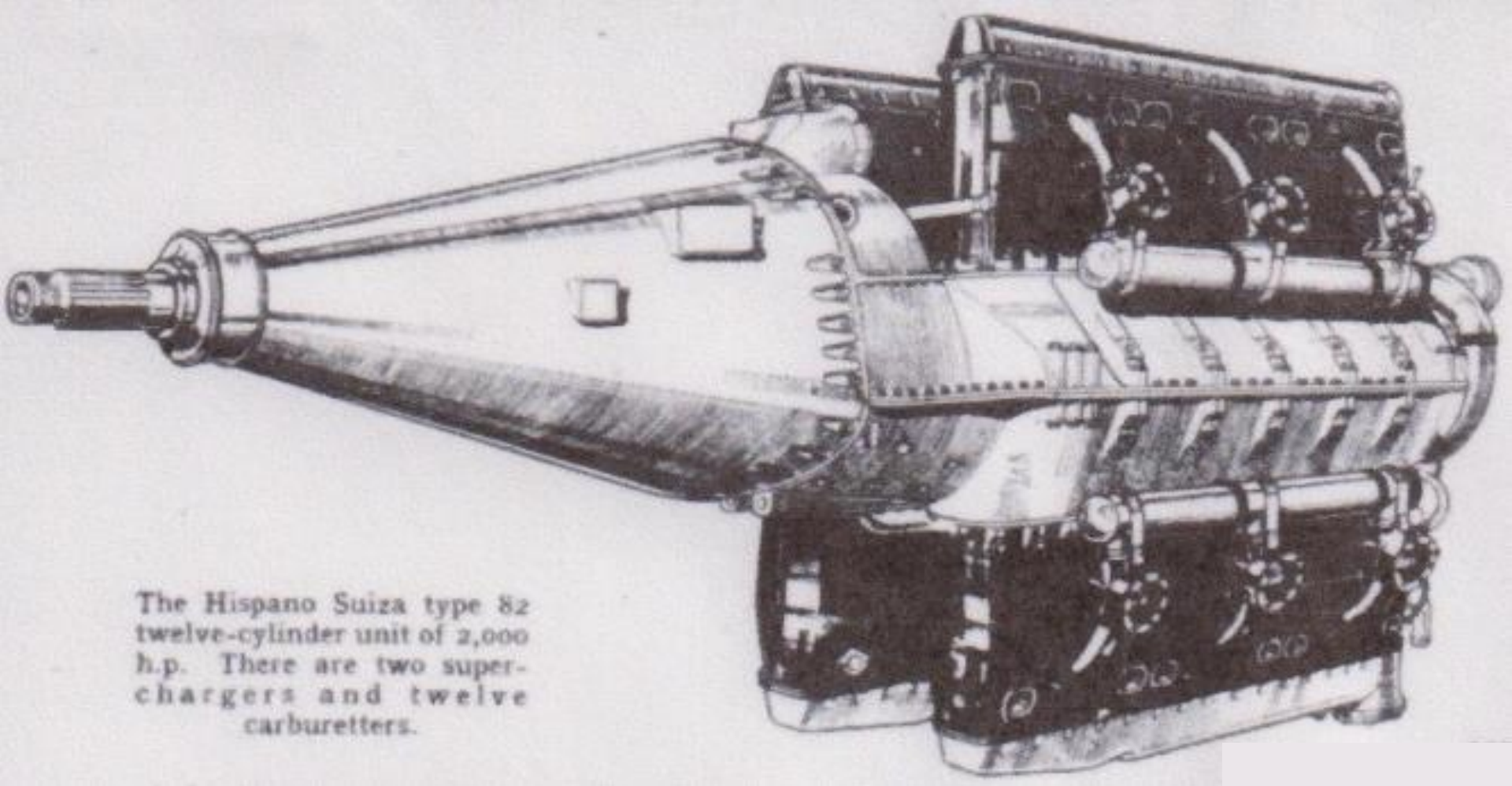
Commanding Attention

"…With the increase in size of commercial machines, the liquid-cooled, built-in engine is commanding attention, as witness the specifying of the 2,000-hp Allison Xs for the projected Seversky transatlantic seaplane and the development of the new Hispano for France's new commercial giants. The installation of four of these Hispanos is being suggested instead of fitting six lower-powered units. This would, of course, simplify maintenance problems…"

***FLIGHT,* December 8, 1938**



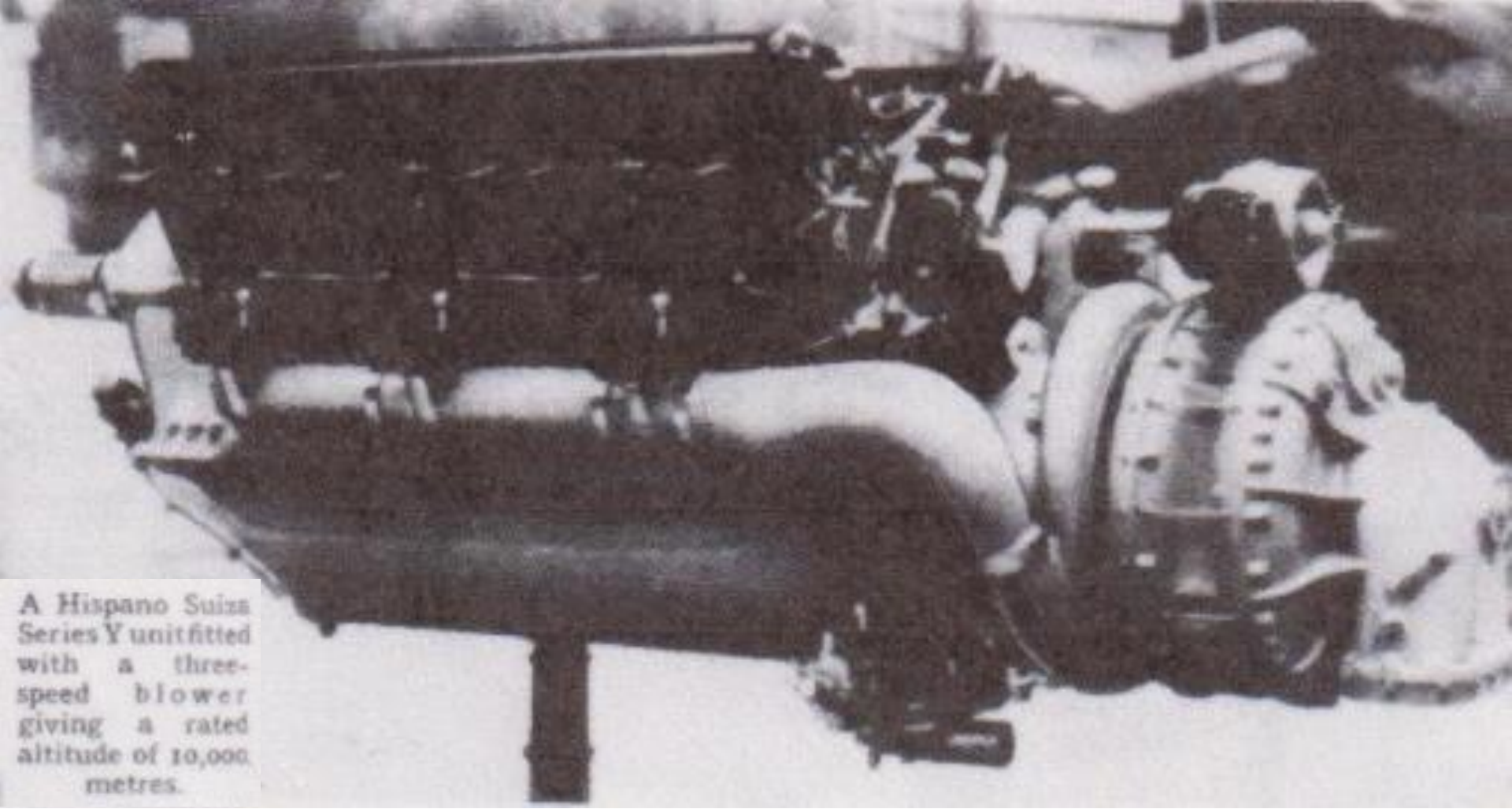
<u>Above</u>: the Seversky Aircraft Company's "Super-Clipper" flying boat was a 1938 design to meet a Pan Am specification for a 100-passenger trans-Atlantic "flying cruise ship" - with luxury cabins spread throughout the fuselage, tail-booms and wing and including a large dining hall. The aircraft was designed to fly 5K miles in luxury-liner comfort.



The Hispano Suiza type 82 twelve-cylinder unit of 2,000 h.p. There are two superchargers and twelve carburetters.

"…The type is being developed in two forms - the Type 82 and 90. The former has been studied for concentric opposite-revolving airscrews but otherwise its design is similar to the Type 90…"

***FLIGHT,* December 8, 1938**



A Hispano Suiza Series Y unit fitted with a three-speed blower giving a rated altitude of 10,000 metres.

"…The twenty-four cylinders are arranged in four banks of six, there being two crankshafts, as in our Napiers. Cylinder banks are similar to those used for the well-established Series Y twelve-cylinder Hispano. The cylinder capacity is 72 litres, the compression ratio 7:1 the nominal power 2,000-hp at 2,400 rpm and the dry weight 2,200 lbs…"

***FLIGHT,* December 8, 1938**

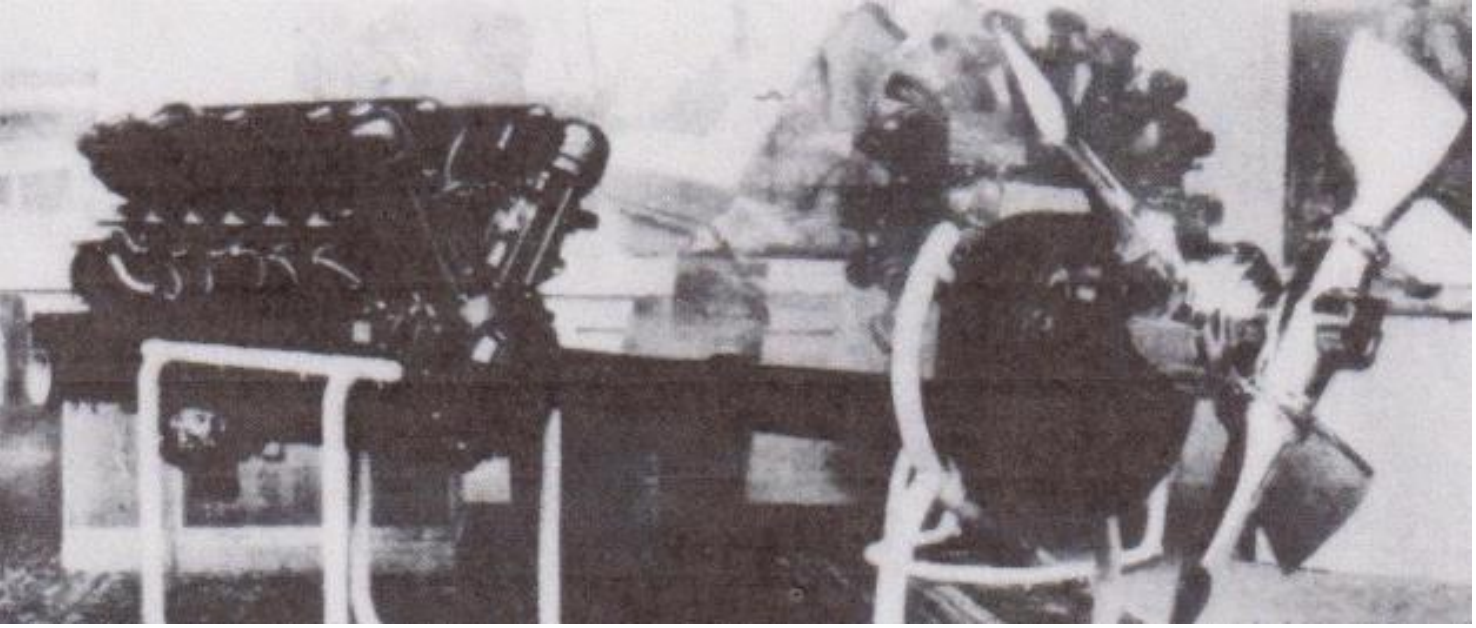
"…There are two centrifugal blowers each serving a group of twelve cylinders. These have automatic mixture controls with a take-off override; they run at ten times engine speed and give a boost equivalent to 880mm of mercury. The crank-shafts are generally similar to those used for the 12Y and are fitted with dynamic dampers on the Sarazin principle. …"

***FLIGHT,* December 8, 1938**

RE: the *centrifugal pendulum absorber* was first patented in 1937 by *R. Sarazin* (another version was patented by *R. Chilton* in 1938). Sarazin's work was used during WWII by Pratt & Whitney for aircraft engines with increased power output. The power increase caused an increase in torsional vibrations which threatened durability; this resulted in the P&W R-2800 engine that used pendulum weights attached to the crankshaft. The function of a centrifugal pendulum absorber is, as with any tuned mass absorber, based on an *absorption principle* rather than a *damping principle.* The distinction is significant since dampers reduce the vibration amplitude by converting the vibration energy into heat. Absorbers store the energy and return it to the vibration system at the appropriate time. Centrifugal pendulum absorbers, like tuned mass absorbers, are not part of the force/torque flow.

"…There are four magnetos and, following usual Hispano-Suiza practice, three carburetors to each bank. The Type 90 engine weighs rather less than the 82, the figure quoted being 2,160 lbs…"

***FLIGHT,* December 8, 1938**



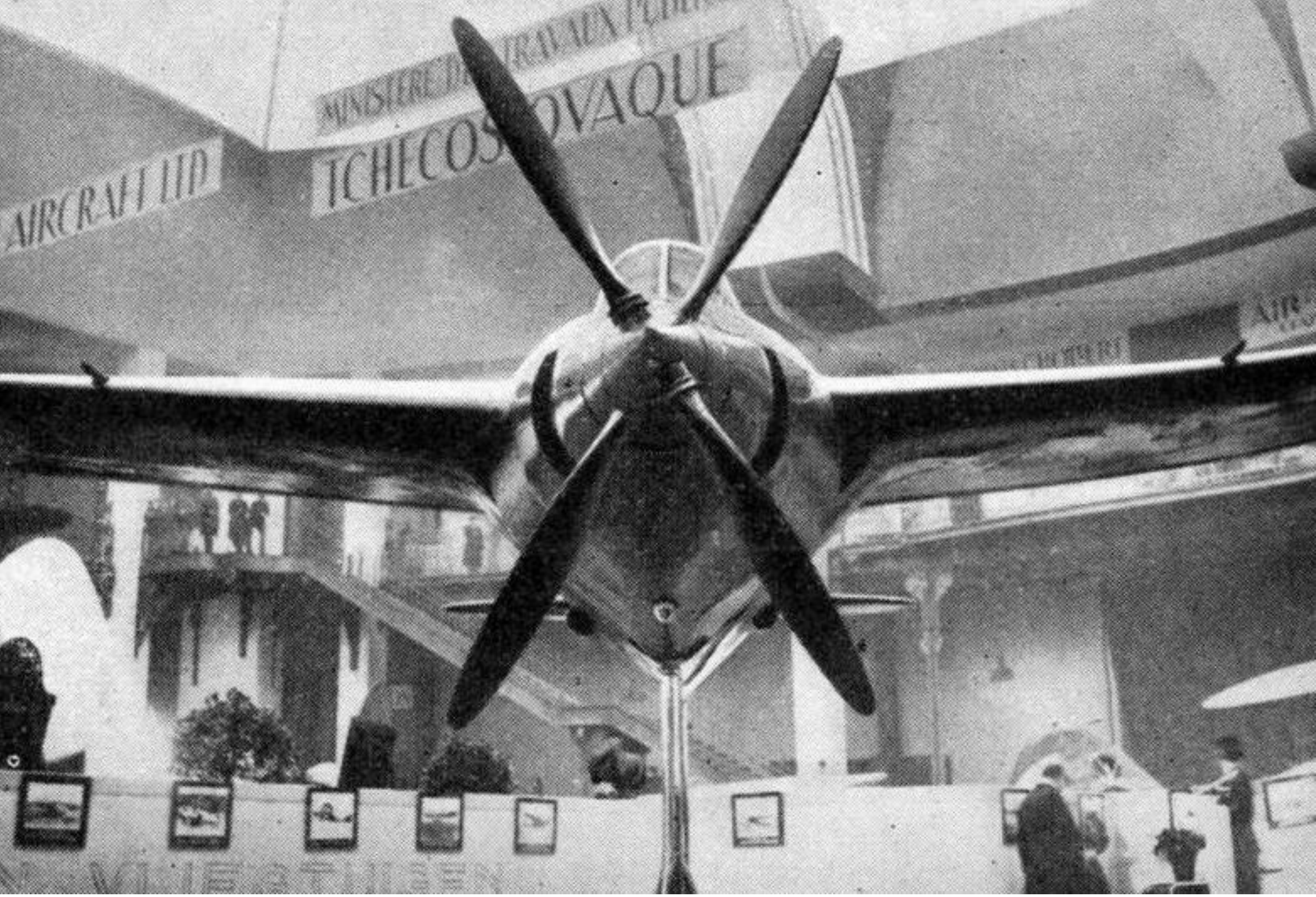
(Left) The latest version of the Lorraine Sterna with extension shaft and oppositely rotating airscrews. This combination has been fitted in the Koolhoven F.K. 55 fighter.

"…Shaft-drive is also evident on the Lorraine (Société Nationale de Construction de Moteurs, of Argenteuil). The engine thus equipped is a vee-twelve Sterna of 900-hp and the drive arrangements appear to be similar to those employed in the Petrel installed in the Koolhoven single-seater fighter two years ago. The present version of that machine – the F.K. 55 – is actually fitted with a Sterna…"

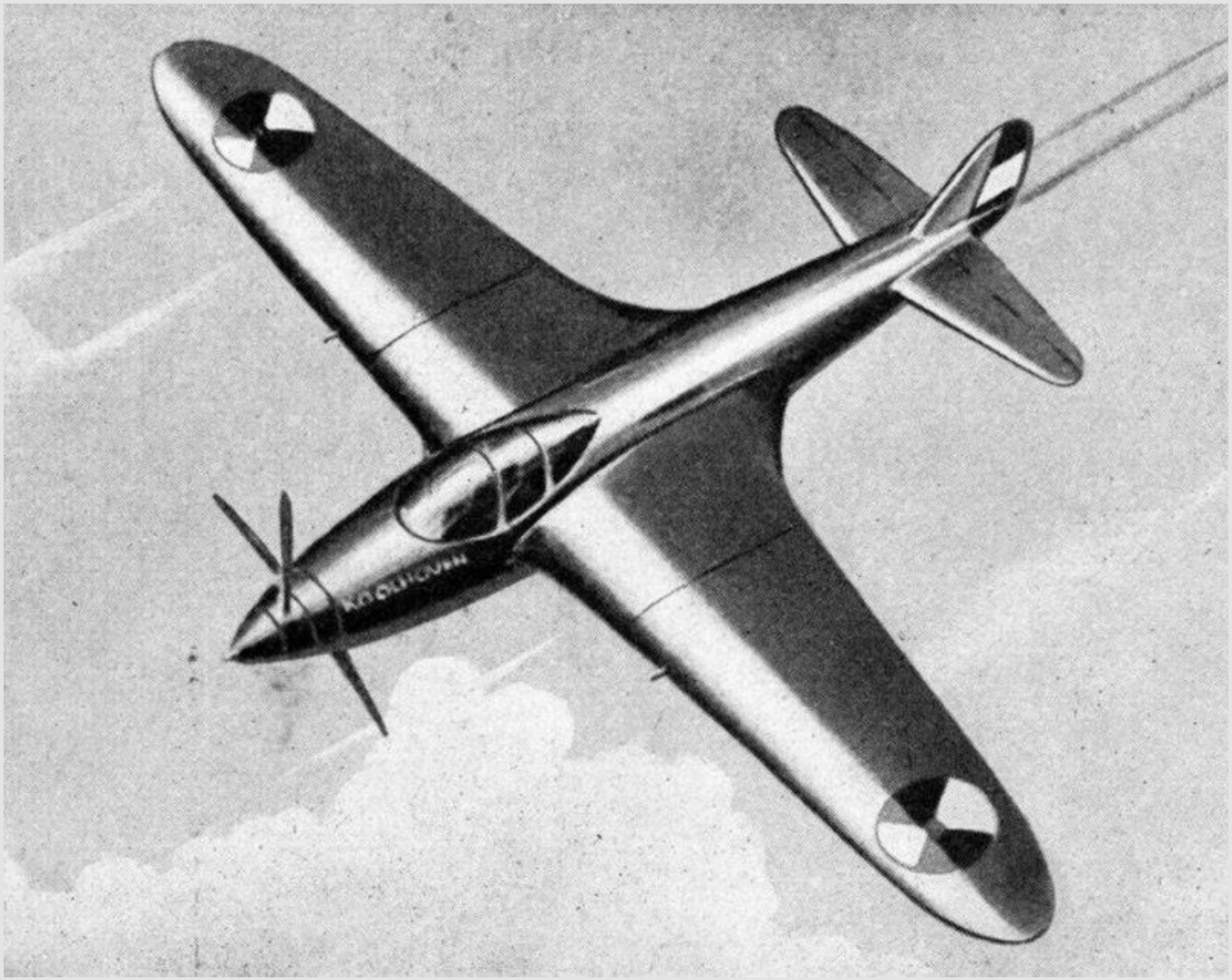
***FLIGHT,* December 8, 1938**

RE: the Koolhoven F.K.55 was a Dutch fighter prototype of the 1930s, which did not progress beyond the prototype stage. The design for a high-performance, single-seat fighter of radical design with contra-rotating propellers and an engine housed behind the pilot was begun in late 1937 and completed in early 1938.

The production version would have used the 1,200 hp Lorraine 12R Sterna Engine.



<u>Above</u>: the F.K. 55 flew for the first time on June 30, 1938. It flew for two minutes then landed. Underpowered, the FK.55 was cancelled that same year.



"…Other Sterna developments include left- or right-hand rotation; raised (désaxé) reduction gear, permitting the installation of a shell gun; two-speed supercharger giving 900-hp at 5,000 ft. and 850-hp at 14,750 ft. and direct petrol injection in conjunction with the use of a Planiol supercharger. It would appear that the larger Eider engine of 1,300-odd hp has been discontinued…"

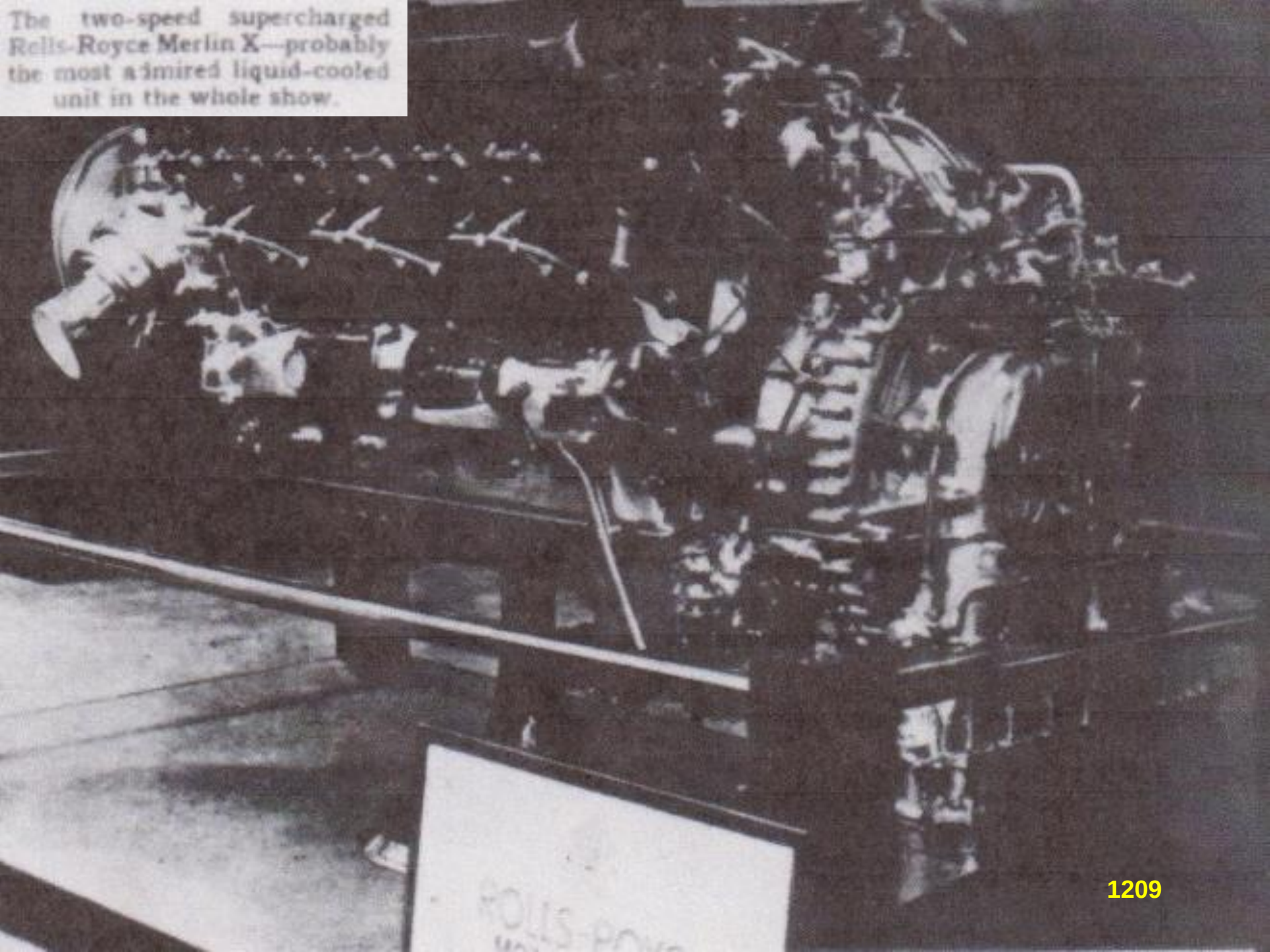
***FLIGHT,* December 8, 1938**

Merlin X

"…Despite the development work by S.N.C.M. on liquid-cooled units, it seems that a good deal more will be needed before large-scale production can be embarked upon…"
***FLIGHT,* December 8, 1938**

"…On the other hand, the Rolls-Royce Merlins, represented this year by a fully supercharged model and the new Merlin X with two-speed supercharger, are already being produced in quantities…"

***FLIGHT,* December 8, 1938**



The two-speed supercharged Rolls-Royce Merlin X—probably the most admired liquid-cooled unit in the whole show.

Making an Impression

"…Apart from the two-speed blower, there is added interest in the announcement of new ratings on 100-octane fuel both for take-off and at altitude…"

***FLIGHT,* December 8, 1938**

"…Figures are being quoted on the Rolls-Royce stand for the Merlin R.M. 2M rated on 100 octane fuel. The normal output at 7,870 ft. is 1,265 hp and the maximum at 9,500 ft., 1,285-hp with 1,320-hp available for take-off. The fully supercharged Merlin II, III and IV give 1,015-hp for take-off on the same fuel…"

***FLIGHT,* December 8, 1938**

"…Even more impressive are the figures for the Merlin R.M. 2 S.M. with two-speed blower. The international rating at 7,870 ft. is 1,265-hp and the maximum at 9,180 ft., 1,285 hp. Take-off output is 1,320-hp. With the supercharger in top gear the output is 1,150-hp at 15,400 ft., the maximum available for level flight at high altitudes being 1,160-hp at 16,730 ft…"

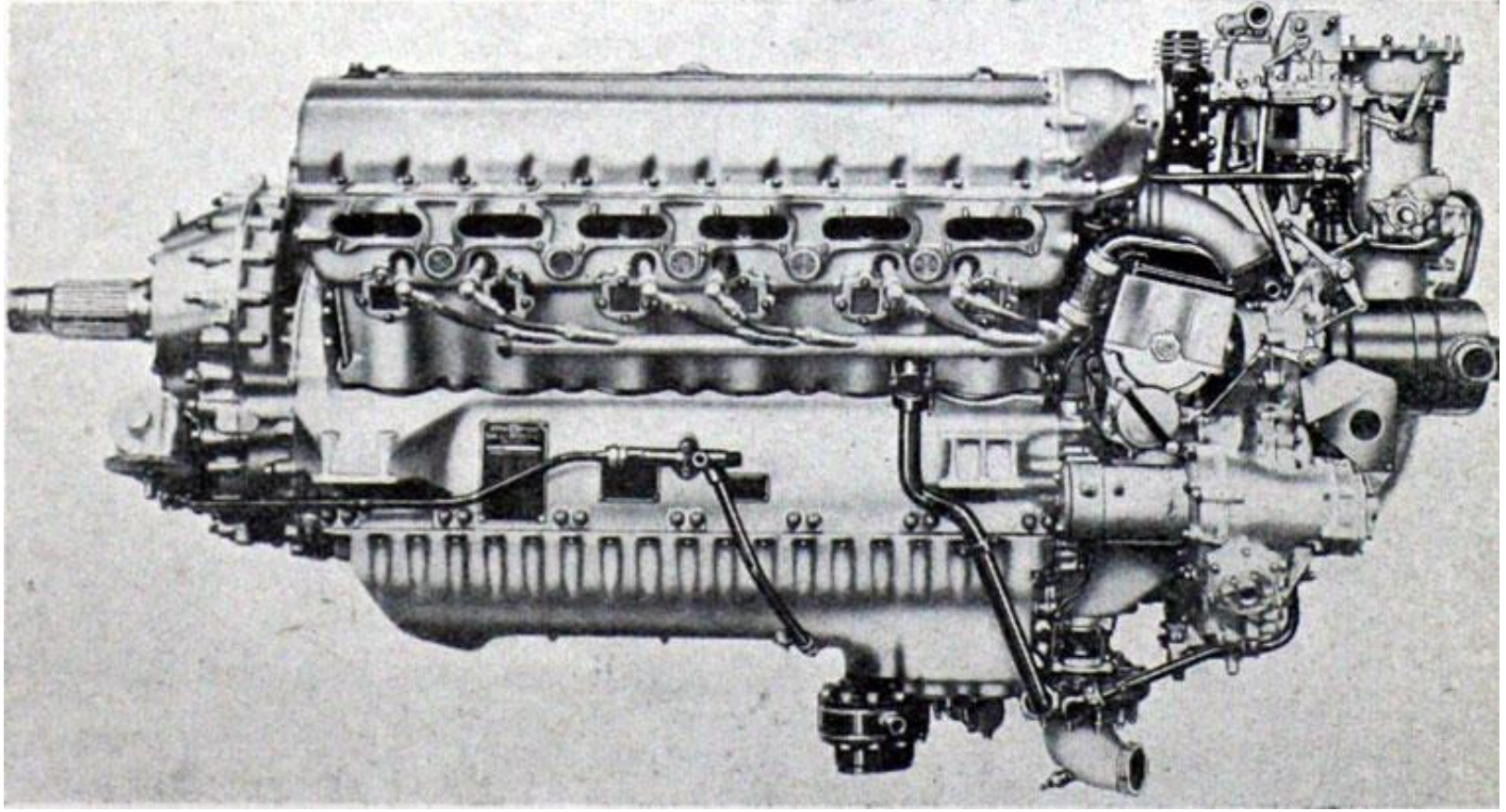
***FLIGHT,* December 8, 1938**

"…Of particular interest is the announcement of 'potential' power which may be regarded as the theoretical full-throttle power of the supercharged engine at sea-level. The maximum potential output of the Merlin II is 1,800-hp, the potential specific power working out at 66.6-hp per-liter, or 300-hp per-sq. ft. of frontal area.."

***FLIGHT,* December 8, 1938**

"…It is also revealed that the speed-change gear for the two-speed blower in the Merlin X is operated by oil-pressure from the scavenge system and that the time to change gear under full-power conditions is of the order of one second…"
***FLIGHT,* December 8, 1938**

Also Rans



"…Though there is no example of the new Peregrine engine on the Rolls-Royce stand, a large photograph of this promising new unit shows such features as its compactness and the layout of the downdraught carburetor…"

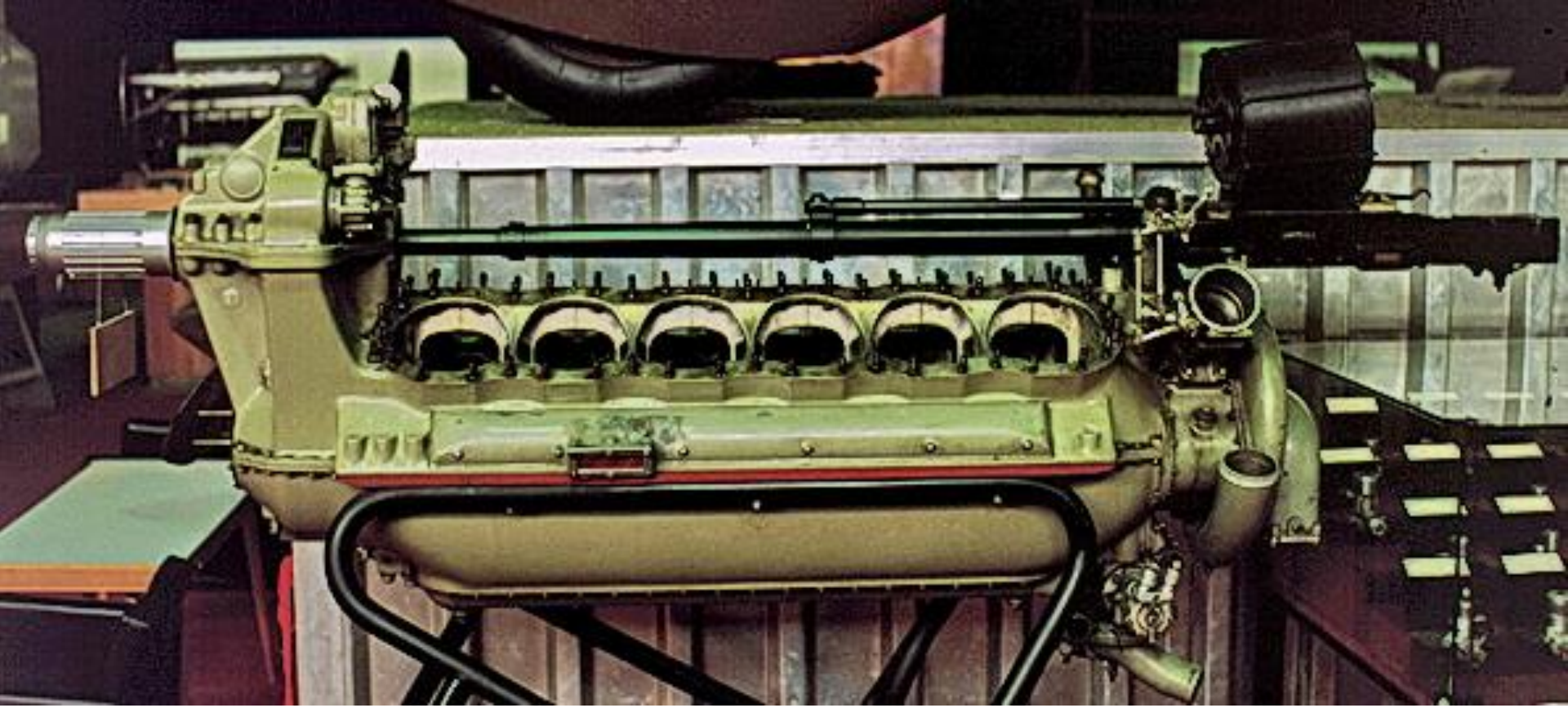
***FLIGHT,* December 8, 1938**

<u>Above</u>: the Peregrine was an 885-hp, liquid-cooled V-12 piston aero-engine designed in the early 1930s. It was essentially a "rationalized" version of their R-R Kestrel, which had seen widespread use. The engine had a bore of 5-inches and a stroke of 5.5-inches, providing 21.2 liter capacity.

"…The Hispano-Suiza 12Ydrs shown on one of the aircraft stands is fitted with a three-speed supercharger giving 920-hp at 32,800 ft. This appears to be a special show-piece and little or no data are available. Officially Hispano-Suiza are showing a 12 Y engine of the latest series; despite its larger capacity, this engine compares unfavorably with the Merlin in output…"

***FLIGHT,* December 8, 1938**

RE: the Hispano-Suiza 12Y was an aero-engine produced by Hispano-Suiza for the French Air Force prior to WWII. The 12Y became the primary French 1K-hp class engine and was used in a number of famous aircraft, including the Morane-Saulnier M.S.406 and Dewoitine D.520.



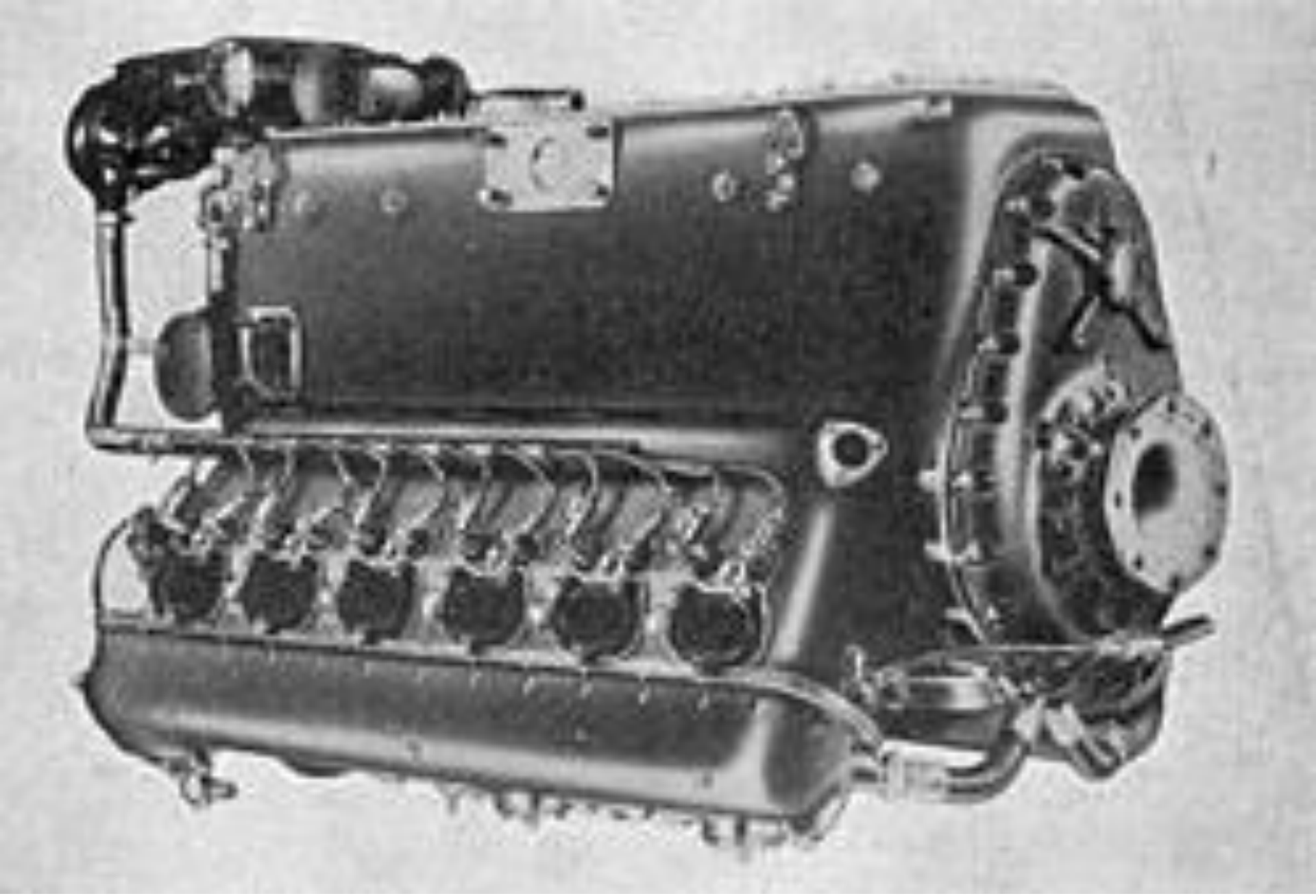
The 12Y was based on the earlier (and somewhat smaller) 12X. The 12X did not see widespread use before the 12Y replaced it and became one of the most powerful French designs on the eve of WWII. The 12Z was being designed, but that came to an abrupt end with the fall of France and the German occupation.

<u>Caption</u>: "Hispano-Suiza 12Ydrs V-12 aero-engine, showing installation of 20mm Hispano-Suiza HS.404 autocannon between cylinder banks, firing through the propeller. Both banks of cylinders have been removed for better view. Supercharger is at bottom right."

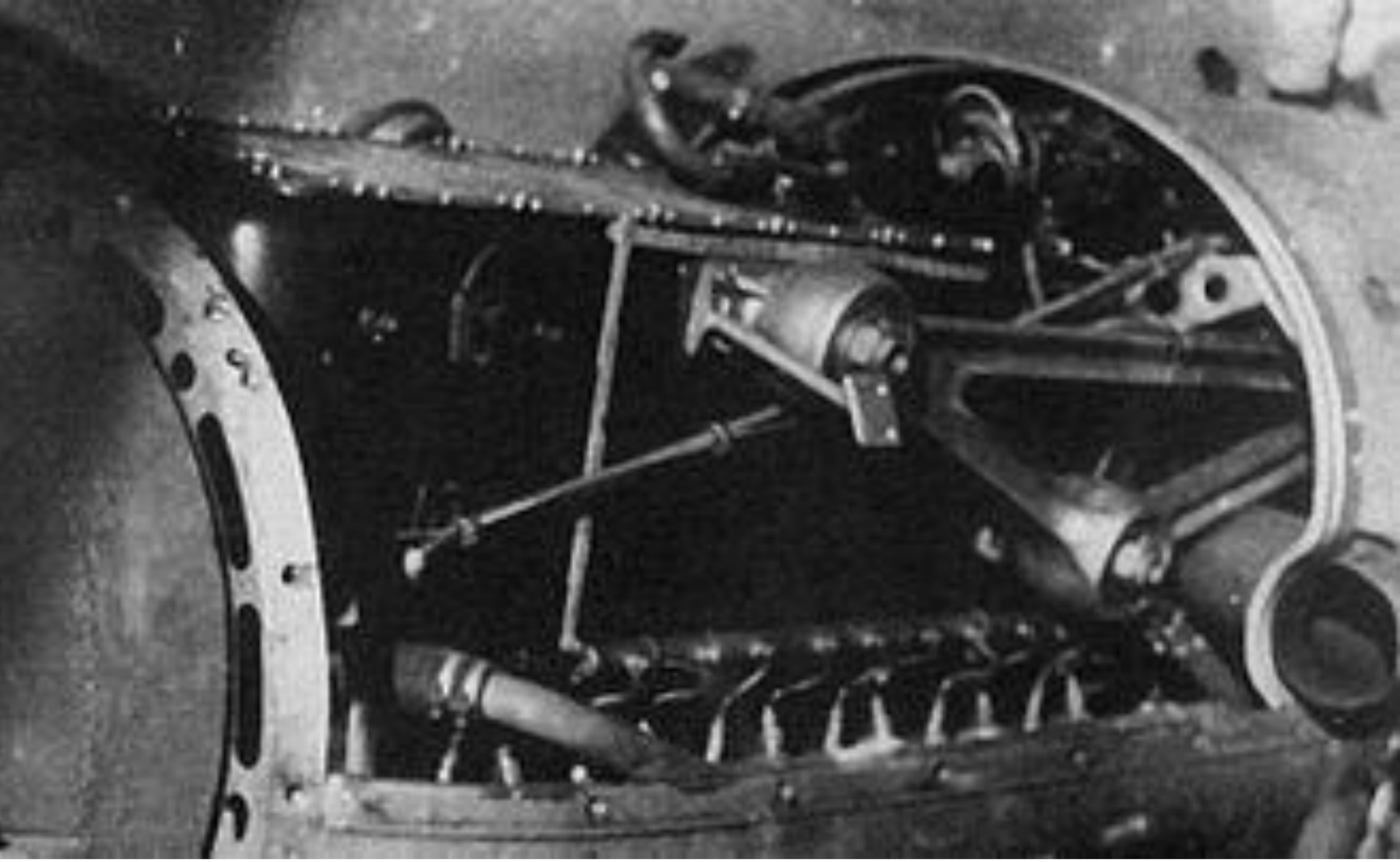
"…Another unit which, though it has a greater displacement than the Rolls-Royce, is hardly as powerful, is the Daimler-Benz D.B. 600. This engine is quickly leaving its teething troubles behind and is installed in a large proportion of the machines in the German Air Force. The makers say that they adopted the inverted type to keep the upper part of the engine as narrow as possible so as not to interfere with the pilot's visibility in single-seaters. The advantage gained seems to be more theoretical than actual…"

***FLIGHT,* December 8, 1938**

RE: the Daimler-Benz DB 600 was a German aero-engine designed and built prior to WWII as part of a new generation of German engines. It was a liquid-cooled, inverted V-12 engine which powered the Messerschmitt Bf-110 and Heinkel He-111, among others. Most newer DB engine designs used in WWII were based on this engine design.



Daimler Benz DB-600

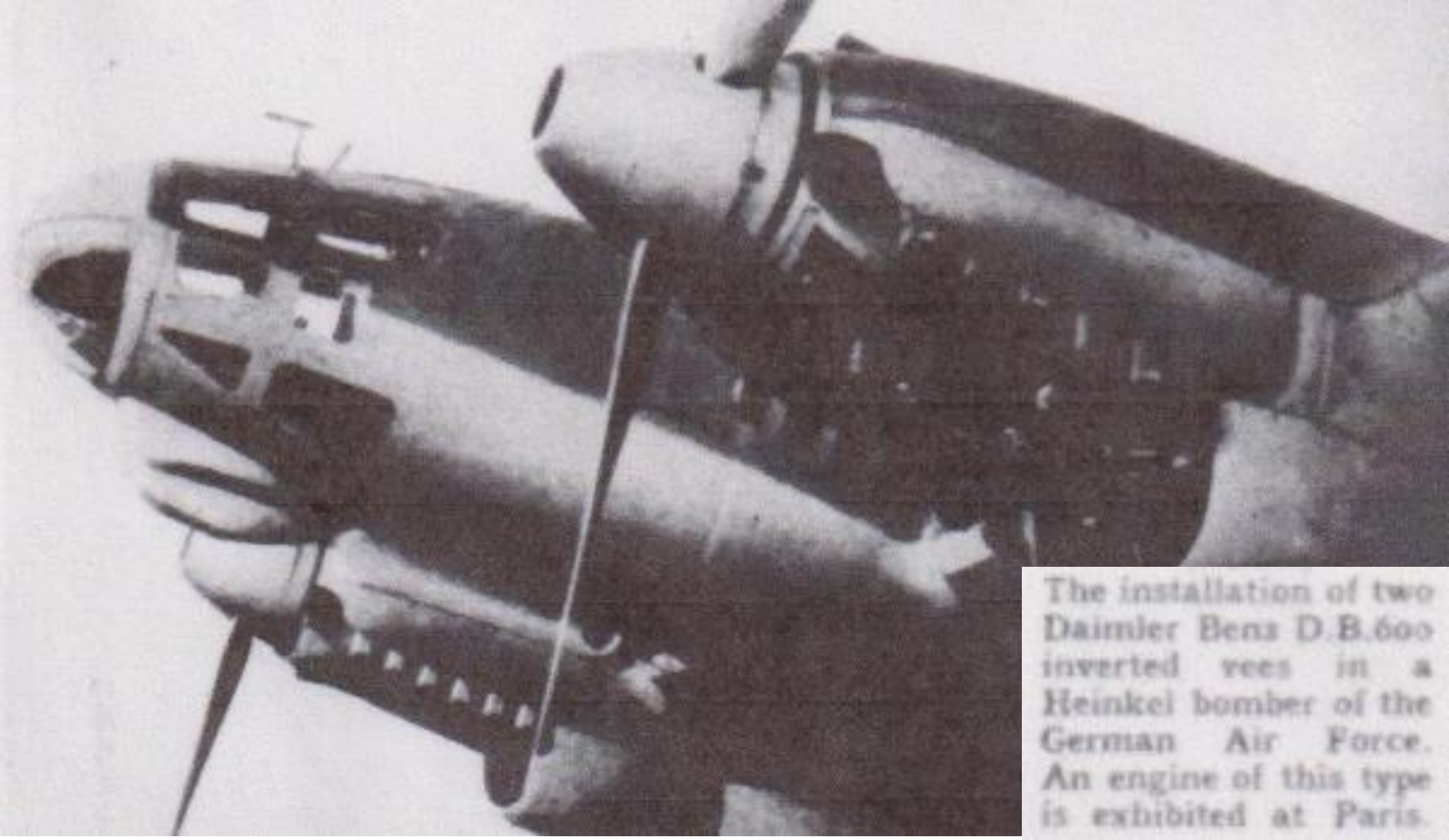


DB-600A in a Heinkel He-111B nacelle

"…An interesting feature on the fully supercharged model is a time switch which automatically cuts-out the override boost after five minutes. There is no evidence on the Daimler Benz petrol engine of direct injection or coil ignition. The carburet-or is of the Daimler-Benz pressure-type and the magnetos of Bosch manufacture…"

***FLIGHT,* December 8, 1938**

An Improved Daimler-Benz



"…In their publicity matter the makers mention the speed records of the Messerschmitt and Heinkel fighters as having been set-up with a D.B. 600 engine, though actually the Heinkel which reached 634 km/hr had a D.B. 601, details of which are not yet available…" 1225

***FLIGHT,* December 8, 1938**

Deutschland Uber Alles

"…Junkers are presenting a Jumo 211 petrol engine. Direct-injection is available with this unit…"
***FLIGHT,* December 8, 1938**

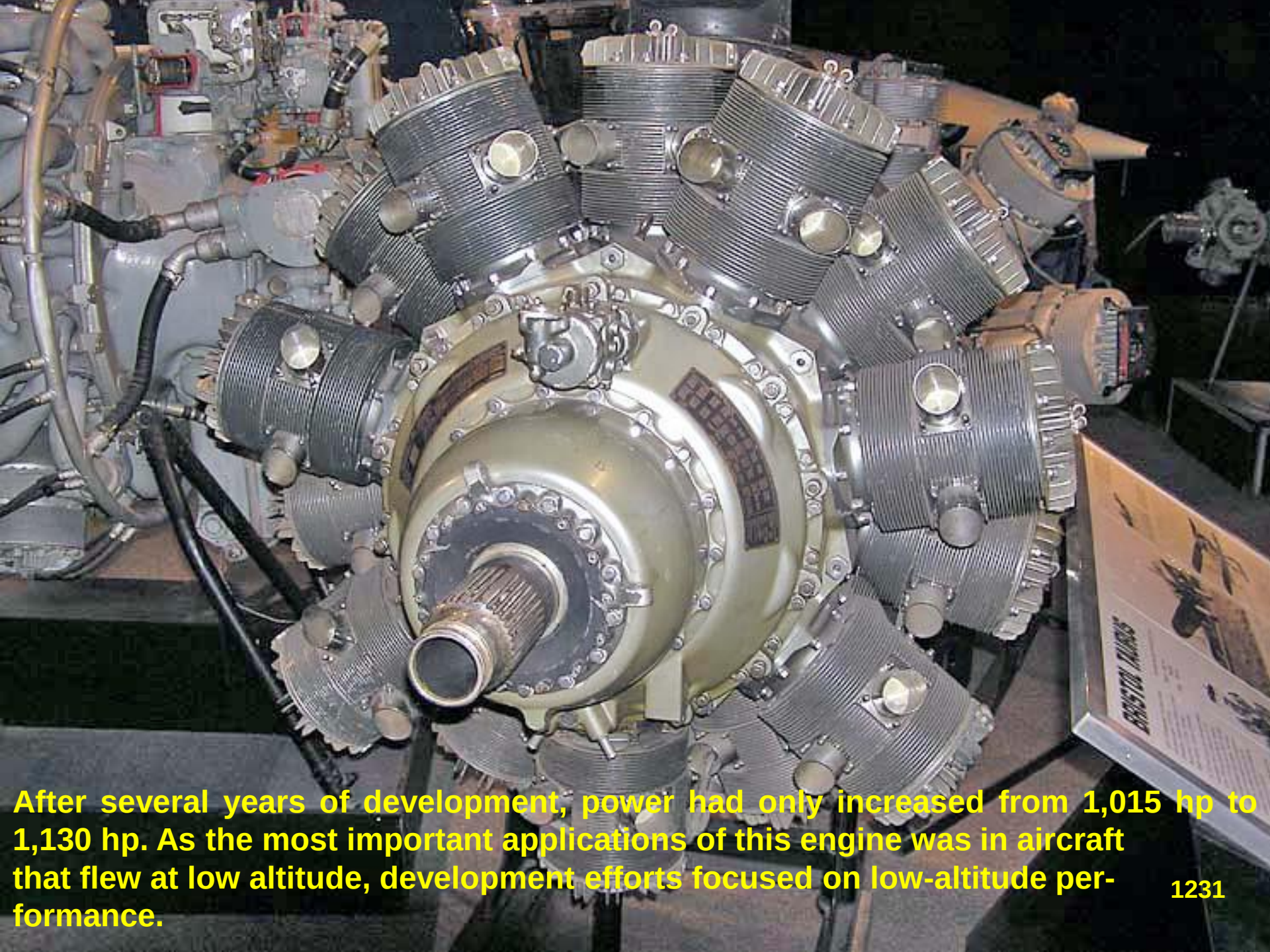
Meeting the Challenge

"…In spite of the advances made on the Continent during the past two years with air-cooled units, Great Britain, with the De Havilland and Cirrus in-lines and the Bristol and Armstrong-Siddeley radials, makes a challenging show…"
***FLIGHT,* December 8, 1938**

"…Bristols have put on a magnificent exhibition comprising the two-speed supercharged Pegasus XVIII, which gives 885-hp (max.) at 15,500 ft.; the small-diameter Mercury VIII, which delivers 920-hp for take-off with 100 octane fuel; the Perseus XII sleeve-valve unit (905 hp max. at 6,500 ft.); Hercules II (1,375-hp max. at 4,000 ft.); Aquila (600-hp for take-off); and the magnificent new 14-cylinder Taurus sleeve-valve engine, which is 46-1/4 in. in diameter, runs at speeds between 2,500 and 3,000 rpm and has a maximum output of over 1,000-hp…"

***FLIGHT,* December 8, 1938**

RE: the Bristol Taurus was a 14-cylinder two-row radial aero-engine, produced by the Bristol Engine Co. starting in 1936. The Taurus was developed by adding cylinders to the existing single-row Aquila design and transforming it into a twin-row radial engine, creating a powerplant that produced just over 1K-horsepower with very low weight. The Taurus used sleeve-valves, resulting in an uncluttered exterior and little mechanical noise. It offered high power with a relatively low-weight. It was also compact, with a diameter of 46 in. which made it attractive for fighters. Unfortunately, the Taurus was described as "notoriously troublesome," with protracted development and a slow growth in rated power.



After several years of development, power had only increased from 1,015 hp to 1,130 hp. As the most important applications of this engine was in aircraft that flew at low altitude, development efforts focused on low-altitude performance.

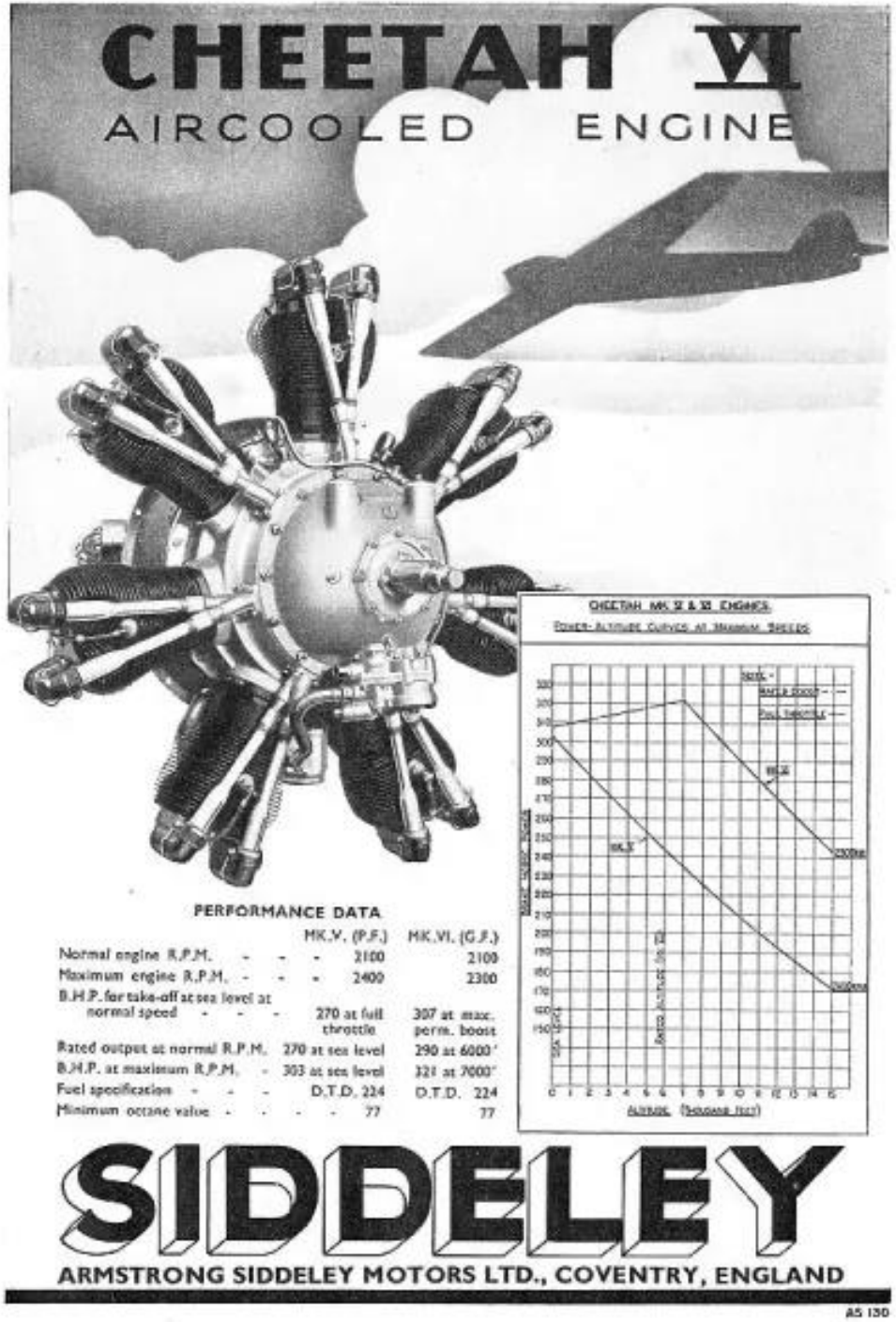
"…The Hercules is shown with a Rotol airscrew, cowling (with leading-edge exhaust collector ring and a single large outlet), intake for the downdraught carburetor, quickly detachable mounting and external oil-cooler. A Bronzavia carburetor may be specified…"

***FLIGHT,* December 8, 1938**

RE: the Bristol Hercules was a 14-cylinder, two-row radial aero-engine produced by the Bristol Engine Co. starting in 1939. It was the most numerous of their single-sleeve valve designs, powering many aircraft in the mid-WWII timeframe. The Hercules powered several military aircraft types, including Bristol's own Beaufighter, although it was more commonly used on bombers. The Hercules also saw use in civilian aircraft and was licensed for production in France by SNECMA.



Cut-away Bristol Hercules engine at
The Museum of Flight,
East Fortune, Scotland



"…One of the most attractive of the smaller engines in the show is the new Siddeley Cheetah XI, a moderately supercharged unit with a bore of 133.3mm and a stroke of 137mm, giving a capacity of 12.42 liters. An innovation is the reduction gearing; vibration is avoided by a flexible hub mounting for the airscrew The cylinders and valve gear are entirely new, the valves being splayed-out quite sharply. A helmeted cowling about 41-inches in diameter is to be standardized. Take-off power is about 460-hp at 2,825 rpm; international rating 415-hp at 2,050 rpm, at 7,500ft.; and maximum power 435 at 8,750 ft…"

***FLIGHT,* December 8, 1938**

"…De Havillands, with their Gipsy Twelve, are showing some of the Continental manufacturers what a large-geared and supercharged air-cooled inverted engine should be like. This unit, apart from the Walter Sagitta as installed in the Fokker fighter, seems so far to be the only one of type and size likely to meet with any great success…"

***FLIGHT,* December 8, 1938**

RE: the de Havilland Gipsy Twelve was a British aero-engine developed by the de Havilland Engine Co. in 1937. Approximately 50 were manufactured. It was a/k/a as the "Gipsy King" in RAF service.



De Havilland Gipsy King aircraft piston engine
on display at the de Havilland Aircraft Museum, London

EXEMPLE DE MOTEUR EN V INVERSE A REFROIDISSEMENT PAR AIR

De HAVILLAND " Gipsy - Twelve Engine "

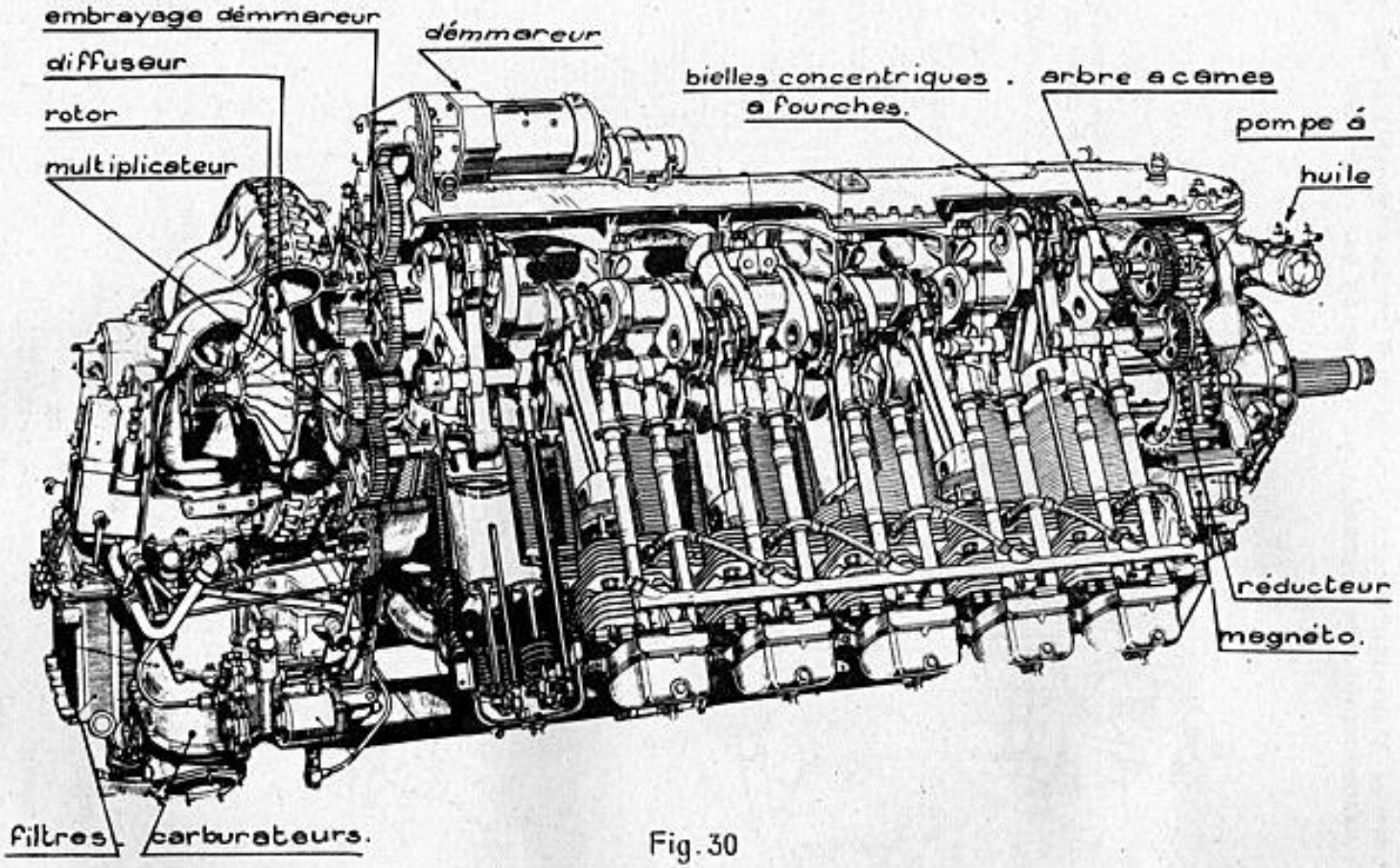
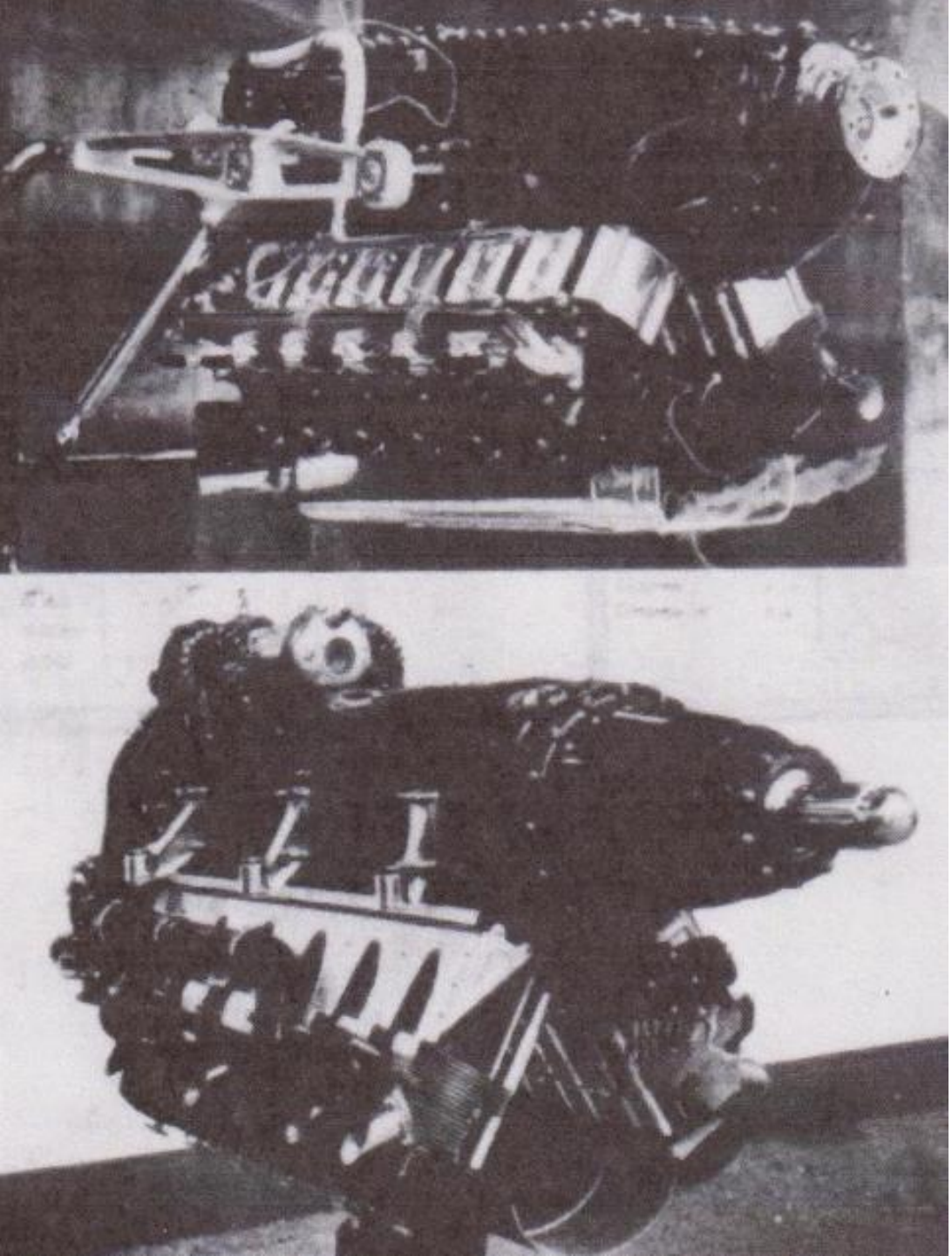


Fig. 30

Puissance nominale	:	405 CH
Altitude correspondante	:	2.286 m.
Régime correspondant	:	2.400 t/min.
Cylindrée	:	18 litres,372
Alésage et course	:	118 et 140
Taux de compression	:	6
Poids	:	479 kg
Puissance au litre	:	22 CH/litre
Puissance au litre à 1000 tour/minute	:	9,2
Poids au cheval	:	1,175 kg/CH.

Remarquer que, 1° la disposition en V ou en 2 lignes impose le parallélisme des soupapes lorsqu'elles sont commandées par culbuteurs, 2°- la disposition en V inversé facilite considérablement le logement des accessoires qui se trouvent nécessairement placés en-dessous de l'axe du compresseur. Pour le refroidissement l'air s'engouffrant entre les 2 branches du V et sort latéralement entre les cylindres.



"…There is a fair selection of lower-powered, air-cooled vee-twelves, including the new Argus A.S. 410-1 unit; the new Hirth, which is a competitor of the Argus; the Renault, which has been slightly improved since last year; the Salmson moteur canon and the Walter Sagitta already mentioned…"

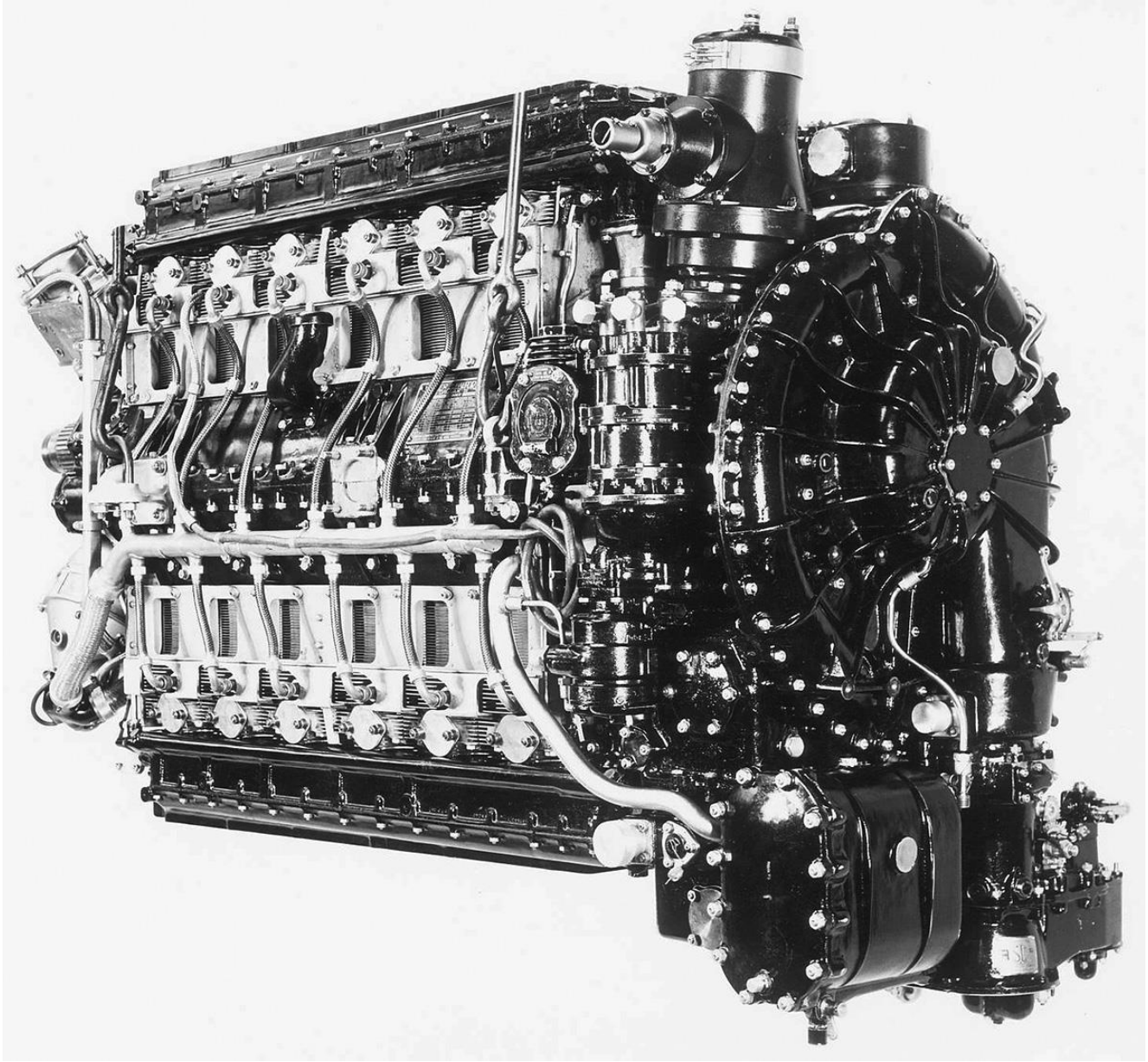
***FLIGHT,* December 8, 1938**

Caption: "A comparison of German and French practice in the construction of inverted air-cooled vee-twelves. At the top is the new Hirth and below is the Renault."

"…It was fortunate that details of the unique 24-cylinder Napier Dagger VIII were released just before the show. This unit is rated at 925-hp at 9,000 ft. and delivers 1,000-hp at 8,750 ft. The close finning of the cylinders is noticeable in comparison with earlier models and accessories include an S.U. up-draft carburetor, Amal flame trap, Napier gear-type fuel pump, De Havilland constant-speed airscrew control unit and Rotax hand or electric starter. The net dry-weight of the engine is 1,390 lbs. and the fuel consumption under maximum cruising conditions at sea-level is 66-1/2 gallons-an-hour…"

***FLIGHT,* December 8, 1938**

RE: for the Dagger VIII, Napier developed a nose cowling with air ducts between the upper and lower cylinders. This was done in an attempt to make sure that the engine, once installed in an aircraft, was properly cooled. The Dagger VIII (E110) was first run in 1938 and had a maximum output of 1K-hp at 4,200 rpm at 8,750 ft. with 5.0 psi of boost. The engine was rated at 925-hp at 4,000 rpm at 9K ft. with 4.0 psi of boost and 955-hp for take-off at 4,200 rpm with 6.0 psi of boost. Its cruising output was 830-hp at 3,600 rpm at 7K ft. with 3.5 psi of boost. Fuel consumption at cruise was 0.461 lbs./hp/hr. The engine weighed 1,390 lbs.



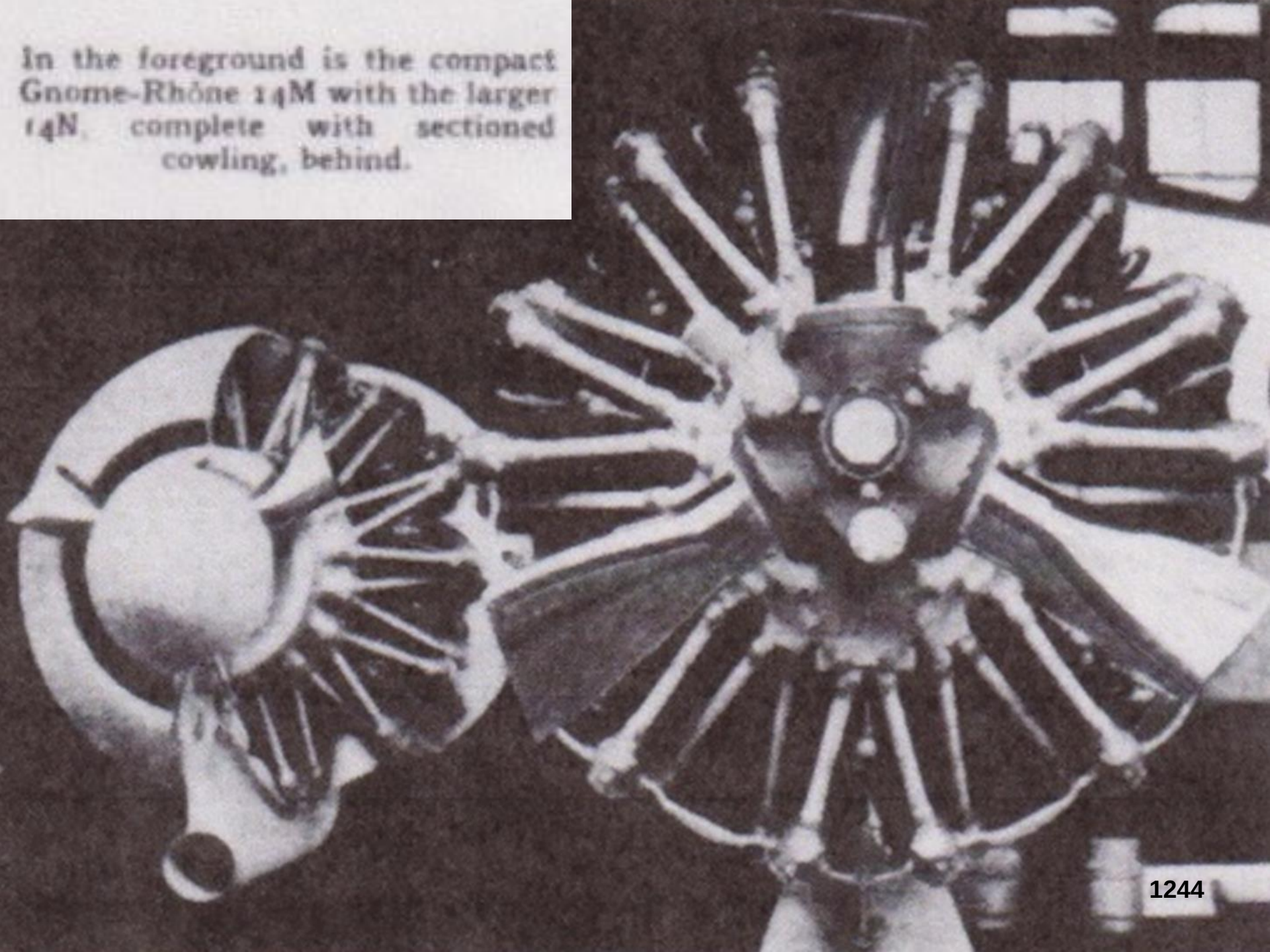
Rear-view of a Dagger VIII highlighting the engine's supercharger housing that conceals a two-sided impeller. The updraft carburetor can be seen on the right-side of the engine.

Vive la France!

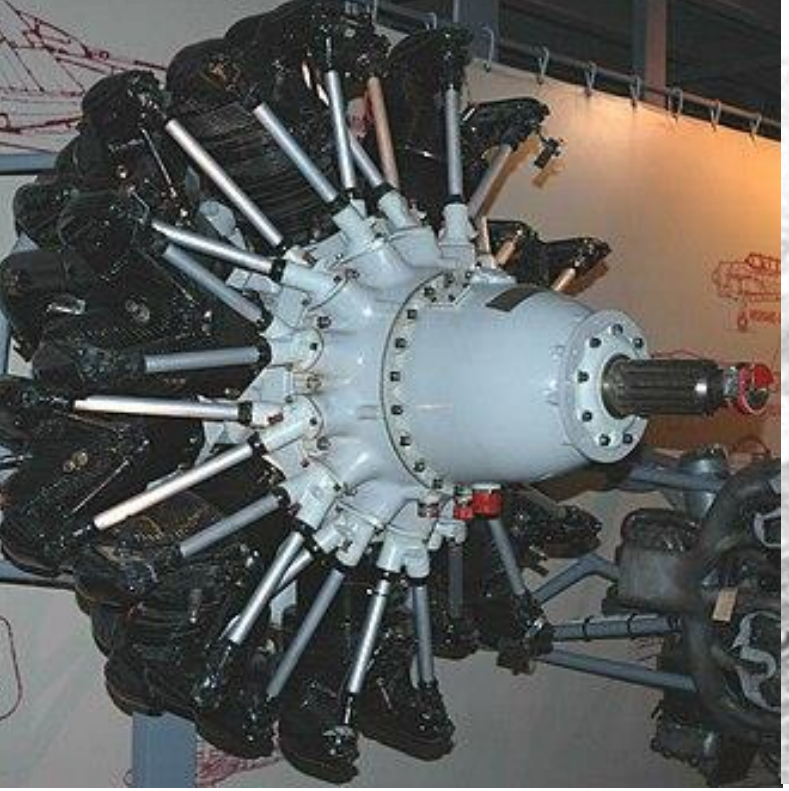
"…The French two-row radials are being developed along the same lines as last year (i.e., small diameter and high-speed), excepting some of the larger types, like the Renault…"
***FLIGHT,* December 8, 1938**

"…The Gnome-Rhéne stand is devoted to engines of the 14N and 14M series, there being no evidence of the big eighteen-cylinder unit, which, far as is known, has not yet been in the air…"

***FLIGHT,* December 8, 1938**



In the foreground is the compact Gnome-Rhône 14M with the larger 14N, complete with sectioned cowling, behind.





"…The 14M is one of the most attractive-looking engines in the show and is being installed in a proportion of the new Potez 63 fighter-bombers being delivered to the French Air Force…"

***FLIGHT,* December 8, 1938**

RE: the Gnome-Rhône 14M-05 Mars (left) was a small 14-cylinder two-row air-cooled radial engine that was used on several French and German aircraft during WWII

<u>Right</u>: caption: "Potez 63/11. 1st flight 31/12/1938"

"…The larger 14N shown with its cowling, a remarkable feature being the small diameter of the air inlet. The drag must approach 'liquid-cooled' figures and it would be interesting to get comparative data on this and the new Mercier cowling for radial engines…"

***FLIGHT,* December 8, 1938**

RE: while having the same appearance, number of pistons (14) and two-row layout typical of Gnome-Rhône radial engines, the 14M was built to a smaller frame intended to power a lighter class of aircraft. It was designed with lower displacement and power, smaller in size and with less weight compared to the larger, heavier Gnome-Rhône 14N and its well-known predecessor.

"…Hispanos are showing the 14 A.B. small-diameter two-row radial, which is in the same class as the small Gnome-Rh-one…"

***FLIGHT,* December 8, 1938**

RE: the Hispano-Suiza 14AB (a/k/a Hispano-Suiza Type 80) was a 14-cylinder twin-row air-cooled radial engine. In 1929, the Hispano-Suiza Co. bought a license to produce the Wright Whirlwind engine. The technology from that engine was used to produce a number of different radial engines with greater displacements, power and number of cylinders.



The most significant of this series of engines was the 14AB, which was a very compact design with relatively good performance. Some 2,500 engines were produced. The 14AB suffered from cooling problems and many aircraft originally designed for the 14AB were redesigned to use the more reliable Gnome-Rhône 14M series of engines or imported Wright and P&W R-1535 engines.

<u>Caption</u>: “Hispano-Suiza 14AB (Musée de l’Air et de l’Espace)”

Newcomers

"…Welcome newcomers are the Pratt & Whitney Twin Wasp Junior and the Twin Wasp, the latter being cut exactly in half along the longitudinal centerline, showing the close tolerances and fine workmanship demanded in the modern aero-engine…"

***FLIGHT,* December 8, 1938**

RE: the P&W R-1535 Twin Wasp Junior was an American aero-engine developed in the 1930s. The engine was introduced in 1932 as a 14-cylinder version of the 9-cylinder R-985 and was a two-row, air-cooled radial design. Displacement was 1,535 cu. in.; bore and stroke were both 5-3⁄16 in. The P&W R-1830 Twin Wasp was an American air-cooled radial aero-engine. It had 14 cylinders arranged in two rings of seven. It displaced 1,830 cu. in. and its bore and stroke were both 5.5 in. The design traced its history to 1929 experiments at P&W on twin-row designs. Production began in 1932 and it was widely used during the 1930s.





"…The unit is of the latest series C-type and gives 1,200-hp for take-off. The Wasp Junior is a 750-hp model and is similar to the powerplant of the Vought dive bomber…"

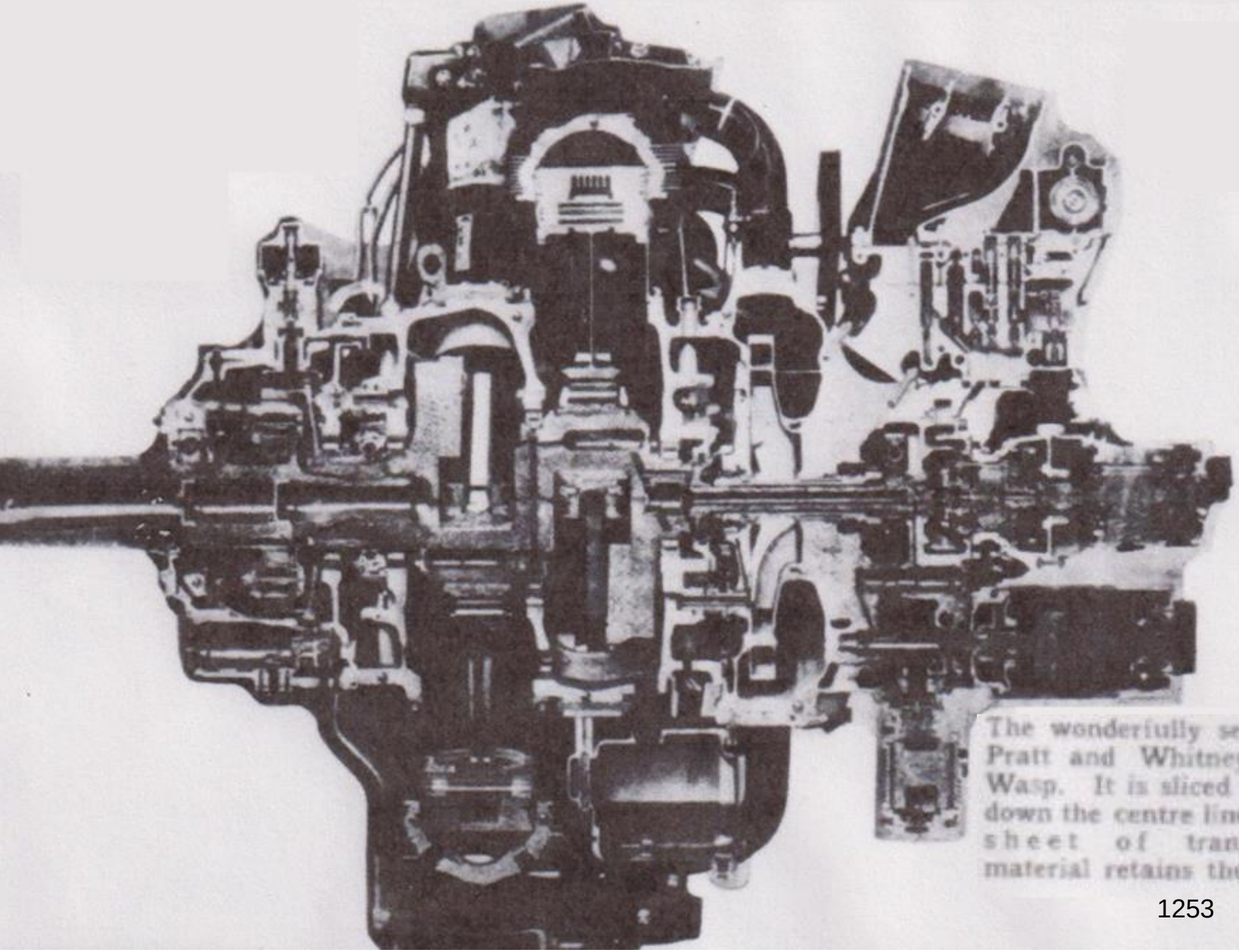
***FLIGHT,* December 8, 1938**

Left: caption: "Pratt & Whitney Twin Wasp Junior, at the National Museum of Naval Aviation, Pensacola, Florida"

Right: caption" "Pratt & Whitney R-1830 Twin Wasp radial aero-engine on display at the Imperial War Museum Duxford"



<u>Above</u>: the Vought SB2U Vindicator used a single P&W R1535 “Twin Wasp Junior” radial engine to drive a two-bladed propeller at a fixed speed



The wonderfully sectioned Pratt and Whitney Twin Wasp. It is sliced exactly down the centre line and a sheet of transparent material retains the parts.

The Cyclone

"…The Wright exhibit is a Cyclone G.102-A. It may be explained that the A-series runs at rather higher revs than other Cyclone models and uses fuel of 90-octane number instead of 100. The output is 913-hp. The Chandler-Groves non-icing downdraught carburetor is one of the more interesting features…"

***FLIGHT,* December 8, 1938**

RE: the Wright Cyclone G.102-A was a powerful, 9-cylinder, single-row air-cooled radial engine produced by the Curtiss-Wright Corp. in the late 1930s. It was part of the larger R-1820 Cyclone family of engines, which were widely used in numerous military and civilian aircraft from the 1930s to the 1950s.



Caption: “Douglas assembly plant in El Segundo, California. SBD Dauntless air-frames are receiving Cyclone engines, in this August 1943 photograph.”



Wright R-1820 G

The G.102-A engine, along with other versions of the G-series, were used to power important aircraft of the era such as the Douglas DC-3, Boeing 307 Stratoliner and the Lockheed Hudson

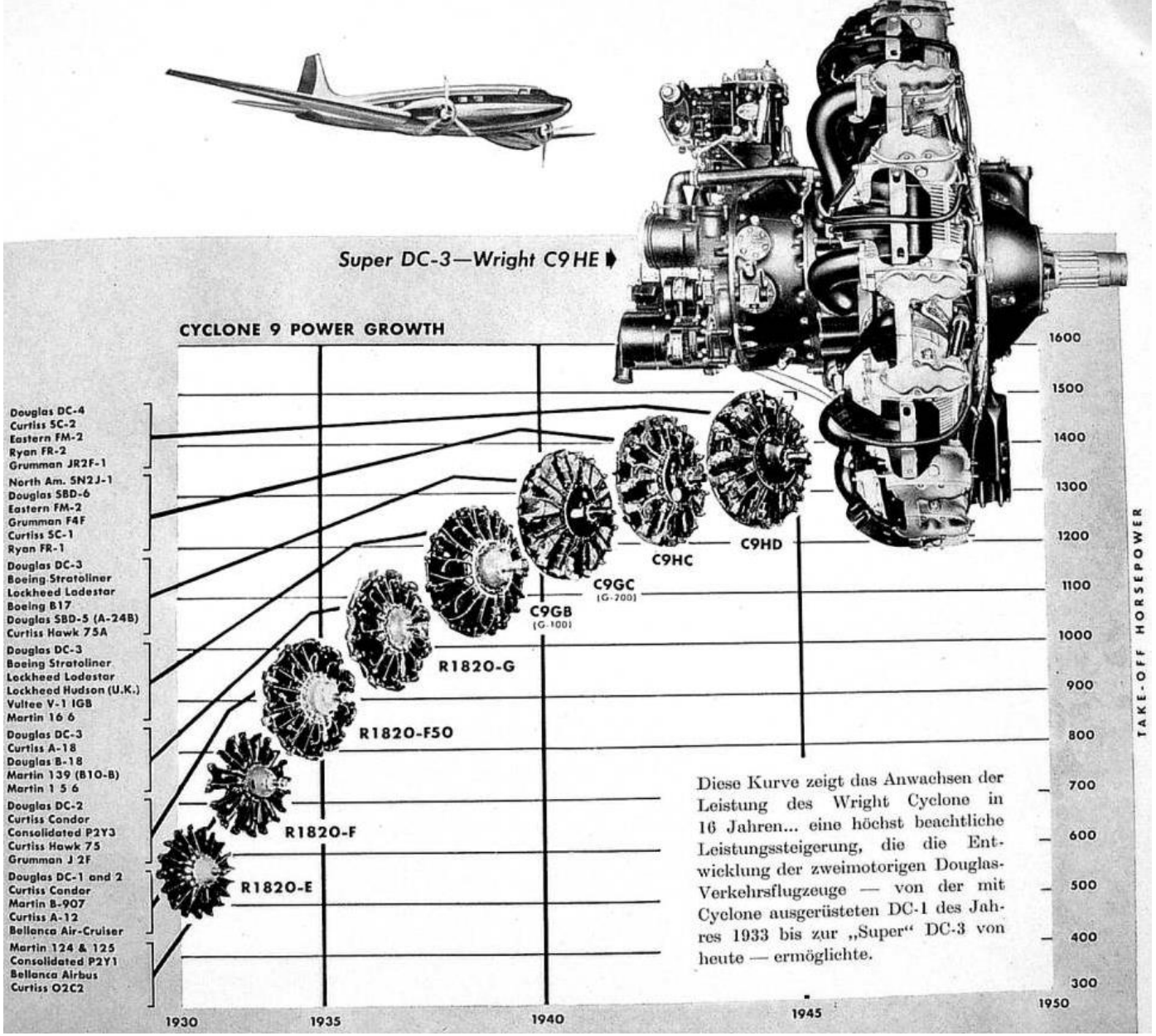


Diagram of the evolution of the Cyclone engine, showing the different versions, the years in which they appeared, some of the models that mounted them, and the power outputs at the launch of the versions.

By Comparison





"…Instructive comparisons with the Cyclone are afforded by the Bramo-Fafnir and BMW 132 radials among the German exhibits. Both these units are already well known…"

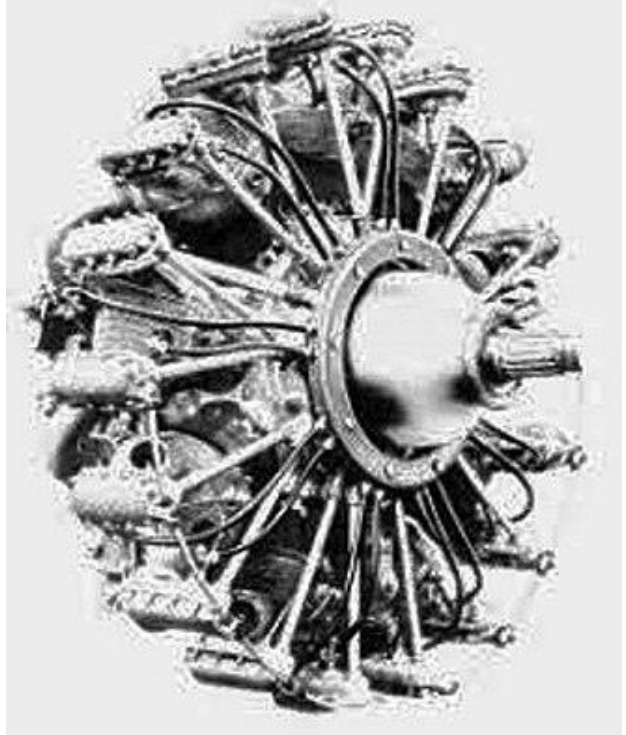
***FLIGHT,* December 8, 1938**

RE: the Bramo 323 Fafnir (top) was a 9-cylinder radial aero-engine. Based heavily on Siemens/Bramo's earlier experience producing the Bristol Jupiter under license, the Bramo 323 saw limited use. The BMW 132 (bottom) series was the principal large radial engine used in Germany during the early 1930s. It was, essentially, a copy of the P&W Hornet. In 1929, BMW obtained a license to build the Hornet. From 1929-45, more than 21K BMW 132 engines were built. The 9-cylinder engine had a displacement of 1,690 cu. in. and produced 725-970-hp, depending on model.

It was used primarily in the three-engine Junkers Ju 52/3m transport.

Misc. Radials





"…Among the miscellaneous radials of various sizes are the Lycoming R-680-D.5 of 380 hp, the Lorraine Algol 120 of 600 hp, which is available with solid fuel-injection, the 70-hp Potez three-cylinder unit and the various Salmsons, a new five-cylinder unit…"

***FLIGHT,* December 8, 1938**

RE: the Lycoming R-680 (top) - the first aero-engine produced by Lycoming - was a 9-cylinder, air-cooled radial engine. It was produced in two types; the E and B series (both were essentially the same). The B4E was available in a trainer version with a front exhaust collector "ring" for use without cylinder air baffles. R-680 received Approved Type Certificate No. 42 on Feb. 4, 1930. The Lorraine 9N Algol (bottom) was a French 9-cylinder radial aero-engine built and used in the 1930s. It was rated at up to 500-hp, but more typically operated in the 300-400-hp range.

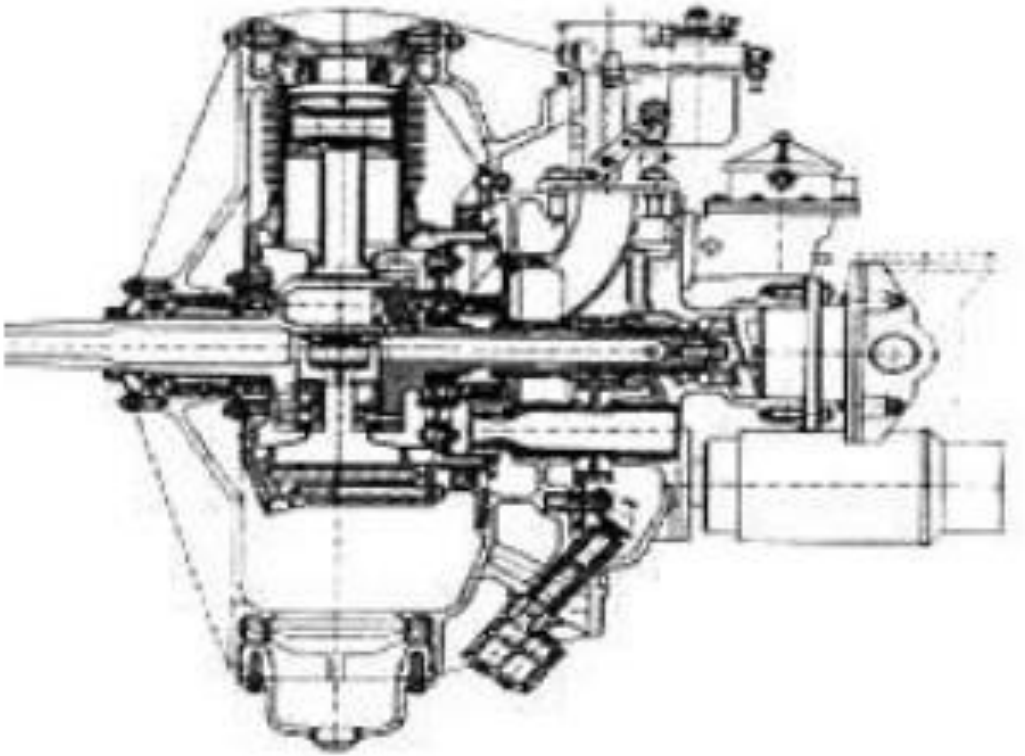
Attracting Attention

"…The little Mawen rotaries are attracting a good deal of attention. The prototype of the 75-hp unit has done 350 hours of testing. The nine-cylinder 130-hp model has 550 hours to its credit and the five-cylinder 20-hp unit over 600 hours. Figures for the 7 B-1 unit are 75-hp at 3,313 rpm; maximum rpm, 3,500; capacity, 2.16 liters; compression ratio 6.8:1; weight, 80.5 kilogrammes…"

***FLIGHT,* December 8, 1938**

RE: in the 1930s, Swedish businessman *Axel Wenner-Gren,* together with Frenchman *Emile Mathis*, invested in an aircraft engine named "Mawen" (a combination of the names MAthis and WENner-Gren). The company; *Mawen Motor Corporation,* was located in NYC. From 1936 on, several types of engines were developed under a rotary engine principle, as well as several bi-rotating engines.



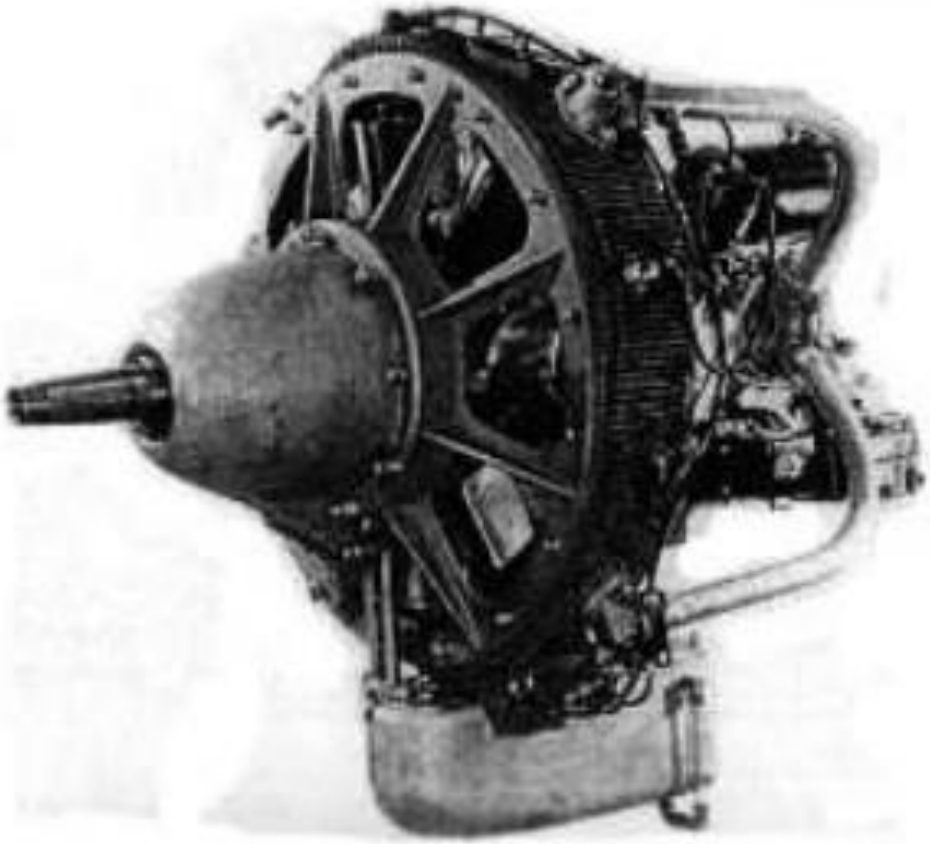


Based on the patents (1919) of the Hungarian *Ignacz Sklenar*, the engine was known as the "Mawen-Rotant." The first would be the 5-cylinder star in which the cylinders rotated in the opposite direction to the helix. The five cylinders rotated at 1/5 of the engine speed; the 7-cylinder engine rotated at 1/7 of the crankshaft speed and a 9-cylinder engine rotated at 1/9 of the propeller shaft speed. The 5-cylinder engine was small and only produced 20-hp. The crankshaft rotated at 4K rpm and the cylinders at 800 rpm.

Left: caption: "Sklenar Principle"

Right: caption: "7-cylinder Mawen"





The 20S was 80-hp with seven cylinders and the Mawen 25S was designed for 100-hp. The 20S (left) and 25S (right) were developed in the U.S. by aeronautics professor *André J. Meyer,* a Dutch resident who was in-charge of the Werner-Gren Aeronautical Laboratory in Lexington, KY. However, they were built in France by Mathis and in Sweden, by Aberg.



The French 9-cylinder engine produced 150 nominal hp and 170-hp with a supercharger. While the cylinders were turning at 400 rpm, the crankshaft was turning at 3,600 rpm, reduced by half in the reduction gear, or 1800 rpm. A 14-cylinder engine with two 7-point engines, theoretically, produced 700-hp. In the end, the engine proved unsuccessful.

<u>Caption</u>: "Photograph of a cylinder block from the Mawen rotary engine, which rotates within a ring containing the intake and exhaust ports"

Flat Engines

"…Flat engines range from the Evergreen Potez, complete with a cowling of comparatively conventional shape, to such types as the 70-hp flat-four Minié and the 50-hp Lycoming…"
***FLIGHT,* December 8, 1938**
RE: *Établissements Victor Minié,* based in Colombes, France, only built low-power, flat-four aero-engines using light alloy castings. The 4 B0 was available with either single or dual ignition but all others had dual ignition. The 4.D series (also dual ignition engines) were larger and more powerful. Production began in 1938 but was Halted by the Occupation of France, production began again in 1946, continuing until the company closed in 1954. The name "Horus" was used with all Minié's engines from the mid-1930s until 1949. Apart from the D4 Horus, all post-war engines had separate head and cylinder castings rather than the pre-war pairs.

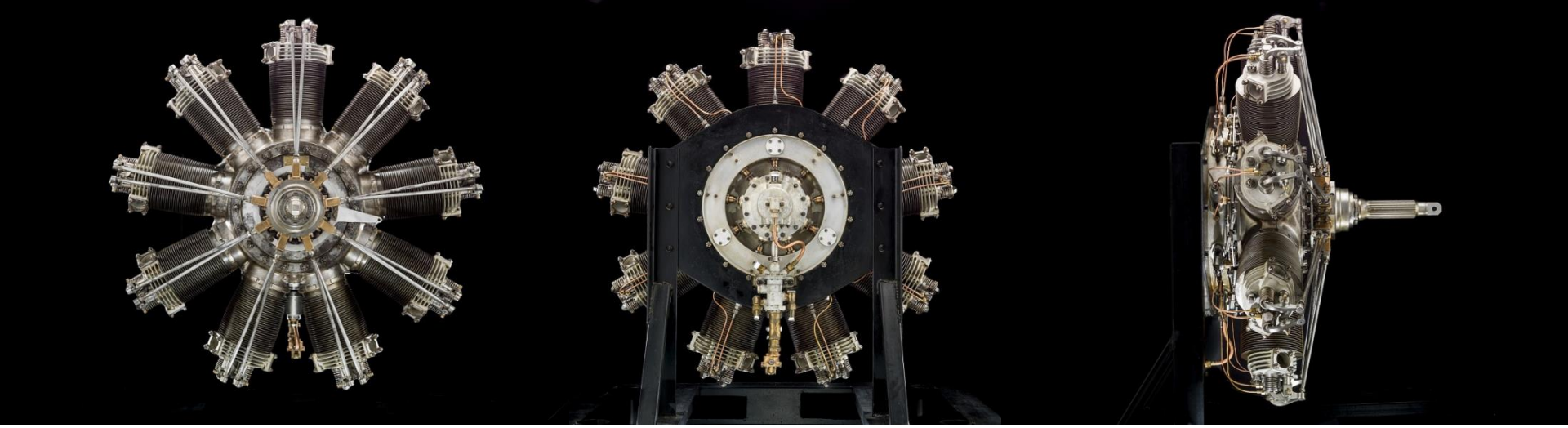
Minié 4.D4 Horus at the Flugausstellung Peter Junior, showing the early paired cylinder castings



In-lines

"…There is the usual array of attractive four and six in-lines with De Havilland and Cirrus well to the fore. The Bloch concern have weighed in with a four and a six which are distinctive chiefly in the grouping of the cylinders…"
***FLIGHT,* December 8, 1938**

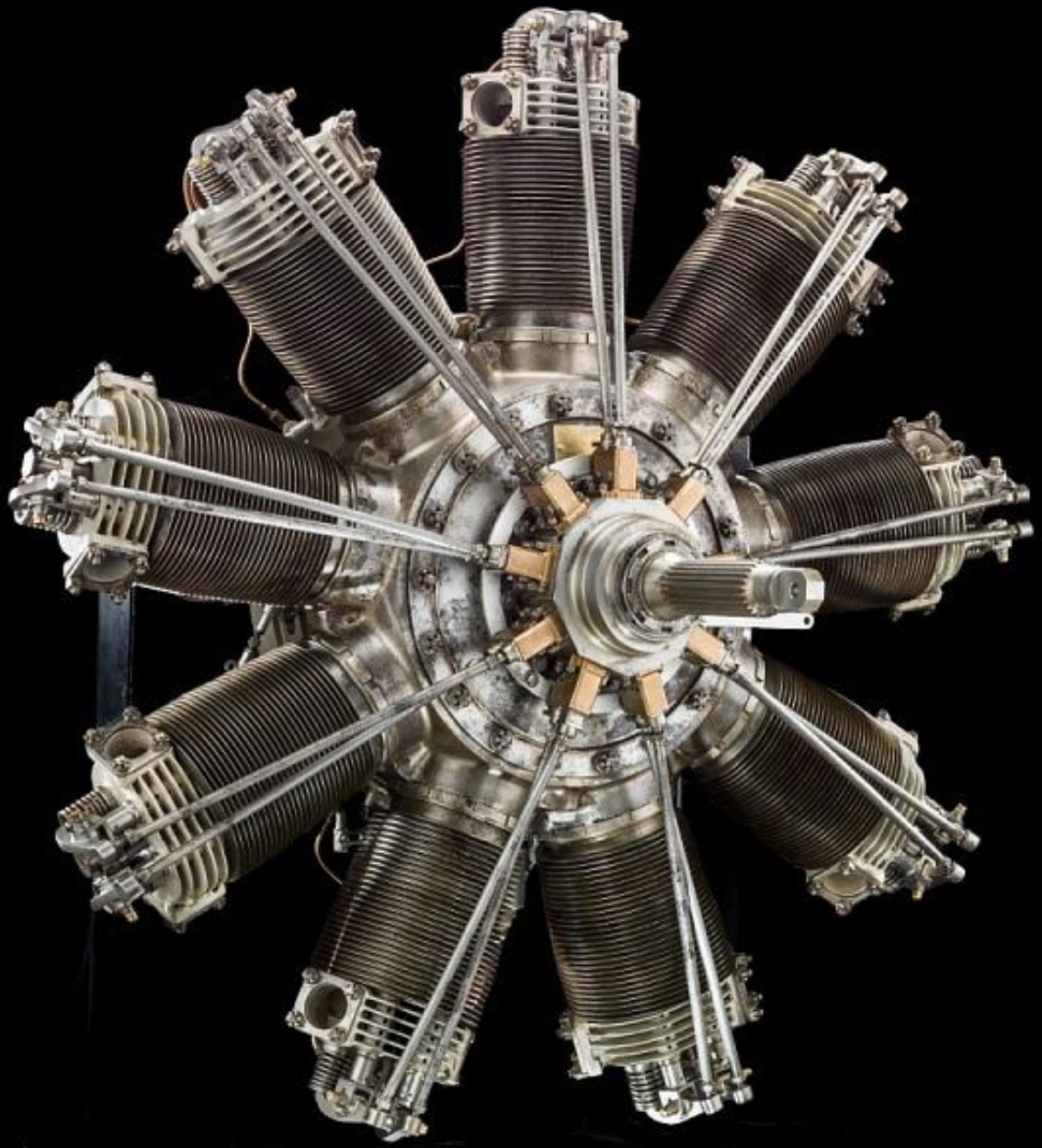
Little Evidence



"…There is little evidence of Diesel progress apart from the experimental 1,500/2,000-hp 16-cylinder unit shown by the French Air Ministry, though examples of the Daimler-Benz airship engine; the Coatalen vee-twelve and the Clerget radial, may be studied."

***FLIGHT,* December 8, 1938**

RE: *Pierre Clerget* was inspired by the Gnome to produce an improved rotary engine in 1911. It was a 7-cylinder, 725 cu. in. engine rated at 80 hp at 1,200 rpm. Thousands of these engines were manufactured in France and Britain. Larger 9-cylinder rotary engines began production in 1913. In the 1920s, Clerget transitioned to 4-stroke diesel engines, which initially had dimensions similar to the rotaries. The Clerget 9A (above, left-to-right) was built by Clerget, Blin and Cie of Paris, with development beginning in 1928. On Sept. 28, 1929, in a Morane 135 aircraft, it became the first diesel aircraft engine to fly in France. This engine was followed by the 200 shp 9B in 1930, the 250 shp 9Br (which was reversible in flight) in 1931 and the 300 shp 9C, in 1932.



1275

Part 9

Dynamic Duo

A Historical Comparison

The Kestrel and Merlin: Some New Facts: About Two Famous Liquid-cooled Units: A Historical Comparison

FLIGHT, **May 20, 1937**

RE: introduction to an article entitled: "R-R's Latest"

Of Special Interest

"THIS being a period of recollection, the results of a comparison recently made by Rolls-Royce between the Eagle I - the first Rolls-Royce engine to go into large-scale production - and one of their modern Kestrel series (concerning which the latest information is given hereafter) is of special interest…"

***FLIGHT,* May 20, 1937**

Apples & Apples

"…The Kestrel X has been chosen because, like the Eagle, it is rated at full-throttle at sea-level, precluding the complications introduced into a direct comparison by supercharging…"

***FLIGHT,* May 20, 1937**

Ups & Downs

"…The power output per-unit of cylinder capacity has increased by 20 per cent, the b.m.e.p. by 59 per cent, the specific weight has been reduced by 52 per cent and the fuel consumption by 33 per cent…"

***FLIGHT,* May 20, 1937**

"…In spite of these advances, the normal running life between overhauls is 500 hours, compared with the 60 hours obtainable in 1915, indicating that the large increase in performance has been combined with corresponding gains in reliability. These improvements, of course, have been made possible by all-round development and improved materials and fuels…"

***FLIGHT,* May 20, 1937**

"…Comparison between the Eagle I and a modern Kestrel supercharged type like the XVI, which gives 745-hp at 14,500 ft., would show an even more striking contrast…"
***FLIGHT,* May 20, 1937**

Composite Cooling

"…All the Kestrel engines, with exception of the unsupercharged models, are cleared for operation with two-position variable-pitch airscrews and have been tested for composite cooling, which implies that the system may be operated right up to its boiling point under a slight degree of pressure which permits the use of a smaller radiator than would be possible with a normal system of water cooling…"

***FLIGHT,* May 20, 1937**

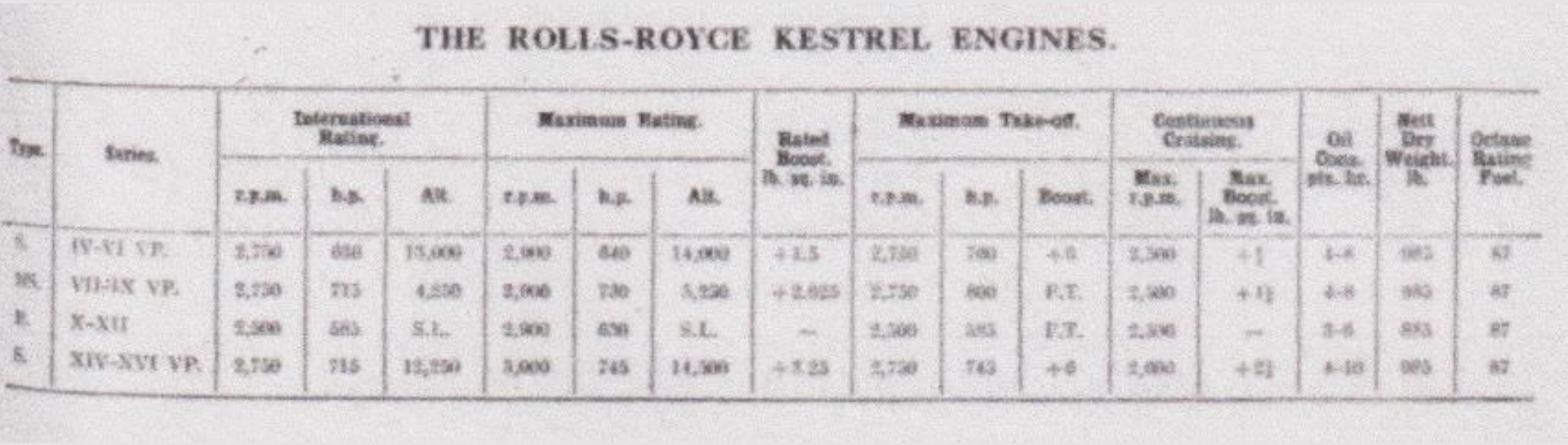
"…Since the radiator is inadequate to dissipate all the heat generated on the climb, a slight degree of boiling occurs, but in level flight the engine operates as a straightforward water-cooled unit…"

***FLIGHT,* May 20, 1937**

"…By locating the radiator in a special cowl having an adjustable flap at its exit, the cooling can be controlled and the radiator drag at high speed reduced. Composite cooling, therefore, reduces the direct drag due to the size of the radiator and also the interference drag…"

***FLIGHT,* May 20, 1937**

Kestrel Performance Data



THE ROLLS-ROYCE KESTREL ENGINES.

Type.	Series.	International Rating.			Maximum Rating.			Rated Boost. lb. sq. in.	Maximum Take-off.			Continuous Cruising.		Oil Cons. pts. hr.	Nett Dry Weight. lb.	Octane Rating Fuel.
		r.p.m.	h.p.	Alt.	r.p.m.	h.p.	Alt.		r.p.m.	h.p.	Boost.	Max. r.p.m.	Max. Boost. lb. sq. in.			
S.	IV-VI V.P.	2,750	630	15,000	2,900	640	14,000	+1.5	2,750	700	+6	2,500	+1	4-6	925	87
MS.	VII-IX V.P.	2,750	715	4,250	2,900	730	5,250	+2.625	2,750	800	F.T.	2,500	+1½	4-6	950	87
R.	X-XII	2,500	585	S.L.	2,900	650	S.L.	—	2,500	685	F.T.	2,300	—	3-6	955	87
S.	XIV-XVI V.P.	2,750	715	12,250	3,000	745	14,500	+3.25	2,750	765	+6	2,600	+2½	4-10	995	87

"…All the Kestrel engines have completed the supplementary test for running at economical cruising consumption and for dive-bombing at speeds in excess of the maximum rpm. The main performance data relating to the current Kestrel series, which are available with a wide range of standard ace-ssories, are given in the accompanying table…"

1292

***FLIGHT,* May 20, 1937**

Merlin Supplemental Data

"…Some additional information on the Merlin has lately been released. This engine has a bore and stroke of 5.4 in. and 6 in. respectively, giving a total cylinder capacity of 1,647 cu. in., or 27 liters This engine has been designed for high-temperature liquid-cooling, using ethylene glycol as the cooling medium. The international rated power is 990-hp at 12,000 ft., the maximum output being 1,050-hp on standard service fuel of 87 octane number. The net dry-weight is 1,318.5 lbs…"
***FLIGHT,* May 20, 1937**





Two recent Merlin installations: above, in the Hawker P.4/34 light bomber, and, on the right, the Fairey to the same specification. Both radiators have a flap to suit cooling to varying flight conditions. (*Flight* photographs)

R&D

"…In addition to intensive engine development, the Rolls-Royce Company has concentrated recently on the development of engine installations possessing the combined advantages of reliability, low-drag and minimum weight…"
***FLIGHT,* May 20, 1937**

"…To these ends, the engine mounting has been arranged to permit the radiator being carried close to the crankcase and by mounting the header tank round the nose of the reduction gear, the amount of piping in the system has been reduced to a minimum…"

***FLIGHT,* May 20, 1937**

"…Advantage of recent research in the reduction of cooling drag has been taken by enclosing the radiator in a low-drag cowl in which the cooling is done by air at relatively low velocity. The flow of cooling air is controlled to suit various flight conditions by an adjustable flap at the exit from the cowl…"
***FLIGHT,* May 20, 1937**

"…A great deal of work has also been done on exhaust systems and a type has now been evolved which combines good noise and flame-damping properties with weight and head resistance…"

***FLIGHT,* May 20, 1937**

EFS

"…The investigation of the complex problems affecting powerplants is carried out by Rolls-Royce's special Experimental Flight Section, where all manner of questions are explored and teething troubles overcome…"

***FLIGHT,* May 20, 1937**

"…Valuable work in connection with the initial proof tests of new engines, the development of low-drag cooling systems, efficient exhaust systems and flight problems associated with the use of variable-pitch airscrews has already been done. It is thus possible to make recommendations based on practical results to aircraft requiring information on power-plant layout."

***FLIGHT,* May 20, 1937**

Liquid-cooled V-type

Liquid-cooled power units with V-type cylinder formation
***Wonders of World Aviation,* August 2, 1938**
RE: introduction to an article entitled: “Rolls-Royce Merlin and Kestrel”

Taking the Lead

"FOR a long time, the firm of Rolls-Royce, Ltd. has been closely identified with the development of the V-type liquid-cooled aero-engine…"

***Wonders of World Aviation,* August 2, 1938**

RE: R-R produced a range of piston engine types for aircraft use in the first-half of the 20th century. Production of own-design engines ceased in 1955 with the last versions of the Griffon; licensed production of Teledyne Continental Motors general aviation engines was carried out by the company in the 1960s and '70s. Examples of R-R aircraft piston engine types remain airworthy, with many more on public display in museums.



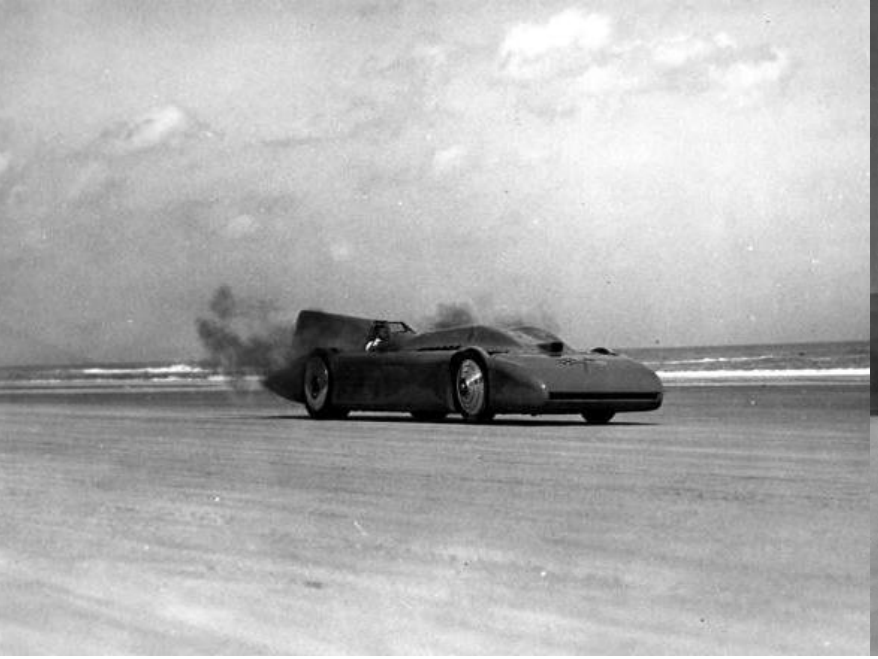
<u>Caption</u>: “A preserved Rolls-Royce Griffon 58, one of the last Rolls-Royce piston engines to be produced. The red and white ‘dumb-bell’ object to the left of the engine is an air-raid siren exhibit.”

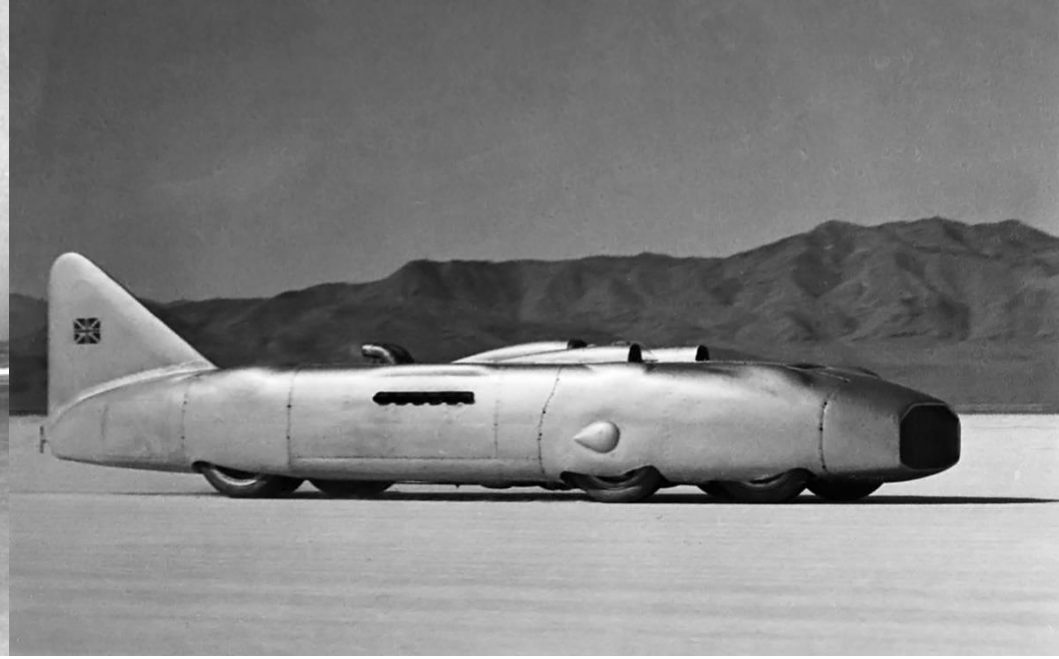
On Land and Sea

"…The Rolls-Royce R-type engine made a name for itself in connection with the last two Schneider Trophy races and also contributed to the success of many record-breakers on land and water…"

***Wonders of World Aviation,* August 2, 1938**

RE: the R-type was used with great success in the Schneider Trophy seaplane competitions held in England in 1929 and 1931. Shortly after the 1931 competition, an R engine using a special fuel blend powered the winning Supermarine S.6B aircraft to a new airspeed record of over 400 mph. Over its 18 years, the Schneider Trophy race did much to influence progress in aviation, most demonstrably in the increase in speed; from 45.71 mph, in 1913, to 340.08 mph in 1931. *A.F. Sidgreaves,* Managing Director of R-R, declared that it had compressed ten years of engine development into two. And yet, the heated competition did not really fulfill the original hopes of *Jacques Schneider,* who had envisioned it as a means of accelerating the development of reliable flying boats for rapid air transport around the world. Instead, by becoming, primarily, a quest for speed, the race had cost the lives of three British, two American and seven Italian pilots and ultimately led to the creation of more military aircraft than its founder had in mind.





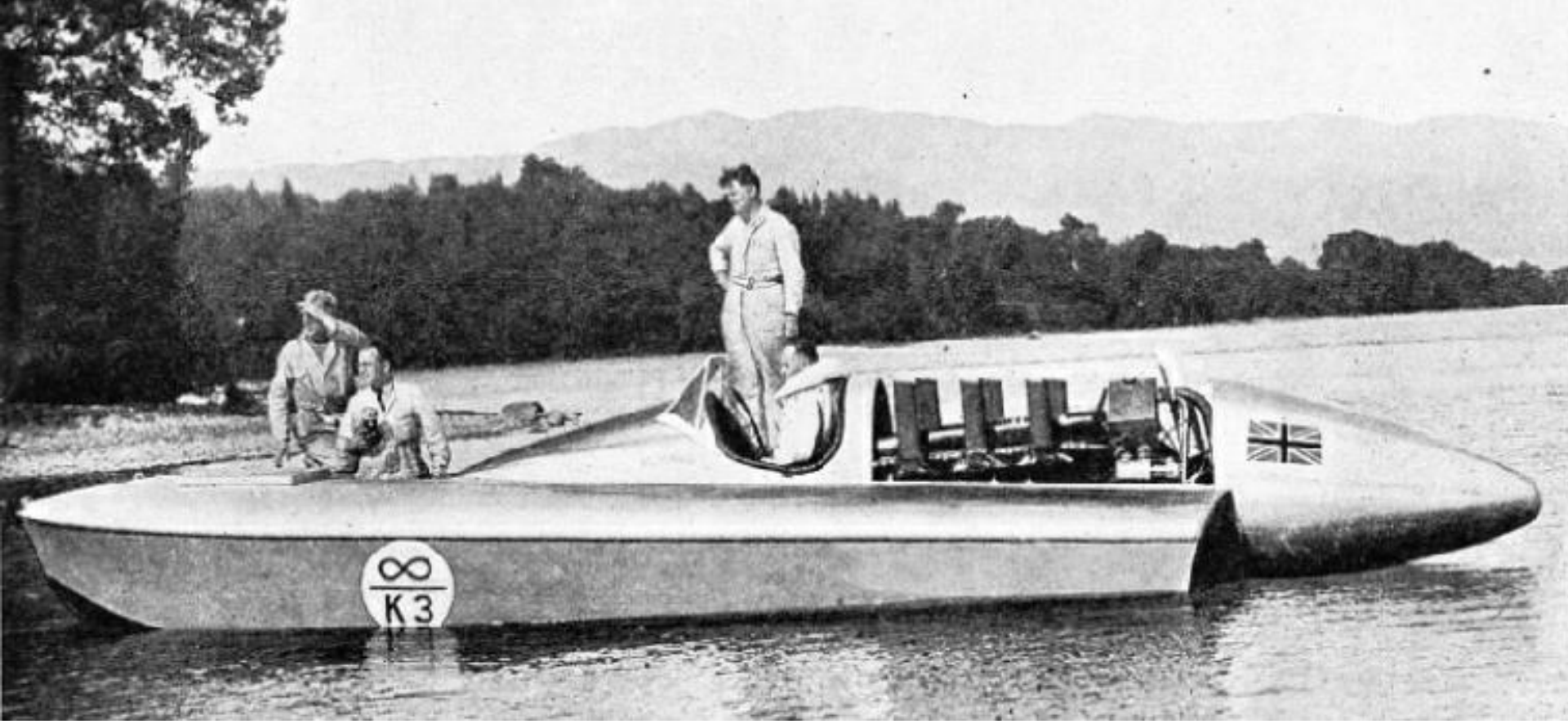
"…Sir Malcolm Campbell used one in his 1935 Blue Bird, the first car to exceed 300 miles-an-hour. Captain Eyston used one when he increased the world's land speed record to over 311 miles-an-hour in 1937…"

***Wonders of World Aviation,* August 2, 1938**

RE: "Blue Bird" (or "Bluebird") was the name of various cars and boats used by *Sir Malcolm Campbell,* his son *Donald* and other family members to set land and water speed records

<u>Left</u>: caption: "Campbell-Railton Blue Bird"

<u>Right</u>: caption: "George Eyston in the Thunderbolt on the Bonneville Salt Flats in 1937"



"…The world's water speed record of 129.5 miles-an-hour was achieved in 1937 by Sir Malcolm Campbell with a Rolls-Royce R-type engine…"

***Wonders of World Aviation,* August 2, 1938**

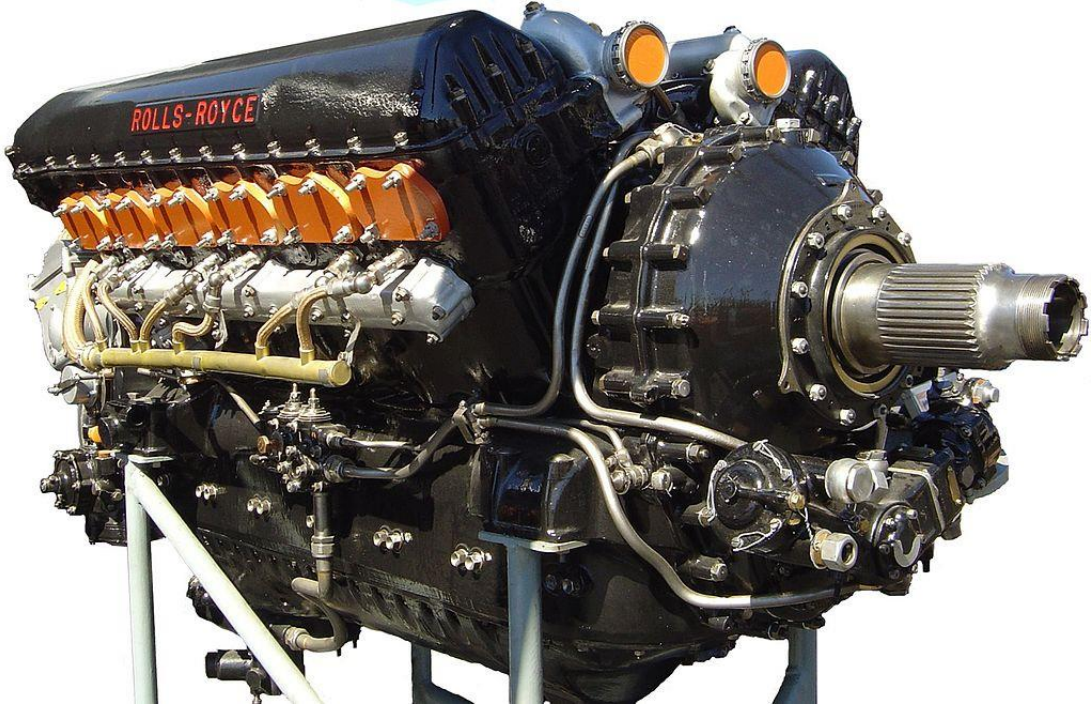
RE: the development of the racing hydroplane was so rapid that speeds had been increased from 60 to 130 mph in a twenty year period. In September 1937, *Sir Malcolm Campbell* regained the record for Great Britain with his Rolls-Royce engined *Blue Bird*. He attained a speed of 129.5 mph on Lake Maggiore.

<u>Caption</u>: "SIR MALCOLM CAMPBELL AT THE WHEEL of his hydroplane, *Blue Bird*, during preliminary trials on Loch Lomond, Scotland"

1312

The Power to Serve





"…Representative of the name of Rolls-Royce today are the Kestrel and Merlin types of engines, both of which are extensively used in high-performance service aircraft…"

***Wonders of World Aviation,* August 2, 1938**

RE: the R-R Kestrel (internal type F) was a 21.25 liter V-12 aero-engine. It was R-R's first cast-block engine and was used as the pattern for most of their future piston-engine designs. Used during the interwar period, it was fitted to several British fighters and bombers of the era. During the WWII era, some 50 versions of the Merlin were built by R-R in Derby, Crewe and Glasgow, as well as by Ford of Britain at their Trafford Park factory, near Manchester.

<u>Left</u>: caption: "Streamlined Kestrel installation of the Hawker Hind" 1314

<u>Right</u>: caption: "The Rolls-Royce Merlin"

"…The Series XVI Kestrel is a fully supercharged engine developed for use with modern fuels. It has an international rating of 690-bhp at 11,000-feet and its maximum power rating for level flight is 745-bhp at 14,500-feet. It is a twelve-cylinder engine, with cylinders arranged in two banks of six inclined to each other at an angle of 60-degrees. The cylinders have a bore of 5 in. and a stroke of 5-1/2 in…"

***Wonders of World Aviation,* August 2, 1938**

RE: in 1925, R-R began designing a radically new 12-cylinder engine in which each of the two banks of six cylinders were formed from a single aluminum-alloy block. Named the "Kestrel," the engine was fitted with hand-starting gear and could achieve up to 745-hp at 14,500 ft. in later models. Kestrels were installed in numerous British and foreign aircraft, including the Hawker Hind.

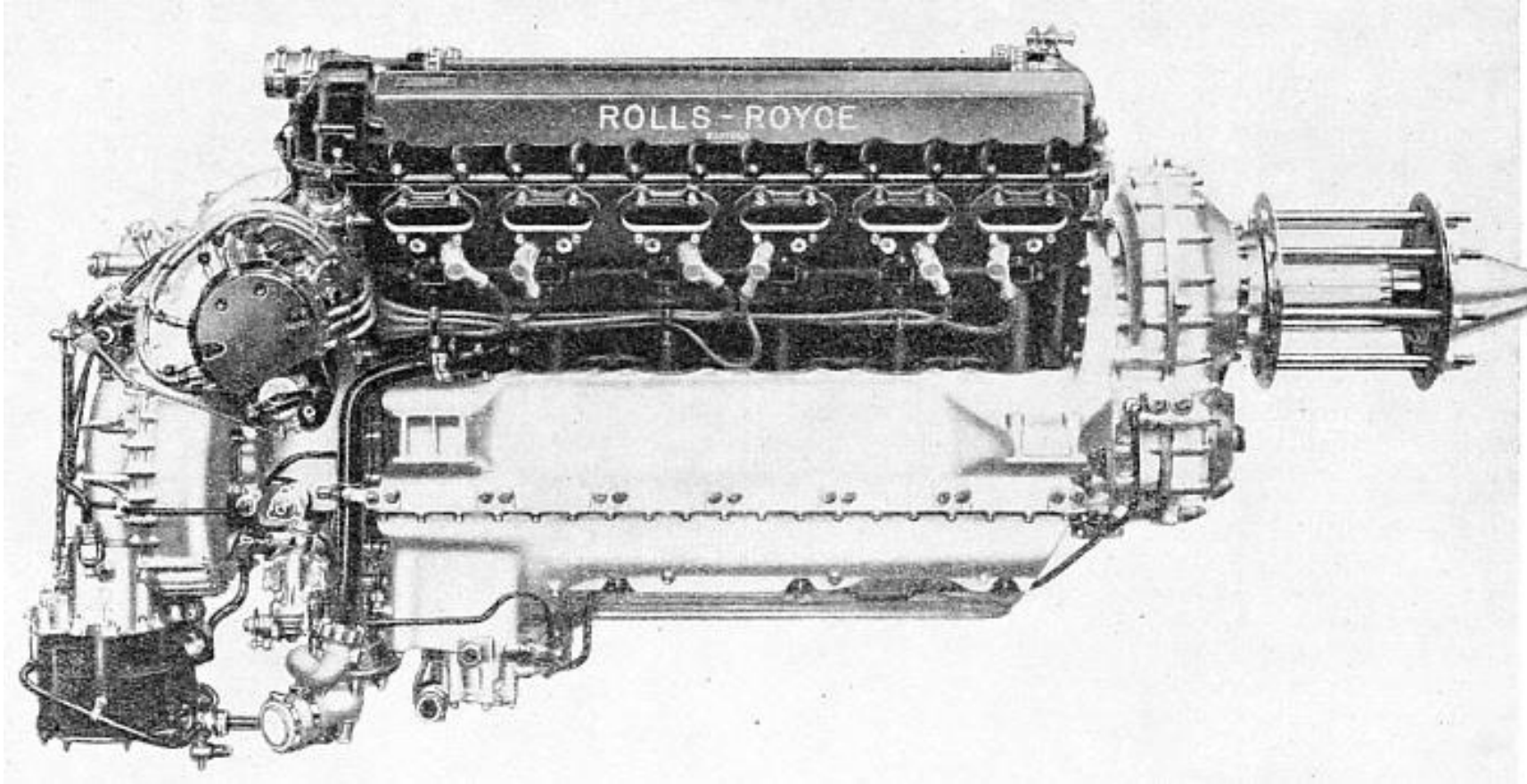
"…The Kestrel design has been improved from time-to-time without its basic features being altered. Higher degrees of supercharging and improved forms of supercharger, for instance, have been used and many minor refinements have been introduced…"

***Wonders of World Aviation,* August 2, 1938**

RE: in early Kestrel variants, unsupercharged engines were available in two compression ratios; "A" engines had a compression ratio of 6:1 and "B" engines a higher compression ratio of 7:1. The Kestrel was designed to be fitted with a gear-driven supercharger (in early Kestrel variants "MS" engines were moderately supercharged and "S" engines were fully supercharged). A number of Kestrel variants were produced by rebuilding or modifying earlier Marks.

"…The engine uses 'composite cooling;' the cooling system may be operated right up to its boiling point under a slight degree of pressure, which makes possible the use of a smaller radiator than would otherwise be necessary. A slight amount of boiling when the aircraft is climbing is allowed for, as the radiator is not big enough to dissipate all the heat generated during a climb…"

***Wonders of World Aviation,* August 2, 1938**



<u>Caption</u>: "COMPOSITE COOLING is a feature of the Rolls-Royce Kestrel engines. In level flight the engines are entirely water-cooled. When climbing a slight amount of boiling is allowed for, thus permitting a smaller radiator to be used than would otherwise be permissible. Reduction gearing for driving the propeller is provided and a choice of three gear ratios is available."

"…In level flight, the engine is entirely water-cooled. The radiator is located in a cowl which has an adjustable flap at its exit to control the degree of cooling. This system reduces the drag at high speeds…"

***Wonders of World Aviation,* August 2, 1938**

"…The Series XVI Kestrel engine has a compression ratio of 6:1 and is fitted with a 'boost-control' of the automatic servo type. Another fitting is an accelerator pump with delayed action, which allows rapid and positive acceleration to be obtained. There is also a device for enriching the mixture when taking-off…"

***Wonders of World Aviation,* August 2, 1938**

RE: as a response to the fuel-injection systems developed by Bosch, in 1936 a Kestrel engine was fitted with a pressurized carburetor system to improve fueling at high altitudes. The resulting behavior of the engine when flight-tested by the Farnborough institute was seen to be: ". . . one of the smoothest engines they had used at high altitudes."

"…The Series XVI Kestrel is available in three types with different reduction ratios for the airscrew drive - 1:632, 1:553 and 1:477. Its performance figures with a variable-pitch air-screw differ slightly from those already quoted. With a var-iable-pitch airscrew it has an international rating of 715-bhp at 12,250-feet. The dry-weight of the Kestrel engine is 955 lbs…"

***Wonders of World Aviation,* August 2, 1938**

"…Hand starting gear is fitted to the engine, but provision is made for other methods of starting, to be fitted when preferred. Among the accessories that can be fitted to the engine are pumps for a retractable undercarriage and for a hydraulically operated gun turret…"

***Wonders of World Aviation*, August 2, 1938**



<u>Above</u>: Kestrel XVI (VP) (1937): 773-bhp maximum power with 3.25 psi boost at 3,000 rpm for 5 minutes using 87 octane fuel, 640 / 670 hp maximum continuous power. Fully supercharged, compression ratio 6:1.

Rolls-Royce Merlin XX

Model	Merlin XX.
Type	12 cylinders, vee 60 degrees, pressure water cooled, geared drive, supercharged, 4-cycle.
Construction	2-piece aluminum alloy crankcase. 2 aluminum alloy cylinder blocks with integral heads. Steel cylinder liners. 2 inlet valves and 2 exhaust valves (sodium cooled) per cylinder actuated by overhead camshaft. 6-throw 1-piece counterbalanced crankshaft supported in 7 plain bearings. Spur reduction gear, ratio 0.42:1.
Supercharger	Gear-driven 2-speed supercharger, ratios 8.15:1 and 9.49:1.
Carburation	1 S.U. AVT40 twin-choke updraft carburetor with automatic mixture control and automatic boost control.
Ignition	2 B.T.H. C5SE12-S or 2 Rotax NES12-4 magnetos. 2 spark plugs per cylinder. Shielded wiring.
Lubrication	Pressure feed, 70 lb./sq.in. (4,9 kg/cm²).
Starter	B.T.H. hand and electric starter.

Bore	5.40 in.	137 mm
Stroke	6.00 in.	152 mm
Displacement	1,649 cu.in.	27,0 l
Compression ratio	6.0:1	6,0:1
Width	29.8 in.	0,757 m
Height	41.2 in.	1,046 m
Length	70.6 in.	1,793 m
Frontal area	5.8 sq.ft.	0,54 m²
Weight	1,450 lb.	658 kg
Weight/horsepower	0.98 lb.	0,44 kg
Fuel consumption (cr.)	0.52 lb./h.p./hr.	235 g/hp/hr
Oil consumption (cr.)	0.022 lb./h.p./hr.	10 g/hp/hr
Gasoline rating	100 octane (D.E.D. 2475)	100 octane
Oil grade (viscosity)	100 S.U. (D.T.D. 472-B)	20,5 cs
Output/displacement	0.90 h.p./cu.in.	54,8 hp/l
Output/piston area	5.38 h.p./sq.in.	0,83 hp/cm²
Piston speed (max.)	3,000 ft./min.	15,2 m/sec
B.m.e.p. (max.)	238 lb./sq.in.	16,7 kg/cm²

Output (take-off)	1,280 h.p./3,000 r.p.m./54.3 in. (1 380 mm) Hg. boost
Output (combat)	1,480 h.p./3,000 r.p.m./6,000 ft. (1 800 m)
	1,480 h.p./3,000 r.p.m./12,500 ft. (3 800 m)
Output (cruising)	1,100 h.p./2,650 r.p.m./9,250 ft. (2 800 m)
	1,040 h.p./2,650 r.p.m./16,000 ft. (4 900 m)
Merlin 21:	Same as Merlin XX, but has reverse coolant flow.
Merlin 22:	Similar to Merlin XX.

"…The Merlin engine is a more recent production of the Rolls-Royce Company. It is of the 12-cylinder fully super-charged V-type. Its 54 in. bore and 6 in. stroke are larger than those of the Kestrel. These figures give the Merlin a total cylinder displacement capacity of 27 litres…"

Wonders of World Aviation,

August 2, 1938

RE: the first major version to incorporate changes brought about through experience in operational service was the XX, which was designed to run on 100-octane fuel. This fuel allowed higher manifold pressures, which were achieved by increasing the boost from the centrifugal supercharger.

"…This engine is fitted to many types of military aircraft, including such widely different types as high-speed fighters and heavy bombers. It is used where the maximum performance of the aircraft is required at altitudes of the order of 15,000-feet…"

***Wonders of World Aviation,* August 2, 1938**

RE: the Merlin II and III series were the first main production versions of the engine. The Merlin III was the first version to incorporate a "universal" propeller shaft, allowing either de Havilland or Rotol manufactured propellers to be used.

"…In its main constructional features the Merlin follows well-tried Rolls-Royce practice, but incorporates innovations of recent years. It is designed for cooling by ethylene glycol. This method of cooling operates at a relatively high temperature and the high temperature difference between the cooling liquid and the surrounding air permits the use of a small radiator - an enormously important feature in modern streamlined aircraft of high-performance. The radiator is enclosed in a pressure cowl and the flow of cooling air is controlled by an adjustable flap at the rear of this cowl. Drag is reduced to the absolute minimum by this means…"

***Wonders of World Aviation,* August 2, 1938**

RE: another improvement introduced with the Merlin X was the use of a 70%-30% water-glycol coolant mix rather than the 100% glycol of the earlier versions. This substantially improved engine life and reliability; removed the fire hazard of the flammable ethylene glycol and reduced the oil leaks that had been a problem with the early Merlin I, II and III series.

"…A centrifugal pump of high capacity is used for the cooling fluid. The supercharger, although its general design is based on previous practice, is arranged to deal with the large volume of air required by the Merlin engine working at maximum output…"

***Wonders of World Aviation,* August 2, 1938**

RE: the Merlin XX utilized the two-speed supercharger, designed by R-R, resulting in increased power at higher altitudes than previous versions of the engine

Special Carburetor Design

"…The carburetor is of special design and embodies many interesting features. It is of the updraught type and the richness of the mixture is automatically controlled by aneroids operated by atmospheric and supercharger pressures…"

***Wonders of World Aviation,* August 2, 1938**

RE: the Merlin XX featured a re-designed supercharger incorporating re-designed inlet and improved guide vanes on impeller with revised blower gear ratios: 8:15:1 for low-gear; 9:49:1 for high-gear as well as a new, larger, SU twin-choke updraft carburetor

"…Should the aneroid system fail the mixture returns automatically to fully rich, thus preventing damage to the engine through its running on a too weak mixture. Also, over-boosting of the engine with the cruising control in the weak position automatically opens the power jet to the full rich position…"

***Wonders of World Aviation,* August 2, 1938**

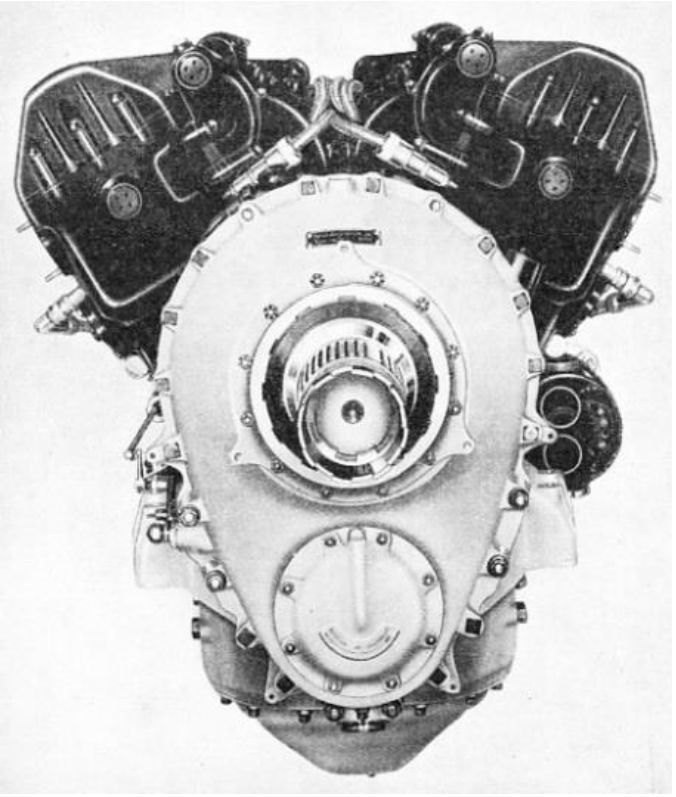
"…Any possible tendency towards freezing of the throttles at high altitudes is prevented by circulating the scavenge return oil through the hollow throttle valves. A bypass is incorporated in the system to prevent damage should the pressure become excessive…"

***Wonders of World Aviation,* August 2, 1938**

"…The twin fuel pumps are driven by independent shafts, so that if one fails, the working of the other is not interfered with. Each pump, working alone, is of more than sufficient capacity to meet the maximum demands of the engine…"
***Wonders of World Aviation,* August 2, 1938**

"…Dual ignition is provided, two twelve-cylinder type magnetos being used. The complete ignition system is screened for use in radio-equipped aircraft. The standard accessories include high- and low-pressure air-compressors, a hydraulic servo-pump for operating a retractable undercarriage, a shaft-driven electrical generator, a hydraulic pump for gun turret operation, a revolution counter, gun synchronizing gear and electric and hand starting gear. The electric starting gear is a twelve-volt electric motor mounted in a vertical position on the starboard-side of the engine…"

***Wonders of World Aviation,* August 2, 1938**



"…The Merlin engine, as will be seen from the illustration, has a small end section. Its lines are clean and the various auxiliary drives are arranged in neat fashion. Provision is made in the lubricating system to provide the oil-pressure for the operation of a variable-pitch airscrew…"

Wonders of World Aviation,

August 2, 1938

The Little Engine That Could

"…The international rating of the Merlin is 990-bhp at an altitude of about 12,000-feet. Under these conditions the engine is turning at a speed of 2,600 revolutions-a-minute. The maximum power is obtained at about 16,000-feet and 3,000 revolutions-a-minute and is approximately 1,030-bhp. Without oil the engine weighs 1,325 lbs."

***Wonders of World Aviation,* August 2, 1938**

RE: by the end of WWII, the "little" engine was delivering over 1,600-hp in common versions and as much as 2,030-hp in the Merlin 130/131 versions specifically designed for the de Havilland Hornet. Ultimately, during tests conducted by R-R at Derby, an RM.17.SM (the high-altitude version of the Merlin 100-Series) achieved 2,640-hp at 36 lbs. boost on 150-octane fuel with water injection.



Despite its size, the Merlin engine was powerful. Its comparably diminutive 27-liter displacement outperformed the 39-liter Daimler-Benz and 42-liter BMW engines used by the Luftwaffe. Aside from its wartime contribution, post-war aviation was significantly impacted by the R-R Merlin engine that helped win WWII. Many nations created airplane engines that integrated the technologies and the design philosophy of the Merlin.

Part 10

Par Excellence

First Details

First Details of Rolls-Royce Merlin I and II: Latest Model Has Non-Detachable Cylinder Heads: 1,030 hp at 16,250 ft.

***FLIGHT,* September 23, 1937**

RE: introduction to an article entitled: "Vee-Twelve Par Excellence"

Sea Change



"THE past year or two has seen the familiar Kestrel-engined bi-planes slide into obsolescence and new, cleaner monoplanes take form, fly and reach the production stage…"

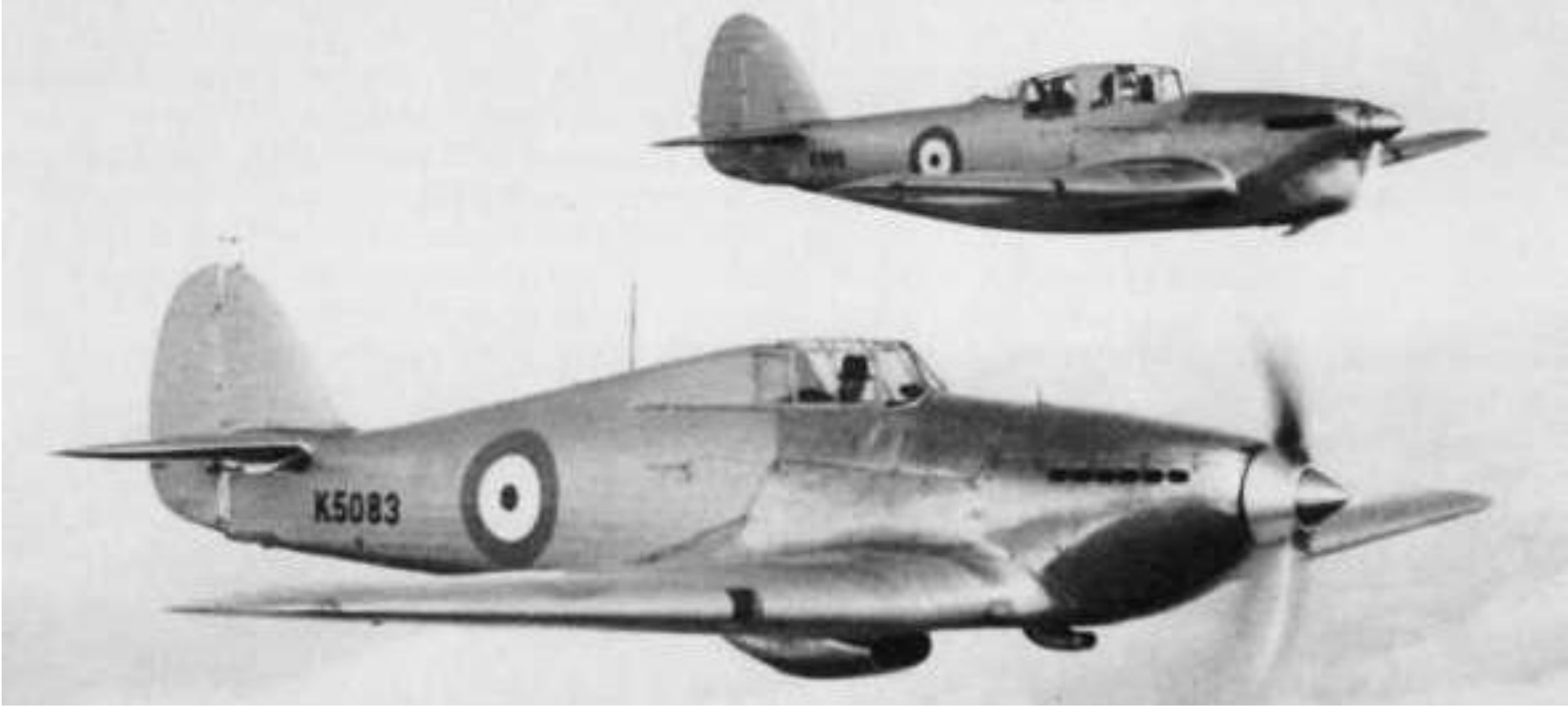
***FLIGHT,* September 23, 1937** 1342

<u>Caption</u>: "Hawker Demon bi-plane with Rolls-Royce Kestrel Engine"

Familiar Faces

"…Several of these newcomers, powered with Rolls-Royce Merlin engines, have retained the characteristically sleek nose associated with a Rolls-Royce power unit…"

***FLIGHT,* September 23, 1937**



"…Later a more 'snub' cowling may be supplied for the Merlin if the nose-position pressure radiator cowling as fitted to the Hawker Henley is deemed to be preferable to the mid-ventral or ventral installation. There are at present high-performance fighters and bombers featuring each of the three systems…"

***FLIGHT,* September 23, 1937**

RE: the Hawker Henley was described by a contemporary publication as being: "Streamlined, bullet-nosed, with wings rather like the fins of a gigantic fish."

<u>Caption</u>: "The prototype Henley and Hurricane flying together"



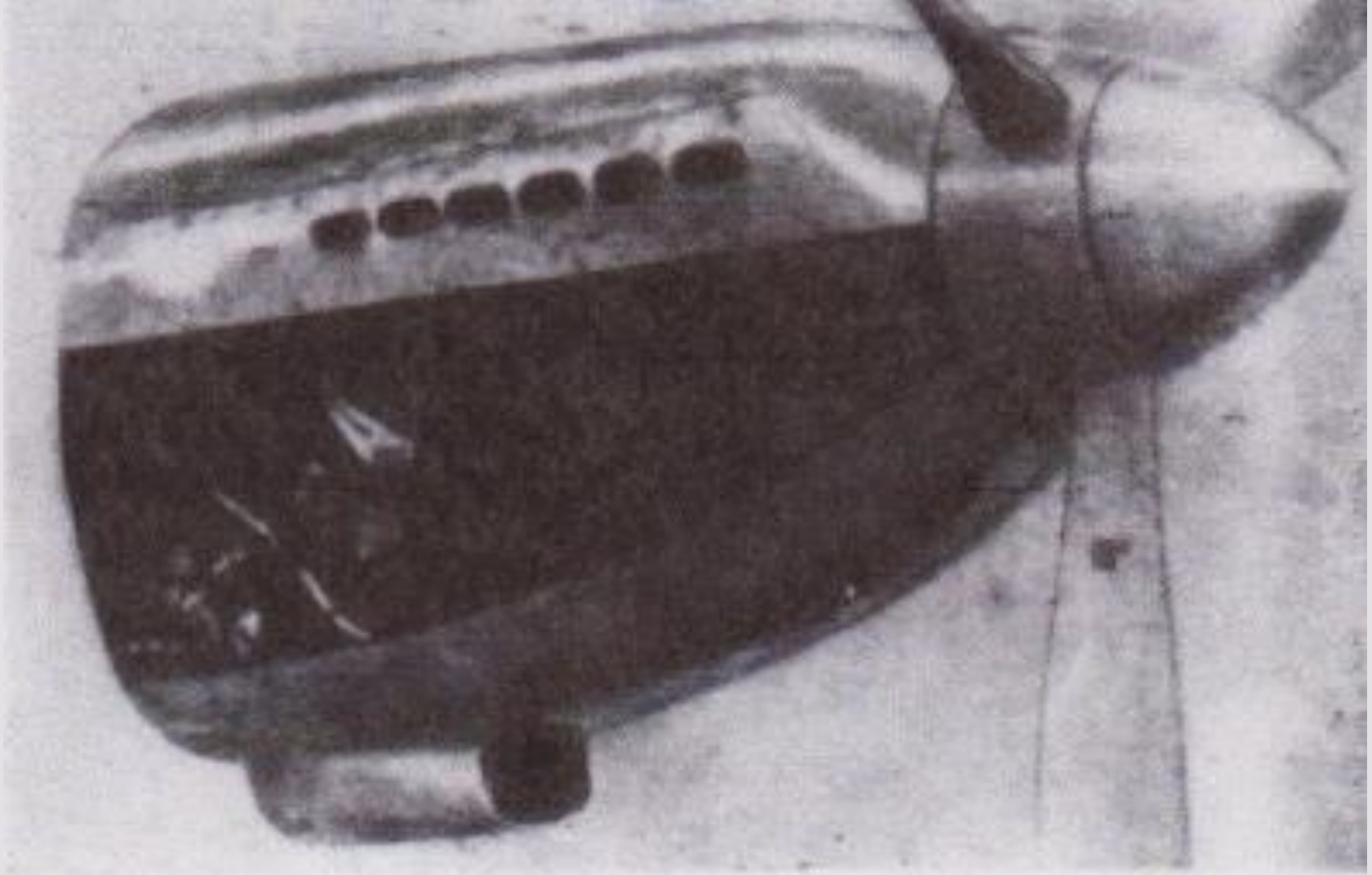
<u>Above</u>: the "ribbed" appearance of the rear fuselage; formed of fabric stretched over a wooden framework that surrounded the main metal structure, was a type of construction that was beginning to look old-fashioned when the Henley first flew. However, the same structure used on Hawker Hurricanes proved surprisingly strong and stood-up to hits from German 20mm cannon shells better than the monocoque fuselage of the Spitfire and was much easier to repair. It was an aircraft that pilots loved to fly, had outstanding performance and was both rugged and reliable. Two-hundred examples of the Henley were built

<u>Caption</u>: "The prototype Hawker Henley K5115 in side-view. Notice that, unlike the Hurricane, the Henley had a retracting tail-wheel. The observer/gunner had pull-down side windows."

Time Has Come

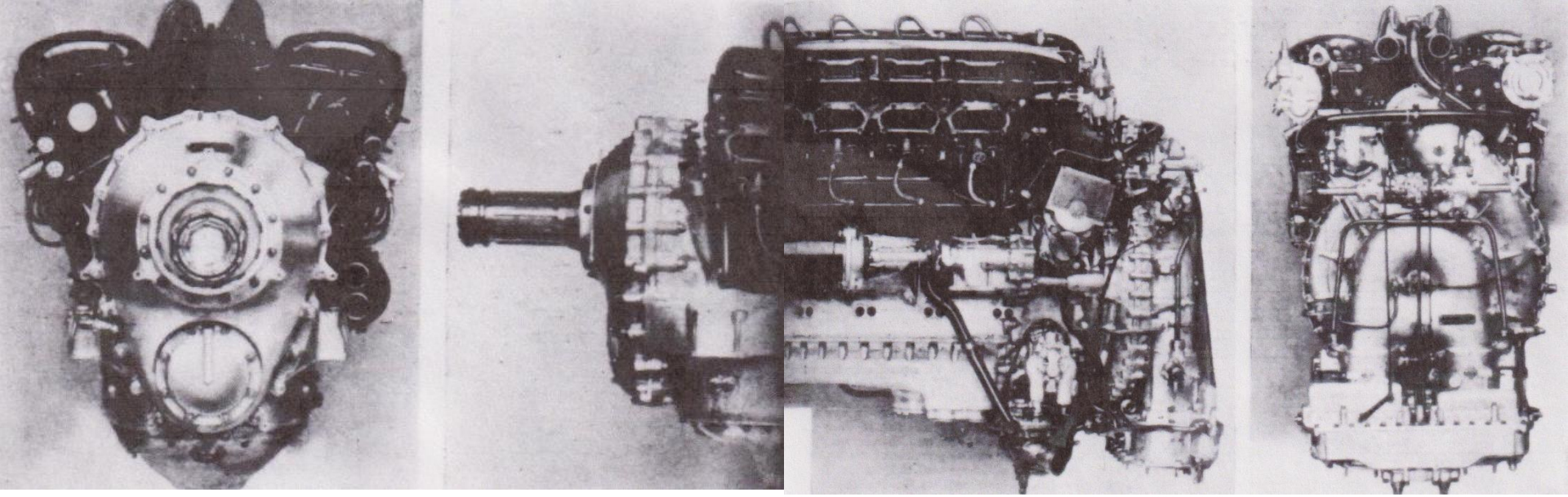
"…The time has now come when the origin of the many 'horses' beneath these cowlings may be investigated and the Merlin engine, which has already earned itself a world-wide reputation, can be discussed in detail…"

***FLIGHT,* September 23, 1937**



That the Merlin lends itself to clean and efficient cowling can be gathered from this illustration. Oil radiator and air intake can be seen, while the glycol radiator would probably be in the ventral position in this installation.

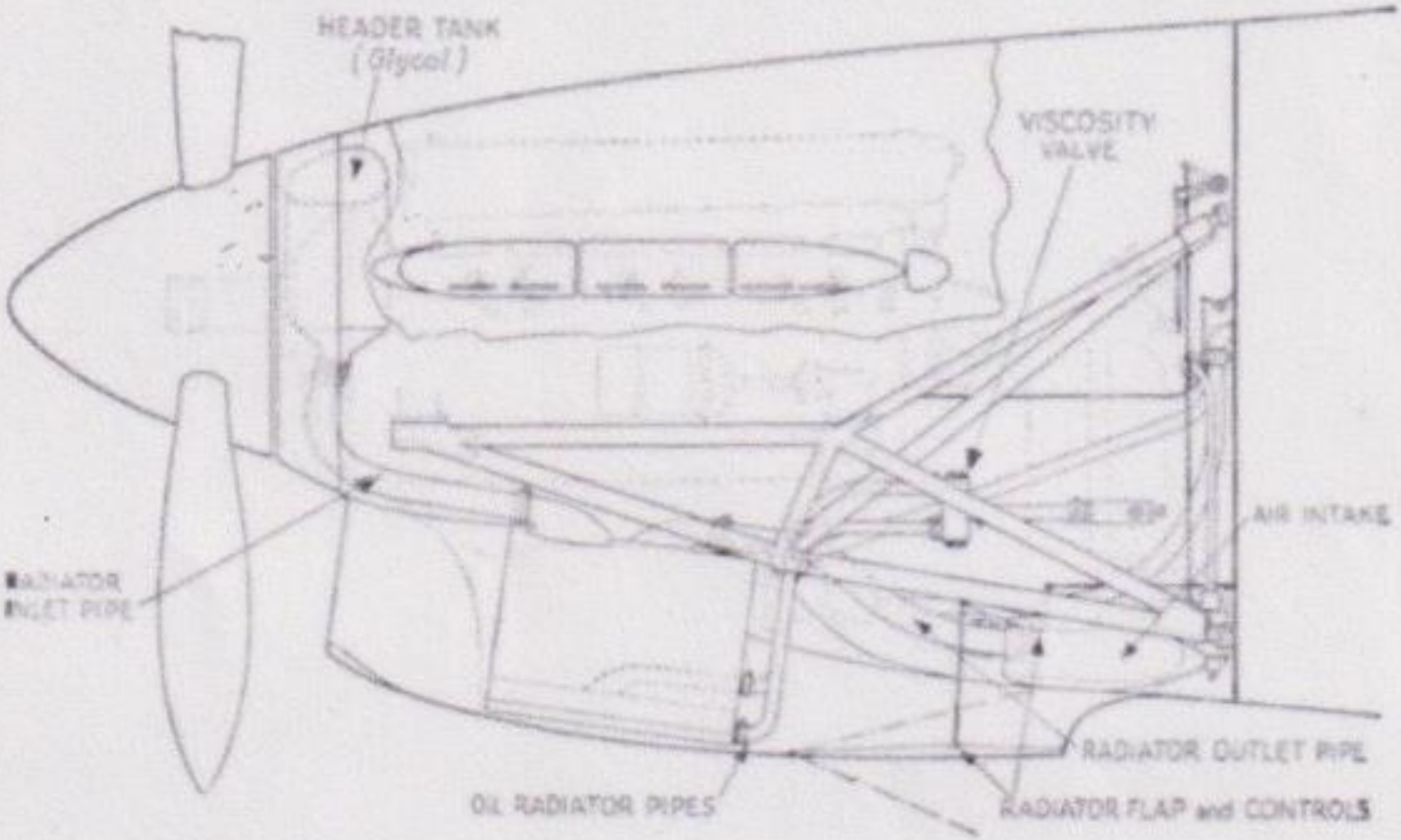
Proving-out



<u>Caption</u>: The Merlin I, with detachable cylinder heads and flat-topped cam covers. The external appearance also differs from that of the Merlin II in the cast coolant pipes.

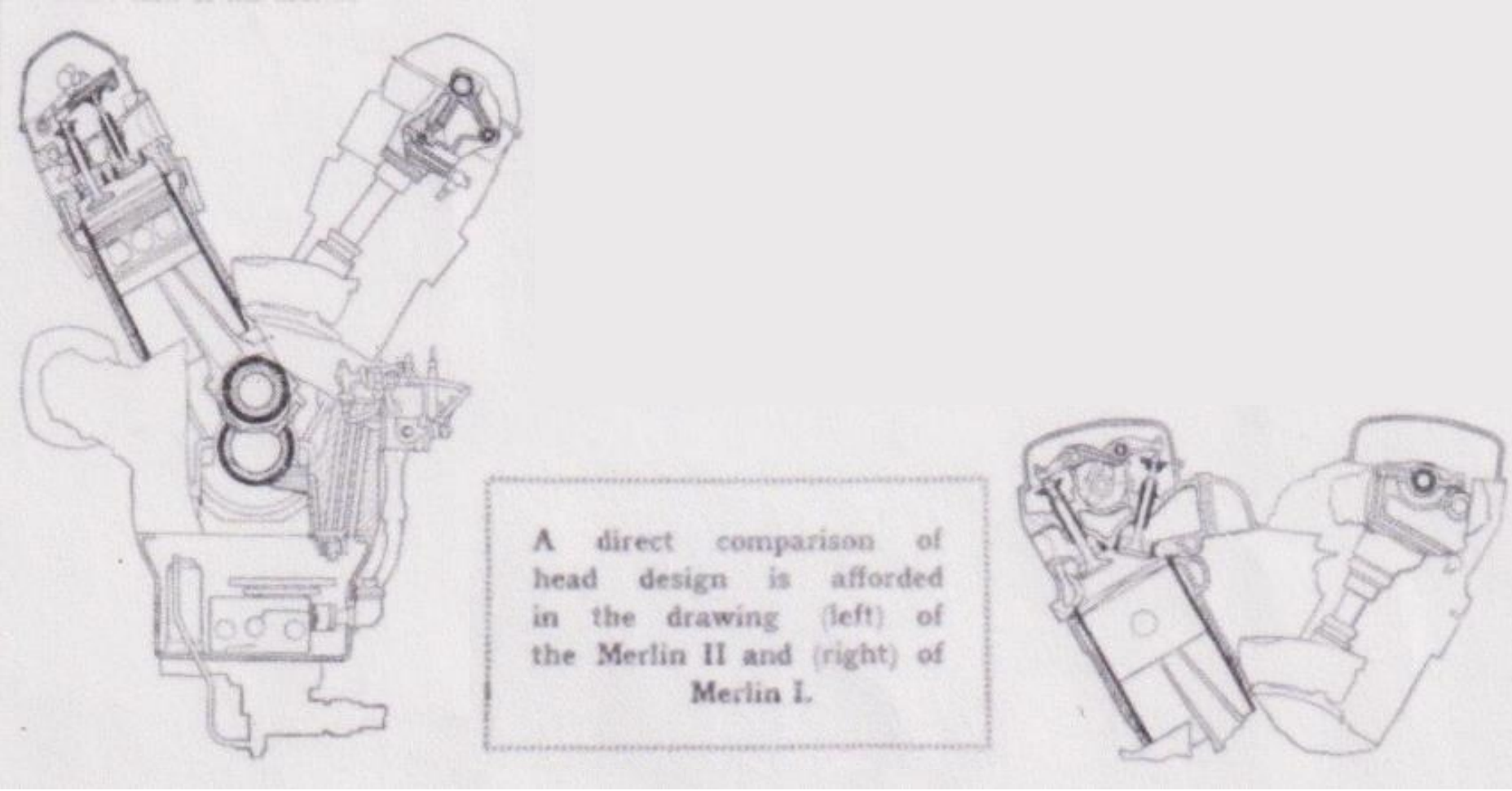
"…Merlin I and II engines have now flown for over 2,000 hours and exacting tests have shown a marked superiority over the early Kestrels, particularly in respect to the harsh treatment they will stand. It is claimed that no serious breakage has ever occurred in a Merlin II engine even under extreme flying conditions…"

***FLIGHT,* September 23, 1937**



Cooling systems and details of mounting are clearly shown in this drawing of a typical Merlin installation.

Distinctly Different



A direct comparison of head design is afforded in the drawing (left) of the Merlin II and (right) of Merlin I.

"…The chief difference between the Merlin I (or F) and II (or G) lies in the cylinder heads. Detachable 'ramp' heads were used on the Merlin I's, while the Merlin II's have blocks and heads cast in a unit, following the firm's extensive experience with this arrangement…"

***FLIGHT,* September 23, 1937**

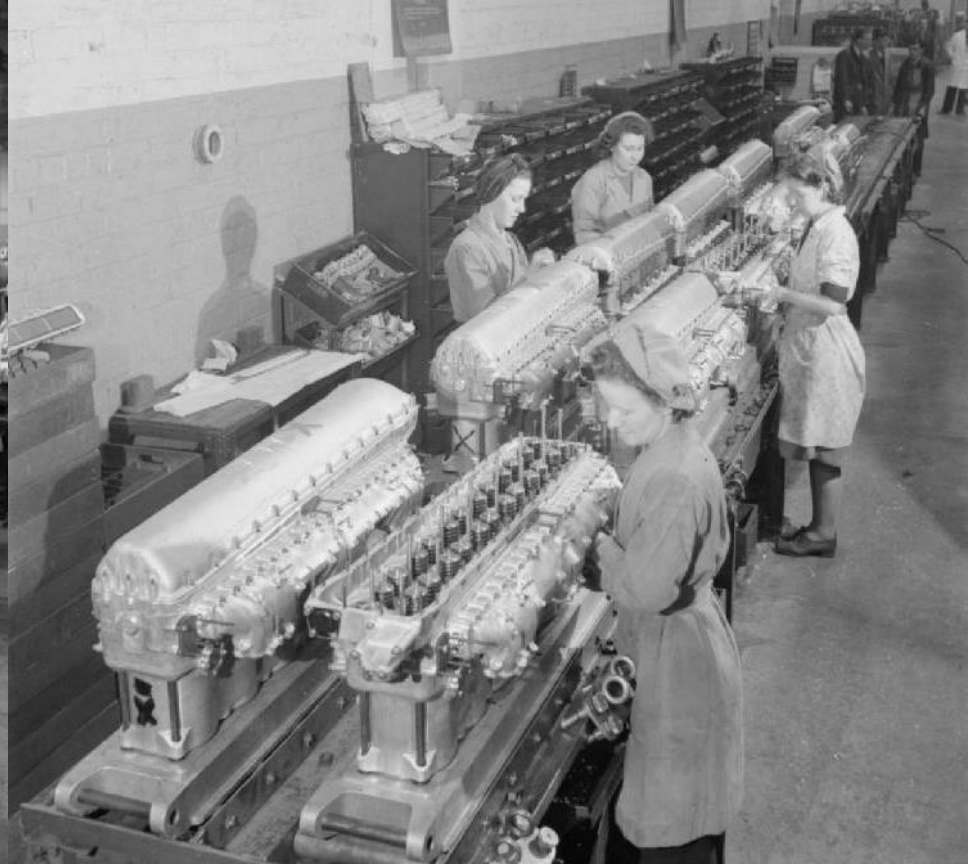
Maintaining Tradition

"…In keeping with the Rolls-Royce policy of many years standing, the general design embodies twelve cylinders in two banks of six set at 60-degrees. The cylinder banks have a common crankshaft, which at the front-end has a splined coupling to the spur-type reduction gear and at the rear-end drives the supercharger, camshafts and auxiliaries through a spring drive unit…"

***FLIGHT,* September 23, 1937**

I vs. II





"…The Merlin II cylinder block, like that of the Kestrels, is an aluminum casting fitted with 'wet' steel liners. An aluminum-alloy joint ring is arranged between the top shoulder of the liners and the block while at the bottom, a shoulder bears directly onto the crankcase. Fourteen long studs, the reaction of which is entirely upon the liners, secure each of the blocks…"

***FLIGHT*, September 23, 1937**

Left: caption: "The engine is ready for it's cylinders"

Right: caption: "Cylinders being assembled"

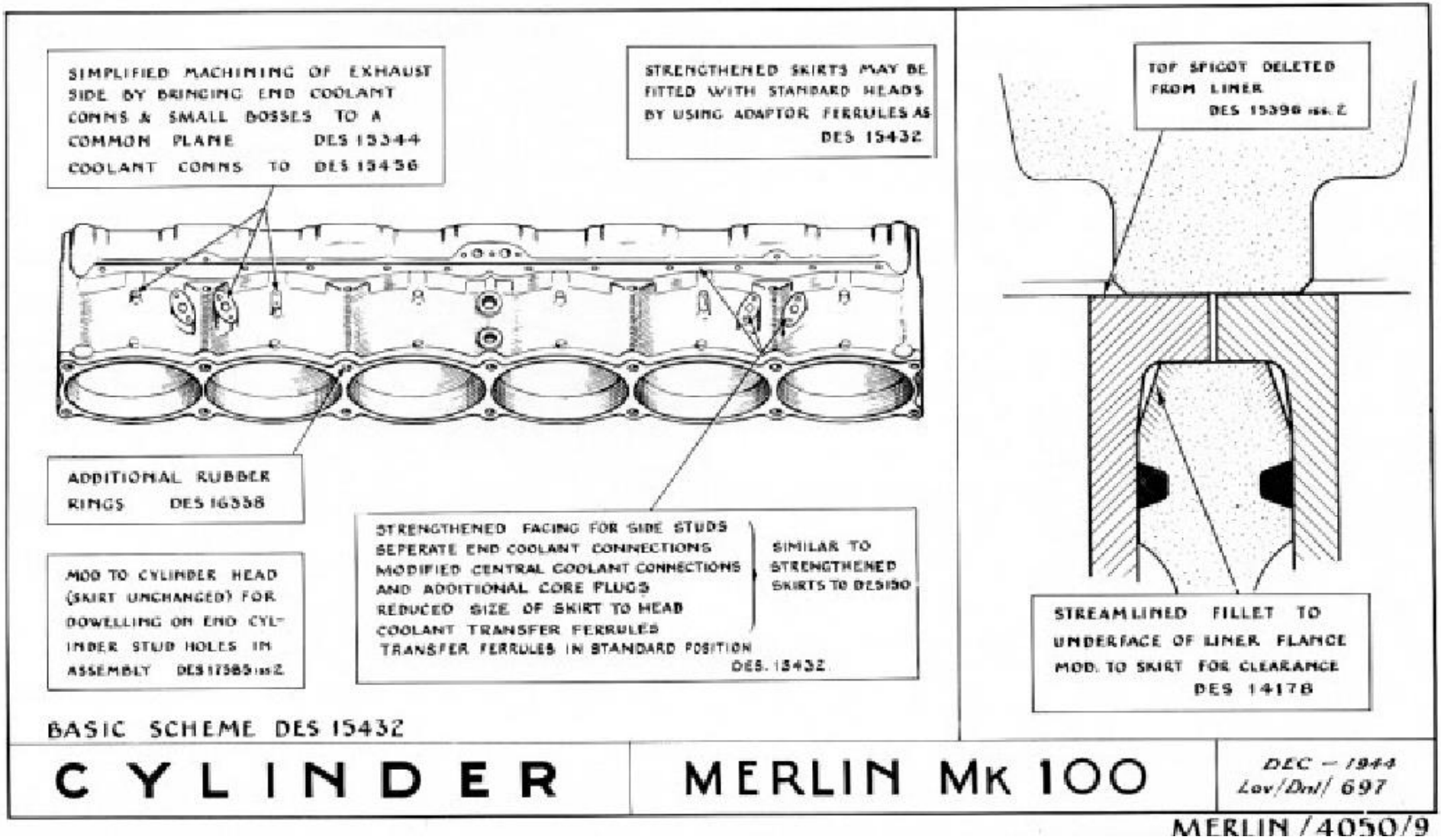
"…The lower coolant joint is a spring-loaded rubber ring located in an external groove on the liners. Oil from the overhead camshaft and rocker mechanism returns down stainless steel tubes let into the block, which are sealed from the coolant by rubber rings at each end and which carry the middle ten holding-down studs. An additional six studs on each side of the block - a system first tried on the Kestrel XVI - improve the face joints and prevent disturbance of the liners when the blocks are removed. The top ends of the additional studs are blanked-off and the lower ends made accessible through small separate covers on the blocks below the exhaust ports…"

***FLIGHT,* September 23, 1937**

"…Special 'turbulent' combustion chambers in a detachable head are a feature of the Merlin I in which the top flange of each liner is sandwiched between head and skirt with an aluminum joint ring above and below the flange. The head-liner-skirt assembly is secured by the usual fourteen large studs…
***FLIGHT,* September 23, 1937**

"…Both Merlin models have four valves per cylinder, each with two concentric return springs. Two sodium-cooled exhaust valves are on the outside of the head and two inlet valves on the inside. All four valves of the Merlin II are parallel to the centre-line of the block, but the two inlet valves in the detachable head of the Merlin I are inclined at about 45-degrees to the exhaust…"

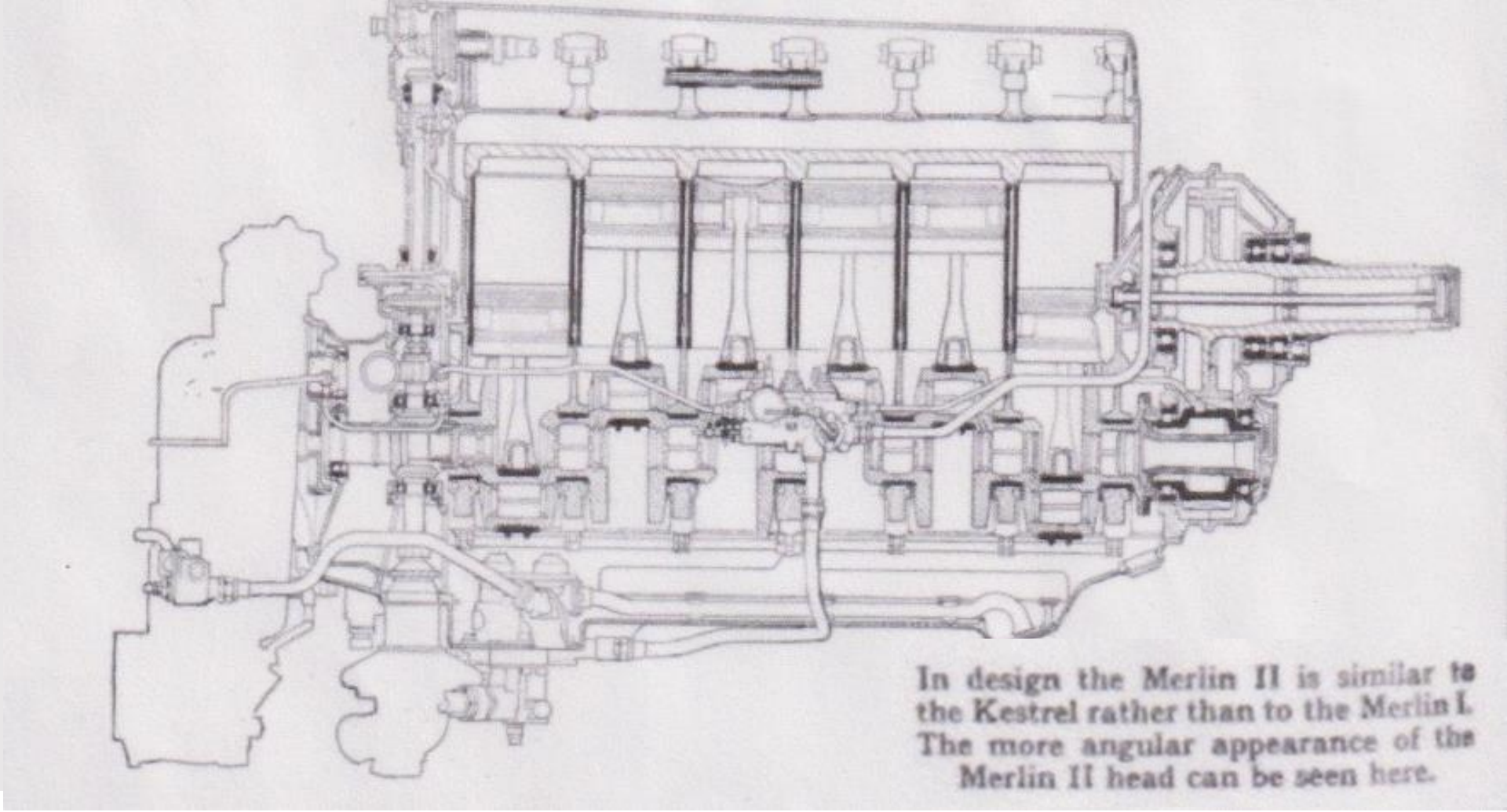
***FLIGHT,* September 23, 1937**



<u>Caption</u>: "Two cylinder blocks were required for each 12-cylinder engine. This engine was actually based on the old Liberty V-12 from World War I."



Cores being made for the Rolls Royce Merlin cylinders



In design the Merlin II is similar to the Kestrel rather than to the Merlin I. The more angular appearance of the Merlin II head can be seen here.

"…Inclined shafts from the wheelcase drive the overhead camshafts through bevel gears and each valve has its own rocker. The Merlin II camshaft assembly closely re-sembles that of the Kestrels…"

***FLIGHT,* September 23, 1937**



Caption: “A cut-away showing the water jackets and pistons in-place. The head is also bolted in-place.”

"…In both engines the exhaust valves have phosphor-bronze guides; high-silicon-chrome steel seatings are screwed into the heads. Engaging surfaces and the valve crown of the Merlin II are specially surfaced with 'Brightray' steel. Aluminum-bronze seatings are inserted for the inlet valves, which have cast-iron guides. The stem tips are stellated…"

***FLIGHT,* September 23, 1937**







<u>Above</u>: caption: “Grinding any flash or imperfections away”

<u>Upper Left:</u> caption: “Worker pressure-testing the cylinder block”

<u>Lower Left</u>: caption: “Checking all dimensions on a jig”

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"…Piston and connecting-rod assemblies on the two engines differ little from Kestrel practice. Forged aluminum alloy pistons carry three pressure and two scraper rings. Forked-type, wholly machined, connecting rods of H-section steel are employed. The plain forked rod works on the outside of a split steel bearing shell lined on both sides with lead-bronze. The doubly forked rod carries the bearing and works on its inside surface on the crankshaft…"

***FLIGHT,* September 23, 1937**

"…The drive to all auxiliaries and the centrifugal blower employs a torsionally flexible shaft with positively limited twist, conveying the drive from the crankshaft to three planetary slipper gears which drive the impeller at 8.588 times engine speed. The gears are friction-driven by alloy segments held in contact with the inside rim of the gears by light springs. As engine speed and therefore slipper wheel speed increases, the radial pressure of the springs is augmented by centrifugal force and the torque which the planets can transmit increases as the square of the speed…"

***FLIGHT,* September 23, 1937**

"…Aluminum alloy is used for the supercharger impeller, which has radial blades and a guide vane ring. At normal engine speed the impeller speed is about 22,330 rpm. A fixed datum type automatic boost regulator is fitted to maintain a constant boost-pressure without continual reference to boost gauge and adjustment from the throttle…"

***FLIGHT,* September 23, 1937**

"…The Merlins have hollow, balanced crankshafts carried in seven special lead-bronze bearings. All bearing caps are held between closely fitting cheeks and have two vertical bearing studs and two long transverse bolts through each cap. The transverse bolts pass through the crankcase as well as the caps and increase the rigidity of the whole engine…"
***FLIGHT,* September 23, 1937**

"…A spur-type reduction gear of 0.477:1 ratio is fitted to the Merlins. Half the casing is cast integrally with the crankcase and in this respect it differs from the Kestrels. The pinion, which is hollow, has roller bearings and is concentric with, though separate from, the crankshaft. In this way all load due to gearing is isolated from the crankshaft. The driven shaft carries the airscrew and has roller bearings and a ball-thrust bearing suitable for tractor or pusher installations…"

***FLIGHT,* September 23, 1937**

"…Oil pumps are carried on the lower half of the crankcase and have their drive from the wheelcase through an idler gear. The dry sump system is employed and two scavenge pumps drain from the front and rear-ends of the crankcase, each having a filter which detaches easily downwards for cleaning…"

***FLIGHT,* September 23, 1937**

"…The pistons and fioating steel gudgeon pins, which have phosphor-bronze bushes, are splash-lubricated; a baffle in the lower half preventing excess oiling. A single-pressure pump provides, first, 150 lbs./sq. in. for v.p. airscrew operation and, secondly, the high-pressure feed - between 60 and 70 lbs./sq. in. - for the big-end and crankshaft bearings and the fuel pump bush…"

***FLIGHT,* September 23, 1937**

"…Finally, between 4 and 8 lbs./sq. in. is provided for the low-pressure system, feeding camshaft, rockers and auxiliaries. Each stage has a relief valve..."

***FLIGHT,* September 23, 1937**

"…A full complement of drives is taken from the wheelcase, which is sandwiched between the blower and crankcase at the rear of the engine. The connection with the crankshaft is through the spring drive, then forward again to bevels in the wheelcase. The upper vertical shaft deals chiefly with cam-shaft drives and a lower with pump drive…"

***FLIGHT,* September 23, 1937**

"…In addition to the two magnetos a dual gear-type petrol pump, water pump, generator, hand and electric starters and engaging mechanism, which are taken from the wheelcase, other drives are taken from the camshafts, namely, B.T.H. air-compressor, generator pump for gun turret operation, revolution counter and R.A.E. air-compressor. Either of the fuel pumps can work separately if the other fails…"

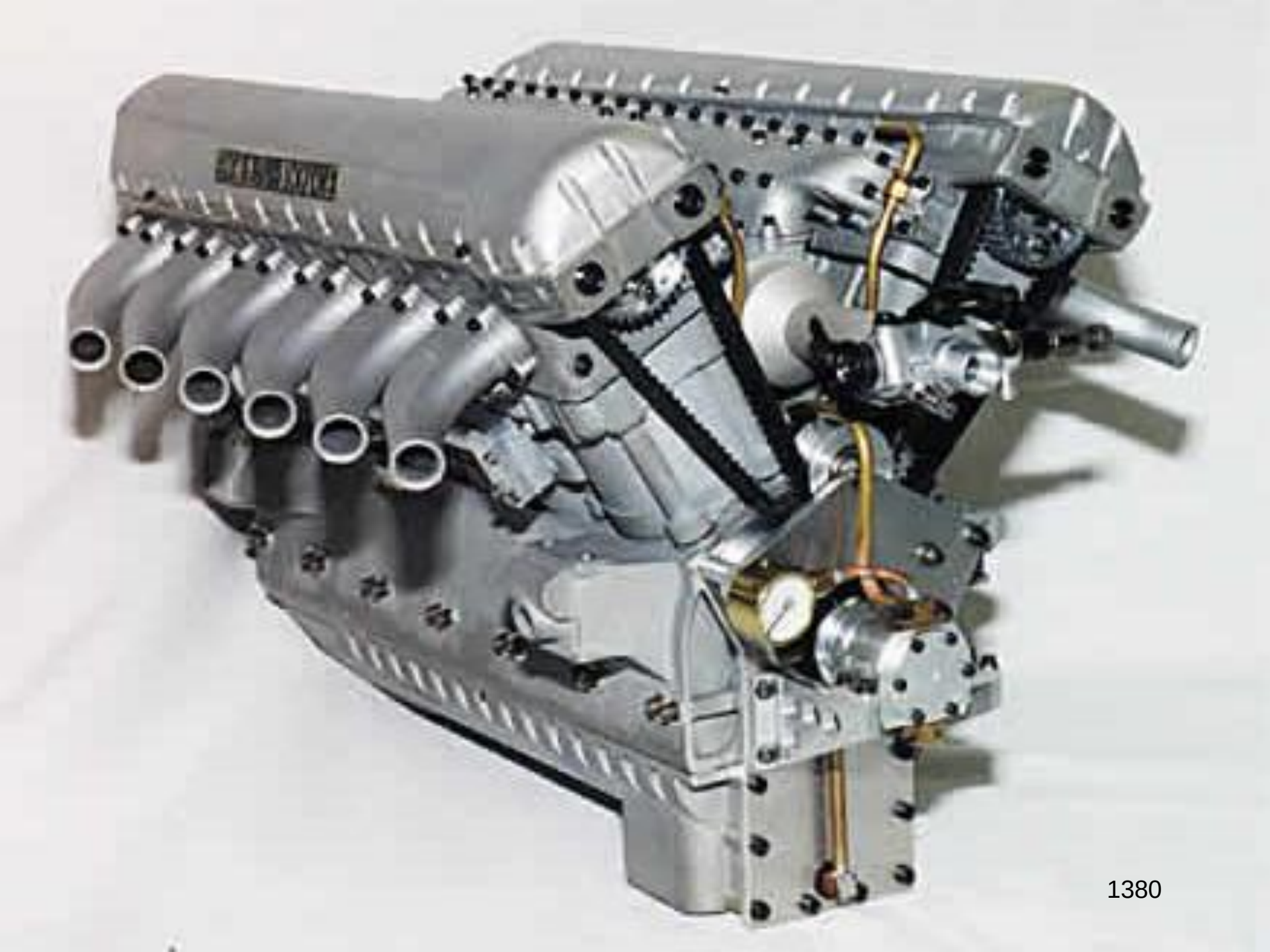
***FLIGHT,* September 23, 1937**

"…The Rolls-Royce/S.U carburetor would require a separate article to describe it in any detail. It is of the twin-choke tube, updraught type, with a separate diffuser to each choke placed at right angles to the airstream, A semi-automatic two-stage mixture-control device, operated by air-intake pressure, boost and/or pilot's lever is provided. Each main jet is controlled by an aneroid…"

***FLIGHT,* September 23, 1937**

"…As on the Kestrels, plugs are arranged on opposite sides of the combustion chamber, and the 'A' side (starboard) magneto fires all inlet side plugs and the 'B' side all exhaust, or outside, plugs."

***FLIGHT,* September 23, 1937**



1380

Part 11

Masterpiece

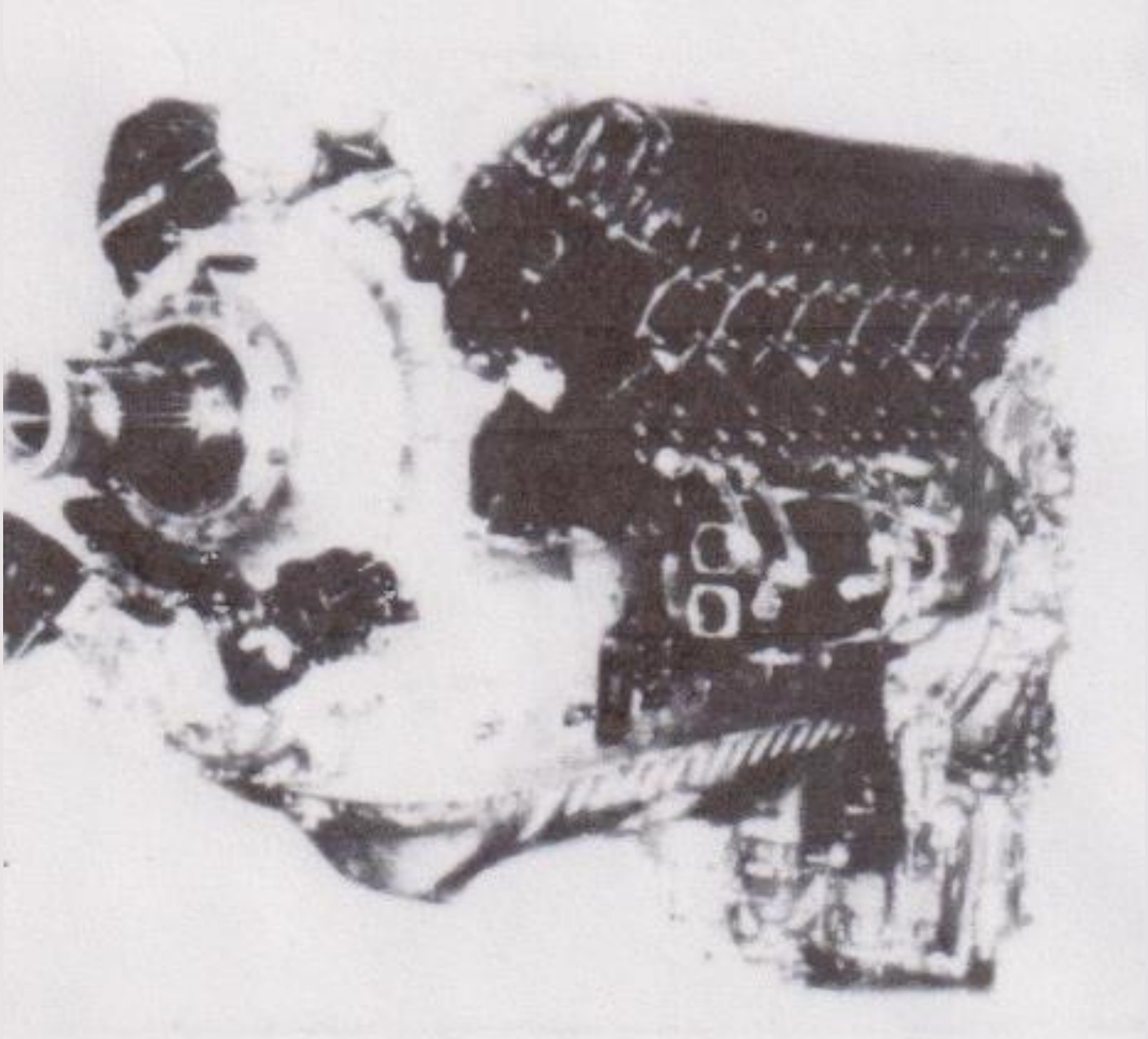
Impressions and Details

Impressions of a visit to various Rolls-Royce factories. Details of the new Merlin XX with two-speed supercharger.
***FLIGHT,* February 26, 1942**
RE: introduction to an article written by *G. Geoffrey Smith,* M.B.E., entitled: "A British Masterpiece"

Forever Famous

"IN the world of aircraft engineering, no engine has acquired greater fame than the Rolls-Royce twelve cylinder V-type liquid-cooled Merlin…"

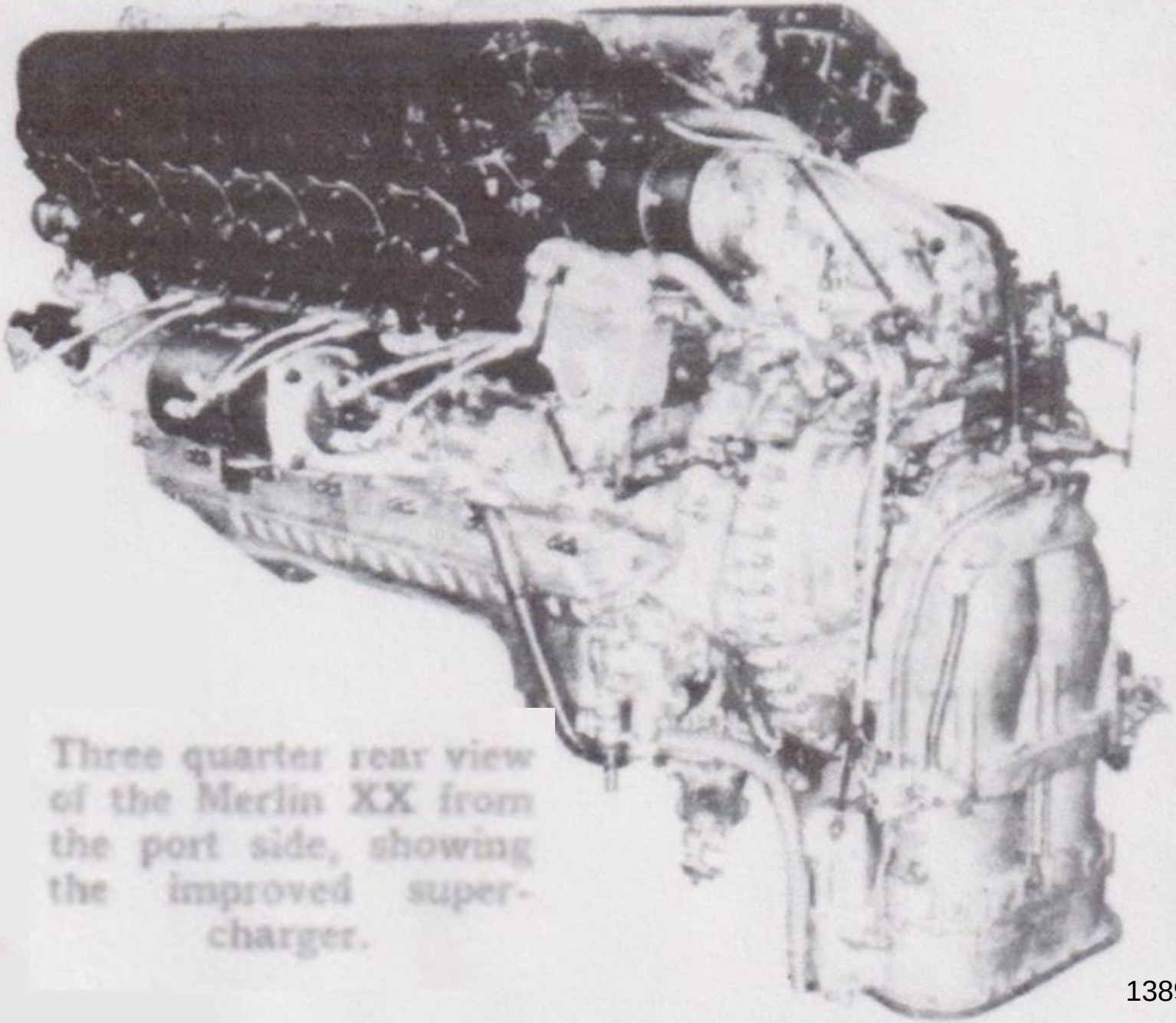
***FLIGHT,* February 26, 1942**



Merlin XX engine—threequarter front view from the port side.

World Leader

"…Lucky it was that this country possessed at the outbreak of war an engine so powerful and so wonderfully developed that it has remained in its basic form to this day, the unchall-enged leader of the world in the liquid-cooled class…"
***FLIGHT,* February 26, 1942**



Three quarter rear view of the Merlin XX from the port side, showing the improved supercharger.

A Wonderful Success

"…The reminder is deserved rather than needed that we largely owe to the existence of the Rolls-Royce Merlin the wonderful success of the RAF in the Battle of Britain in the Autumn of 1940. The importance of that victory at a critical juncture of the war will be appreciated the more as time rolls on…"

***FLIGHT,* February 26, 1942**

20/20 Foresight

"…Some ten years ago the company realized that it would be necessary to produce a new engine to take the place of the Rolls-Royce Kestrel which was in production at that time and they decided, in November 1932, to go ahead with the design of an engine of about 27-litres capacity…"

***FLIGHT,* February 26, 1942**

World-Famous

"…The engine materialized in the form of the world-famous Rolls-Royce Merlin and ever since, the process of development by research, experiment and concentration upon details has continued and resulted in a continuous increase of power available…"

***FLIGHT,* February 26, 1942**

Original Conception

"…So far-seeing and gifted were the designers in evolving the original design that the successive types up to the latest and far more powerful Merlin XX - to which these notes primarily refer – remain substantially the same…"

***FLIGHT,* February 26, 1942**

"…Even the crankshaft and bearings, the pistons, cylinder blocks, crankcases are basically the same as in the original conception, though naturally innumerable detail improvements have been effected as constant study and experiment and metallurgical improvements have been made possible…"
***FLIGHT,* February 26, 1942**

Benefits of Concentration

"…The effect of such amazing foresight in planning the entire engine with such a reserve to provide for future developments and power increases will not be lost upon the engineering world…"

***FLIGHT,* February 26, 1942**

Beyond All Measure

"…Not only has it meant that progress could be concentrated upon this single design and maintained as a continuous progressive policy but, equally important, that the Royal Air Force maintenance service has been simplified beyond all measure…"

***FLIGHT,* February 26, 1942**

Stores and Spares

"…For example, rocker gear as well as the general mechanism of the later types are dimensionally the same and, therefore, interchangeable with the original Merlin II so that the problem of stores and spares in scattered establishments, always a major consideration in the field, has been appreciably eased…"

***FLIGHT,* February 26, 1942**

Incalculably Great

"…One may go further in instancing the benefit accruing from the retention of a given type over a long period. Not only is it possible for the development and experimental staffs to center upon their task of extracting greater power and enhanced qualities of endurance from a type the whims and idiosyncrasies of which are familiar and well understood, but also in the workshops the benefits arising from concentration upon a standardized basic design are incalculably great…"
***FLIGHT,* February 26, 1942**

Production Technique

"…Thus, components which originally entailed 100 man-hours in production, for example, can be and, indeed, have been, reduced to a fifth of that figure by expert study of production technique and the introduction of specialized plant which is facilitated by a big demand for particular parts…"

***FLIGHT,* February 26, 1942**

"…Quite obviously, repetition work is of enormous help to the Production Engineer since it makes possible the installation of special equipment for a given part entailing intricate operations and the planning of a production technique which, in the aggregate, means perhaps six engines in place of one produced by piecemeal methods…"

***FLIGHT,* February 26, 1942**

Wrong Conception

"…This point is especially stressed for other reasons. For example, there is frequently a wrong conception of what the term 'modification' implies. All too often the notion prevails that modifications are something to be avoided like the plague, spelling delay and hold-ups, but this is more often than not a complete fallacy; a modification can, and often does, prove beneficial…"

***FLIGHT,* February 26, 1942**

A Highly Desirable State-of-Affairs

"…It has been my privilege, at Rolls-Royce's invitation and with Ministry of Aircraft Production approval, to visit their huge engine factories and, manifesting itself more than anything else, is the evidence of constantly improving manufacturing technique, hand-in-hand with increasing BHP, mainly as a result of expert collaboration between the production and design departments - a highly desirable state-of-affairs and one for which I have pleaded repeatedly in articles in FLIGHT and AIRCRAFT PRODUCTION and, indeed, since my RAF days when serving in the Engine Production Department of the Air Ministry in the Great War…'

***FLIGHT,* February 26, 1942**

Designing for Production

"…In years gone by there has been a tendency to accord to designers too much unbridled sway - let us confess it whether we are thinking of aircraft, automobile or any other branch of engineering. No superman can be expert in every sphere of engineering…"

***FLIGHT,* February 26, 1942**

"…And yet obvious though the fact may be, we could all quote cases in which either due to a lack of practical workshop knowledge or a failure to collaborate as closely with production personnel as the need demanded, designs have been introduced demanding slow, laborious and costly machining processes. Often the necessary special tools have not even been available…"

***FLIGHT,* February 26, 1942**

"…This is most certainly not the case in Rolls-Royce Works. Today, and for long past, the practice has been for the Chief Production Engineer, who maintains close contact with departmental heads, to encourage suggestions for modifications in the design to simplify production processes and assembly. With a progressive spirit of advancement these suggestions are passed-on and considered promptly by the designing staff and, if they are acceptable from the engineering aspect, approval is at once forthcoming and a new sequence of manufacturing operations introduced…"

***FLIGHT,* February 26, 1942**

"…To quote a case-in-point as applied to foundry work (and here the reader will need no reminder that the lightweight Merlin engine embodies many intricate castings of aluminum alloy and efficient foundry work is an all-important phase of production), it has been usual hitherto for R-R engines to embody joints with flanges on the inside…"

***FLIGHT,* February 26, 1942**

Practice-Makes-Perfect

"…Study of the difficulties of the foundryman in extracting the time would be saved and the risk of breaking the sand reduced if the inside were left flush and the flange changed to the outside edge. The recommendation was made, the modification accepted and a speeding-up of production achieved. A case of practice-making-perfect…"

***FLIGHT,* February 26, 1942**

Rate-of-Output

"…But one could quote many other instances of improved rate-of-output due to reduced machining operations or amended design by this willing and expert collaboration between Production Chiefs of the various work of this important group…"

***FLIGHT,* February 26, 1942**

A New Complexion

"…This collaboration may perhaps give a new complexion to the much abused term 'modification' and what it has all too often implied quite erroneously. In short, it often spells better performance and improved speed in manufacture rather than delay…"

***FLIGHT,* February 26, 1942**

Generations

"…This particular contact work to achieve accelerated production is largely carried-out by brilliant young Engineers working under the encouragement and guidance of long-service Rolls-Royce Engineers whose names are (or should be) household words…"

***FLIGHT,* February 26, 1942**

A Collaborative Effort

"…And what pleased the writer in investigating this aspect of the subject was the appreciation shown on the one hand by the Production Engineer of the assistance received from the Foundry Engineer; and later when touring the foundry with that worthy, the corresponding satisfaction displayed at the readiness with which his recommendations are received by the Production Engineer for consideration and eventual adoption…"

***FLIGHT,* February 26, 1942**

The Shadow Factory Scheme

"…By and large this process of eliminating complexities in the Merlin engine has resulted in many hundreds of man.-hours being saved per-unit and the total output so speeded up that each week hundreds of engines emerge from the several great magnificently planned and equipped factories in the Midlands, in the North and in the West. These factories will long remain as a monumental testimony to the foresight of those who evolved the Government shadow factory scheme and entrusted the management to the parent aircraft firms…"

***FLIGHT,* February 26, 1942**

RE: R-R's "shadow factories" were designed for mass production and a high-degree of machine tooling, using a large proportion of unskilled or semi-skilled labor. As a result, their output was fairly inflexible; making design changes required re-tooling and re-jigging. R-R operated a three-tier system: Glasgow (and later other license factories) only manufactured major variants in large numbers; Derby became, in GM Ernest Hives' words, "a huge development factory rather than a manufacturing plant" and Crewe was somewhere between the two. R-R chose Crewe for its first shadow factory because of its good road and rail links to Derby. Derby was where new designs were tested and the first 200-300 engines of a mark built. Once the snags had been worked-out, designs could be passed on to Crewe or Glasgow for mass production, with Crewe being able to change variants more quickly, but at a higher cost-per-engine. R-R's policy of apprenticeships and highly skilled labor had the unforeseen advantage that it could promote a nucleus of skilled staff from Derby.

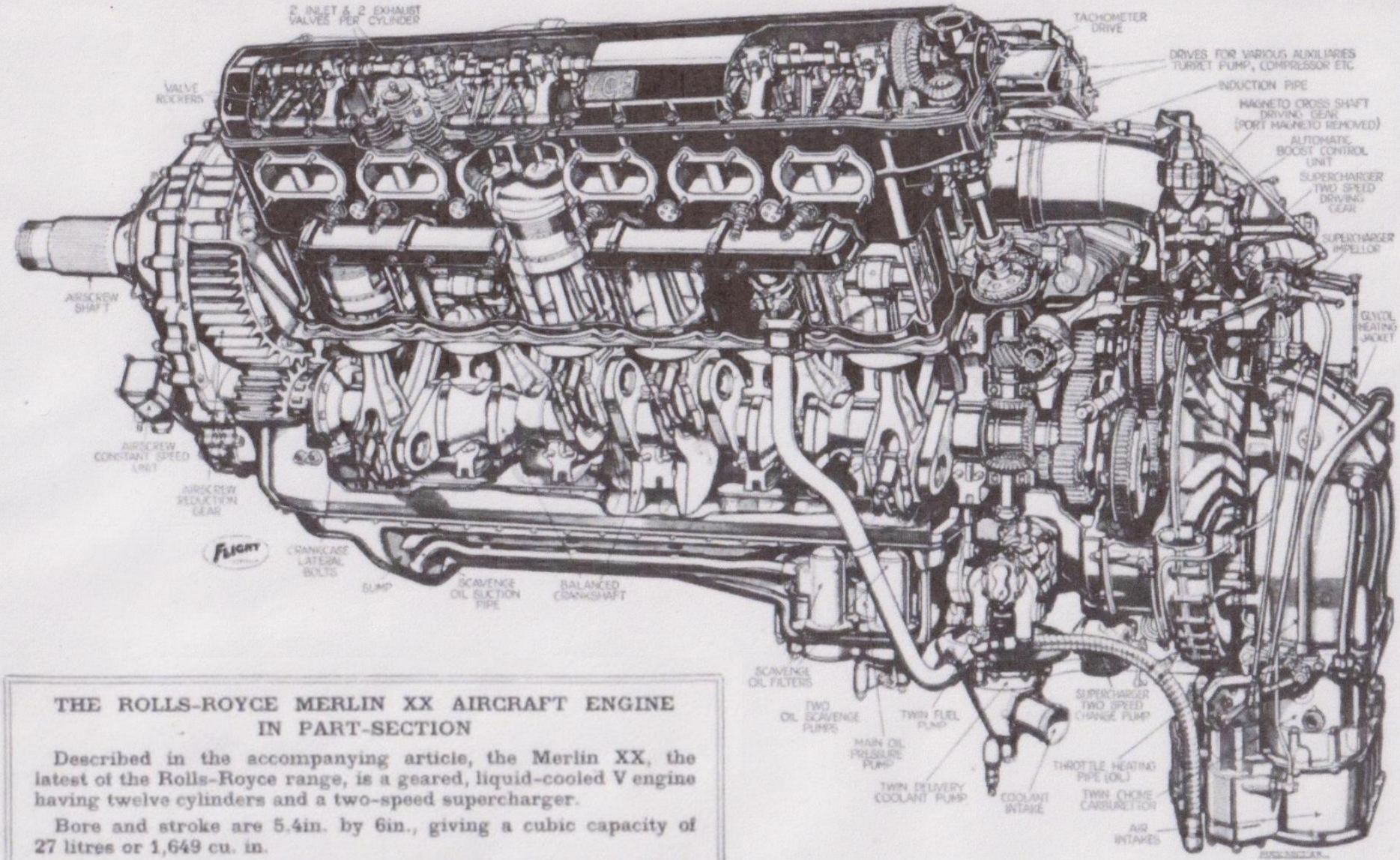
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XX

"…From this general discourse on the works angle, we may pass to the latest example of the Rolls-Royce aircraft engine, the Merlin XX and its features of design…"
***FLIGHT,* February 26, 1942**

"…The increase in the power output of the new engine can be ascribed mainly to research and improvements in the super-charger design and to the development of high-octane fuels which permit the use of higher boosts and cylinder operation-al pressures…"

***FLIGHT,* February 26, 1942**



THE ROLLS-ROYCE MERLIN XX AIRCRAFT ENGINE IN PART-SECTION

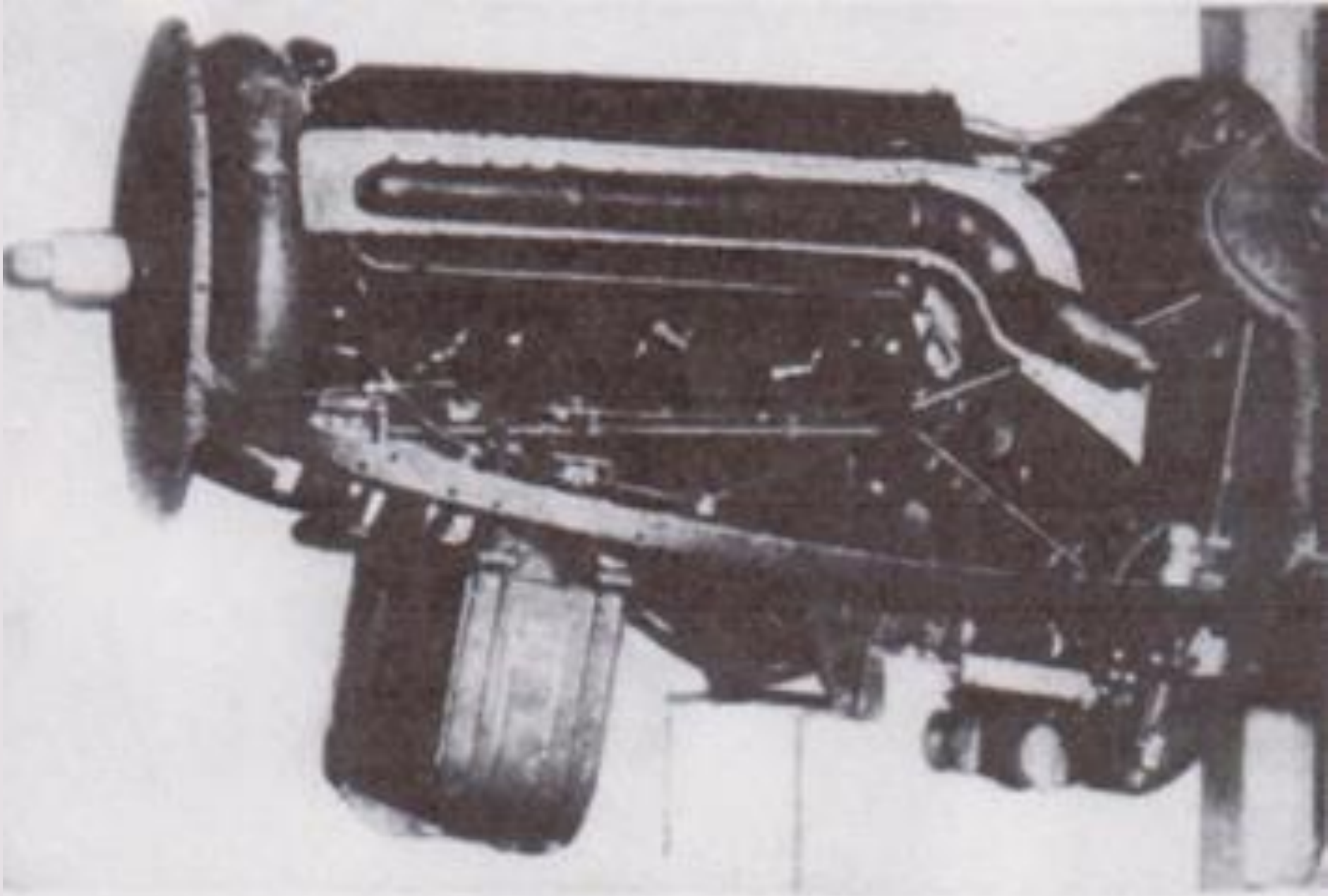
Described in the accompanying article, the Merlin XX, the latest of the Rolls-Royce range, is a geared, liquid-cooled V engine having twelve cylinders and a two-speed supercharger.

Bore and stroke are 5.4in. by 6in., giving a cubic capacity of 27 litres or 1,649 cu. in.

Maximum power with the low gear supercharger in use is 1,260 h.p. at 12,250ft. altitude, and with high gear 1,175 h.p. at 21,000ft.

"…Modern aircraft engines are completely self-contained units with the radiator subsidizing an oil-cooler, an automatically controlled cooling system and incorporating an auxiliary gearbox and all necessary pipes and electrical wiring forward of the bulkhead…"

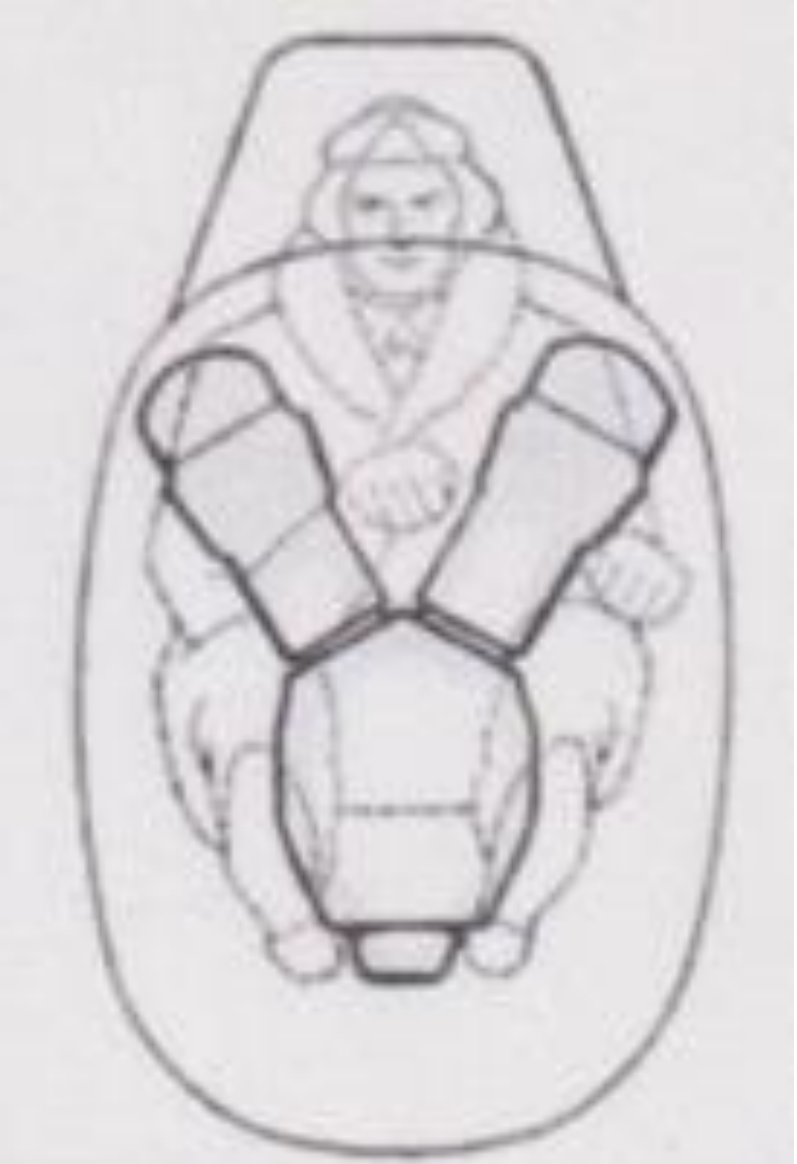
***FLIGHT,* February 26, 1942**



Typical Merlin XX power plant installation with its cowling removed.

"…Thus, the task of installation has been greatly simplified. The complete power unit may be removed or the engine and its mounting alone disturbed leaving the bulkhead in position with the auxiliary drive gearbox and aircraft impedimenta in-situ. Interchange of engines may thus be readily effected…"
***FLIGHT,* February 26, 1942**

Minimum Frontal Area



Showing the small frontal area of a V type liquid-cooled engine

"…The great attraction of the V-type liquid-cooled engine is the small frontal area it presents, enabling the use of a minimum section of fuselage. This attribute is particularly appealing in fighter design, in addition to the improved vision that it provides for the pilot in single-engined types. A point in favor of liquid-cooled engines, too, is their ability to operate at very high boost-pressures when emergency demands such a course…"

***FLIGHT,* February 26, 1942**

New and Improved

"…As already indicated the Merlin XX now in service follows basically the lines and characteristics of its forerunners. It has twelve cylinders arranged V-fashion at an angle of 60-deg., the bore and stroke being 5.4 in. x 6 in. respectively, giving a swept volume of 1,649 cubic-inches. The compression ratio is 6-to-1…"

***FLIGHT,* February 26, 1942**

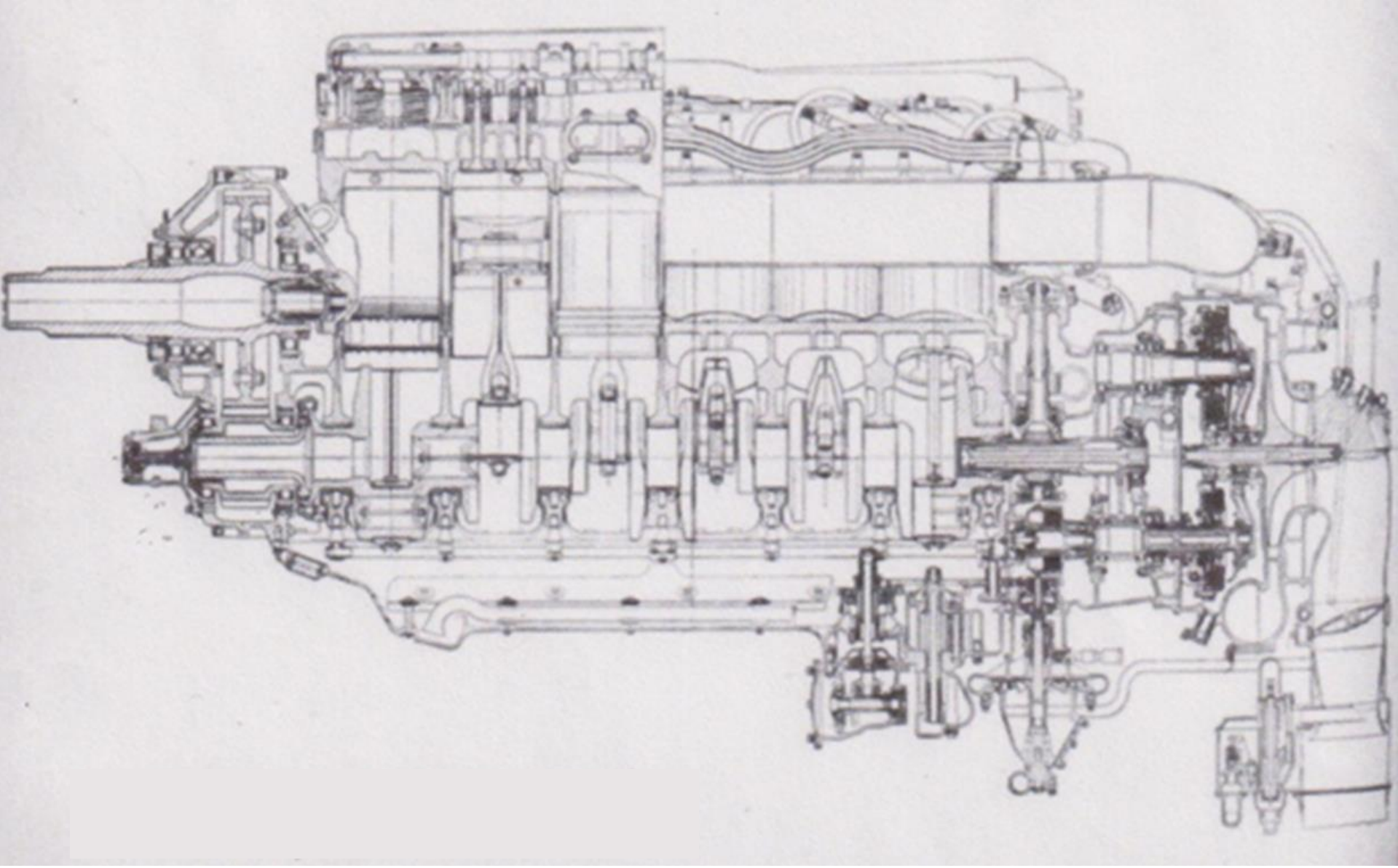
"…A two-speed supercharger is now fitted; the low gear ratio being 8.15 to 1 and the high gear 9.49 to 1 and, as already indicated, it is primarily in the modifications and improvements to the supercharger by which the increase of power available has been achieved. It is of the high-speed centrifugal type embodying an impeller which is driven from the rear-end of the crankshaft through a two-speed gear, the high gear being normally engaged above 6,000 ft…"

***FLIGHT,* February 26, 1942**

"…To relieve the gear teeth from the exceptional loads which result from impeller inertia (their respective rotational speeds are 21,597 and 25,148 rpm) following sudden acceleration and deceleration of the engine, a spring drive is incorporated consisting of a torsionally flexible shaft…"

***FLIGHT,* February 26, 1942**

"…The impeller inertia, in combination with the friction drive which incorporates the two-speed gear mechanism illustrated, comprising three layshaft driving spindles each embodying a centrifugally loaded clutch with Ferodo linings, serves to damp-out torsional oscillation of the shaft which drives the camshaft and auxiliaries as well as the supercharger…"
***FLIGHT,* February 26, 1942**



<u>Caption</u>: “Longitudinal section of the Rolls-Royce Merlin XX twelve-cylinder engine with two-speed supercharger. It scales 1,450 lbs. dry – 1.13 lbs. per-horsepower”

"…The clutches of the two-speed mechanism are held initially in engagement by light springs and as the speed of rotation of the crankshaft and, therefore, of the centrifugal weight increases, the pressure of these springs is augmented by a centrifugal force and, consequently, the torque which the clutches can transmit increases as the square of the speed As the torque required to drive the impeller increases at a somewhat similar rate, the gear is capable of driving the impeller with a predetermined margin of torque above that causing slip…"

***FLIGHT,* February 26, 1942**

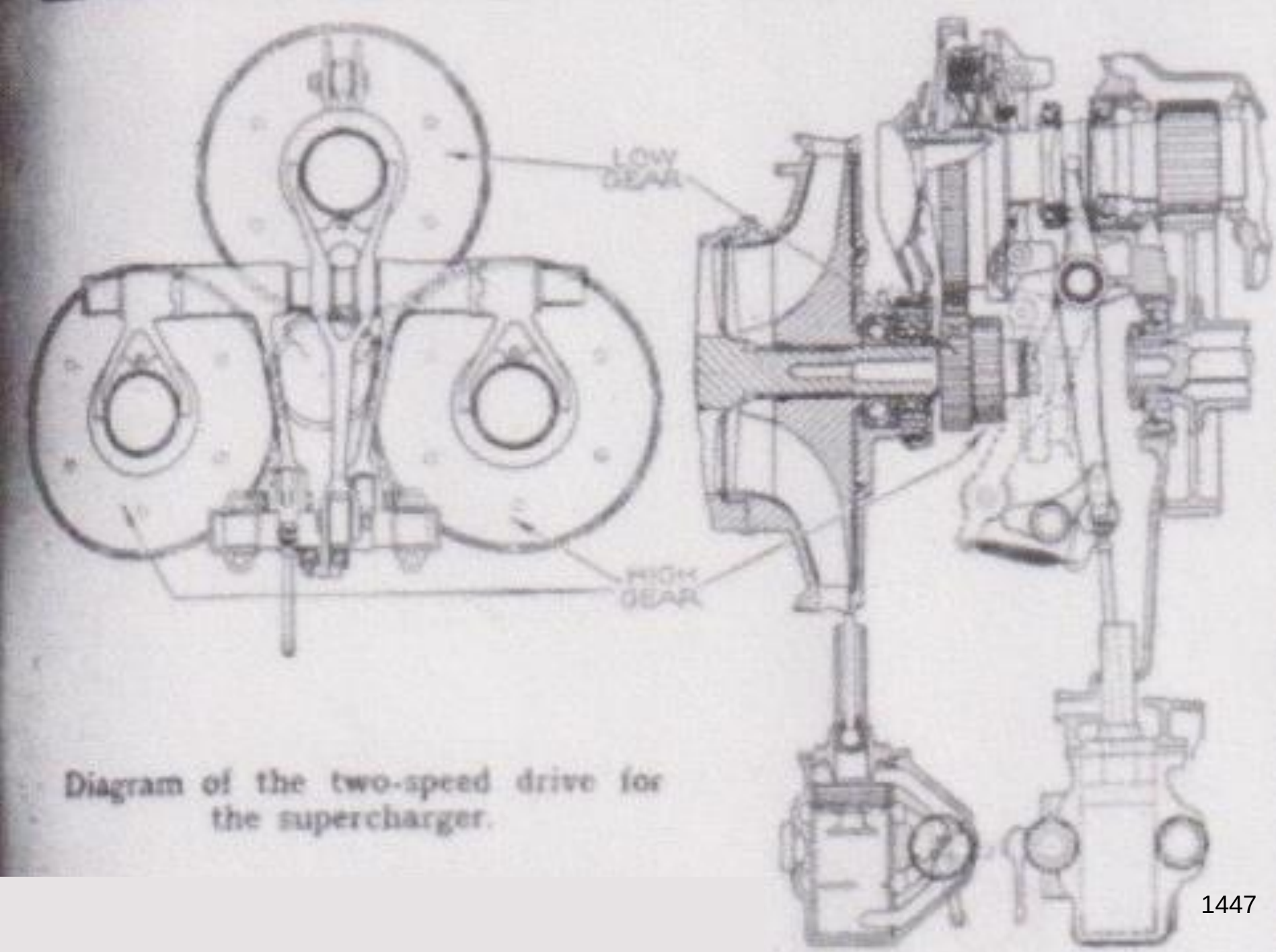


Diagram of the two-speed drive for the supercharger.

"…The redesigned supercharger casing has an improved form of central entry which gives a better and freer flow of air to the blower. The rotating and fixed guide vanes, too, have been amended. The rotating guide vanes are formed of steel and are matched to the rotors of RR56 aluminum alloy. The rotors are balanced separately and together to approximate to dynamic balancing on knife edges…"

***FLIGHT,* February 26, 1942**

"…The diffuser vane ring is an aluminum die-casting bolted by means of special shaped bolts to the supercharger casing These important changes in conjunction with a larger twin-choke up-draught S.U. carburetor, designed as a complete separate unit, have resulted in a greater weight-of-mixture entering the cylinders and thereby a marked increase of power…"

***FLIGHT,* February 26, 1942**

"…Using 100-octane fuel, the International Power Rating of the Merlin XX is with the low-gear supercharger; 1,240-hp at 2,850 rpm at 10,000 ft. and +9 lbs./sq. in. boost and 1,175-bhp at 2,850 rpm at 17,500 ft. and +9 lbs./sq. in. boost. The rated altitude, that is the lowest height at which full throttle is permissible at the international (climbing) rpm, is 10,000 ft. in low-gear and 18,000 ft. in high-gear…"

***FLIGHT,* February 26, 1942**

Increase of 250-hp

"…These figures represent an increase of nearly 250-hp over the Merlin II of identical cylinder dimensions and illustrate, in a convincing manner, the technical progress achieved: by years of 'toil, tears and sweat,' to borrow a classical phrase from our worthy Prime Minister…"

***FLIGHT,* February 26, 1942**

Pinnacle of Fame

"…Nor is the limit of attainment yet in sight. A talk with the Chief Engineer gave one encouragement and enlightenment as to further far-reaching improvements which should surely serve to maintain the Merlin on its pinnacle of fame for years to come…"

***FLIGHT,* February 26, 1942**

More for Less

"…It should be added that the achievement of extracting so much extra power from a given cubical capacity, in this case 27 litres, has increased the dry-weight of the engine by only 75 lbs., that is, to 1,450 lbs., which on the power rating of 1,280-bhp gives a ratio of 1.13 lbs. per-horsepower - the prodigious figure of over 100-bhp per cylinder!..."

***FLIGHT,* February 26, 1942**

10 Years Later

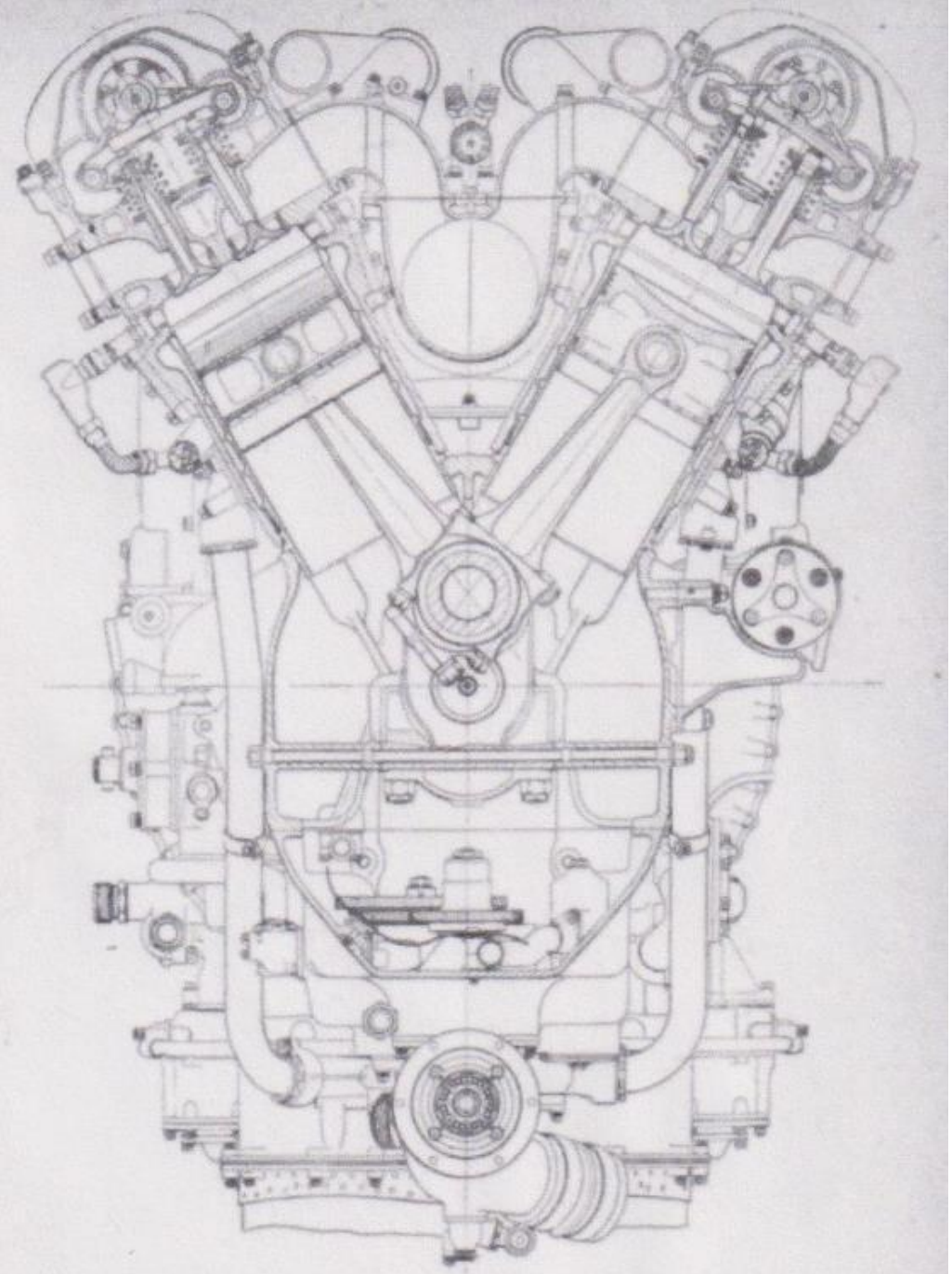
"…And yet remarkable as those figures may seem, we have the even more amazing figures of the 'R' racing-type Buzzard engine to reflect upon…"

***FLIGHT,* February 26, 1942**

"…That engine, specially developed by Rolls-Royce for the Schneider Trophy, which it won outright, gave 2,300-bhp at 3,200 rpm and scaled 1,630 lbs. = 11 oz. per-bhp. It was a masterpiece of precision engineering in 1931 and remains a symbol of British efficiency ten years later…"

***FLIGHT,* February 26, 1942**

Aluminum Largely Used



Section through No. 5 cylinder looking towards rear of engine.

"…The cylinder block of the Merlin is a single aluminum casting comprising the head and the coolant jacket. 'Wet' cylinder liners of steel are provided which start life as a 26 lb. forging and finish-up weighing 7 lbs. only. The liners have shoulders which fit against the crankcase and the cylinder block at opposite ends. A coolant joint is effected around the base of each liner by means of two rubber rings fitting grooves in the liner…"

***FLIGHT,* Feb. 26, 1942**

"…A joint ring of aluminum alloy is arranged between the upper shoulders of each liner and the cylinder block. The resulting joints are maintained by means of 14 long studs which extend from the crankcase through to the tops of the cylinders. Except for the four end studs, the remaining ten pass through corrosion-resisting tubes which form oil return ways and make coolant joints at either end by means of rubber rings held in annular recesses in the block casting. Two main coolant pipes extend from the centrifugal pump to the rear connections of each cylinder block…"

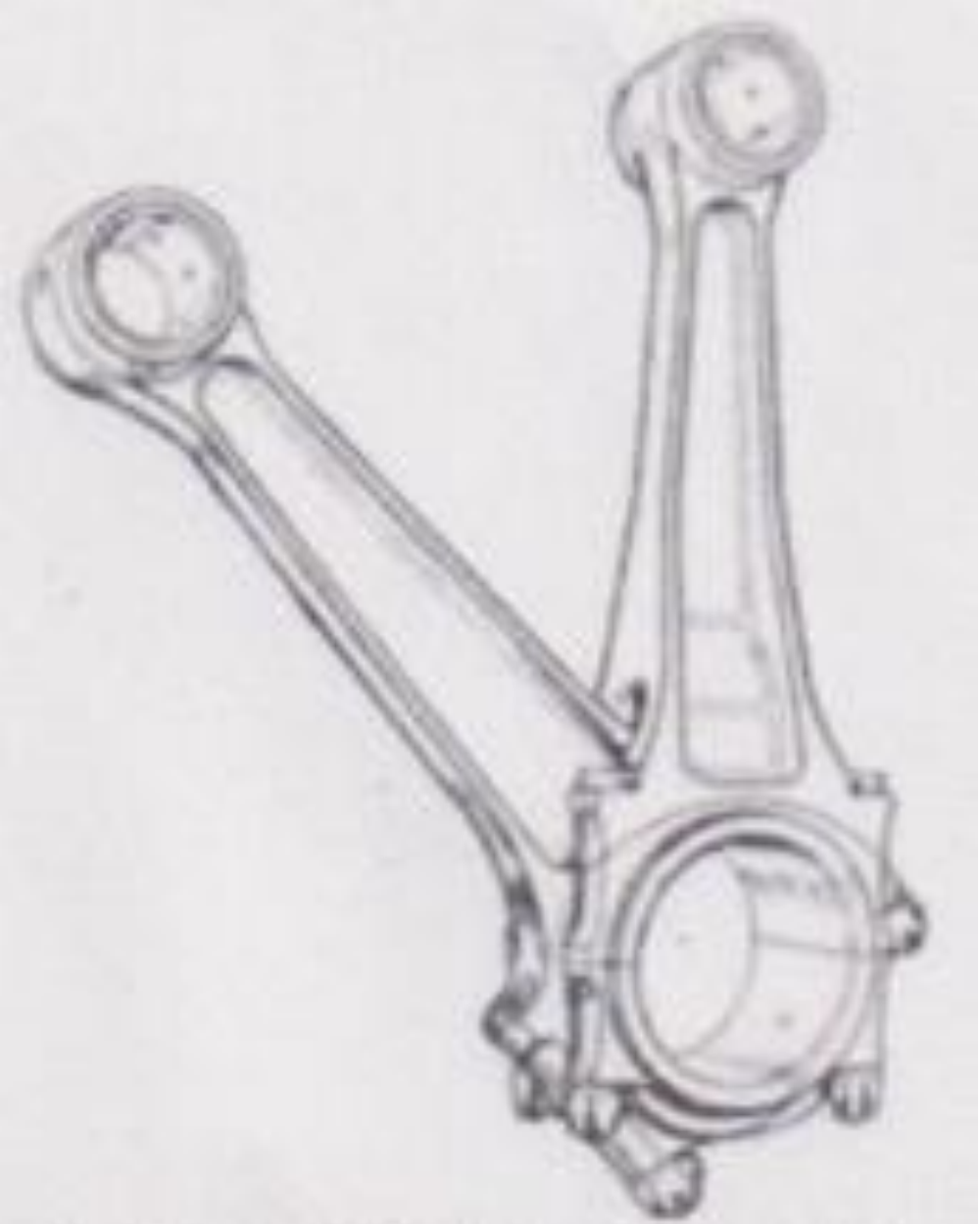
***FLIGHT,* February 26, 1942**

"…Two inlet and two exhaust valves are provided for each cylinder operated by an overhead cam shaft through the medium of rockers having aluminum bush-bearings. All valves are placed parallel with the centerline of the cylinders. Sodium-cooled exhaust valves are utilized operating in phosphor-bronze guides. The seatings, which are screwed into the head, are of high silicon chromium steel and the engaging face and crown of the valves are surfaced with 'Brightray.' The stem tips are of Stellite. Inlet valves work in cast-iron guides and also have high-silicon chromium steel seatings. Each valve has two concentric valve springs retained by a collar and split wedge. Adjustment is effected by means of a tappet screw and lock-nut…"

***FLIGHT,* February 26, 1942**

"…The camshafts are driven by inclined shafts and bevel gears from the wheelcase at the rear of the engine and each camshaft has additional gear wheels for driving various auxiliaries…"

***FLIGHT,* February 26, 1942**



A pair of forked H section connecting rods with lead bronze lined steel bearing shells

"…Forged aluminum pistons are employed, having three pressure rings and two drilled scraper rings and a hardened-steel floating gudgeon pin. Forked H-section connecting rods scale 8-1/2 lbs. and 7-1/2 lbs. respectively in the raw state; when machined all over 2-3/4 lbs. and 2-1/4 lbs. They are provided with lead-bronze bearings for the crank-pin and a floating phosphor-bronze bush is fitted in the small end…"

***FLIGHT,* February 26, 1942**

Hollow Steel Crankshaft

"…The hollow crankshaft compels admiration as a supreme fxample of design and perfect finish. It is a one-piece forging reduced during machining from 280 lbs. to a finished weight of 180 lbs. At the front-end there is a flange bolted to it which transmits the drive through an internally toothed annulus to a short floating roller quill shaft which drives the reduction gear pinion through internal splines at the front-end. Thus, the crankshaft end-bearing is insulated from loads due to the gearing…"

***FLIGHT,* February 26, 1942**

"…The airscrew shaft, which has a reduction of 0 = 420-to-1, is carried in roller bearings and a ball thrust is provided. It scales but 34-1/2 lbs. of its original 108 lbs. as a forging. Lubrication is of the dry-sump system and there are two gear-type scavenge pumps working in parallel to drain the front and rear of the lower half crankcase. The supply system comprises a main and low-pressure circuit served by a single pressure-pump…"

***FLIGHT,* February 26, 1942**

"…Two screened magnetos are spigoted to the wheelcase, and each is arranged to fire all twelve cylinders independently on opposite sides of the combustion chambers. Dual gear-type fuel pumps are driven in tandem from the L.H.-side of the wheelcase and deliver fuel direct to the float chambers.."

***FLIGHT,* February 26, 1942**

Twin-Choke Updraught Carburetor

"…An improved type of S.U. carburetor is employed having increased diameter of chokes and two independent float chambers with two saddle-type cork floats - one around each main diffuser well - and control the fuel inlets by needle valves. The effect of banking on fuel level has thus been reduced…"

***FLIGHT,* February 26, 1942**

"…The automatic boost-regulator controls the supercharger delivery pressure by an automatic servo mechanism working through a differential linkage to limit the throttle opening and to protect the engine from damage resulting from overboosting. It is of the progressive-type with the boost-pressure determined by the degree of throttle opening and maintained automatically within a range determined by the altitude, this range increasing as the throttle opening is increased…"

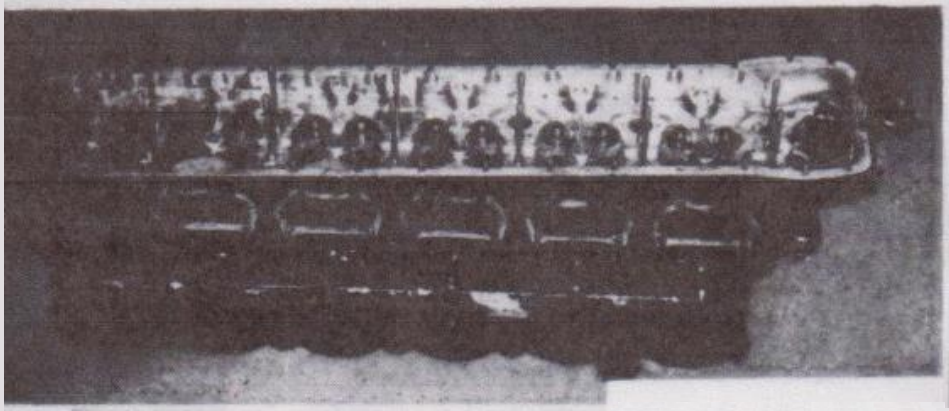
***FLIGHT,* February 26, 1942**

"…Until the rated boost-pressure is reached, the boost-pressure is not maintained over the whole throttle range. The regulator consists of an aneroid (balance flexible metallic bellows) which is exposed to the boost-pressure. The aneroid is coupled to a piston-valve to admit boost-pressure to one side or the other of a relay piston which is interconnected with the throttle control. Thus, the opening of the throttle is controlled to suit the intake-pressure…"

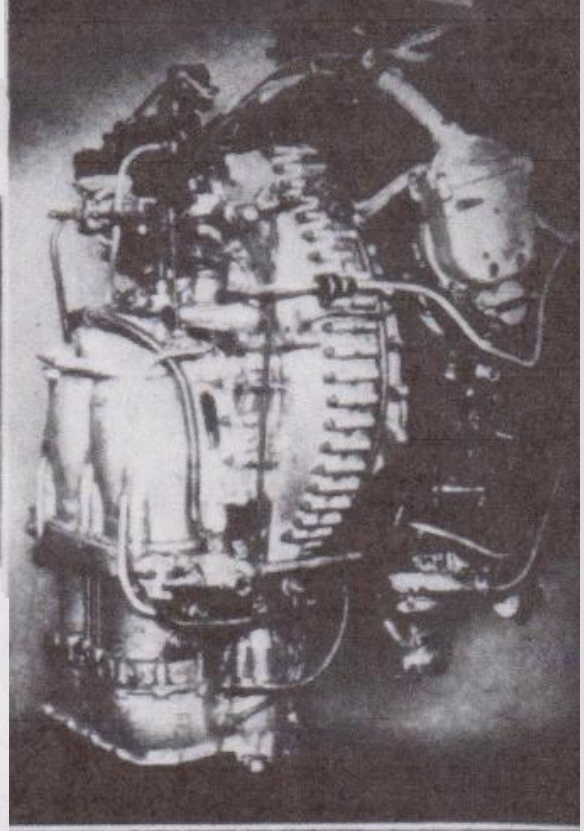
***FLIGHT,* February 26, 1942**

"…Production assembly and servicing have been facilitated by making the supercharger and the carburetor as separate but complete sub-units ready to bolt on to the engine. For starting both hand and electric gear are provided…"
***FLIGHT,* February 26, 1942**

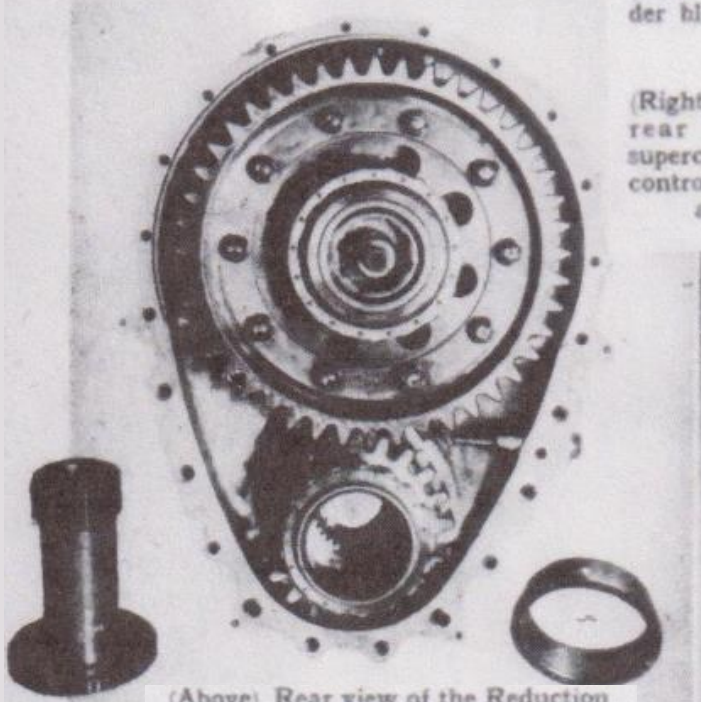
FEATURES OF THE ROLLS-ROYCE MERLIN XX.



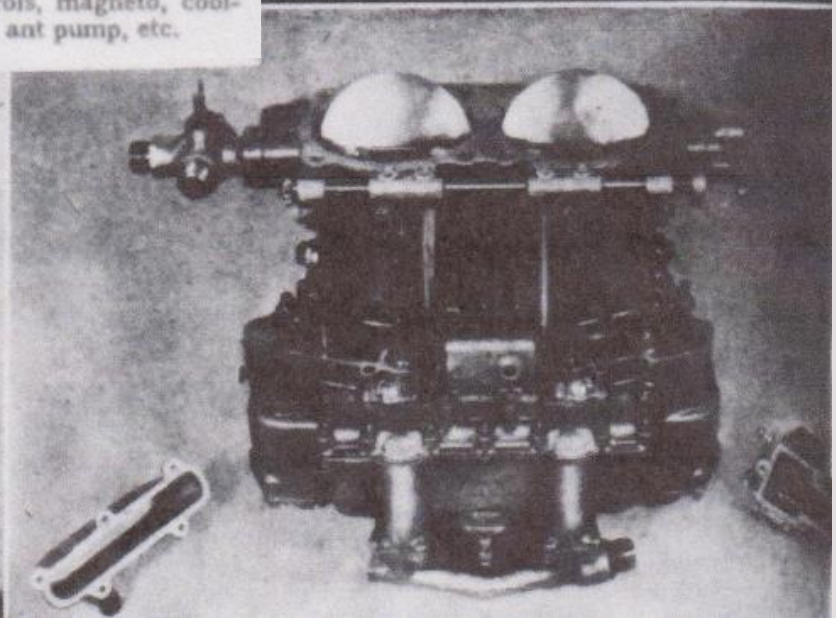
(Above) One-piece cylinder block—exhaust side.



(Right) Three-quarter rear view showing supercharger assembly, controls, magneto, coolant pump, etc.

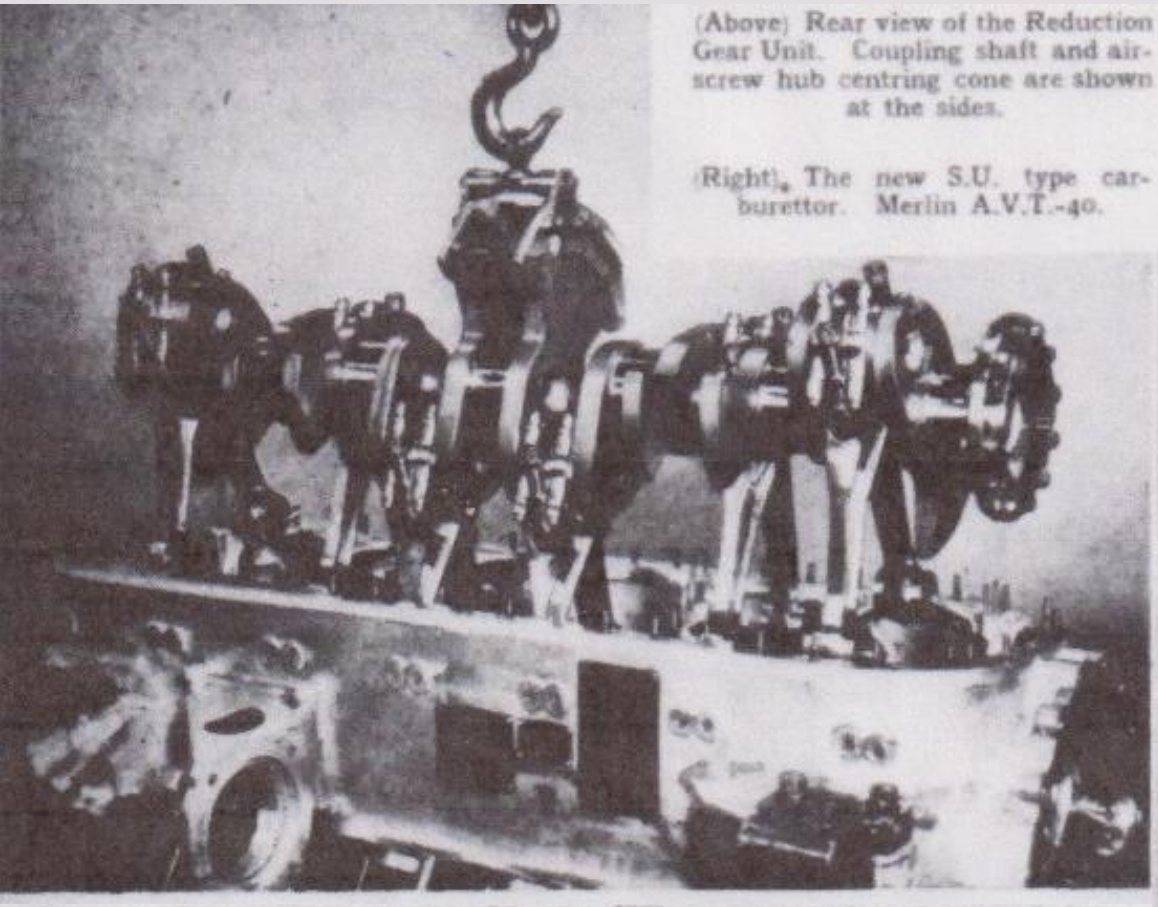


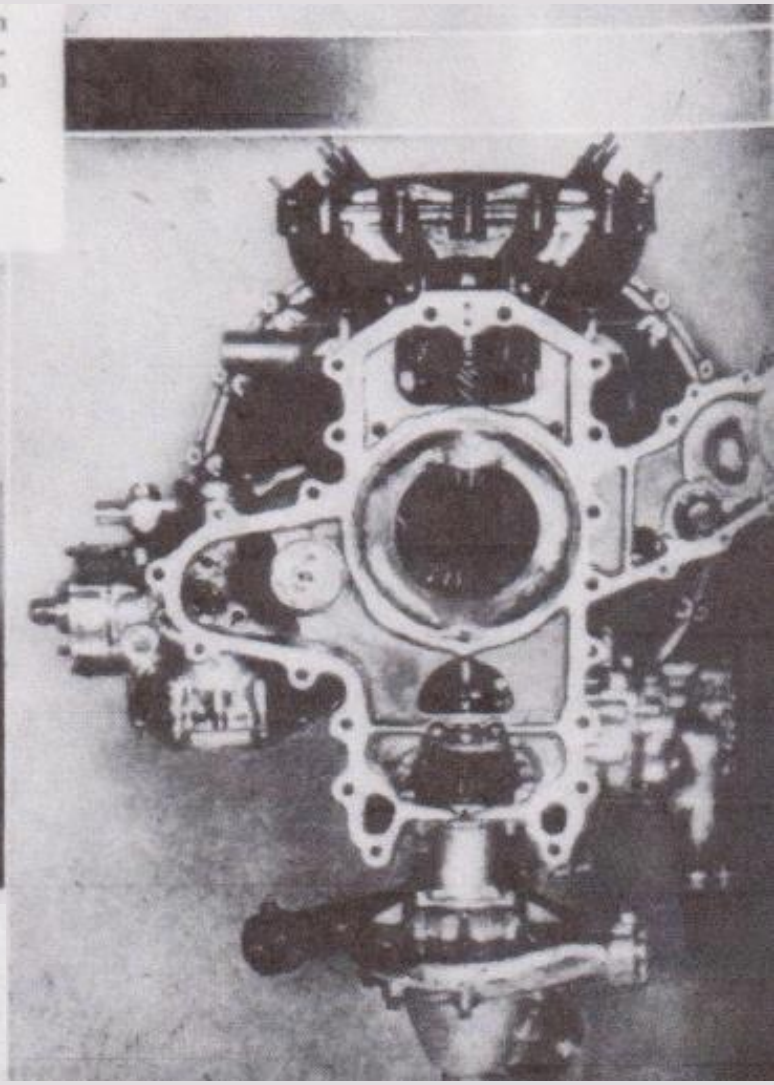
(Above) Rear view of the Reduction Gear Unit. Coupling shaft and airscrew hub centring cone are shown at the sides.



(Above) Rear view of the Reduction Gear Unit. Coupling shaft and air-screw hub centring cone are shown at the sides.

(Right) The new S.U. type carburettor. Merlin A.V.T.-40.





(Above) Crankshaft of the Merlin XX engine being lowered into upper half of crankcase during assembly.

(Right) Front view of the wheelcase of the new Merlin for auxiliary drives.

High-Performance

"…The increase in the operational altitude of the latest engine, as compared with its forerunners, has necessitated improved magneto performance. Intensive development was necessary to provide efficient ignition in the rarefied atmospheric conditions encountered at higher altitudes. This effect of height also reacts adversely in other ways, notably on the fuel and lubrication systems and, as may be imagined, many problems have had to be solved in this connection…"

***FLIGHT,* February 26, 1942**

"…It will not be overlooked that all high-performance fighter aircraft at present in the service of the RAF are powered by liquid-cooled in-line engines; similarly the fastest fighters of other nations engaged in the war are equipped with this type of engine because of the small frontal area and thereby minimum drag…"

***FLIGHT,* February 26, 1942**

For Twin-engined Aircraft

"…The clean lines of the Merlin Spitfire installation are an excellent example of the reduced frontal area presented by liquid-cooled engines since the size of the bulkhead to which the engine installation is fixed is only 10.5 sq. ft. in. area. This area is not governed entirely by the size of the engine and it has been demonstrated that, by arrangement of various auxiliary fittings, a bulkhead as small as 8.5 sq. ft. can be utilized on twin-engined aircraft…"

***FLIGHT,* February 26, 1942**

The Sum of its Parts

"…In the Merlin XX engine there are nearly 11,000 separate pieces. Included in this total are parts of 4,500 different varieties. Although aluminum enters very largely into the design of this light-weight engine, the total of 1,450 lbs. weight is divisible as follows:

Steel	**47.0 per cent**
Aluminum	**43.6 "**
Brass and Bronze	**2.5 "**
Other materials	**6.9 "**

***FLIGHT,* February 26, 1942**

Home Brewed

"…The makers state that only 12 different classes of steel are used throughout, including special-purpose steels; one made of cast-aluminum alloy and two grades of wrought-aluminum. All the aluminum is produced from the world-famous Rolls-Royce Hiduminium range of alloys developed by the Rolls-Royce Company…"

***FLIGHT,* February 26, 1942**

The Test Houses

"…The rows of test houses, a feature of the different Rolls-Royce factories, are of extremely modern design with the latest dynamometer equipment. Bright and neatly maintained control rooms, sound and vibration-proof with a varied array of recording instruments, enable the testing staff to watch through the observation window the 2-1/2-hour endurance test of engines lit-up by floodlights in the adjoining test house. What a contrast to the days of escaping oil, freezing air currents and deafening noise reverberating through the body and the necessity to use ear plugs! After two hours the engines are stripped for examination, reassembled and subsequen-tly given the final test of 1/2-hour duration…"

***FLIGHT,* February 26, 1942**

Honorable Mention

"…The test houses are a department where male labor, perhaps naturally, is now used exclusively, but it would be an omission on the writer's part if particular mention were not made in this summary of the manufacture of the Rolls-Royce Merlin to the increasingly important part that women are playing…"

***FLIGHT,* February 26, 1942**

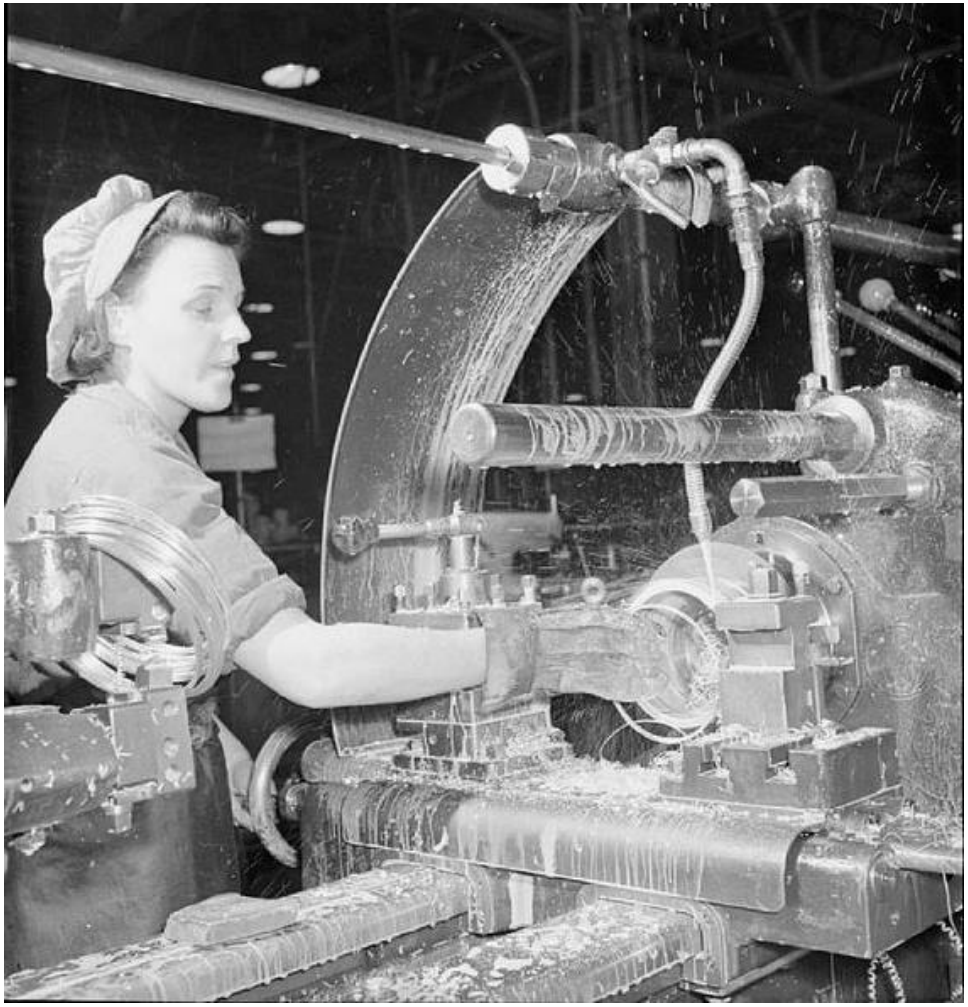
Seeing is Believing



"…Just whether the skilled management, the guiding influence which carries the eventual responsibility, or the women operatives themselves, deserve the greater measure of credit, I will leave others to decide, but the proportion of women workers and the skill and dexterity of their work have to be seen to be believed…"

1491

***FLIGHT,* February 26, 1942**



"…In the largest of the dispersal factories the management have built-up the creditable proportion of over 50 per cent women labor, as well as a high percent age of unskilled workers and remember, this is on complicated mechanism composed of the finest and most expensive materials demanding a degree of accuracy unsurpassed in any other branch of engineering. Not only in the machining and fitting shops, the metallurgical, radiological and standards rooms has this desirable state been reached…"

***FLIGHT,* February 26, 1942**

"…The foundry is another example of the successful employment of women operatives where their deft fingers are particularly suited and busily applied to aluminum-alloy castings of every conceivable shape, save only the largest sizes where undue fatigue might be experienced…"

***FLIGHT,* February 26, 1942**

"…Their work, too, is highly appraised, a common remark of the management being that they are ready and eager to learn, and are, generally speaking, more manageable when proficient in that they obey assiduously the production technique laid-down. Their keen spirit and seeming pride in their work are apparent to any observer…"

***FLIGHT,* February 26, 1942**

"…But the particular foundry I refer to is no ordinary one. Surely nothing exists in this country to surpass it either in layout or equipment, with possibly one notable exception…"
***FLIGHT,* February 26, 1942**

A Mechanized Foundry

"…It is almost completely mechanized, with progressive roll-er-track systems, automatic delivery of materials, reclamation methods and a remarkable sand-reconditioning plant. But so much could be said of that efficient and impressive foundry and its equipment that it must remain for the moment as a subject for special treatment…"

***FLIGHT,* February 26, 1942**

An Engine Every Hour



"…From the test-beds the engines are conveyed to the Despatch Department, where, having learned something of the 'Engine Every Hour' speed in the largest of the works, I anticipated seeing long lines of finished engines such as occasional impressive photographs portray…"

***FLIGHT,* February 26, 1942**

1500

"…You will see nothing of long lines of idle aircraft engines at Rolls-Royce. As quickly as they reach the terminal point of the track with their pass tags affixed, one-by-one they are placed in substantial wooden cases and slung onto trucks waiting in the sidings…"

***FLIGHT,* February 26, 1942**

"…With a confidence born of the knowledge and conviction that they constitute a British engineering feat well and truly done, the engines are despatched for operational duty in many spheres to add luster to the already brilliant achievements of the RAF pilots who operate them."

***FLIGHT,* February 26, 1942**

Part 12

An Improved Spitfire

Sky’s the Limit

Notable British Engine Progress: Two-stage, Two-speed Supercharger Enabling Stratosphere Flight

***FLIGHT,* December 17, 1942**

RE: introduction to an article written by *G. Geoffrey Smith,* MBE, entitled: "Rolls-Royce Merlin 'Sixty-One'"

Cause & Effect

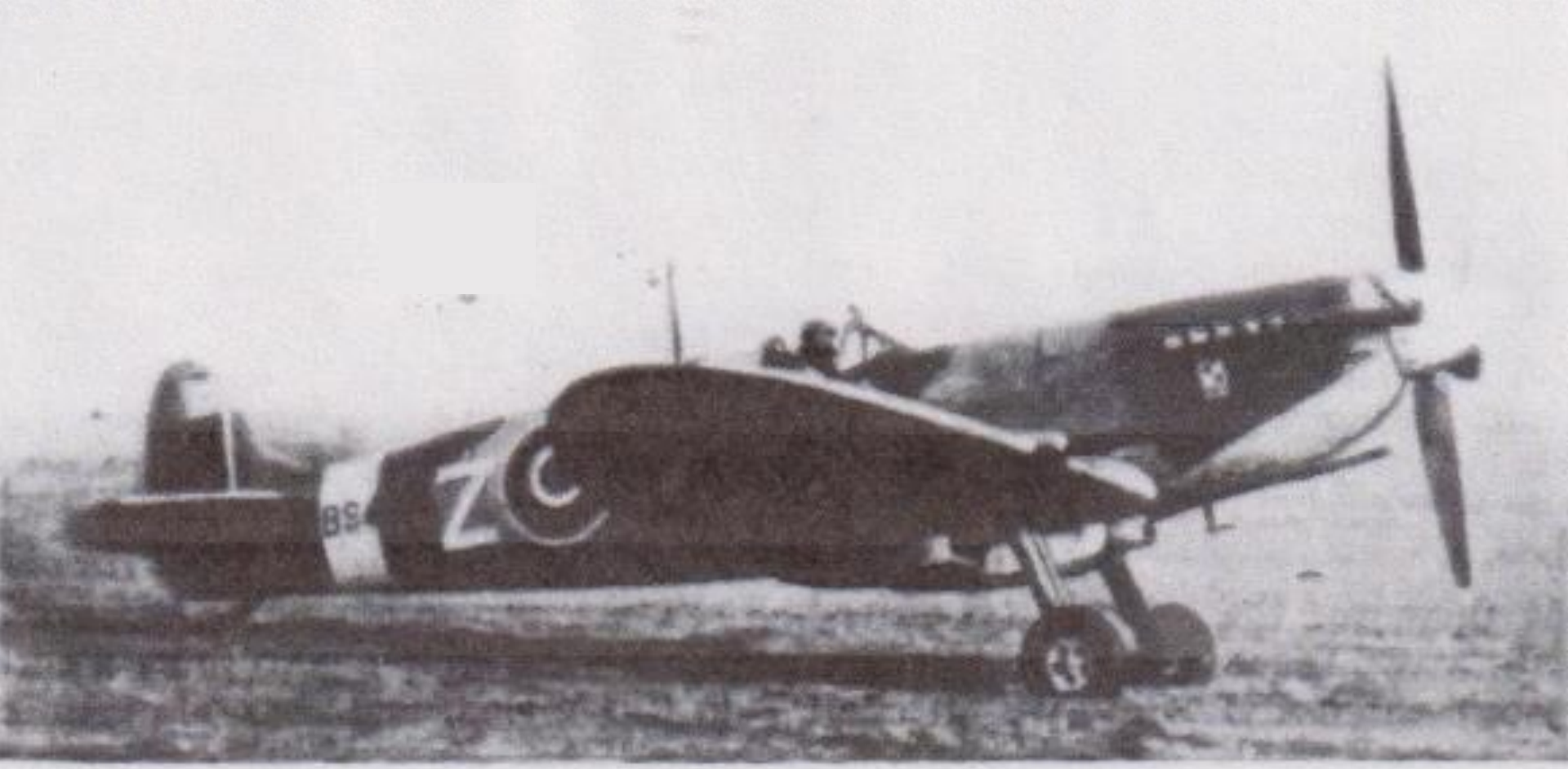
"PROGRESS in the design of superchargers, particularly during the last three years, is responsible for aircraft engines of a given size developing far greater power at high altitudes…"
***FLIGHT,* December 17, 1942**

Type No. 61

"…British technical achievement in this field is of the greatest importance in maintaining ascendancy over the enemy and Rolis-Royce Engineers are to be congratulated upon the introduction into service types of the first proved type of two-stage, two-speed supercharger. It is on operational duties in the Spitfire and bears the type number '61'…"

***FLIGHT,* December 17, 1942**

First Glimpse



Three-quarter view of the improved Spitfire fitted with the R.-R. Merlin 61 engine and Rotol four-blade airscrew.

"…A month ago, the existence of a new Spitfire fitted with the new Type 61 Merlin engine was revealed and brief details appeared in FLIGHT of December 10th…"

***FLIGHT,* December 17, 1942**

Details are to be released this week of the new Rolls-Royce Merlin 61 engine, the feature of which is the two-stage, two-speed supercharger

***FLIGHT,* December 10, 1942**

RE: introduction to an article entitled: "The Merlin 61 Engine"

"…By the aid of the new design double blower with its inter-cooler, the ceiling of the improved Spitfire has been increas-ed to 40,000 ft…"

***FLIGHT,* December 10, 1942**

"…An illustrated description of this new and highly important British development will appear in next week's issue of FLIGHT."

***FLIGHT,* December 10, 1942**

Striking Successes

"…This new Spitfire, which has two cannon and four machine guns, has already achieved striking successes in the air; both over the Channel and in the Middle East theatre of war…"
***FLIGHT,* December 17, 1942**





"…One outstanding achievement was the destruction at a height of over 40,000 ft. of three of Germany's stratosphere reconnaissance aircraft, type Ju-86P, which is reputed to have a pressure cabin, diesel engines and exhaust turbo superchargers…"

***FLIGHT,* December 17, 1942**

RE: in Jan. 1940, the Luftwaffe evaluated the prototype Ju-86P, which could fly at +39K ft., where it was felt it would be safe from enemy fighters

<u>Above L&R</u>: caption: "A Ju-86P high-altitude reconnaissance aircraft, with Jumo 207 turbocharged diesel powerplants"

Of Particular Interest

"…Since the heart of any good aircraft, be it fighter or bomber, is the engine, details now released for publication of the latest Rolls-Royce contribution to the many notable technical achievements of this world-renowned firm are of particular interest…"

***FLIGHT,* December 17, 1942**

Pre-war Perfection

"…The 'Sixty-One' engine is a development of the twelve-cylinder V-type liquid-cooled Merlin, the perfection of which engine before the outbreak of war has meant so much to this country…"

***FLIGHT,* December 17, 1942**

"…The cylinder dimensions of 5.4 in. bore by 6 in. stroke, giving a capacity of 1,649 cubic-inches, or 27 litres, remain the same; compression ratio is 6-to-1, but thanks to the development of a two-speed, two-stage supercharger and an improved larger S.U. twin-choke carburetor, designed as a complete separate unit, the power output has been greatly increased and the engine is capable of maintaining its exceptional performance over a far greater range than hitherto…"
***FLIGHT,* December 17, 1942**

LEADING PARTICULARS

ROLLS-ROYCE MERLIN "61"

Number of Cylinders	12
	Two separate castings of 6 cylinders, with detachable heads. Cylinder banks set at 60°
Bore and Stroke	5.40" × 6.00".
Valves—2 inlet 2 exhaust	per cylinder operated by overhead camshafts via rockers.
Cooling Medium	Pressure water (30% glycol)
Compression Ratio	6.0 : 1.
Supercharger ...	Two-speed two-stage with intercooler.
Carburettor ...	S.U. twin-choke updraught.
Total Capacity ...	1,649 cu. ins. or 27 litres.
Reduction Gear ...	Direct spur
Ratio	.42 : 1
Direction of Rotation ...	Airscrew—right-hand Engine—left-hand
Estimated Net Dry Weight ...	1,600 lb. + 2½%.

"…Operational altitudes with the Spitfire-Merlin 61 combination in conjunction with a four-blade airscrew to absorb the greater power output are now in excess of 40,000 ft. Daily paper talk of air combats in the Battle of Britain at 40,000 ft. was much exaggerated…"

***FLIGHT,* December 17, 1942**

State of Perfection

"…Long years of experiment were necessary to bring the multi-stage supercharger and its necessary intercooling mechanism to its present state of perfection, whilst hand-in-hand the process of extracting more-and-more power from the Merlin has gone on continuously. For example, the XX engine today produces 250-hp more than the III of identical cylinder dimensions…"

***FLIGHT,* December 17, 1942**

Satisfying Demand

"…From single-speed superchargers with a rotor running at the tremendously high speed of 28,000 rpm, i.e., approximately nine times engine speed, the demand for more power at a high ceiling led to the fitting of two-speed mechanism, as in the Merlin XX…"

***FLIGHT,* December 17, 1942**

High or Low

"…For a given boost-pressure, both at take-off and low altitude, a considerable improvement in power output is obtained when using the lower gear and for altitude work, the higher gear is brought into use…"

***FLIGHT,* December 17, 1942**

"…On the 'full,' or high gear, this engine develops 1,175-bhp at 2,850 rpm +9 lbs./sq. in. boost at 17,500 ft. altitude using 100 octane fuel…"

***FLIGHT,* December 17, 1942**

Meritorious Progress

"…Later, in the search for higher boost-pressure, the two-stage supercharger, in conjunction with a two-speed gear, was patiently progressed through the research and experimental stages so that today we have to thank Rolls-Royce Engineers for the ability to fly aircraft at altitudes in a region some eight miles above the earth's surface. Such altitudes involve special protective measures for the safety and comfort of the pilot…"

***FLIGHT,* December 17, 1942**

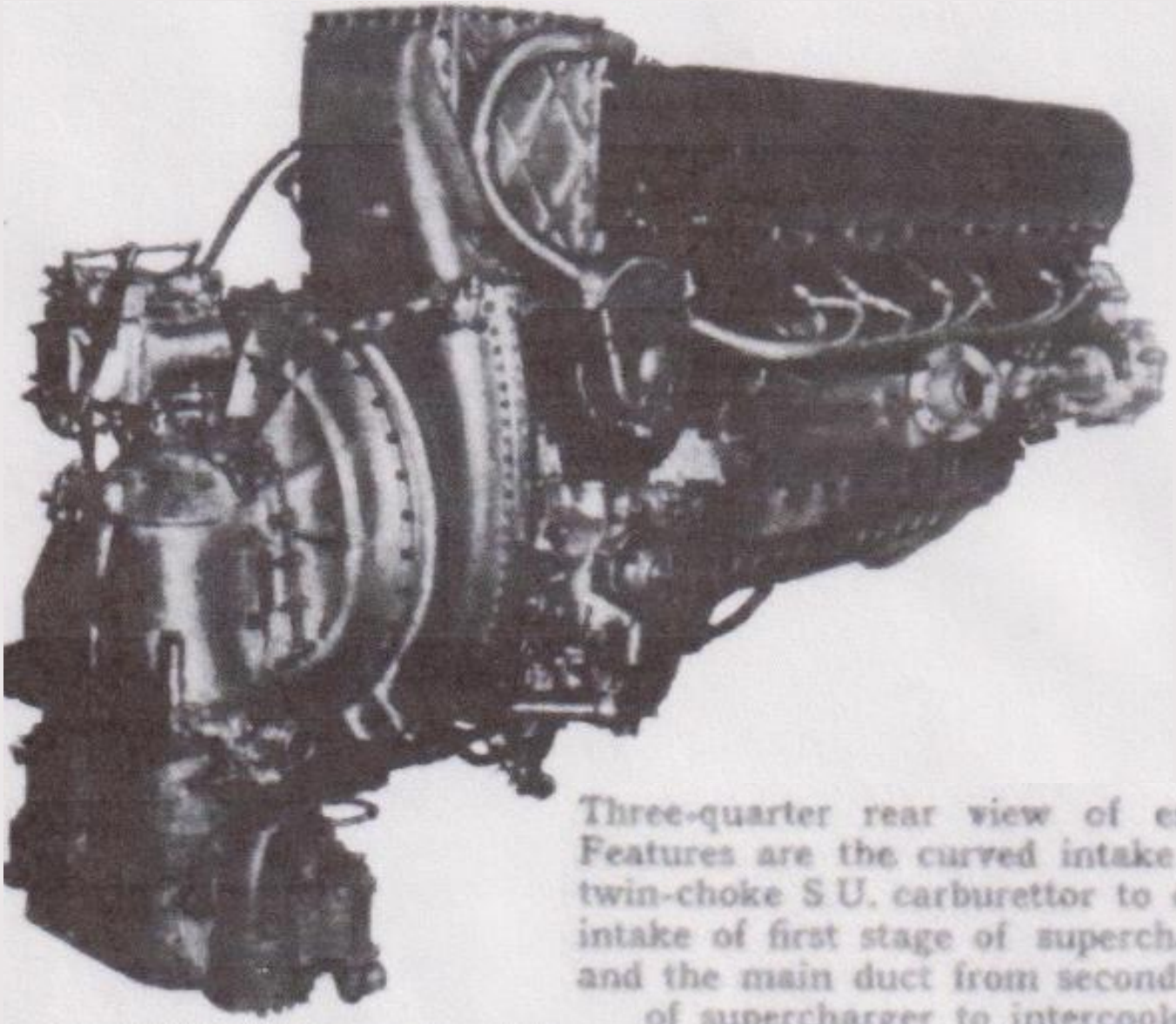
"…We owe it to British technicians to acknowledge the highly meritorious technical progress in not only extracting more power from the Merlin but, at the same time, attaining that ideal without radical changes being necessary to install it in our modern fighters…"

***FLIGHT,* December 17, 1942**

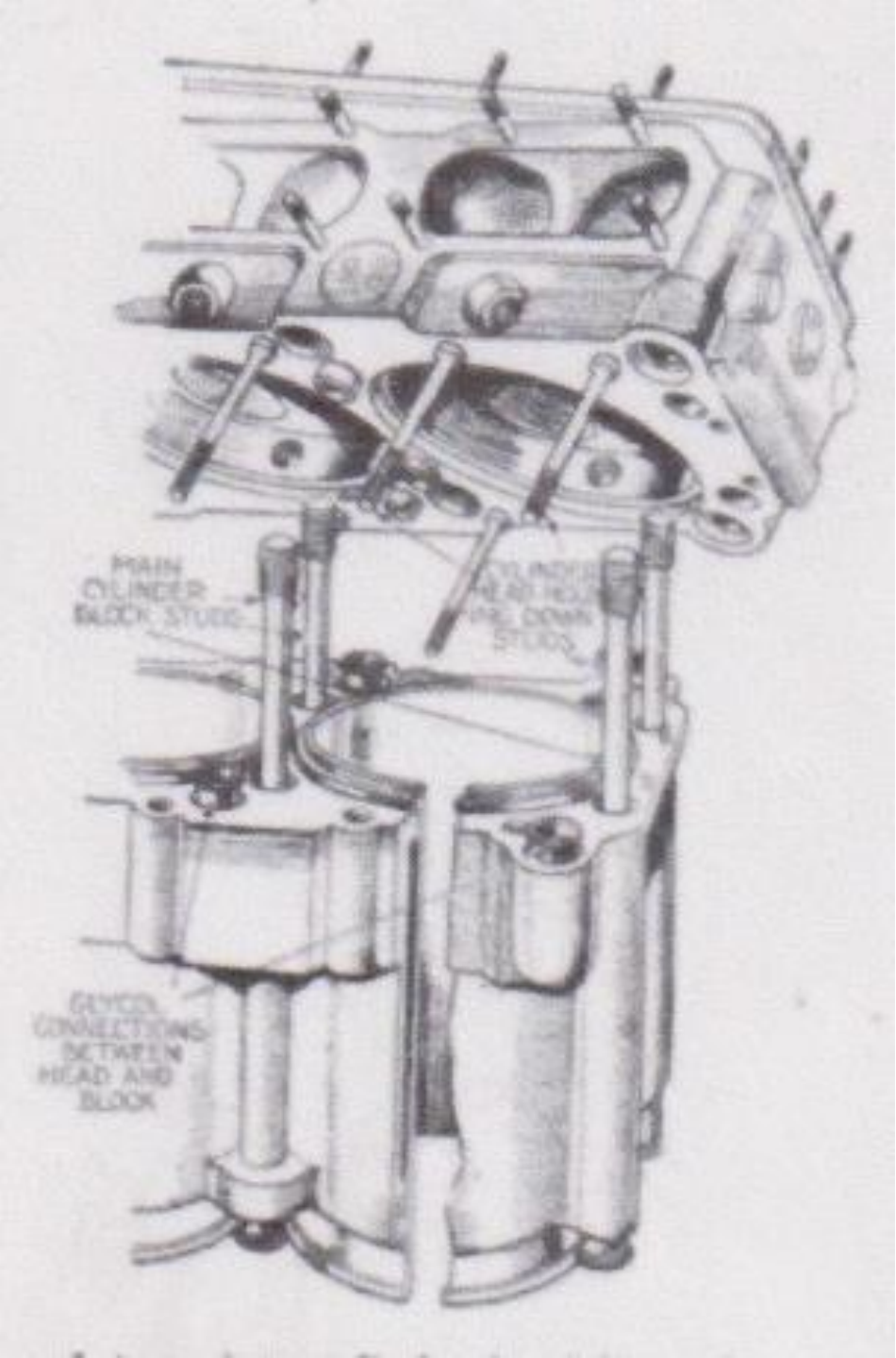
XX vs. “61”

"…Dimensionally, the '61' is slightly longer overall than the Merlin XX because of the intercooler located immediately aft of the cylinders. It scales approximately 1,600 lbs. compared to the 1,450 lbs. of the Merlin XX…"

***FLIGHT,* December 17, 1942**



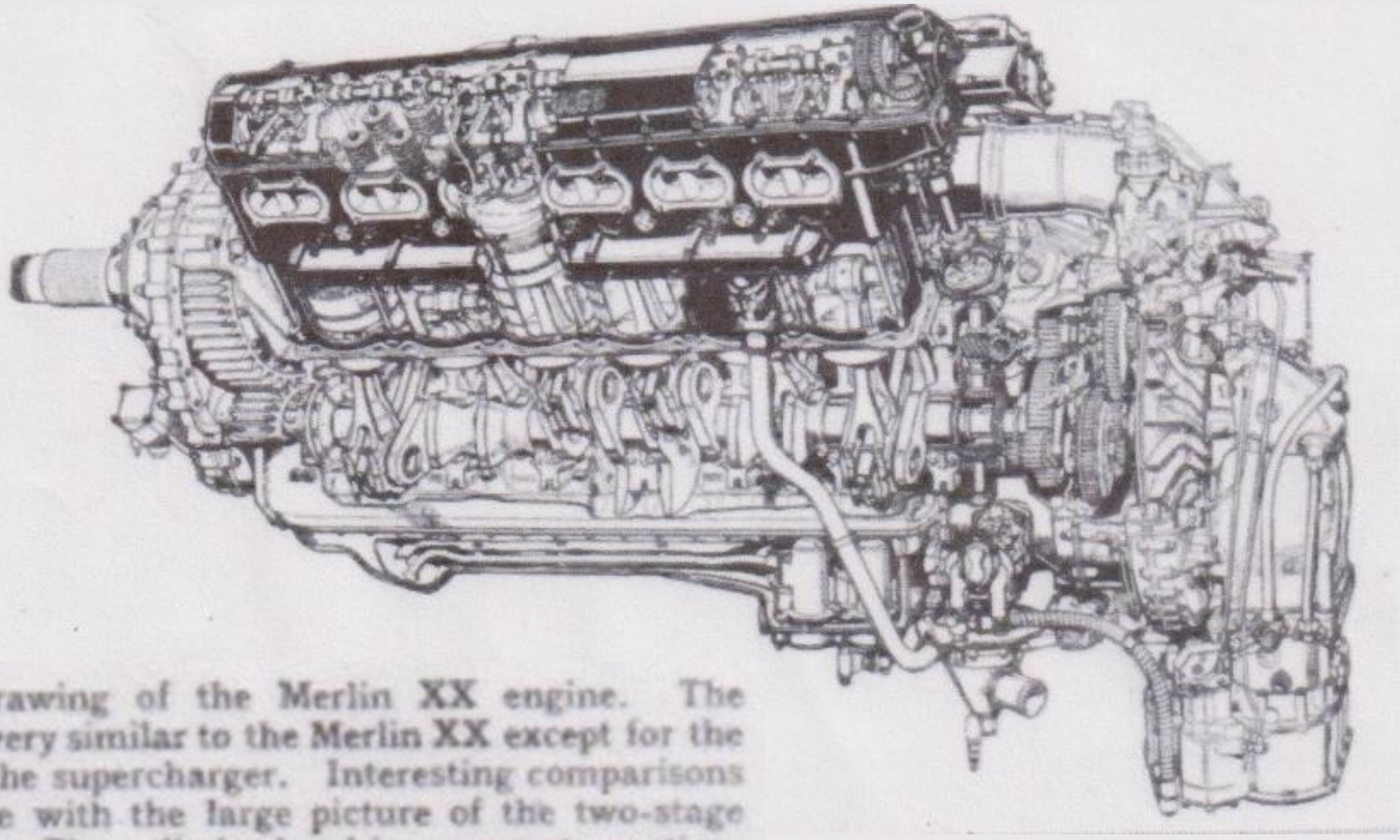
Three-quarter rear view of engine. Features are the curved intake from twin-choke S.U. carburettor to centre intake of first stage of supercharger, and the main duct from second stage of supercharger to intercooler.



"…The only important change in design is the adoption of a two-piece cylinder similar to that designed by Rolls-Royce for the Merlin XX produced by the Packard Co. Thus, the flow of Spitfire and Hurricane fighters from British factories has not been adversely affected by the modifications which gave us the 45 and the XX engines and now the 61…"

***FLIGHT,* December 17, 1942**

Caption: "A two-piece cylinder head is used on the 61 engine as well as on certain Merlin XXs. The head is attached to the cylinder block by a series of studs, with metal-to-metal joints between the engine and cylinder sleeves. The complete head and cylinder block is attached to the crankcase by long studs passing upwards from the crankcase. Circulation of glycol between block and head is through a series of connecting ports with rubber seatings."

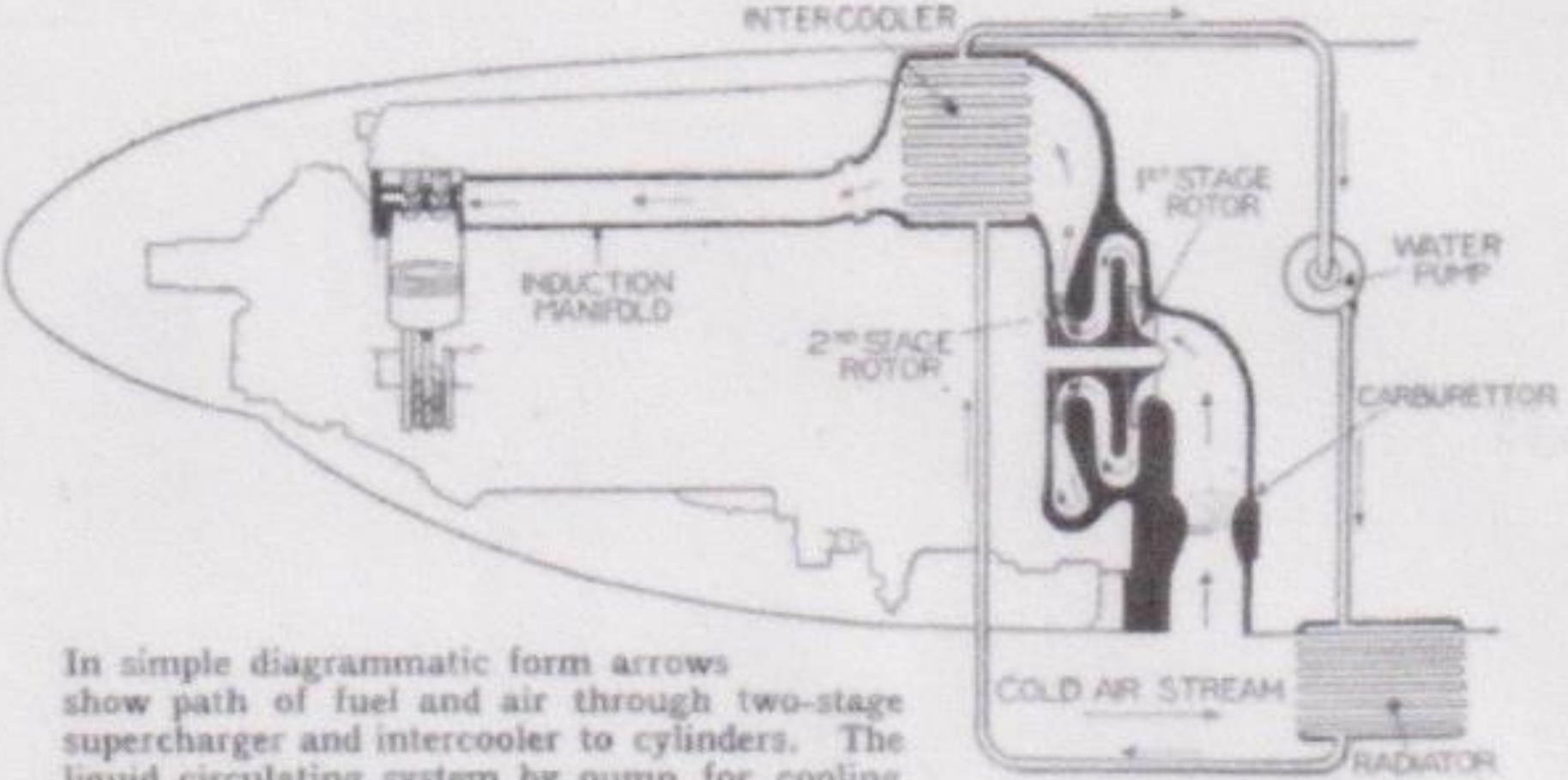


Cut-away drawing of the Merlin XX engine. The Merlin 61 is very similar to the Merlin XX except for the changes in the supercharger. Interesting comparisons can be made with the large picture of the two-stage supercharger. The cylinder head is a separate casting.

Briefly and SImply

"…It will be helpful to recapitulate briefly and simply the object of feeding mixture into an engine by pressure…"
***FLIGHT,* December 17, 1942**

"…The work of a supercharger or blower is to force a certain weight of air into the engine and en route, to mix it with a certain weight of fuel. In a normal car engine the charge of petrol and air is induced by the downward stroke of the piston, but in the case of a supercharged aircraft engine the mixture is forced into the cylinders under pressure (technically known as 'boost-pressure'), created by a centrifugal blower. Thereby, the engine is enabled to consume a greater weight-of-charge and to develop a greater horsepower…"
***FLIGHT,* December 17, 1942**



In simple diagrammatic form arrows show path of fuel and air through two-stage supercharger and intercooler to cylinders. The liquid circulating system by pump for cooling the mixture is entirely independent of the liquid cooling for the cylinder jackets.

"…Weight-of-charge in the cylinders is the important aim, not the volume, since the volume varies with the pressure…"

***FLIGHT,* December 17, 1942**

"…At sea-level, the weight-of-air is 0.076 lbs./cu. ft. at 59-degrees F. and at 20,000 ft. altitude it is 0.046 lbs./cu. ft. Thus, with a normal engine around this altitude, the volumetric efficiency falls appreciably since each cylinder is receiving only about half-weight charge. At 35,000 ft. the air density is roughly a quarter of the figure at sea-level…"

***FLIGHT,* December 17, 1942**

Restoring Boost-Pressure

"…Clearly then, the object of employing a two-speed drive for the supercharger is to speed-up the impellor of the super-charger after a certain altitude has been attained and so force into the engine a greater volume of the less dense air to sup-ply the necessary weight-of-charge to sustain power at still greater altitudes…"

***FLIGHT,* December 17, 1942**

"…The two-stage supercharger, with its independent inter-cooler, carries on the same process in higher altitudes in precisely the same manner, but without recourse to correspondingly increased impellor speeds to which there is a safe limit. Its beneficial effects thus become particularly important when the limit ceiling with a single-stage supercharger on 'full' gear has been attained…"

***FLIGHT,* December 17, 1942**

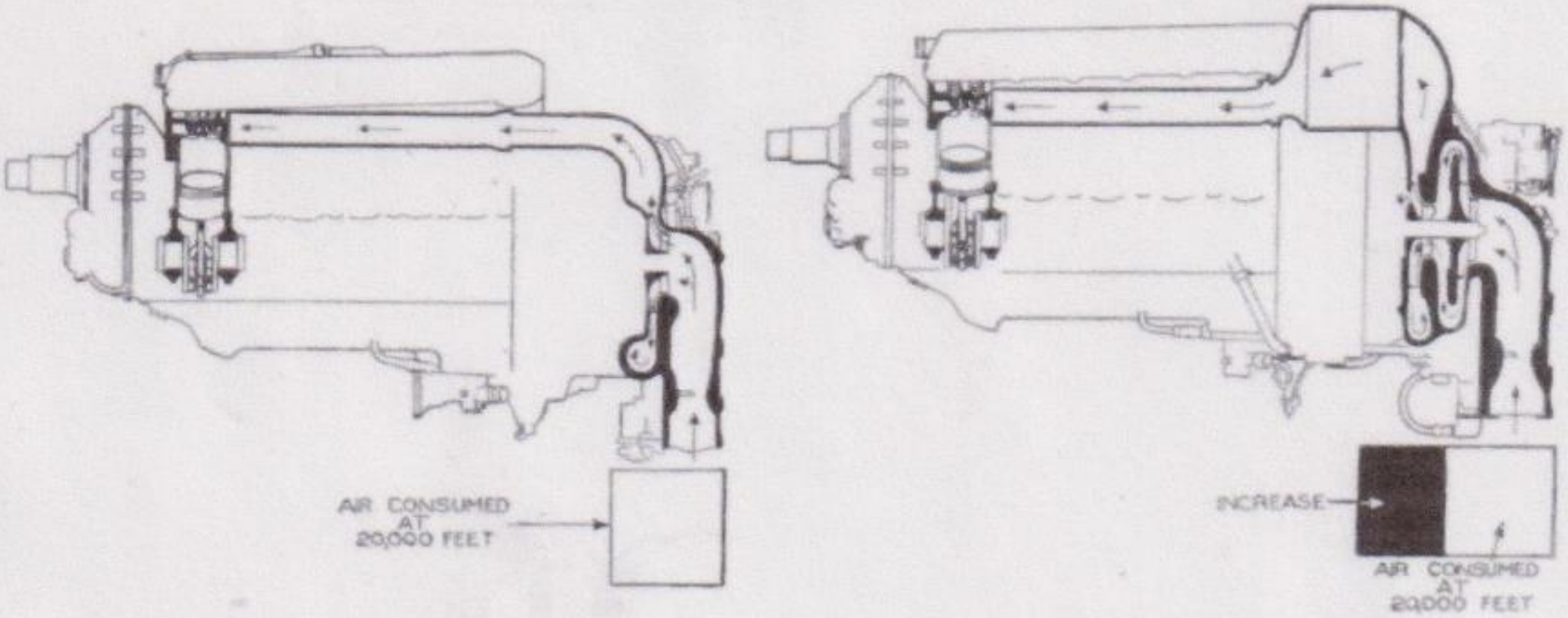
A New Era

"…In the combination of a supercharger with two rotors (or stages) driven by mechanism providing two different gear ratios, the Rolls-Royce achievement is highly progressive and its advent marks a new era in aircraft engine performance. By its use it is possible so to increase boost-pressure that the maximum power developed at sea-level is maintained at much higher predetermined altitudes than formerly..."

***FLIGHT,* December 17, 1942**

"…Having examined the objects and advantages of multi-stage blowers, we may turn to the details and illustrations…"
***FLIGHT,* December 17, 1942**

Twin Superchargers in Series



Diagrams which explain single-stage and two-stage supercharging. The squares indicate diagrammatically the volumetric increase of air achieved by two-stage supercharging over the single-stage. Increase in air volume allows of corresponding increase of charge, with proportionate increase in power.

"…The two-stage supercharger has two rotors on a common shaft and, in effect, constitutes two separate superchargers in series. The mixture of air and petrol which is drawn through the carburetor is compressed by the first-stage supercharger and is then delivered to the inlet of the second-stage supercharger, which is of smaller diameter than the first, where it is still further compressed before being finally delivered to the induction manifold…"

***FLIGHT,* December 17, 1942**

"…The power expended in compressing the large quantity of air required for combustion of the fuel would normally result in considerable heating of the mixture. To reduce the mixture temperature to a normal figure a means of charge-cooling or 'intercooling' is introduced. This process of compression inevitably carries with it heating of the charge. The higher the pressure to which the air is compressed the greater will be its final temperature and that result is a disadvantage as expansion occurs with heat and the weight of the volume of the charge which can enter the cylinder correspondingly reduced…"

***FLIGHT,* December 17, 1942**

"…A simple illustration of heating by compression is a bicycle tire inflator which gets unbearably hot to the hand by continuous strokes of the pump. This is what happens to the charge when highly compressed by the supercharger; hence the necessity for the intercooler is to prevent undue expansion by keeping the charge cool and so ensure maximum weight-per-unit volume…"

***FLIGHT,* December 17, 1942**

Cooling the Charge

"…The way in which this intercooling is carried out is very ingenious. A square, box-like structure is mounted in the induction system between the outlet of the second stage supercharger and the rear of the cylinder blocks. This box contains a stack of horizontal tubes through which water is circulated by a special pump. The hot charge from the outlet of the supercharger is passed, on its way to the main induction pipe, around and between the tubes of this heat exchanger, and in this region of artificial cooling its temperature is considerably reduced…"

***FLIGHT,* December 17, 1942**

"…In addition to the means of cooling the charge by the inter-cooler, there is also an 'interstage' cooling system compris-ing water passages in the supercharger casing between the two rotors. The intercooler, or charge-cooling system, is en-tirely separate from the main cooling system for the cylinder jackets and one of the outstanding advantages of this novel method is that the actual radiator which cools the circulating liquid of the intercooler, and from which the excess charge temperature is dissipated to the atmosphere, may be placed in any convenient position on the powerplant or the air-craft…"

***FLIGHT,* December 17, 1942**





Britain's latest fighter – the stratosphere Spitfire. The main cooling system of the engine has two radiators located in housings below the wings. In each housing is also a small extra radiator; one for cooling the liquid circulating in the intercooler, the other for cooling the engine oil."

"…In the case of the improved Spitfire, it is neatly housed under the wing in a duct which also contains one of the main engine cooling radiators. The engine cooling radiator proper is also underslung in a similar duct on the opposite wing, so giving a well-balanced, workman-like effect. This second duct embodies the engine oil cooler as an integral unit…"

***FLIGHT,* December 17, 1942**

"…A further advantage of the liquid-cooled intercooler is that it can be made considerably smaller than would be the case if the heat interchange was made direct to the atmosphere. Since it is important that the intercooler should be mounted in such a position that the induction system is kept as short as possible, limitations of space and the need for a good view for the pilot would probably mean that a sacrifice in intercooling efficiency would have to be made if direct air-cooling of the charge was employed…'

***FLIGHT,* December 17, 1942**

No Structural Alterations

"…The successful application of this complex system to a Merlin engine so that the combination could still be installed in existing Spitfire aircraft was in itself a praiseworthy accomplishment. Briefly, it entailed a slightly longer nose…"
***FLIGHT,* December 17, 1942**

"…Comparing engines powering the various first-line aircraft, German engines are fitted with a single-stage supercharger driven by a hydraulic coupling and capable of maintaining ground-level pressure in the engine induction system up to 20,000 ft…"

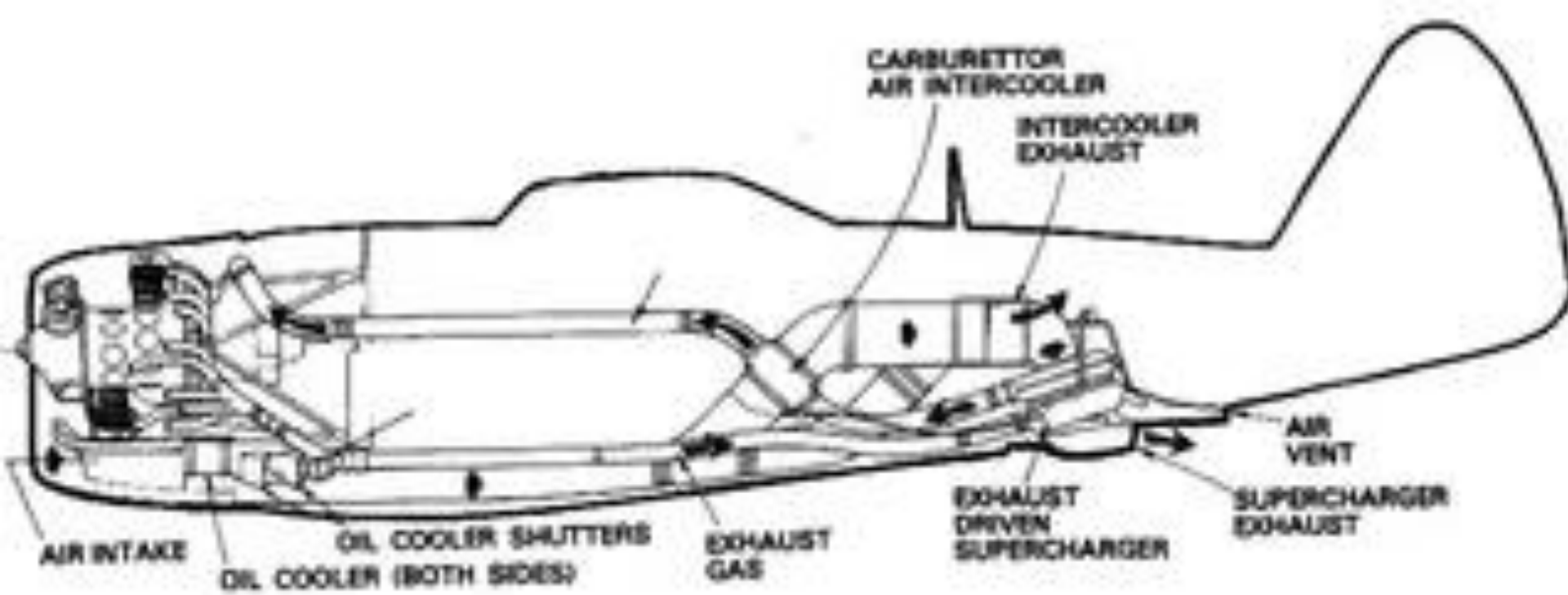
***FLIGHT,* December 17, 1942**

"…Rolls-Royce engines fitted with mechanically driven single-stage superchargers maintain the same pressure up to 30,000 ft. and this increase in altitude has been the main means of our achieving technical superiority…"

***FLIGHT,* December 17, 1942**

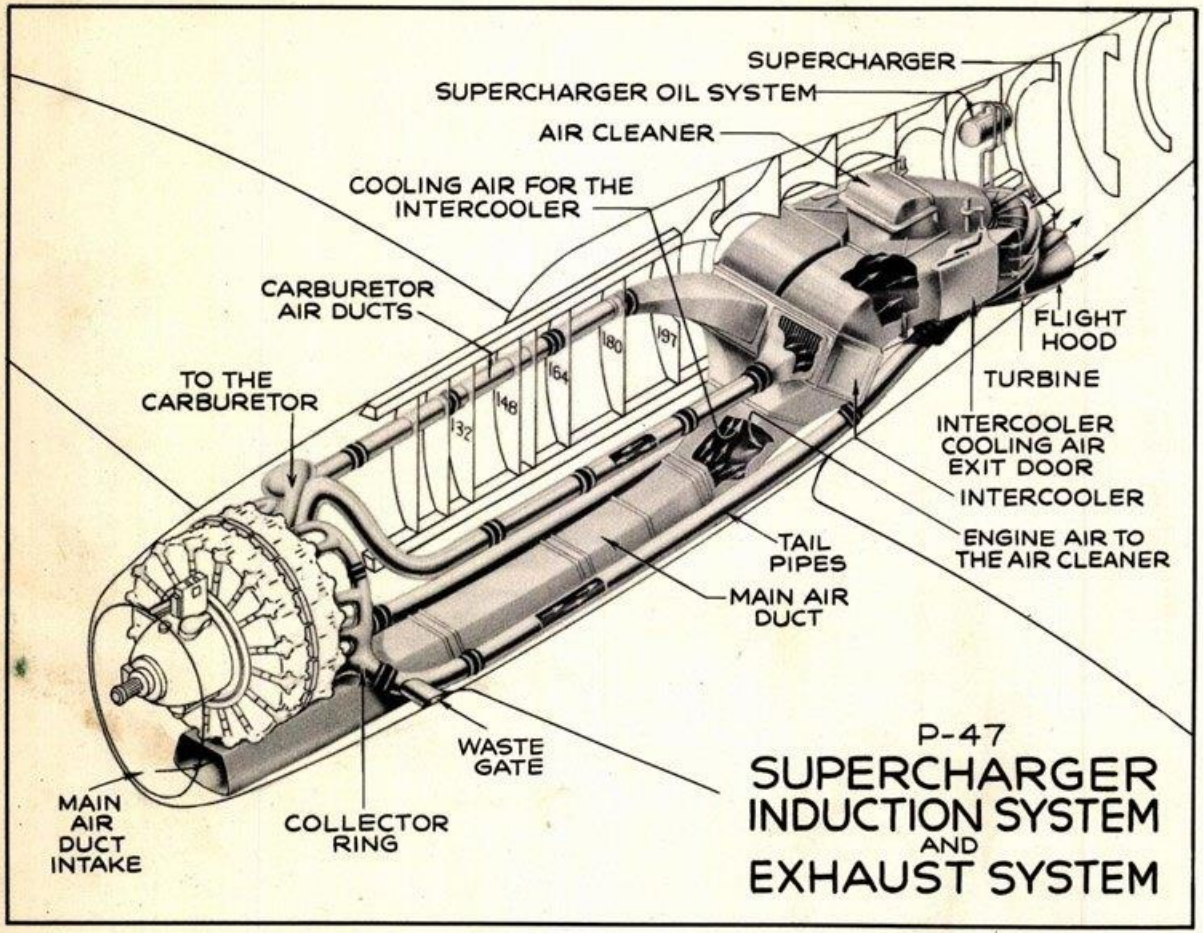
"…Certain American engines are fitted with exhaust turbo-superchargers on the G.E.C. principle, which also maintain sea-level pressure up to 30,000 ft. and, although this system is excellent when applied to bomber aircraft, there are operational reasons which, it is said, make it less suitable for fighters…"

***FLIGHT,* December 17, 1942**



"…We shall know more of this anon as certain U.S.A. fighters, including the Republic Thunderbolt, have a turbo exhaust-driven supercharger…"
***FLIGHT,* December 17, 1942**

<u>Above</u>: Republic Aviation's P-47 Thunderbolt was capable of operating effectively at high-altitude as a long-range bomber escort or at low altitude as a fighter-bomber. That tactical flexibility was enabled by its turbocharged P&W Double Wasp R-2800, two-row, 18-cylinder radial engine. The R-2800 engine was turbocharged, with the turbocharger, intercooler and related subsystems all located behind the pilot. There was a lot of intake ductwork needed to get ambient air routed from the main air duct intake immediately under the engine to the turbocharger and intercooler and then back to the carburetors on the engine.



SUPERCHARGER INDUCTION SYSTEM and EXHAUST SYSTEM

The P-47 supercharger is turbo-driven by the engine exhaust gases. The exhaust gases from the engine are collected by the collector ring. They are then carried into the bottom (or turbine) section of the supercharger. They turn the turbine, which drives the upper (or compressor) section of the supercharger. The exhaust gases then pass from the turbine, through the flight hood and overboard.

Air entering the turbocharger was compressed and, in the process, heated. This air passed through the intercooler where it was cooled before being directed back to the engine and the carburetors for each of the R-2800's 18 cylinders. The air entering the intercooler cooled the compressed-air from the turbocharger's compressor and then was discharged through exit doors on the sides of the P-47's fuselage, aft of the pilot.



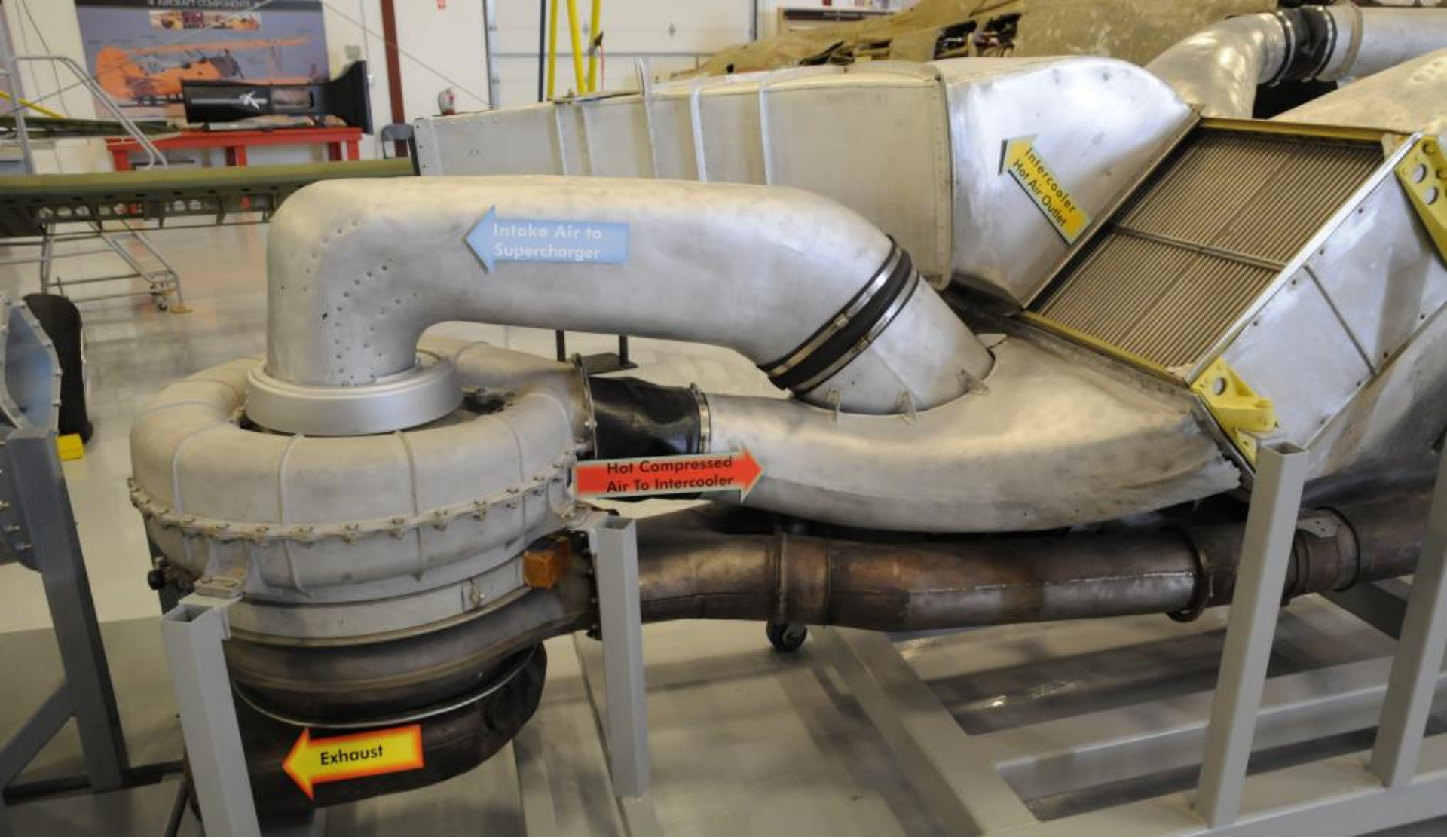
<u>Above</u>: P-47 powertrain. The engine is at the extreme left, the turbocharger is at the extreme right and the intercooler is at the point where the carburetor air duct (top) converges in a 'V' with the main air duct (bottom). The darker exhaust tailpipes flank the main air duct along the bottom of the powerplant.



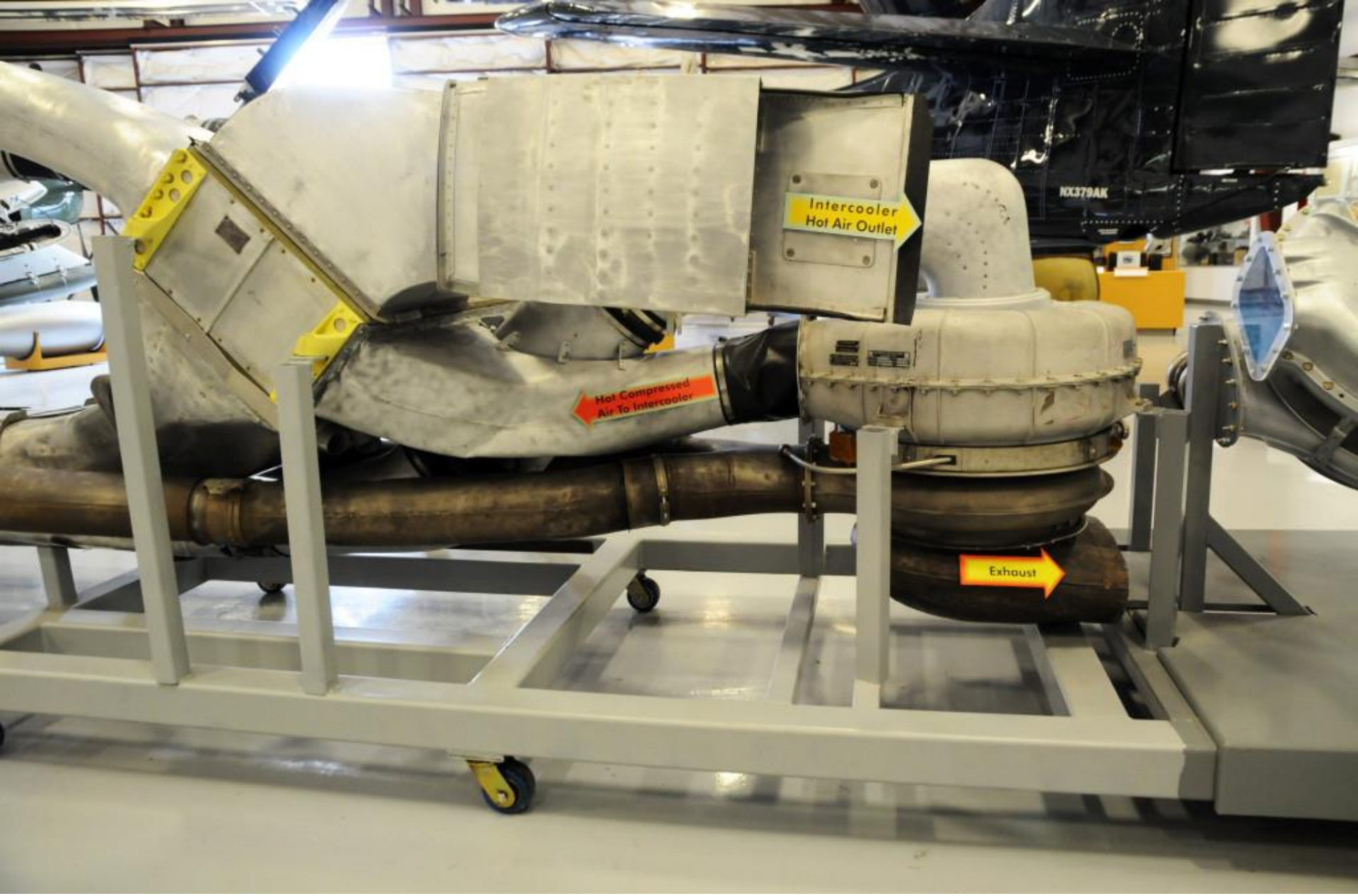
<u>Above</u>: from the front, the P&W R-2800 dominates the view. The main air duct intake is visible under the engine. The carburetor air duct (top) and the main air duct and darker exhaust tailpipe (bottom) are visible to the left, behind the engine.



<u>Above</u>: from the back of the powerplant, the turbocharger dominates the view. As shown by the arrows, intake air enters the compressor section of the turbocharger from the top (grey arrow) and exits via the volute (red arrow), headed for the intercooler. The darker exhaust tailpipe can be seen connecting to the turbine section of the turbocharger (below the red arrow) and exhausting under the turbocharger (yellow arrow).



<u>Above</u>: the photo shows the connection of the exhaust tailpipes to the turbine section of the turbocharger and the exhaust point from the turbine section (beneath the P-47's fuselage). Also shown is the intercooler, which is a heat exchanger that receives cool ambient air from the main air intake duct and warm, compressed-air from the turbocharger's compressor discharge (red arrow). After cooling the compressed-air heads for the carburetors, the intercooler exhausts through rectangular ducts on the sides of the P-47 (yellow arrow).



<u>Above</u>: another view of the P-47's intercooler exhaust duct

First Practical Example

"…Finally, the two-stage supercharger maintains the desired pressure up to 40,000 ft. and stands out above all others as the most potent proved means of obtaining high power and high altitudes…"

***FLIGHT,* December 17, 1942**

"…At 40,000 ft., the charge is being compressed to six times the surrounding atmospheric pressure and the power of the original Merlin III engine has been doubled…"
***FLIGHT,* December 17, 1942**

"…Two-stage and even three-stage superchargers have often been proposed in this country and abroad and designs have been illustrated in these columns, but the Rolls-Royce is the first proved example of a multi-stage supercharger in service…'

***FLIGHT,* December 17, 1942**

New & Improved

"…Every aspect of the performance of the wonderful improved Spitfire has been tremendously improved by the introduction of the Merlin 61…"

***FLIGHT,* December 17, 1942**

"…Although performance at high altitudes presents by far the most difficult problem, the Rolls-Royce two-stage supercharger and intercooler provides advantages which can be interpreted into performance at lower altitude at will…"

***FLIGHT,* December 17, 1942**

RE: commenting on the technical one-upmanship that characterized the battle between German and Allied Engineers, *The Engineer* wrote that: "…the war demands that the performance of all types of aircraft, and particularly that of fighter aircraft, shall continually improve. Ranking above the need for more and more aircraft of all types is the overriding necessity that ours shall have technical superiority over those of the enemy." Describing the engine, the report claimed that: "by using a double-stage supercharger with a water-cooled passage between the first and second stages of the supercharger and a cooler between the supercharger outlet and the induction pipe to the rear cylinder, it is found possible with the new engine to develop double the power output. When operating at a height of 40,000 ft. the charge of air and fuel is now raised by the supercharger to six times the pressure of the surrounding atmosphere." This redesign, concluded the article, had the desired effect. "The results obtained from the improved Spitfire have, we learn, more than fulfilled the hopes and expectations of all who have helped in the work. The advent of the new German Focke-Wulf 190 with its 1,600-hp air-cooled supercharged engine caused some uninformed persons to believe that the Germans had stolen a march on us in the high-performance fighter class of aircraft. But as enemy fighter losses continually show, the improved Spitfire with its new Merlin 61 engine was there to surpass it."



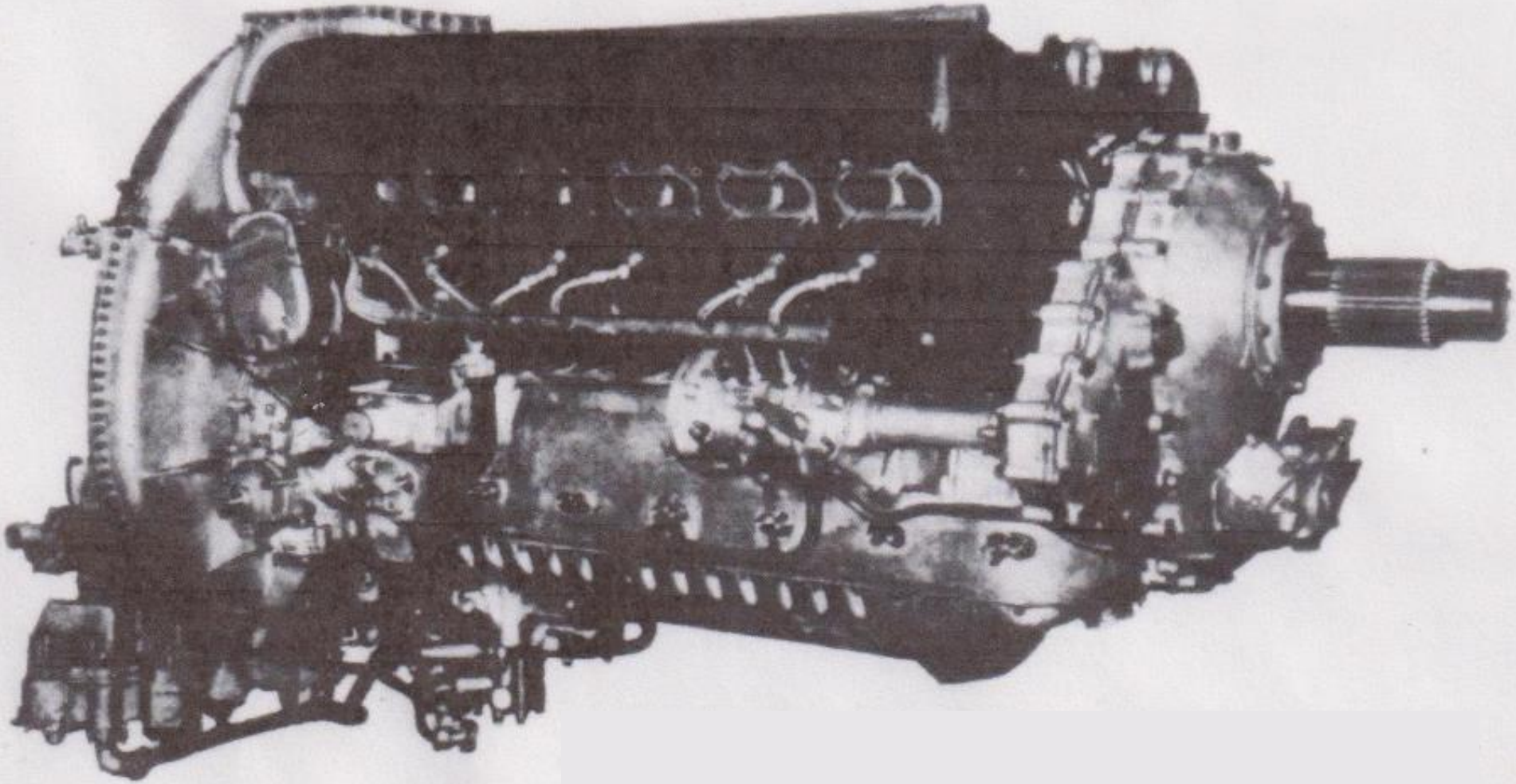
"…Squadrons of the RAF have already been equipped with this outstanding fighter."

***FLIGHT,* December 17, 1942**

RE: designed in response to the Focke-Wulf 190, the Luftwaffe's most effective fighter, the performance improvements brought about by the Merlin 61 supercharged engine enabled the RAF to achieve aerial superiority

<u>Caption</u>: "Rolls-Royce Merlin 61 installation in a Supermarine Spitfire IX, Sept. 1942"

Three-quarter front view of the new Merlin 61 engine described in the accompanying notes. It will be noted that certain accessories have been regrouped. The engine drives a Rotol four-bladed airscrew with Hydulignum blades.



Part 13

Series 100/600

DH Hornet

“Tailor-Made” Power Unit with Handed Reduction Gears for the de Havilland Hornet

***FLIGHT,* January 24, 1946**

RE: introduction to an article entitled: “Rolls-Royce Merlin 130 Series”

Progressive Development

"WITH the advent of the new Series 130 it can truthfully be said that the Merlin has carried progressive development of a basic type farther than any other aircraft engine in the world, for within a period of ten years (the first Merlin was produced in 1936) not only has its power output been increased from less than 1,000 to more than 2,000-bhp but, in addition, more Merlins have been built than any other type…"

***FLIGHT,* January 24, 1946**

Opposite Hands



"…The Merlin 130 and 131 are specially developed variants of the Series 100 engines and have been specifically prepared for installation in the de Havilland Hornet, which is the first twin-engined British aircraft to have handed airscrews. This feature accounts for the designation 130 and 131, the former being a right-hand tractor unit for the port-side and the latter a left-hand tractor for the starboard nacelle…"

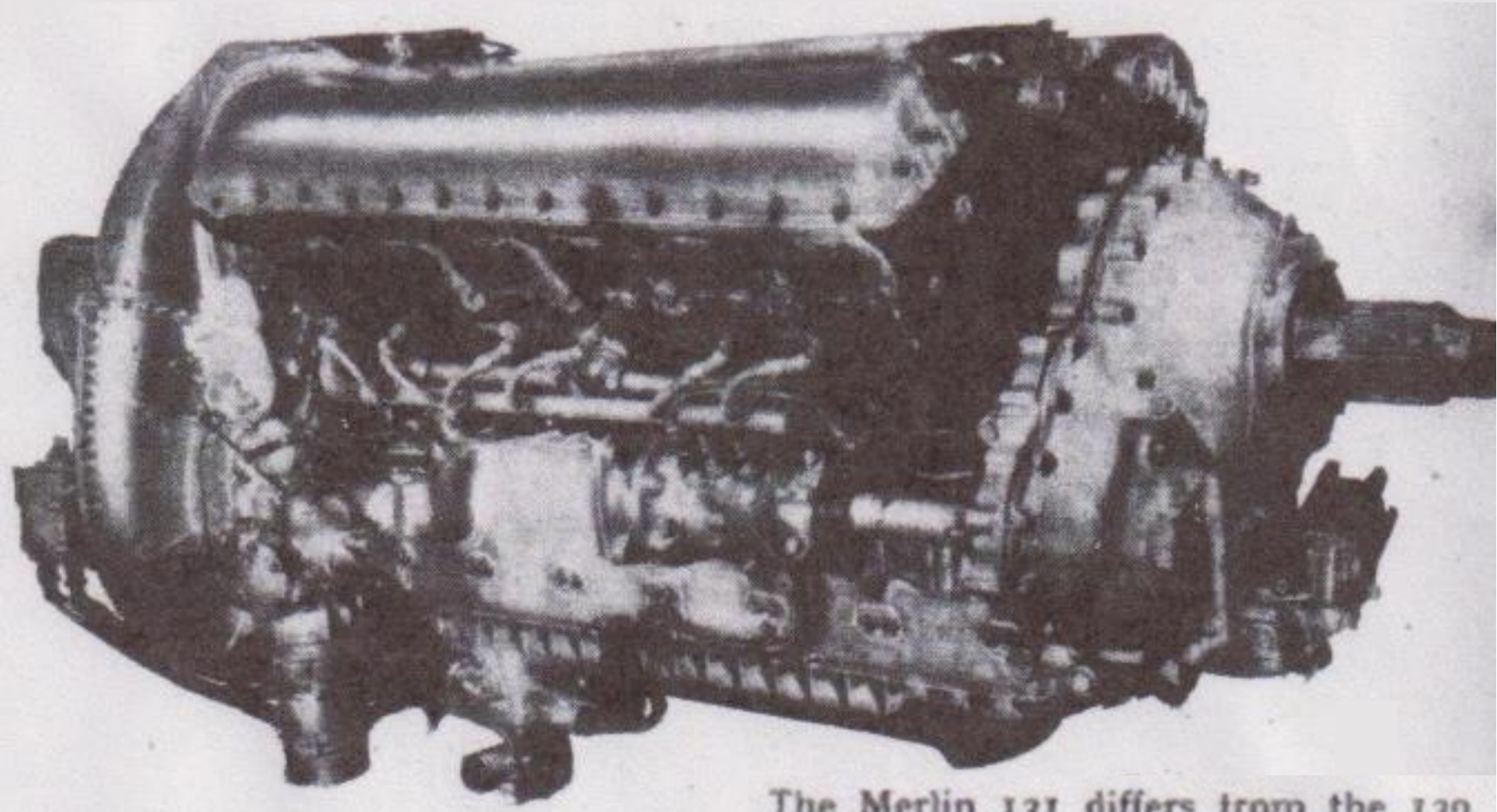
***FLIGHT,* January 24, 1946**

1587

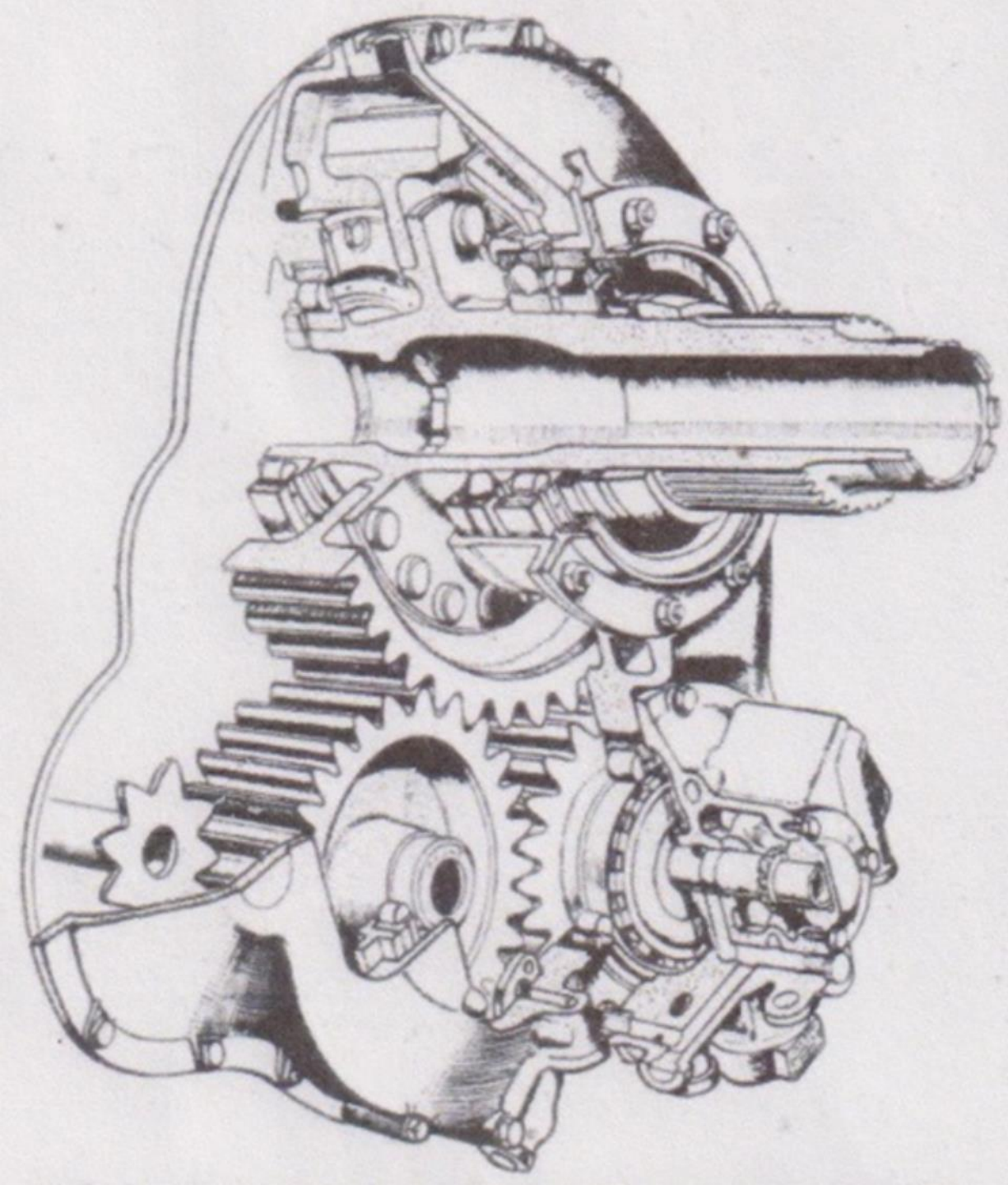
<u>Caption</u>: "De Havilland Hornet F3"

"…As the airscrew on the 130 rotates in the opposite direction to that of the 131, it might at first sight appear that this would involve considerable complication and that it would be necessary for the crankshaft to rotate in the opposite direction - making the engine 'handed' throughout. This, however, is not the case; all that is necessary on a liquid-cooled, in-line engine employing a single spur reduction gear is the introduction of an idler wheel between the driving pinion and the main gear wheel…"

***FLIGHT,* January 24, 1946**



The Merlin 131 differs from the 130 only in that an idler wheel is interposed between the driving pinion and the main gear wheel.



"…The advantage of this simple modification, which is clearly shown in the illustration, is that the two engines have 95 per cent of spares in common and to alter the engine from one 'hand' to the other, it is only necessary to change the reduction gear; the weight increase with the additional gear and bearings is practically negligible and can be discounted…"

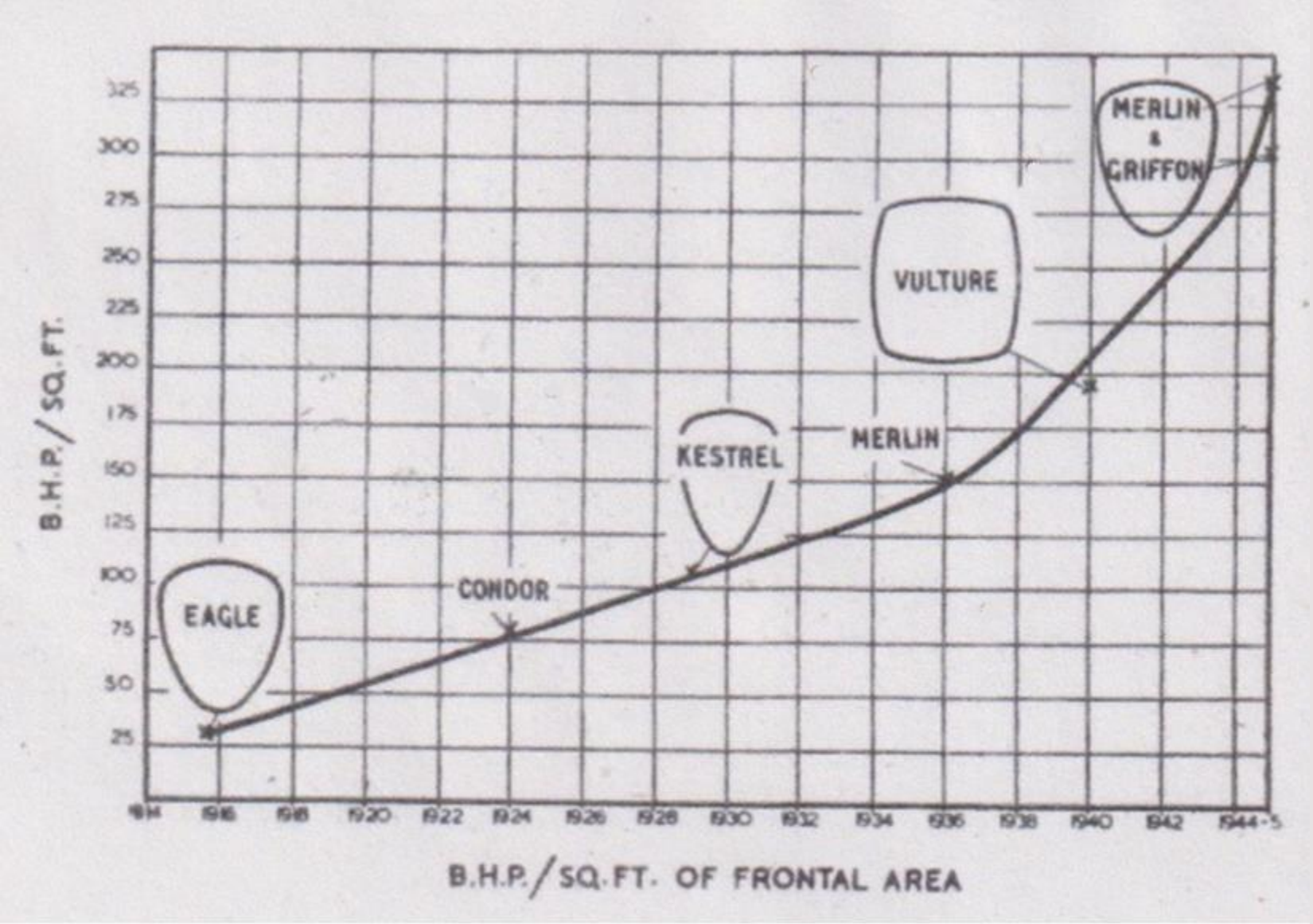
***FLIGHT,* January 24, 1946**

<u>Caption</u>: "Simplicity itself. Reverse reduction of the airscrew by introducing an idler wheel in the reduction-gear casing"

Tailor-made

"…Although the Merlin 100s were the first of a new series of two-stage, two-speed, intercooled types incorporating many improved features, the series 130 and 131 have further new features which enable an improved installation to be effected for fighter aircraft. In fact, it would not be inapt to describe this latest Merlin as being 'tailored' to suit the particular installation; this has resulted in a very low frontal area per-bhp…"

***FLIGHT,* January 24, 1946**



"…An illustration gives a curve of interesting comparisons of frontal-area: power, starting with the Eagle produced at the beginning of the first World War and ending with the Merlin 130 of today…"

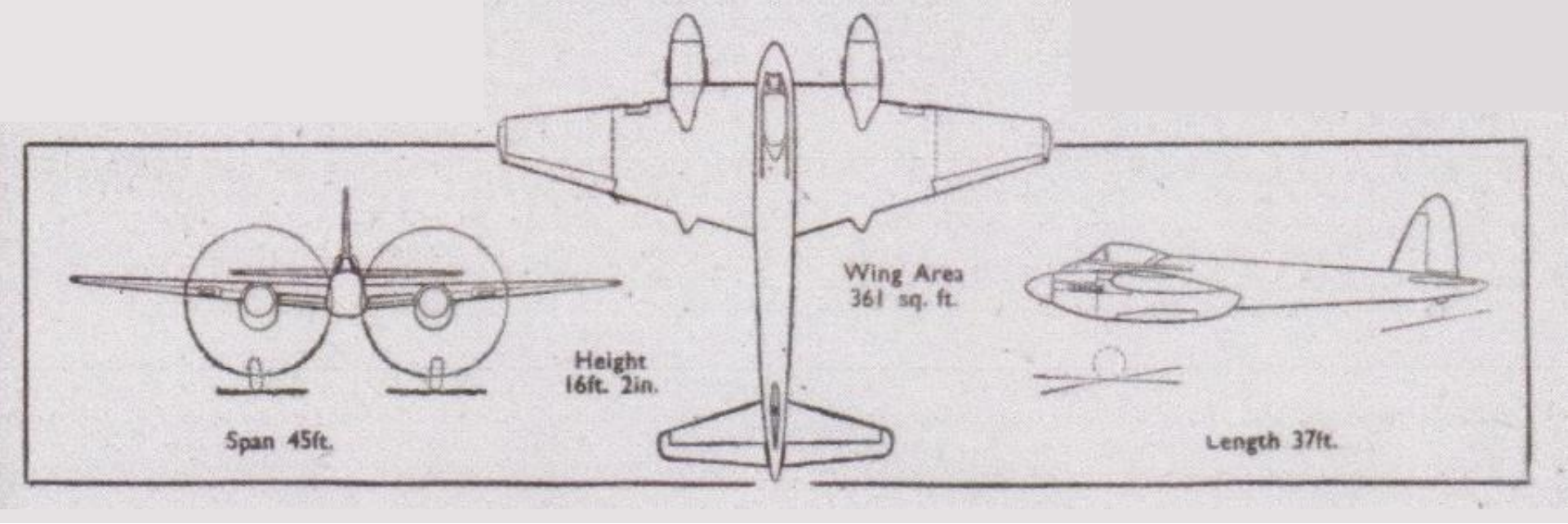
1593

***FLIGHT*, January 24, 1946**

"…From this curve it will be seen that a steady increase in power per-square-foot of frontal area was achieved during the interwar years, every four years producing an increase of roughly 25-bhp/sq. ft., until 1936 and then, with the advent of the Merlin, there was a considerable improvement amounting progressively to 60-bhp/sq. ft. in 1940; 100-bhp/sq. ft. between 1940 and 1944 until, in 1945, the amazing figure of 340-bhp/sq. ft. was achieved with the Merlin 100s…"

***FLIGHT,* January 24, 1946**

History of Collaboration



"…The Hornet is a good example of the excellence which can be obtained when close collaboration exists between the air-craft designer and the engine manufacturer, although sound basic design must obviously be the foundation if extensive developments are planned…"

***FLIGHT,* January 24, 1946**

RE: originally, the intention was to fit handed engines turning 'in and up,' but when tested, the slipstreams were found to be so deflected that the tail control surfaces were ineffective on take-off speeds under 80 mph

<u>Caption</u>: "The D.H. Hornet; compact installation of Merlin 130 and 131 engines"

Initiat Superiority

"…In this connection, when the design for the Mosquito was laid-down in 1939/40, the decision was taken to use Merlin 20s, as they were then sufficiently advanced in design and development to ensure that the Mosquito would have a superior performance to that of any equivalent enemy aircraft. Further, it was predicted by Rolls-Royce that the Merlin 20 would be capable of much greater development and this would ensure the initiat superiority being retained over a period of years…"

***FLIGHT,* January 24, 1946**



"…Even the most casual survey of the Mosquito's record is sufficient to illustrate how well this long-term planning has succeeded and it is sufficient to say that the Merlin 130 and 131 were chosen for the Hornet for precisely the same reasons…"

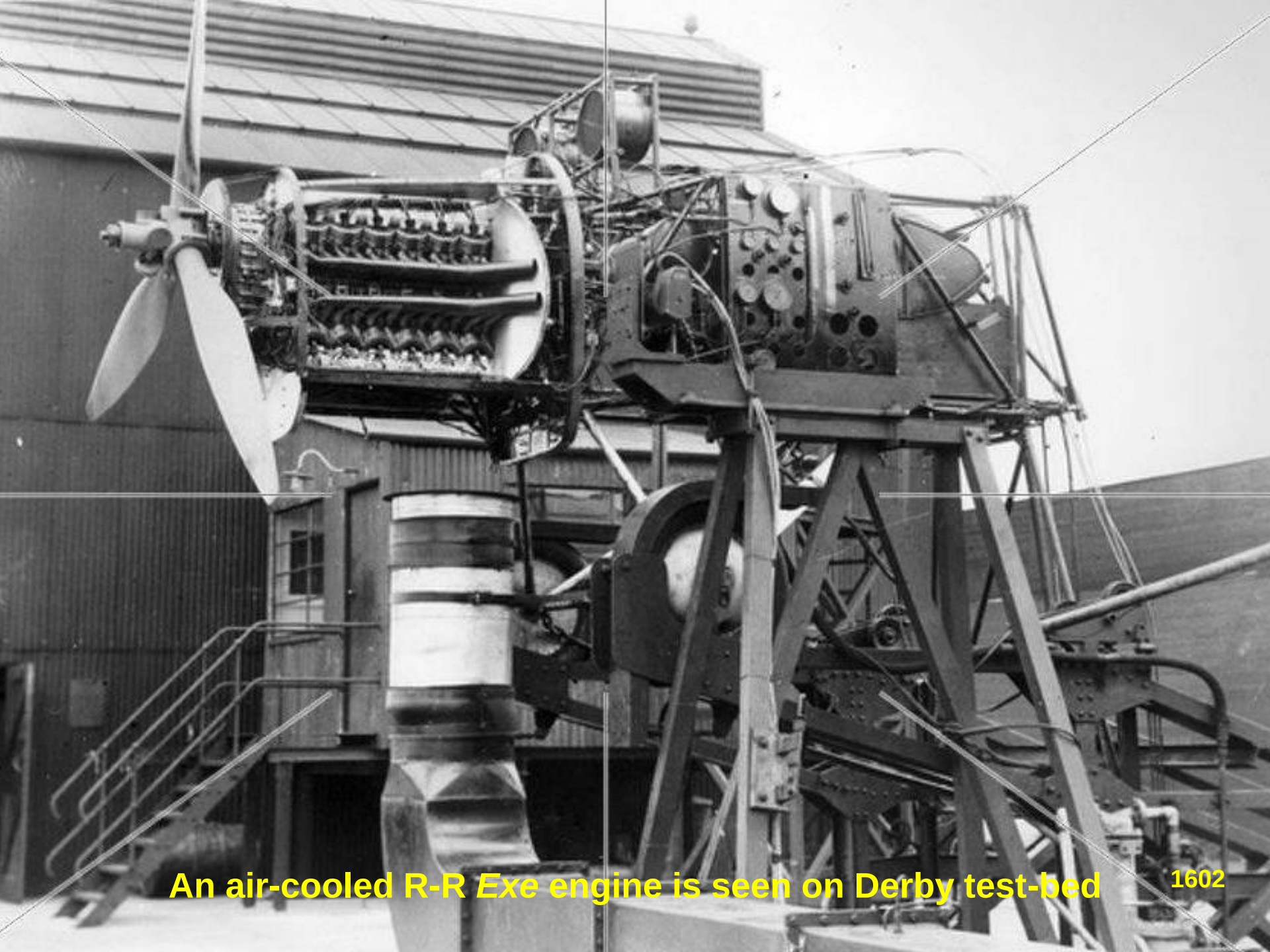
***FLIGHT,* January 24, 1946** 1599

<u>Caption</u>: "Mosquito B XVI of 571 Squadron, 1944"

Specific Power

"…The tabulation of power outputs shows that the Merlin 130 develops a maximum of 2,030-bhp at 1,250 ft., but we have the maker's authority for saying that powers in excess of 2,600-bhp have been recorded on the test-beds at Derby - a specific power of no less than 96.3 bhp/litre…"

***FLIGHT,* January 24, 1946**



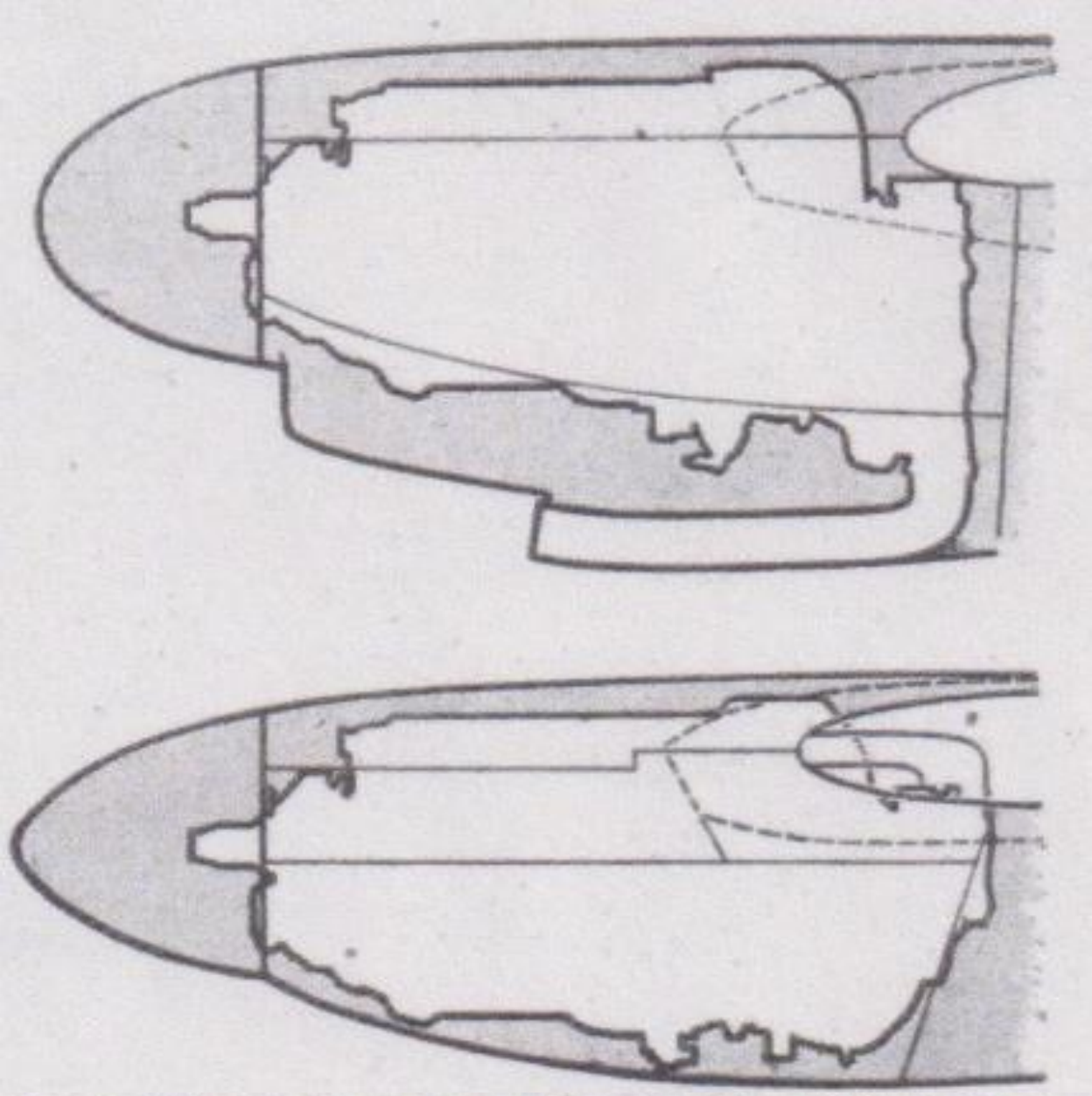
An air-cooled R-R *Exe* engine is seen on Derby test-bed

1602

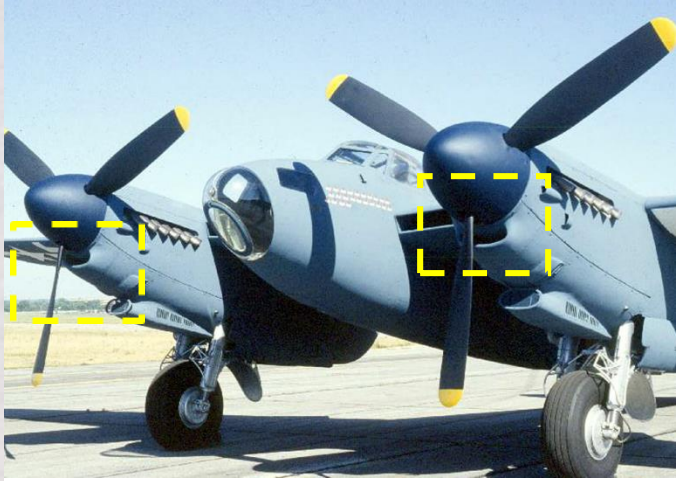
Contradistinction

"…The Hornet Merlin installation probably represents the first attempt to design a production engine into a powerplant in contradistinction to designing the powerplant round the engine…"

***FLIGHT,* January 24, 1946**



Drag still further reduced. The Mosquito (upper) and the Hornet (lower) Merlin installations compared.



"…To eliminate the air-scoop as used on the Mosquito, ducted air intakes are faired into the leading edges of the wing outboard of the engines on the Hornet and the 130 and 131 are the first Merlins to incorporate downdraft systems…"

FLIGHT,

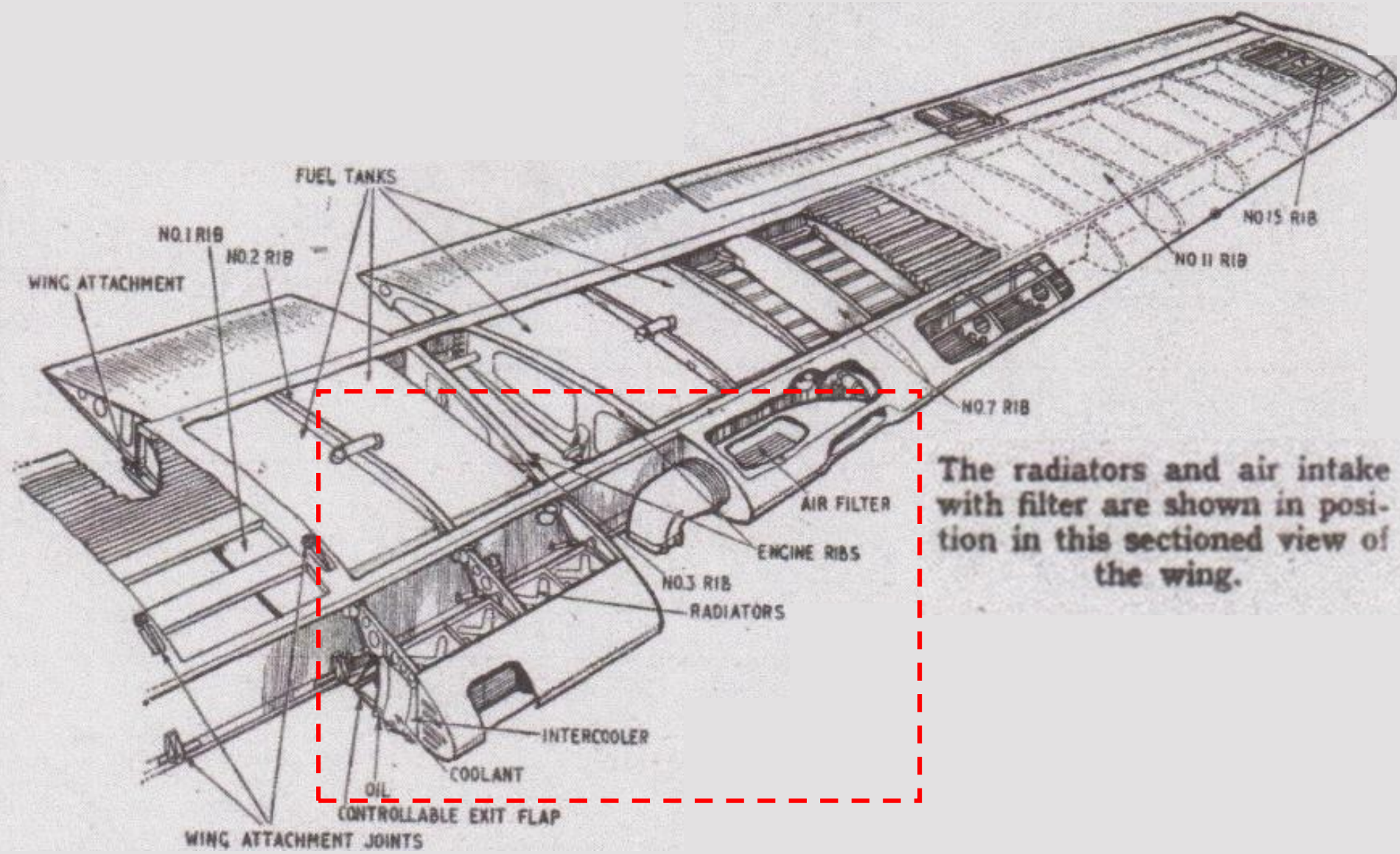
January 24, 1946

<u>Above</u>: Mosquito air-scoops (highlighted)

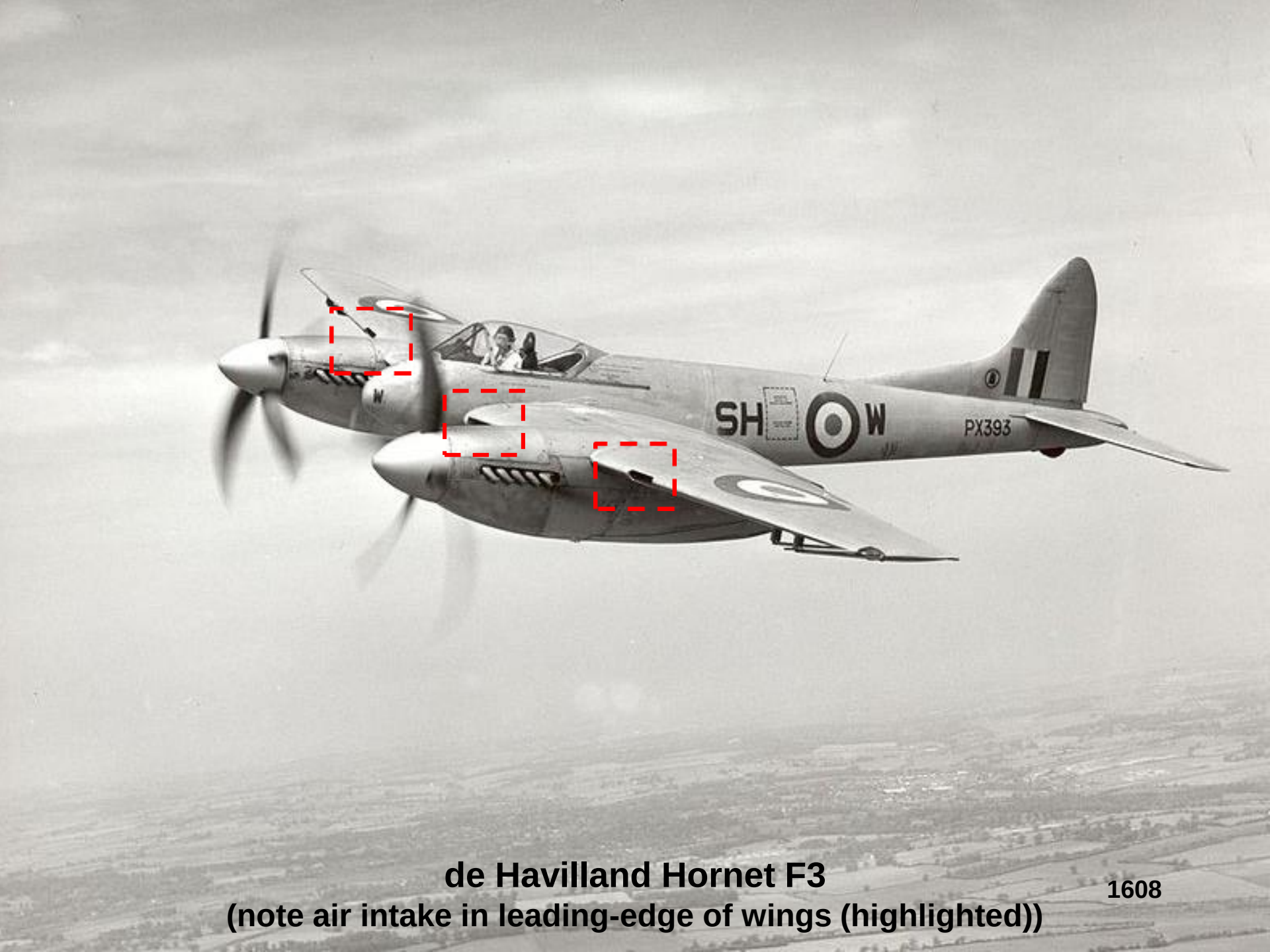
"…An interesting departure from conventional arrangement is found in the induction air intakes. These are situated in the wing leading edges, outboard of the engines, and are connected with the supercharger intakes of the down-draught type by ducts, the whole layout being rather reminiscent of the air-cooling system for Gipsy Twelve engines. In addition, a rotating valve interconnected with the undercarriage brings an air filter into use when the wheels are lowered, that is, whenever the aircraft is on the ground. A Vokes air filter is situated in the lower wall of each duct and suction from the engine supercharger opens a series of hinged metal gills in the lower surface of the wings below the filter. When the main air intake is opened on retracting the landing gear the gills drop back flush with the wing surface and the filter no longer operates. The layout of the system in the wing is shown in a drawing on a previous page…"

***FLIGHT,* January 24, 1946**

RE: excerpt from an article entitled: "The D.H. Hornet"



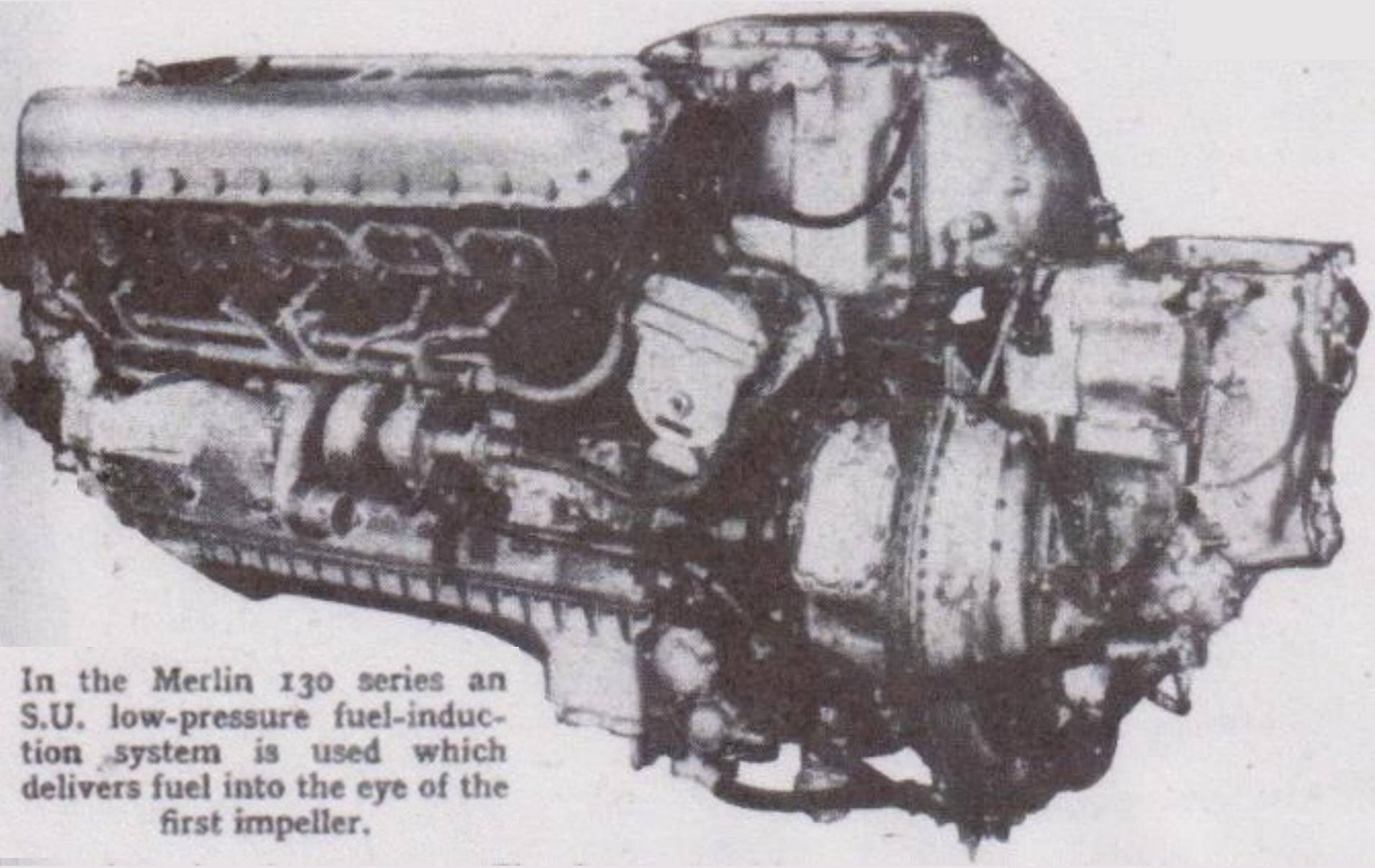
The radiators and air intake with filter are shown in position in this sectioned view of the wing.



de Havilland Hornet F3
(note air intake in leading-edge of wings (highlighted))

"…The Bendix-Stromberg carburetor hitherto used on the Merlin is now replaced on the 130 and 131 by an S.U. low-pressure fuel-injection system, which delivers through a nozzle into the eye of the first impeller and provides extremely accurate fuel metering whilst having a high standard of mechanical efficiency…"

***FLIGHT,* January 24, 1946**



In the Merlin 130 series an S.U. low-pressure fuel-induction system is used which delivers fuel into the eye of the first impeller.

High Continuous Powers



"…Considering all that has been accomplished with the amazing Merlin, it is no surprise to learn that the Hornet has a maximum performance which is only exceeded by the very latest jet-propelled fighters…"

***FLIGHT,* January 24, 1946**

RE: on October 29, 1945, the Hornet was shown to the public at the Farnborough Aviation Festival. Beginning in 1955, Hornets began to be replaced by jet aircraft and by the end of 1956, they were withdrawn from service. Thus, the DH-103 Hornet (above) became the last piston fighter in the RAF (its naval version served the same period).

High-Performance

R-R MERLIN 130 SERIES

	Performance				
	Gear	B.H.P.	R.P.M.	Boost lb/sq. in.	Altitude ft.
Max. T-O power ...	M.S.	1,670	3,000	18	S.L.
Max. Combat power ...	M.S.	2,030	3,000	25	1,250
" " " ...	F.S.	1,890	3,000	25	13,750
Max. Climbing power ...	M.S.	1,420	2,850	12	11,000
" " " ...	F.S.	1,350	2,850	12	22,000
Max. cruising power ...	M.S.	1,205	2,650	9	11,000
" " " ...	F.S.	1,190	2,850	9	25,000

"…In level flight, speeds of more than 470 mph have been achieved and a rate-of-climb of 4,000 ft./min. has been recorded. At a maximum continuous climbing boost of 12 lbs./sq. in., over 1,300-bhp is obtained at 23,000 ft.: a remarkable performance when it is remembered that the 130 and 131 are of the same capacity as the original Merlin II…"

1614

***FLIGHT,* January 24, 1946**



"…Cruising powers of more than 1,100-bhp are available to over 20,000 ft. and, although cruising speeds have not yet been measured on the Hornet, it is known that the North American Mustang with Merlin engines of approximately similar power has a maximum cruise rating of 420 mph and it is expected that the Hornet will improve on this figure by a quite considerable margin…"

***FLIGHT,* January 24, 1946**

<u>Caption</u>: "P-51D nicknamed 'Tika IV' of the 361st Fighter Group"

"…The high-performance figures are largely due to the intensive research and development work on supercharging undertaken by Rolls-Royce coupled with continuous experimental testing to ensure mechanical reliability - it says a great deal for the reliability of the engine that a boost-pressure of 12 lbs./sq. in. is permitted for continuous climbing…"
***FLIGHT,* January 24, 1946**



1617

A Popular Misconception

"…Whilst on the subject of supercharging, it might not be out-of-place to correct a popular misconception about the respective merits of the turbo-supercharger as against the two-speed, two-stage centrifugal supercharger used on Rolls-Royce engines…"

***FLIGHT,* January 24, 1946**



"…It has often been remarked that most American fighters, such as the Lightning and the Thunderbolt, have exhaust turbo-superchargers and that, by utilizing the energy of the exhaust gases, they have established an advantage over the mechanical form of supercharger drive…"

***FLIGHT,* January 24, 1946**

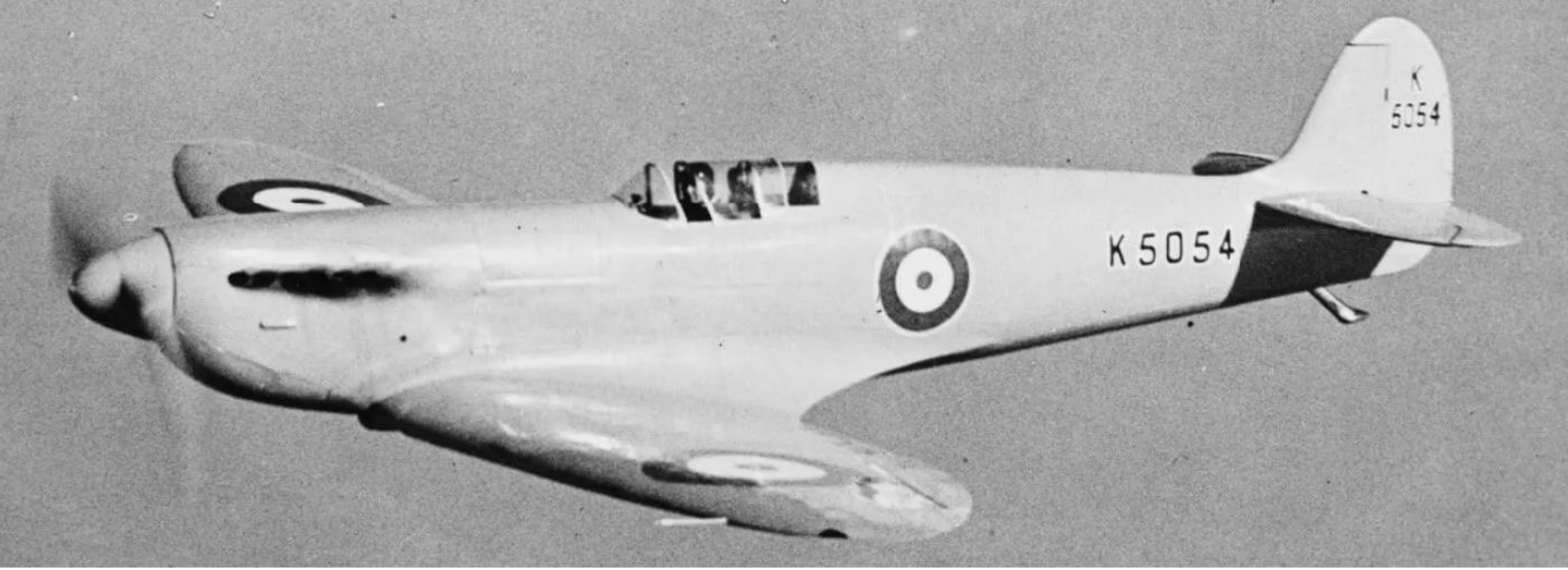
RE: a turbo-supercharger is an exhaust-gas-driven supercharger whereas a supercharger is driven directly by the engine crankshaft

<u>Caption</u>: "One of two turbochargers on the nacelle of a P-38 Lightning fighter"

1620

"…It is not generally realized, however, that, on our high-performance fighters, a well-designed multi-ejector exhaust system results in a considerable augmentation of thrust, which would be lost if turbo-superchargers were employed. On the Hornet there is actually an increase in thrust equivalent to 450-bhp/engine at full-throttle height…"

***FLIGHT,* January 24, 1946**



"…The principle of the Rolls-Royce multi-ejector exhaust system is just the same as jet reaction with a gas-turbine, but the intermittent nature of the ejection from the individual exhaust stacks results in a higher thrust than that obtained from a comparable steady stream…"

***FLIGHT,* January 24, 1946**

RE: during the development of the prototype Spitfire K5054, Rolls-Royce developed the ejector exhausts that became a recognizable feature. After several variations, the exhausts were paired-up to create the triple arrangement seen on each side of the early production Merlins.

<u>Caption</u>: "The Spitfire prototype K5054, pictured, made an eight-minute history-making flight with Vickers-Armstrong Chief Test pilot Captain Joseph 'Mutt' Summers at the controls"

Raising the Bar

"…As the engines of the 100 Series operate at higher ratings than any previous Merlin engine, a target of 100 hours' continuous running at maximum rpm and plus 18 lbs. boost was aimed at to ensure 100 per cent reliability…"
***FLIGHT,* January 24, 1946**

"…It is worthy of note that in flight the maximum duration for these conditions is five minutes! To eliminate the slightest weaknesses that might be revealed, a program of development was initiated which culminated in the successful completion of the 100 hours' continuous running at the conditions stipulated before the engines were passed for production…"

***FLIGHT,* January 24, 1946**

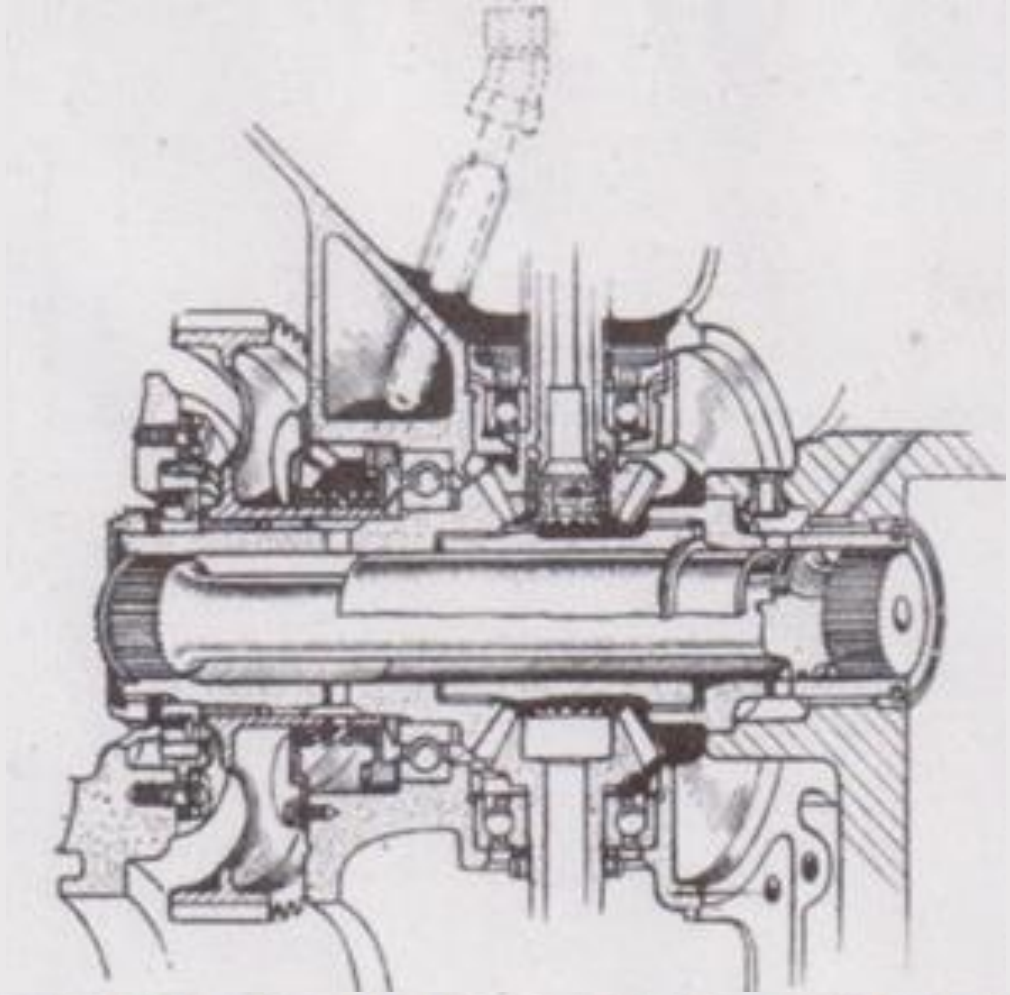
Results of Testing

"…As was to be expected, rigorous testing of this nature indicated points which could usefully be strengthened without unduly adding to weight. The crankcase panels supporting the main bearings have therefore been thickened and extended bosses for the cylinder block and main bearing studs have been incorporated. Additionally, the cylinder head has been reinforced and, by a repositioning of the core-plugs, a reduction in stress concentration has also been brought about…"
***FLIGHT,* January 24, 1946**

"…By virtue of the higher boost ratings, the differential pressure across the valves at high altitudes is considerably increased and the valve springs are, therefore, of increased load capacity…"

***FLIGHT,* January 24, 1946**

"…Refinements introduced include a double-flanged outer-race to the bearing at the forward-end of the rotor shaft, secured in position by bolts. This unusual type of bearing proved to be more reliable than the normal bearing and it permitted an increase in capacity in the space available…"
***FLIGHT,* January 24, 1946**



The modified spring-drive shaft with the outer member completely independent of crankshaft deflections.

"…A redesigned spring-drive is also incorporated, with an outer member completely independent of crankshaft deflections…"

***FLIGHT,* January 24, 1946**

1630

"…The coolant pump has been brought into line with Griffon practice and has a spindle mounted on ball-bearings lubricated from the low-pressure oil system. Service maintenance is eliminated by the employment of a packless-gland coolant seal having a carbon ring on the pump spindle…"

***FLIGHT,* January 24, 1946**

"…Supercharger efficiency is raised by moving the rear bearing of the first-stage rotor from the suction-side to the delivery side. This leaves the suction-side free from restriction and results in a better mass airflow with reduced turbulence…"

***FLIGHT,* January 24, 1946**

"…Further improvement is effected by the adoption of the S.U. fuel-injection system, this eliminating pressure losses occasioned by the restriction of venturi tubes as used with suction carburetors…"

***FLIGHT,* January 24, 1946**

Cumulative Effect

"…The cumulative effect of these modifications is an increase in rated altitude of 2,500 ft. It was undoubtedly the continuous progressive improvement in supercharging which enabled the Merlin to maintain its superiority over all enemy types throughout the war…"

***FLIGHT,* January 24, 1946**

F-I

"…The fuel-injection system comprises a gear-type pump supplying fuel to a five-plunger pump operated by a swash-plate, the stroke and the capacity of the pump being varied by alteration of the angle at which the swash-plate operates; the latter assumes a mean position after compensating for all the variables determining fuel demand…"

***FLIGHT,* January 24, 1946**

"…Variation in pump capacity, by varying the stroke, is governed by a 'Z' shaft and rocking levers linked to an oil-operated servo-piston; this shortens the stroke and a second piston subject to boost-pressure lengthens it, a balance between these two forces being established by a small leak valve…"

***FLIGHT,* January 24, 1946**

"…The sensitive portion of the valve is controlled by a capsule subject to boost on the outside, temperature on the inside and exhaust back-pressure on the end convolution. As with all positive displacement pumps, elimination of air is essential and a de-aerator is therefore interposed between the delivery-side of the gear pump and the suction-side of the plunger pump. By this means all air is extracted before the fuel enters the plunger pump and accurate metering is thus assured…"

***FLIGHT,* January 24, 1946**

Axial-flow Lubrication

"…Owing to production commitments during the greater part of the war it was not possible to incorporate the axial flow system of lubrication on Merlin engines before the introduction of the Merlin 100 Series…"

***FLIGHT,* January 24, 1946**

"…This method of lubrication, whereby the oil is supplied at each end of the crankshaft, ensures a positive oil feed to the big-end bearings as well as the main bearings and gives greater bearing area without increase in journal width or diameter…"

***FLIGHT,* January 24, 1946**

"…Other features of the new oil system are air separators and sludge traps located in No. 1 and No. 7 crankshaft journals. The separators improve the lubrication under aerobatic conditions by ensuring that any air which may have entered the system is purged so that there is no interruption of the oil flow for dangerously long periods. The sludge traps ensure a grit- and sludge-free flow of oil to critical points and thereby increase the life of the bearings…"

***FLIGHT,* January 24, 1946**

In War and Peace



"…The Merlin engine is probably the most compact and versatile power unit that has ever been devised and in its tenth year remains incomparable. No other engine in the history of aviation has such a record of proved reliability and service and by this token it is not in the least surprising that within the short space of six months it has already obtained a similar reputation in post-war civil aviation."

***FLIGHT,* January 24, 1946**

Purpose-built

As a result of experience with Merlins during the war years, Trans-Canada Airlines have decided to use these power units for their trans-Atlantic services and the Rolls-Royce Company have developed the Merlin 620 specially for the purpose

***FLIGHT,* July 25, 1946**

RE: introduction to an article entitled: "Rolls-Royce Merlin for Airlines"

A Fitting Entry

"THE '102,' from which the '620' was developed, was the first engine to pass the British Air Registration Board's new Civil Type-Test and thus, the Merlin - so famous in wartime - has made a fitting entry into the field of post-war civil aviation…"
***FLIGHT,* July 25, 1946**



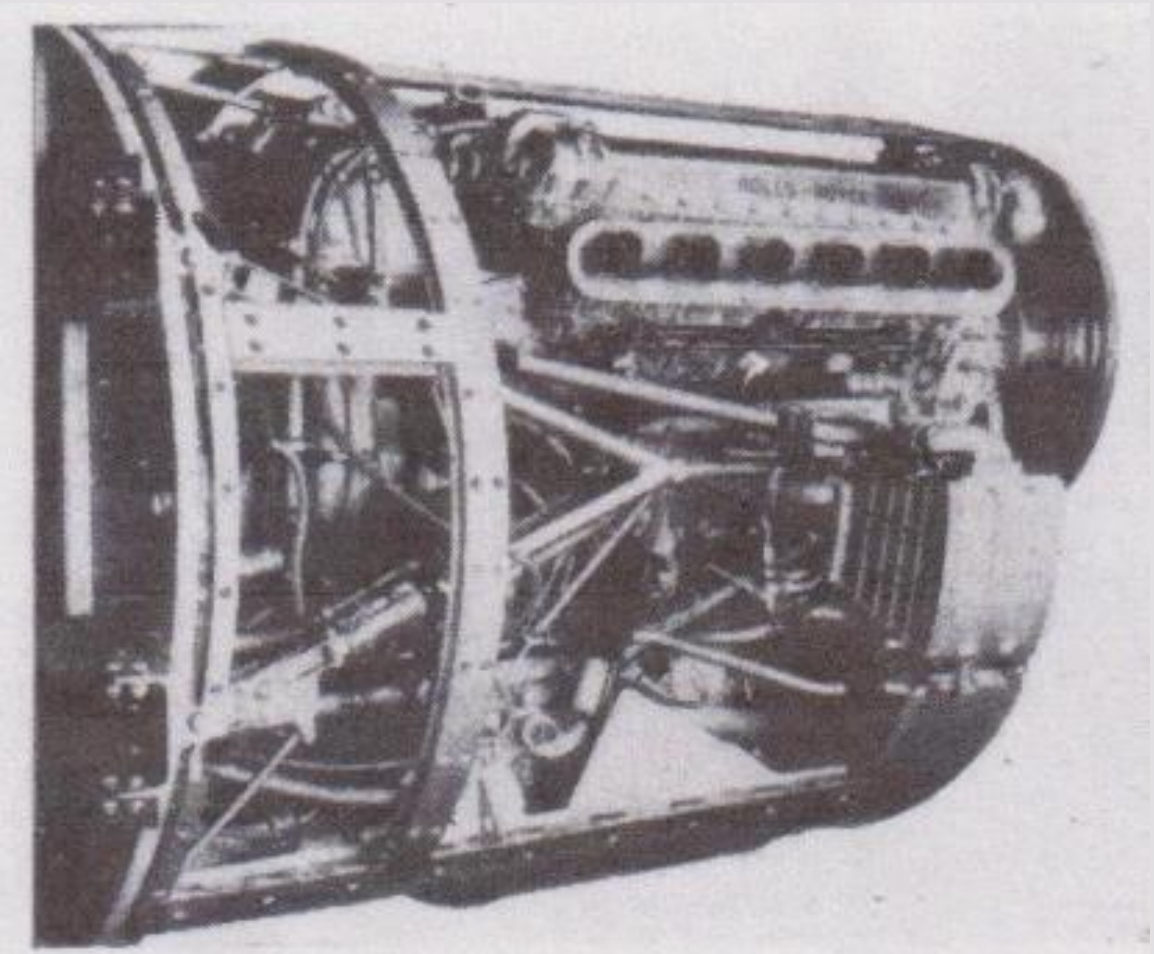
"…Last week, the first Canadian-built D.C.4 M.1 with Merlin 620 engines made a successful initial test flight…"

***FLIGHT,* July 25, 1946**

RE: the Canadian-built D.C.4 M.1, with Merlin 620 engines, refers to the Canadair DC-4M North Star; a unique post-war airliner developed for Trans-Canada Air Lines (TCA). Instead of the standard DC-4's radial piston engines, Canadair installed liquid-cooled R-R Merlin V-12 engines to increase speed. The first six of these aircraft (a/k/a North Star Mk.M1 ST) were originally modified Douglas DC-4s.

1650

Caption: "Trans-Canada Air Lines (TCA) DC-4M-1 North Star"



Another in-line engine with a radial-like installation, the 1,795 h.p. Merlin 620 has been developed for the Canadian-built Douglas D.C.4.M.

Crossing the Pond



"…T.C.A. have been operating Avro Lancasters and Lancastrians across the Atlantic since 1943 and Merlin 620s have been developed for operation under the severe climatic conditions anticipated on this route and in Canada…"

***FLIGHT,* July 25, 1946**

RE: the Avro 691 Lancastrian was a British and Canadian passenger and mail transport aircraft developed from the Avro Lancaster heavy bomber. The Lancastrian was basically a modified Lancaster bomber without armor and/or armament and with the gun turrets replaced by streamlined metal fairings and a new nose section.

"…A Lancaster with Merlin 600-type engines last week crossed the North Atlantic to Dorval via Ruineana and Gander flying at 25,000-feet. Mr. Partington, Rolls-Royce representative, flew as second pilot. Consumption tests are now being made…"

***FLIGHT,* July 25, 1946**

Adaptive Reuse

"…The 620 embodies the latest Merlin features, including petrol injection and is of the two-stage supercharger with intercooler type…"

***FLIGHT,* July 25, 1946**

"…The radiator system is a development of the Avro Lincoln installation and has the same characteristic appearance. At the nose the diameter is 56-inches and it increases up to 60-inches at the mounting to conform with the D.C.4 bulkhead and enable the existing undercarriage arrangement to be retained…"

***FLIGHT,* July 25, 1946**

Merlin 621

"…A further development, the Merlin 621, basically similar to the 620, will replace the 102s as power units for the Tudor Is and IIs and details will be available shortly. Accessories for which provision is made on the Mk.620 include a Douglas cabin blower…"

***FLIGHT,* July 25, 1946**

620 Stats

"…Power figures are as follows:

Take-off:	3,000 r.p.m. + 20 lb	1,740 b.h.p
Cruising:		
M.S. at 10,250 ft	2,650 r.p.m. + 9 lb	1,175 b.h.p.
F.S. at 23,750 ft	2,850 r.p.m. + 9 lb	1,165 b.h.p.
Emergency:		
M.S. at 4,500 ft	3,009 r.p.m. + 20 lb	1,795 b.h.p.
F.S. at 16,750 ft	3,000 r.p.m. + 20 lb	1,650 b.h.p.
Max. Climbing and Emergency Cruising:		
M.S. at 10,000 ft	2,850 r.p.m. + 12 lb	1,405 b.h.p.
F.S. at 20,500 ft	2,850 r.p.m. + 12 lb	1,340 b.h.p.

***FLIGHT,* July 25, 1946**

Part 14

A Better Mousetrap(?)

R-R vs. Packard

Detroit's mass-production know-how yielded over 55,000 Merlin V-12 aircraft engines during WWII. But were they better than the ones built in Britain?

autoweek.com

RE: introduction to an article written by *Graham Kozak* entitled: "Rolls-Royce vs. Packard: Who Built A Better Merlin?"

The Saga

“THE saga of the Roll-Royce Merlin V-12 supercharged air-craft engine is one of the most gripping engineering and manufacturing stories of the 20th century…”

autoweek.com

The Pressure Cooker

"…Here was an incredibly complex piece of machinery, conceived before the clouds of World War II gathered and continuously refined in the pressure cooker of combat that would go on to power some of the most unforgettable piston-driven warplanes ever designed - the Supermarine Spitfire and the P-51 Mustang among them…"

autoweek.com

Two Great Marques



Packard

"…And at the center of its story are two great automotive marques, Rolls-Royce and Packard, which built Merlins by the tens of thousands simultaneously on both sides of the Atlantic…"

autoweek.com

1670

The Merlin Tale

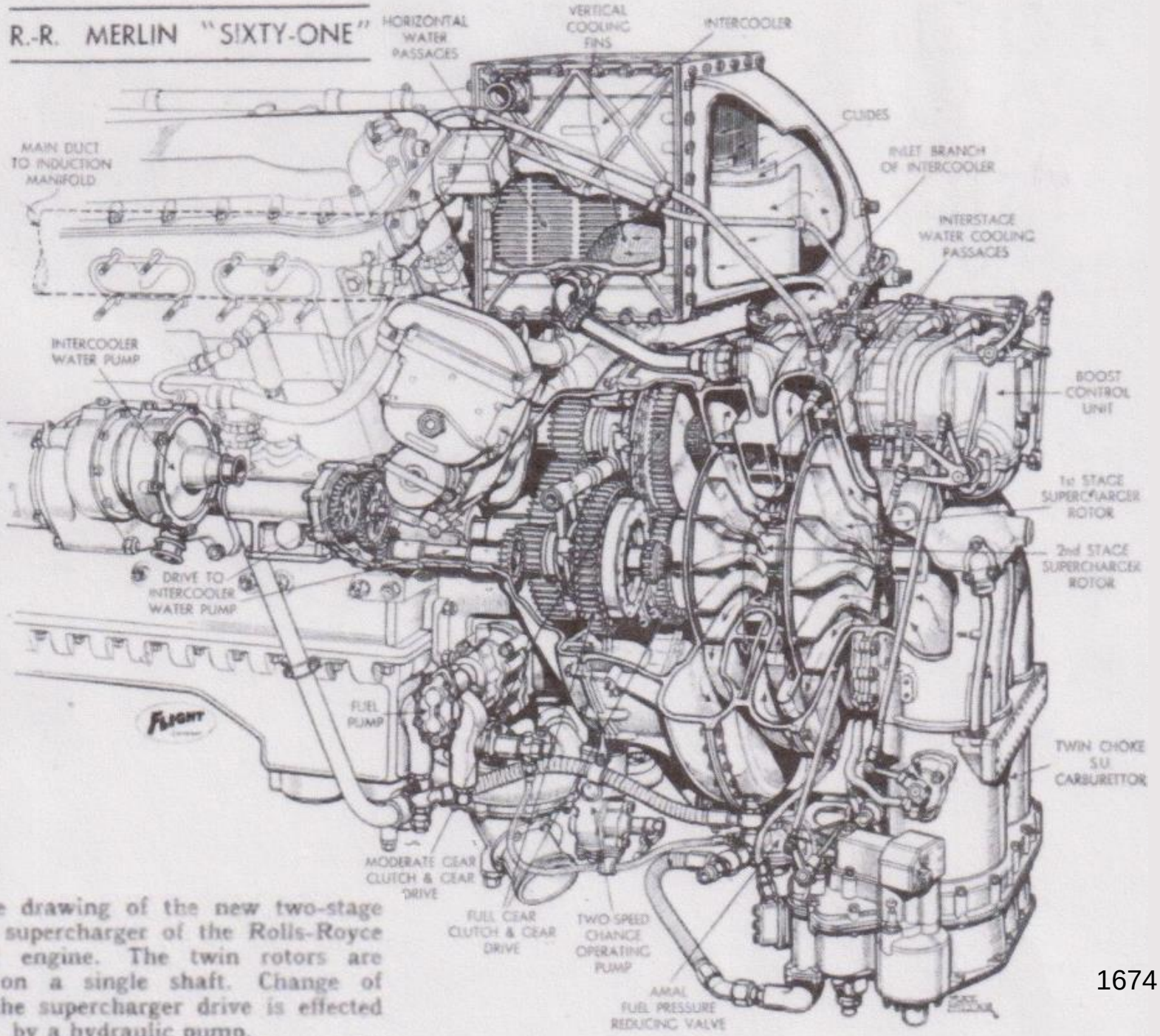
"…If you have even a passing interest in automotive, aviation or military history, you've probably heard some variation of the Merlin tale. The received wisdom, at least in America, usually runs along the lines of: If Rolls-Royce birthed a stupendous engine, Packard brought American mass-manufacturing know-how to the equation, perfecting the design and mechanizing production. And so the Axis powers were beat back by this perfect transatlantic alliance of British ingenuity and American industrial might…"

autoweek.com

"…There are many variations on this basic storyline, more than a few of which are contradictory. Most recently, I was told very matter-of-factly (and by a Brit, if that makes any difference) that Rolls built a more precisely fitted, finely tuned engine that had slightly higher performance potential for a given unit. Packard, by contrast, built one that was ultimately easier to construct consistently and overhaul at specified intervals - and that one of the ways Packard accomplished this was by building Merlins with looser tolerances than its counterpart on the other side of the Atlantic…"

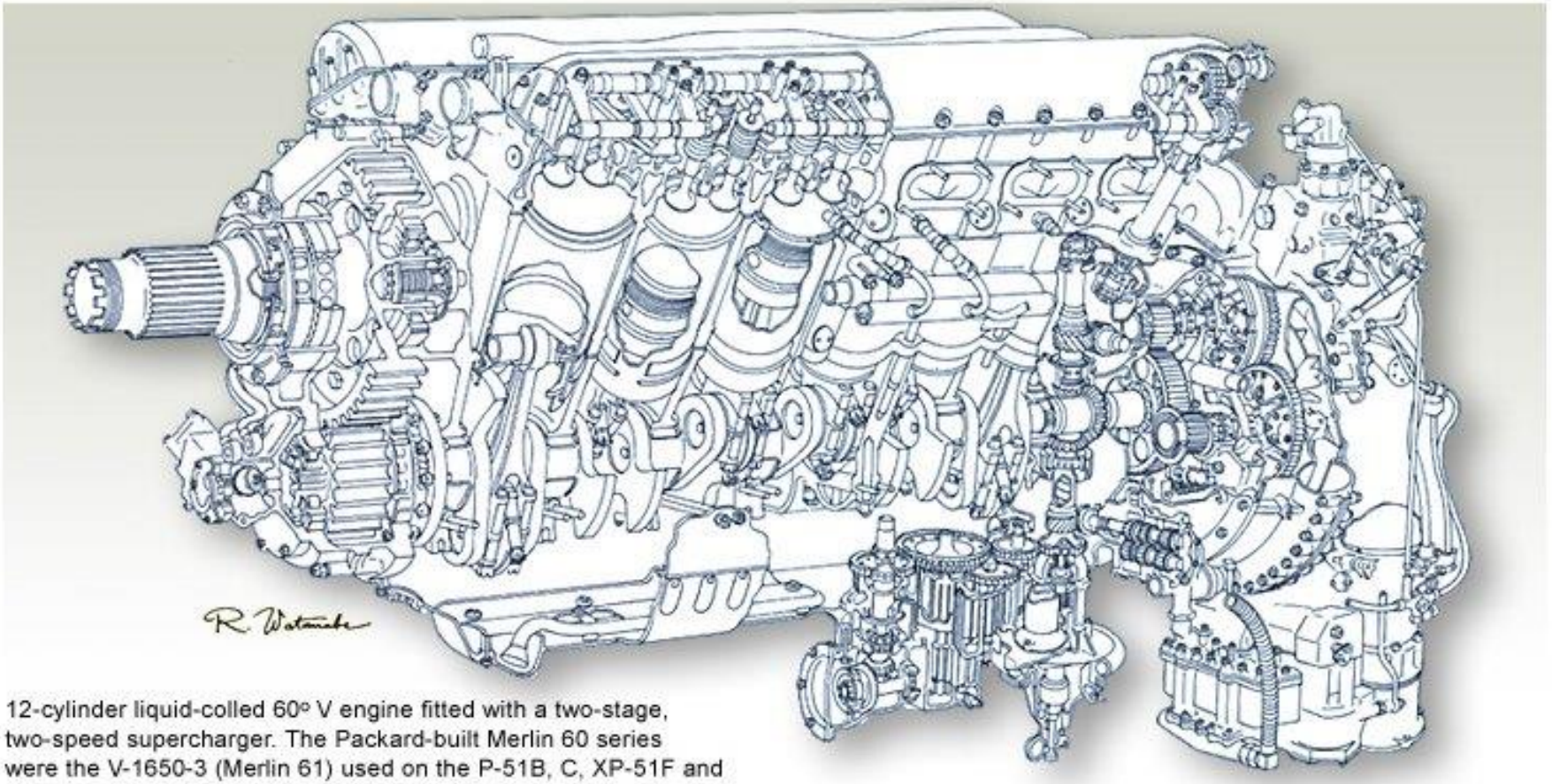
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R.-R. MERLIN "SIXTY-ONE"



Perspective drawing of the new two-stage two-speed supercharger of the Rolls-Royce Merlin 61 engine. The twin rotors are mounted on a single shaft. Change of speed of the supercharger drive is effected by a hydraulic pump.

Packard Merlin 61 Engine



12-cylinder liquid-colled 60º V engine fitted with a two-stage, two-speed supercharger. The Packard-built Merlin 60 series were the V-1650-3 (Merlin 61) used on the P-51B, C, XP-51F and Autralian CA Mk 20, the V-1650-7 (similar to Merlin 68) used on the P-51B-10/B-15, C-5/C-10, P-51D (all blocks), amd Australian CA Mk 21, and the V-1650-9 was developed from the Merlin 100 series and could be fitted with or without water injection

	V-1650-3	V-1650-9
Total swept capacity:	1647 in3 (27ltr)	1647 in3 (27ltr)
Compersion ratio:	6:1	
Dry weight:	1690lb. (766.6 kg)	1745lb. (791.5 kg)
Length:	87.108in (2212mm)	87.141in (2213mm)
Width:	29.97in (761mm)	30.76in (781mm)
Height:	41.63in (1057mm)	44.97in (1142mm)

Perfomance:	V-1650-3	V-1650-7	V-1650-9
Take-off power:	1380 hp (max 5 mins)	1380 hp (max 5 mins)	1380 hp (max 5 mins)
Low blower:	1600 hp at 11,800ft (3600m)	1600 hp at 11,800ft (3600m)	1600 hp at 11,800ft (3600m)
Low blower:	1490 hp at 13,750ft (4190m)	1490 hp at 13,750ft (4190m)	1490 hp at 13,750ft (4190m)
High blower:	1330 hp at 23,000ft (7010m)	1330 hp at 23,000ft (7010m)	1330 hp at 23,000ft (7010m)
High blower:	1210 hp at 25,800ft (7860m)	1210 hp at 25,800ft (7860m)	1210 hp at 25,800ft (7860m)

"…There's an appealing counter-intuitiveness to the notion that a (marginally) sloppier engine makes for a more effective fighter plane powerplant; it's a bit like that chestnut about adding armor to the parts of the bombers with no bullet holes…"

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RE: in 1943, American bombers were suffering from effective German air defense. The USAAF decided that it needed some advice on how to cut losses, so they consulted the brain-trust at the *Statistical Research Group* (SRG) at Columbia University to determine what were their best options. One possibility was to use more armor, but armor weighs alot and adding too much would lower performance considerably. So the USAAF brass asked the SRG how much armor should be used and where to place it for optimal results. The problem of armoring planes was assigned to *Abraham Wald,* a prominent Mathematician/Statistician. Wald was given statistical data regarding aircraft damage; for example, the location of damage from hits by enemy aircraft. Most of the damage was located on the fuselage and very little in the area around motors and the military was expecting to add armor to the fuselage, where the density of hits was highest. However, Wald suggested that the armor be added around the motors, which was the weak point. His advice was taken to heart.

2:1(?)

"…Blueprinted, handmade and expertly tuned Merlins might have been nice to have under ideal circumstances, but WWII demanded materiel in almost unfathomable quantities. On the surface, it's conceivable that two pretty good Detroit-built Merlins were worth one exquisite Merlin handcrafted in Crewe…"

autoweek.com

On the Other Hand…

"…On the other hand, I've also read that Packard's cutting-edge manufacturing methods made for Merlins with tighter, more consistent tolerances. Both of these cannot be true. Or can they?..."

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Pride of Ownership

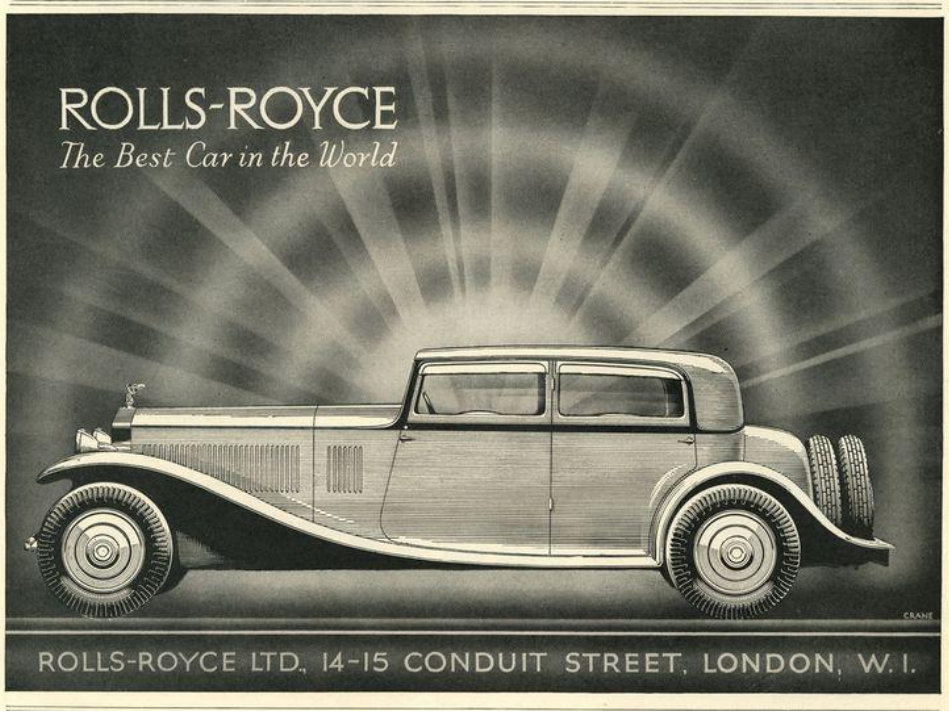
"…Since AUTOWEEK is talking tolerance this week, it seemed like an opportune time to dig a little deeper into the Merlin story - which, after all, is a big point of pride for Packard car owners like myself. I can only imagine Rolls-Royce owners look back on this period of history with equal admiration…"
autoweek.com

Fact or Fiction?

"…But much like Abraham Wald's WWII-era work on aircraft survivability, it's tough to say exactly how much of this neatly packaged story is nothing more than enticing elaboration sp-un around just a few spindles of fact…"

autoweek.com

Like-minded





"…From this modern vantage point, it might seem inevitable that Rolls-Royce would join forces with Packard to produce Merlins. Rolls-Royce Limited was established in 1904; the Packard Motor Car Co. was founded in Warren, Ohio, a few years earlier, in 1899, and set-up shop in Detroit in 1903. Both built their global reputations as top-level luxury automakers on the strengths of their engineering expertise and high production standards…"

autoweek.com

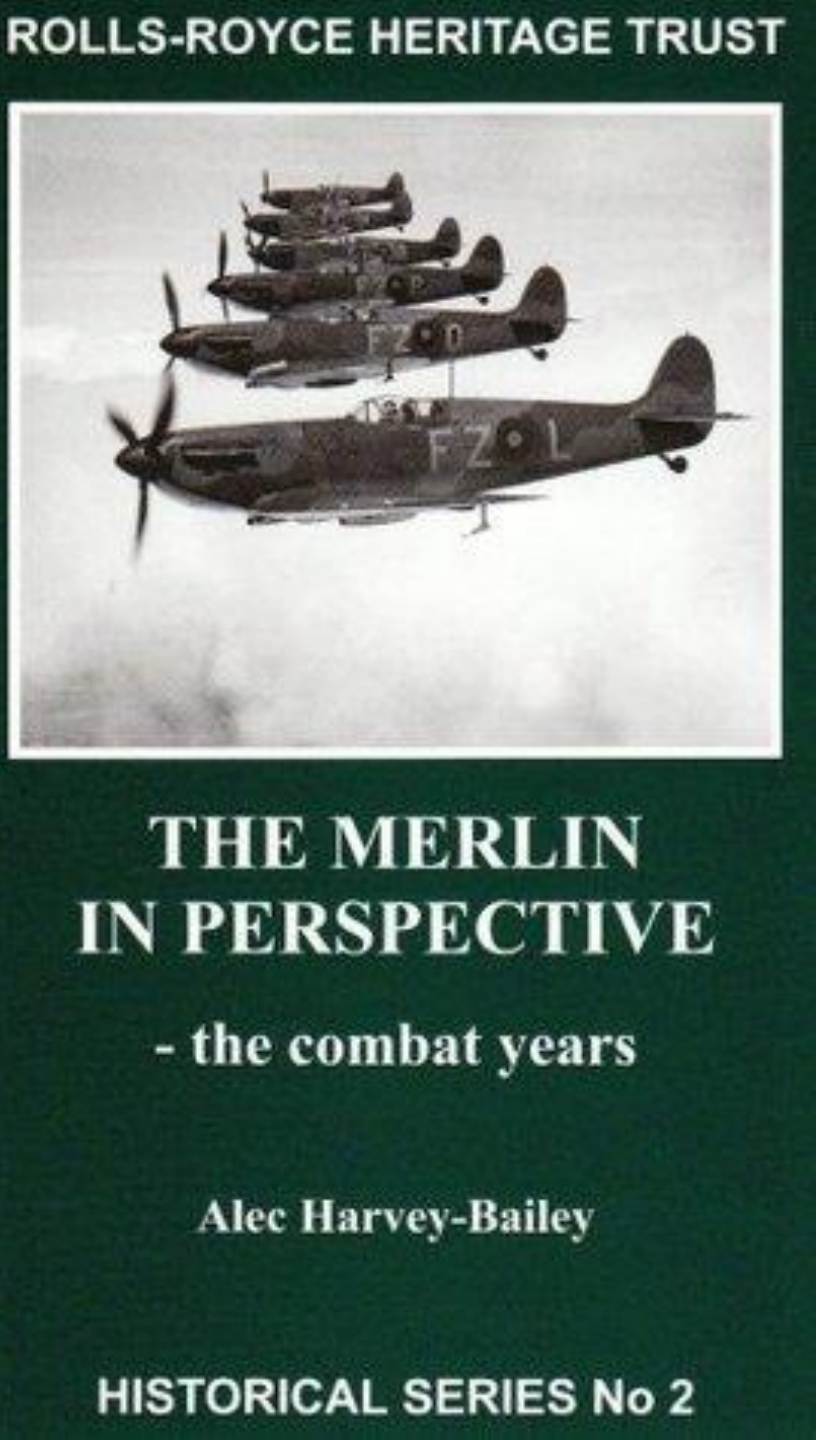
"…As WWII approached, both companies had extensive experience with aircraft engines under their respective belts. Packard's early efforts resulted in the successful Liberty V-12, which arrived several months after the United States' April 1917 entry into World War I. Rolls-Royce began producing its Eagle V-12 in early 1915, also to power warplanes; it started development of the PV-12, the engine that would become the Merlin, in the early 1930s and had running prototypes by 1933…"

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Off-to-the-Races

"…The first 'production' version of the engine was the Merlin I, which arrived in 1936, but fewer than 200 examples were built. The Merlin II was developed about a year later and from there it was off-to-the-races: A dizzying number of variants would follow in quick succession…"

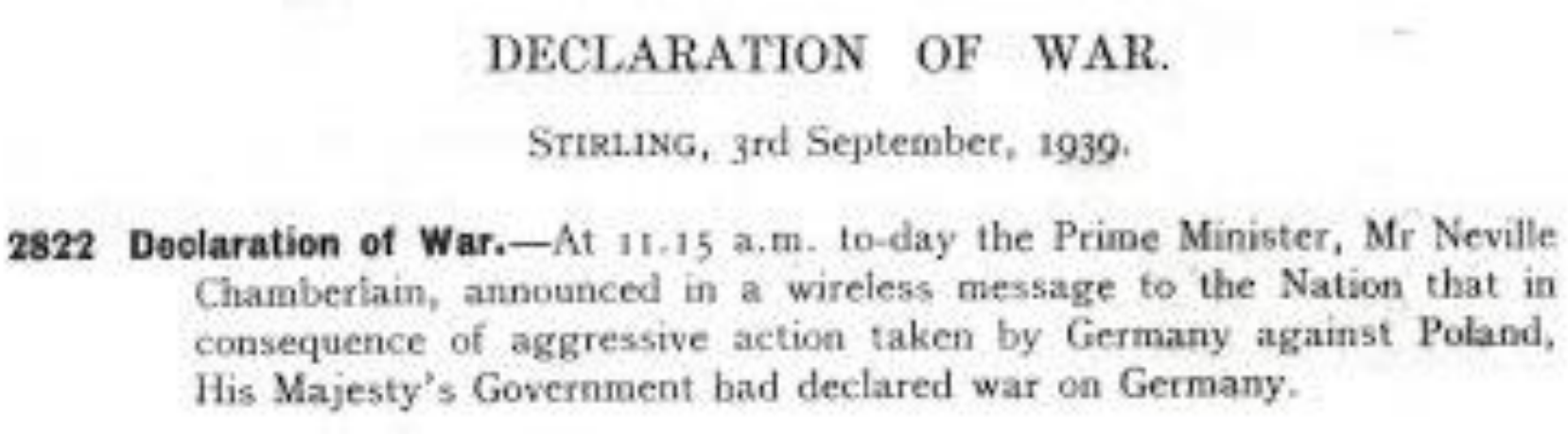
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"…Engineering refinements meant that by the end of the war, the Merlin 66, an intercooled variant of the engine sporting a two-stage, two-speed supercharger, was making 2,050 hp (increased from 1,030 hp in the Merlin II) - and these improved engines were allowing aircraft to operate at significantly higher altitudes as well. If you want to dive into the minutiae of Merlin development, it's worth grabbing a copy of 'The Merlin in Perspective - The Combat Years,' by Alec Harvey-Bailey; there's simply too much info to relate it all here…"

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Ancillary Production



DECLARATION OF WAR.

STIRLING, 3rd September, 1939.

2822 Declaration of War.—At 11.15 a.m. to-day the Prime Minister, Mr Neville Chamberlain, announced in a wireless message to the Nation that in consequence of aggressive action taken by Germany against Poland, His Majesty's Government had declared war on Germany.

"…Packard had investigated the prospect of building Merlins under license as early as 1938. Though these initial discussions went nowhere, the British declaration of war on Germany in September 1939 meant that a new manufacturing partner was urgently needed…"

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Above: on Sept. 2, 1939, British Prime Minister *Neville Chamberlain* issued an ultimatum to Germany; exit Poland or a state-of-war will exist between us. Germany had until Sept. 3rd to respond – they did not and war with Germany was declared



Foreign Exchange Rates
Dollar in Paris ..... 40fr. 80c.
Dollar in London ..... 4s. 9d.
Dollar in Rome ..... 19 lire
Dollar in Brussels ... 29fr. 15c.
Pound in Paris ..... 175fr. 60c.

NEW YORK
Herald Tribune
3 a.m. EDITION

SAILINGS to NEW YORK
Frequent Sailings
UNITED STATES LINES

52nd Year. No. 18,962 — European Edition — PARIS, MONDAY, SEPTEMBER 4, 1939 — In France: 1fr. 25c.

Great Britain and France Declare War on Germany When Hitler Refuses to Call Off Attack on Poland

Nation Told By Roosevelt 'I Hate War'

By Gerald Wrather

WASHINGTON, Sept. 3. — President Roosevelt, speaking over the radio to-night to "the people of America" said that "as long as it remains within my power to prevent it, there will be no blackout of people in the United States."

The President said it was impossible to predict what the future held in store, but that nevertheless "this nation will remain a neutral nation."

He added, however, that he could not "ask every American to remain neutral in thought as well."

"Even a neutral," he said, "has a right to have sympathy with various sides in a conflict based on religious grounds or racial origin. I have such sympathy myself. I have it and I cannot help it. I say that again and again."

The President sent a proclamation of American neutrality and two letters of the same nature to the heads of the belligerent nations, one to Adolf Hitler and the other to Premier Daladier of France.

[illegible] Roosevelt said that nothing in the proclamation would prevent the sale of munitions to belligerents in accordance with existing [illegible] law and American policy.

(President Roosevelt said that neither proclamation nor letters are required to the existing neutrality law, but he did say, that [illegible] neither proclamation nor law made a war inevitable.)

He declared that a war of the present magnitude [illegible] destruction to the non-belligerents in many fields through [illegible].

Calls on Free, Radio for Truth

The President emphasized the importance of the press and radio using the utmost caution to ascertain the truth before they published it.

"When peace is upset anywhere, the peace of all countries is in danger," he continued. "Seriously though we may, we are attachments or are forced to realize that every world that occurs through [illegible] war, every ship that sails into the war zone, every bomb that is dropped, does affect the American nation. Let us keep our [illegible] property or future trade of America resulting [illegible] to Europe as [illegible]. Let us make the simple plea that partisanship and enthusiasm be eliminated and that reflection unify the struggle."

President Roosevelt was [illegible] at 9:40 a.m. (8:40 a.m. Paris time) in a telephone call from William C. Bullitt, Ambassador in Paris, who was now at Tulsa, Bullitt's decision, he [illegible] on his own, came at 8:40 a.m. when getting the [illegible] that Britain was at war with Germany.

The Paris radio flashed to all readers of the Paris edition, "France and Britain are now at war with Germany."

1,500 Set as Toll In Nazi Air Raids On Polish Centers

[illegible] Herald Tribune Reporter

As Britain and France entered into a state of war with Germany yesterday, aerial bombardment by German planes continued in scores of Polish towns and cities.

According to the Polish Embassy in Paris, the number of victims of the air raids of Friday and Saturday was about 1,500, including a large number of women and children.

The city of Cracow, known as the Polish Guernica, because of its defenseless State, was in flames as a result of intense bombardment.

Nazi Planes Over Warsaw

Between 9 and 9 a.m. yesterday, German planes constantly flew over Warsaw in such a height that they were invisible.

These planes bombarded the suburbs districts of Praga and Okecie in an attempt to destroy railroad bridges and a water factory. From the central air large fires could be seen as the result of explosions accompanied with the ringing of church bells.

Four civilians and eleven in have been killed and [illegible] wounded by this morning's raid.

In the air attacks Saturday, [illegible] people were killed. Hospitals and the Lubelski Gubernatorial Palace were [illegible].

The population of Warsaw followed with intense interest reports of the desperate fighting at Bzura, where the Polish armies of Pomorze is still holding and [illegible] repulsed attacks by the two German armies and hopes shelling by the Germans and pocket, including Bydgoszcz [illegible].

Polish Planes Fight, Pardon

Correspondents watched a thrilling battle between twelve German fighting bombers and a single plane piloted by Polish Lieutenant Pardonski of the Polish aviation. Coming suddenly upon the German planes, Pardonski flew into above them, swooped in about seven men, each plane he was attacked until his machine was hit, [illegible] 10,000 feet in a nose [illegible].

The Polish Air Agency reported that, according to provisional estimates, during the day of September 1, the Germans attacked nineteen villages, towns and villages, of which seventeen were cities of more than 10,000 population and twenty-two villages. The agency stated that in these cases the bombs and machine bullets were [illegible].

Declaring that in the majority of bombardments more than 50 per cent of those killed were women and children, the Pat Agency said the most dramatic attack was that on the municipal hospital of Wieluń.

Britain Enters Conflict at 11 a.m., France at 5p.m.; Fleet Blockades Reich; U.S. Studies Arms Embargo

Text of King George's Speech

By United Press

LONDON, Sept. 3.—King George VI tonight broadcast the following message to the British Empire at 6 o'clock:—

This grave hour is perhaps the most fateful in our history. I would send to every household of my people both at home and overseas this message, spoken with the same depth of feeling as each one of you as if I were able to cross your threshold and speak to you myself.

For the second time within the lives of most of us we are at war. Over and over again we have tried to find a peaceful way out of the differences between ourselves and those who are now our enemies. But it has been in vain. We have been forced into this conflict. For we are called with our allies to meet the challenge of the principle, which if it should prevail, would be fatal to civilization and order in the world.

It is this principle which permits a state in pursuit of selfish power to disregard its treaties and its solemn pledges, which sanctions the use of force or threats of force against the sovereignty and independence of other states. Such a principle stripped of all disguise, is simply the most primitive doctrine that might is right, and if this principle were established throughout the world, the freedom of our own country and the whole British commonwealth of nations would be in danger.

Far more than this—the peoples of the world would be kept in bondage of fear and all hopes of settled peace, security of justice and liberty among nations would be ended. . . .

This is the ultimate issue which confronts us. For us, we take up all we ourselves hold dear and the world's order and peace. It is unthinkable that we should refuse to meet the challenge.

It is for this high purpose that I now call my people at home and my people across the seas who will make our cause their own. I ask them to stand calm and firm and united during this time of trial. The task will be hard. There may be dark days ahead and war can no longer be confined to the battlefields. But we can only do right as we see right. We unreservedly commit our cause to God. If we and all we keep resolute and faithful to it, ready for whatever service or sacrifice it may demand, then with God's help we shall prevail.

May He bless us and keep us all.

Von Ribbentrop's 'Nein' at 12:30 p.m. to Envoy's Demand to Stop Aggression, Recall Troops from Poland Brings Notice of War at 5 p.m.

By John Elliott

Fighting Speech Made to Nation By Chamberlain

'We Defend the Right, Right Will Prevail in This Fight,' Premier Says in Broadcast

By Hugh Ailing

LONDON, England—Prime Minister Neville Chamberlain's broadcast this morning at 11:15 without knowledge of a state of war with Germany, follows:—

I am speaking to you from the Cabinet meeting room at 10 Downing Street.

This morning the British Ambassador handed to the German government in Berlin a final note stating that unless we were assured by 11 o'clock that it was prepared to withdraw its troops immediately from Poland, a state of war would exist between the two countries.

I must tell you now that no such undertaking has been received, and that, consequently this country is at war with Germany.

[illegible]

I will now tell you more that we are bound by our obligations and that no [illegible] right will [illegible].

Everything Possible for Peace

[illegible] Everything possible to [illegible] a peaceful [illegible] settlement between Germany and Poland, but Hitler has made it [illegible].

He was [illegible] resolved to attack Poland, using [illegible] and attempts to save [illegible] have failed. We have made [illegible] proposals, which were rejected by the Nazis, for [illegible] to our satisfaction with the [illegible].

These proposals, now [illegible] record in the Press and [illegible] were [illegible] by Hitler and not [illegible] to [illegible] that [illegible] he made [illegible] them, but gave [illegible] to [illegible] to [illegible] the Polish [illegible].

Note Returned to Us Torn

[illegible] we received [illegible] that there was no hope that this [illegible] would [illegible] the use of force to attain his ends.

France and ourselves, in view of our obligations are going [illegible]

Australia, New Zealand Join Hostilities, Canada Pledges Its Support to Britain; Nazis Reject French Ultimatum, Ignore London's; Japanese Promise Neutrality

A quarter of a century after the outbreak of the World War, France and Britain again went to war with Germany yesterday.

Britain was in a state of war at 11 a.m., while France entered the war at 5 p.m.

The immediate cause was the failure of Chancellor Adolf Hitler to reply to the ultimatum sent him by the two countries demanding that he withdraw his troops from Poland.

Prime Minister Neville Chamberlain announced a state of war with Germany in a broadcast at 11:15 a.m.

Daladier Announces War to French People

France's declaration of war was announced to the French people in a radio broadcast last night by Premier Daladier.

"This morning," Mr. Chamberlain said, "the English Ambassador at Berlin handed the German government an official note declaring that unless we were informed by it before 11 o'clock that it was prepared to withdraw its troops immediately from Poland, a state of war would exist between the two countries.

"I must tell you now that no promise has been received and that, in consequence this country is at war with Germany."

Hitler Renews Encirclement Complaint

Premier Daladier told his countrymen that he and the British government had made a final appeal to the Reich to cease hostilities, and Germany's response was a refusal.

In Berlin, Chancellor Hitler rebutted the Germans to resist the "new British policy of encirclement," launched just when "the greatest evil" of the Treaty of Versailles seemed about to succumb."

The formation of a British War Cabinet, in which Winston Churchill will be First Lord of the Admiralty and Anthony Eden, Secretary of State for Dominions, was announced in London.

President Roosevelt called a Cabinet meeting for today. He is expected to make a neutrality proclamation when he is formally notified that a state of war exists in Europe.

American Arms Embargo Expected

The statements of Prime Minister Chamberlain and Premier Daladier that their countries are at war with Germany are believed to oblige the American President to declare an arms embargo.

King George declared in a radio address that, if the principle that might is right were established, "the peoples of the world would be kept in bondage of fear and all hopes of settled peace,

Sins of the Father

"…Ancillary production of the Merlin might have gone to a different American automaker entirely, however, if not for its mercurial founder and namesake…"

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"…In 1940, Ford Motor Co. initially committed to build 9,000 Merlin engines - 6,000 for the British and 3,000 for the American armed forces - in mid-1940, over a year before the United States entered the conflict. The company even went so far as to take delivery of Rolls-Royce blueprints and an example engine before Henry Ford suddenly and controversially backed-out of the deal, asserting that his company would not supply materiel to any foreign powers involved in conflict…"

autoweek.com

"A MONTH ago Henry Ford jolted the imagination of the war-scared U.S. by offering to turn out 1,000 airplanes-a-day if the Government would let him do it his way. Secretary of the Treasury Henry Morgenthau grasped at the magnanimous offer, called son Edsel to Washington to discuss what Ford might make. Upshot: Edsel tentatively agreed to make 6,000 Rolls-Royce liquid-cooled engines for Great Britain, 3,000 for the U.S…"

***TIME,* July 8, 1940**

RE: excerpt from an article entitled: "Business: Ford's Rolls-Royces"

"…Last week Father Henry thought differently. Reason: a fervent isolationist, he will manufacture only for 'Defense, not for Britain.' At once the entire deal was declared off. Defense Commissioner William S. Knudsen issued a pained, circumstantial account; Morgenthau explained that inasmuch as Britain had given the U.S. permission to make the Rolls motor, 'fairness and policy' required that Britain should have the right to buy them. Said Henry Ford: 'My offer to make airplanes, aviation engines or anything else the U.S. Government needs for defensive purposes still stands'…"

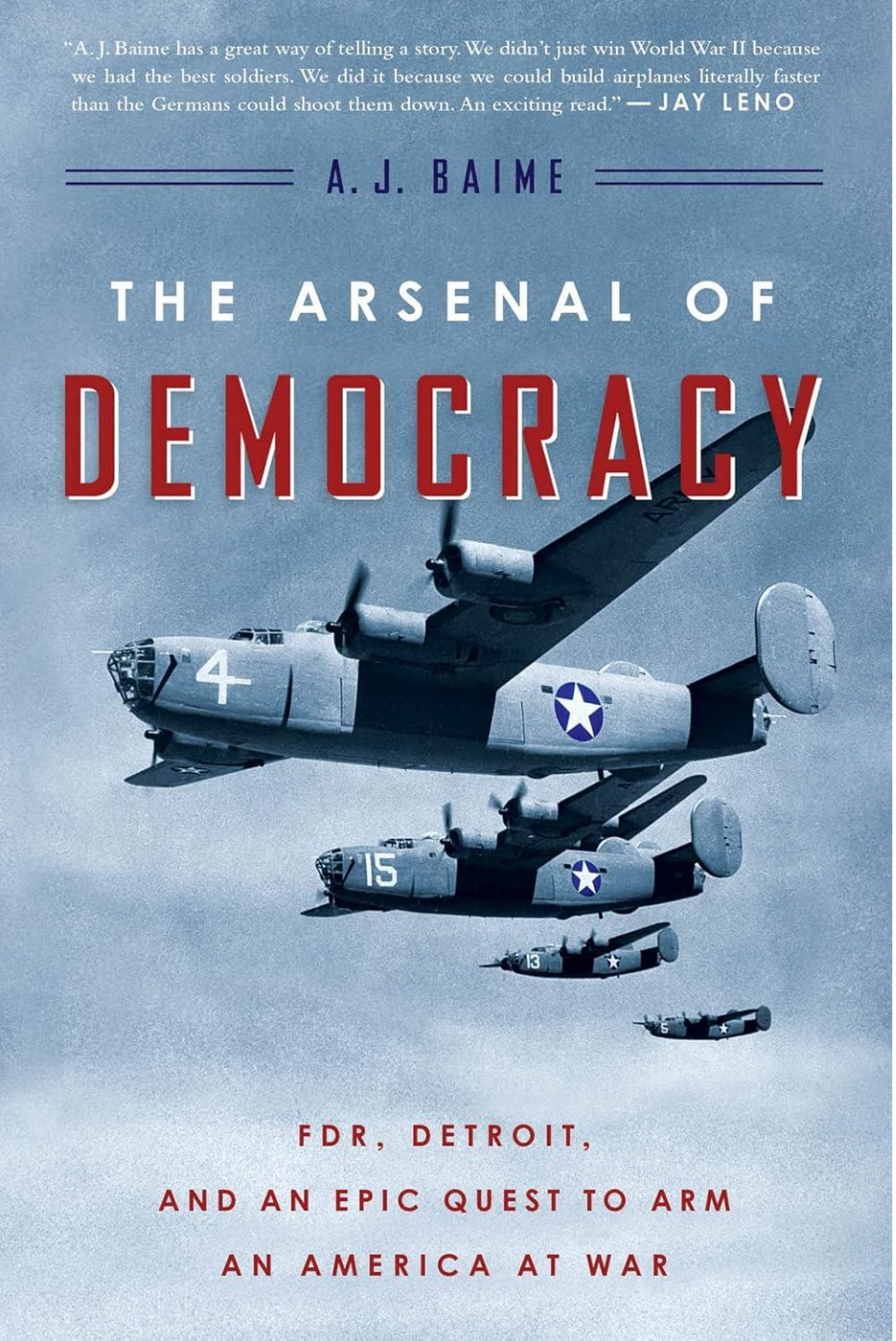
***TIME,* July 8, 1940**

RE: excerpt from an article entitled: "Business: Ford's Rolls-Royces"

"…Repercussions to Henry Ford's stand came fast. The City of San Antonio canceled an order for 22 Ford cars because 'Ford has taken a stand against the Government.' Members of the Canadian Parliament debated confiscation of the Canadian Ford plant. Officials of Ford's plant in Great Britain bought newspaper ads to advise the people that the plant was working for the Government. Members of the Defense Advisory Commission, meanwhile, began negotiations with other motor makers (notably Packard) in an effort to get the $130,000,000 Rolls-Royce order placed."

***TIME,* July 8, 1940**

RE: excerpt from an article entitled: "Business: Ford's Rolls-Royces"



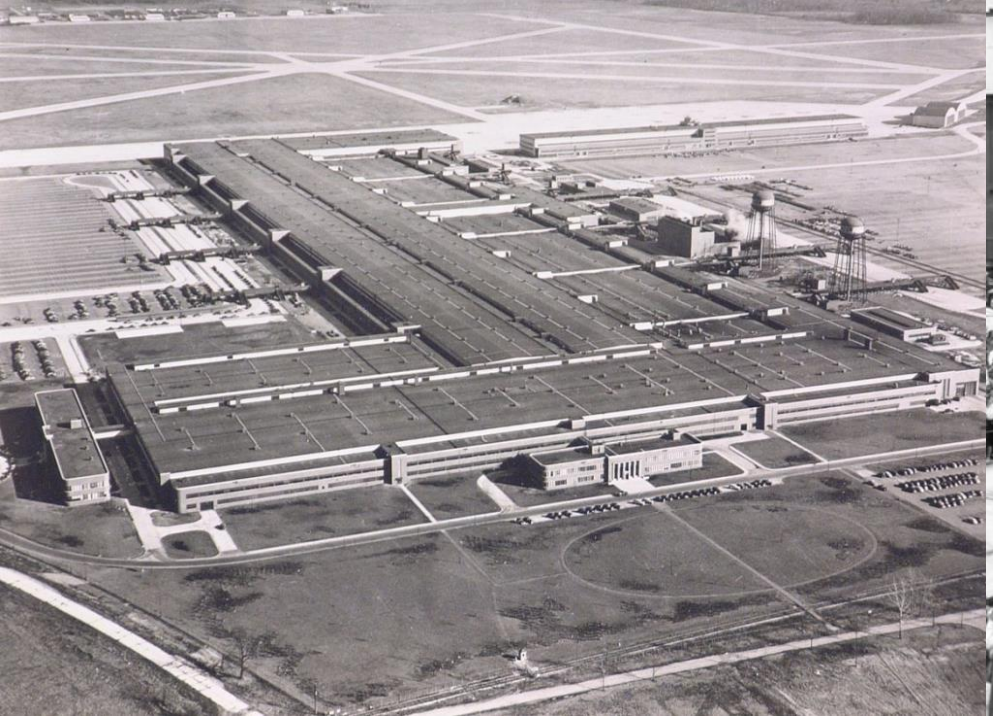
"…A.J. Baime relates this incident, and the detrimental effect it had on Edsel Ford, in 'The Arsenal of Democracy: FDR, Detroit, and an Epic Quest to Arm An America at War'…"

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RE: after Pearl Harbor, *Henry Ford* dedicated his manufacturing empire to America's victory, building a myriad of weapons critical to the war effort, including the B-24 bomber

<u>Caption</u>: "The story of the dramatic transformation of Detroit from 'Motortown' to the 'Arsenal of Democracy,' featuring Edsel Ford, who rebelled against his pacifist father, Henry Ford, to build a manufacturing complex that was crucial to winning WWII"

1700





More B-24 Liberator Heavy Bombers were built during WWII than any other American aircraft type. They were produced by the designer; Consolidated Aircraft, at their San Diego, California and Fort Worth, Texas plants; by Douglas Aircraft at Tulsa, Oklahoma; North American Aviation at Dallas, Texas and, most notably, by Ford at their Willow Run plant (left), located between Belleville and Ypsilanti, Michigan. Ford built 6,972 B-24s in 776 days and produced kits for 1,893 more to be assembled by the other manufacturers. The Willow Run plant completed a B-24 every 63 minutes. At right, B-24M-30-FO 44-51928 - the very last B-24 Liberator bomber to be built at Ford's Willow Run plant is rolled-out of the plant on June 28, 1945.

Tooling-up

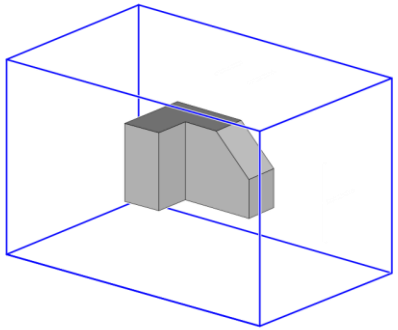
"…Enter Packard. By mid-June 1940, Packard had taken possession of the plans and parts initially given to Ford and began an ambitious program - led by Packard engineering boss Col. Jesse Vincent - to tool Detroit up for Merlin production…"

autoweek.com

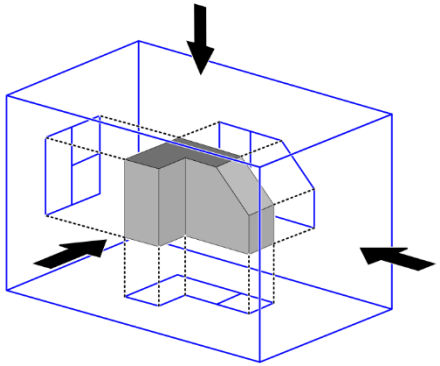
"…This involved everything from the time-consuming task of redrawing plans for the engines from British third-angle projection to the first-angle projection used in American manufacturing to creating the tooling and jigs needed to assemble them…"

autoweek.com

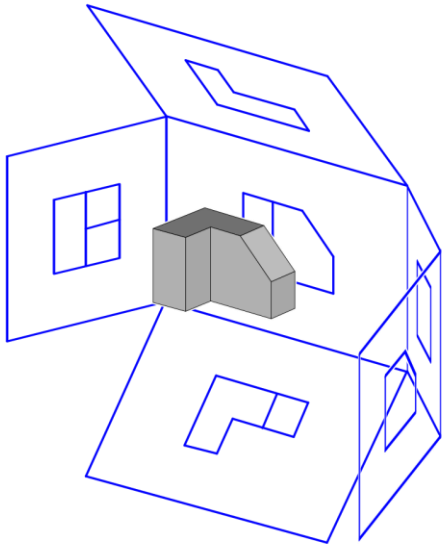
RE: in third-angle projection, the object is conceptually located in quadrant III, i.e., it is positioned below and behind the viewing planes; the planes are transparent and each view is pulled onto the plane closest to it. In first-angle projection, the object is conceptually located in quadrant I, i.e., it floats above and before the viewing planes; the planes are opaque and each view is pushed through the object onto the plane furthest from it.



An image of an object in a box



The same image, with views of the object projected in the direction of sight onto walls using first-angle projection



Similar image showing the box unfolding from around the object

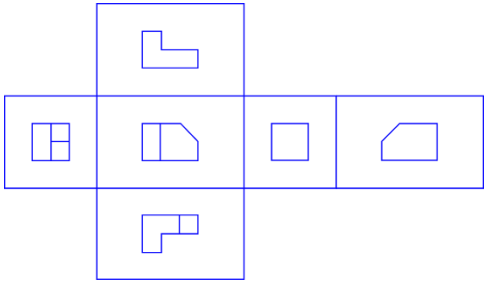
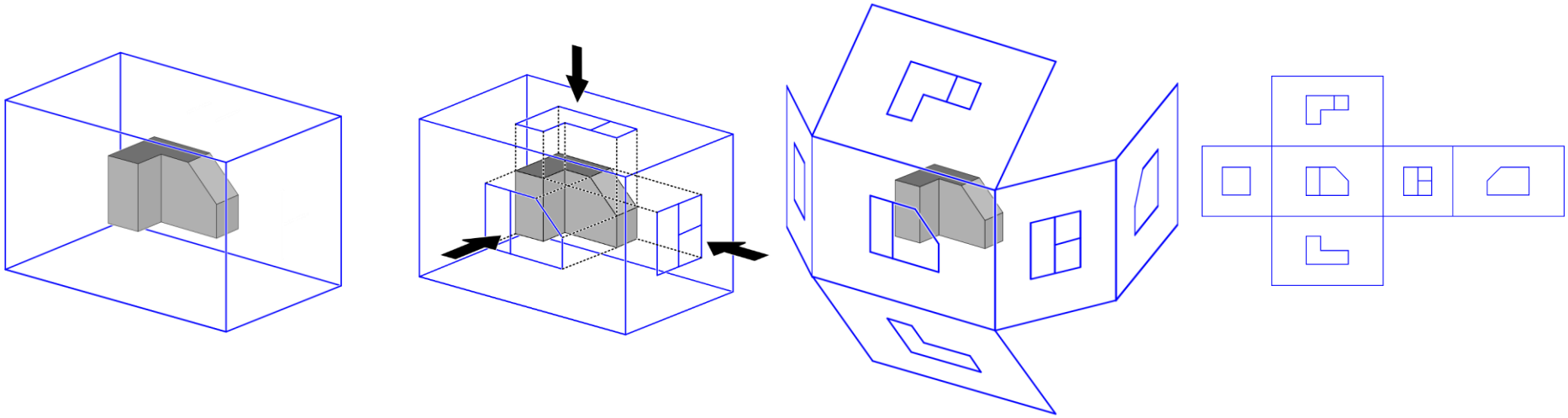
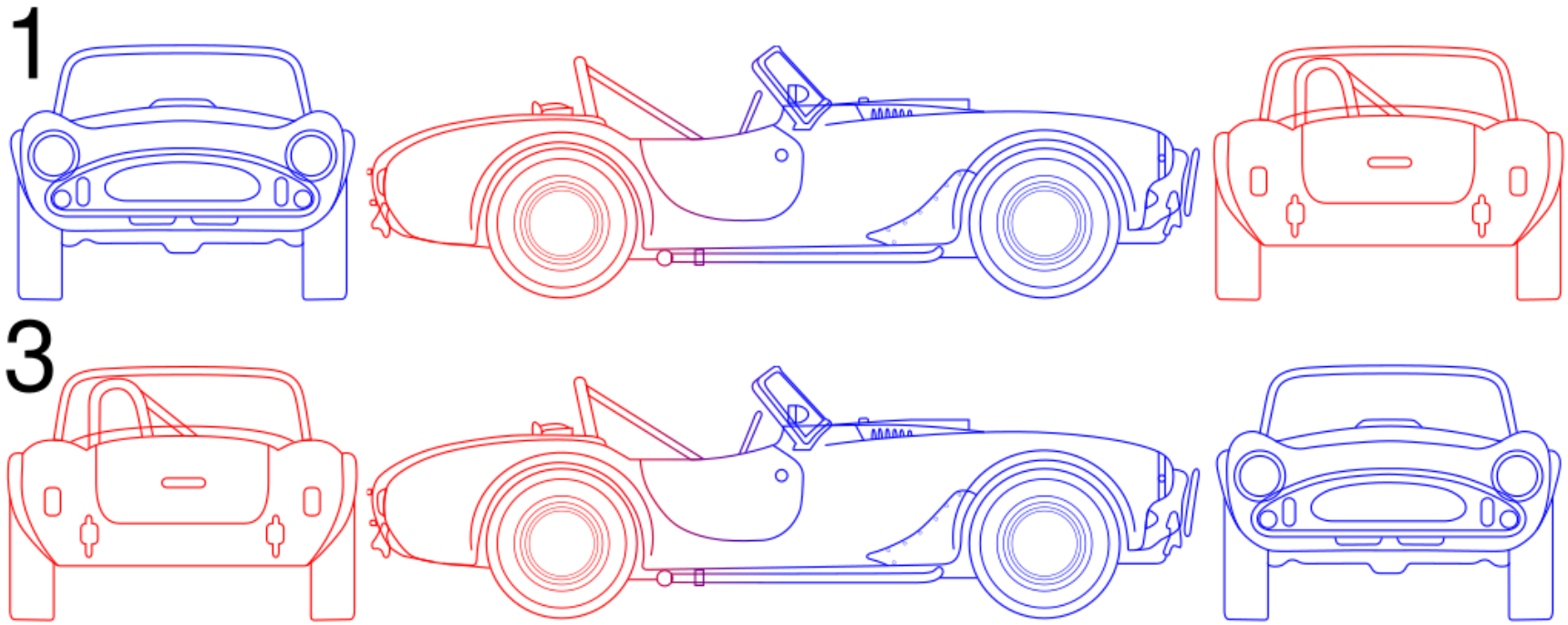


Image showing orthographic views located relative to each other in accordance with first-angle projection

Extending to a six-sided box, each view of the object in a first-angle projection is projected in the direction (sense) of sight of the object, onto the (opaque) interior walls of the box; that is, each view of the object is drawn on the opposite side of the box. A two-dimensional representation of the object is then created by "unfolding" the box, to view all of the interior walls. This produces two plans and four elevations.



<u>Above</u>: construction of third-angle projections of a six-sided box. The individual views are the same as in first-angle projection, only arranged differently.

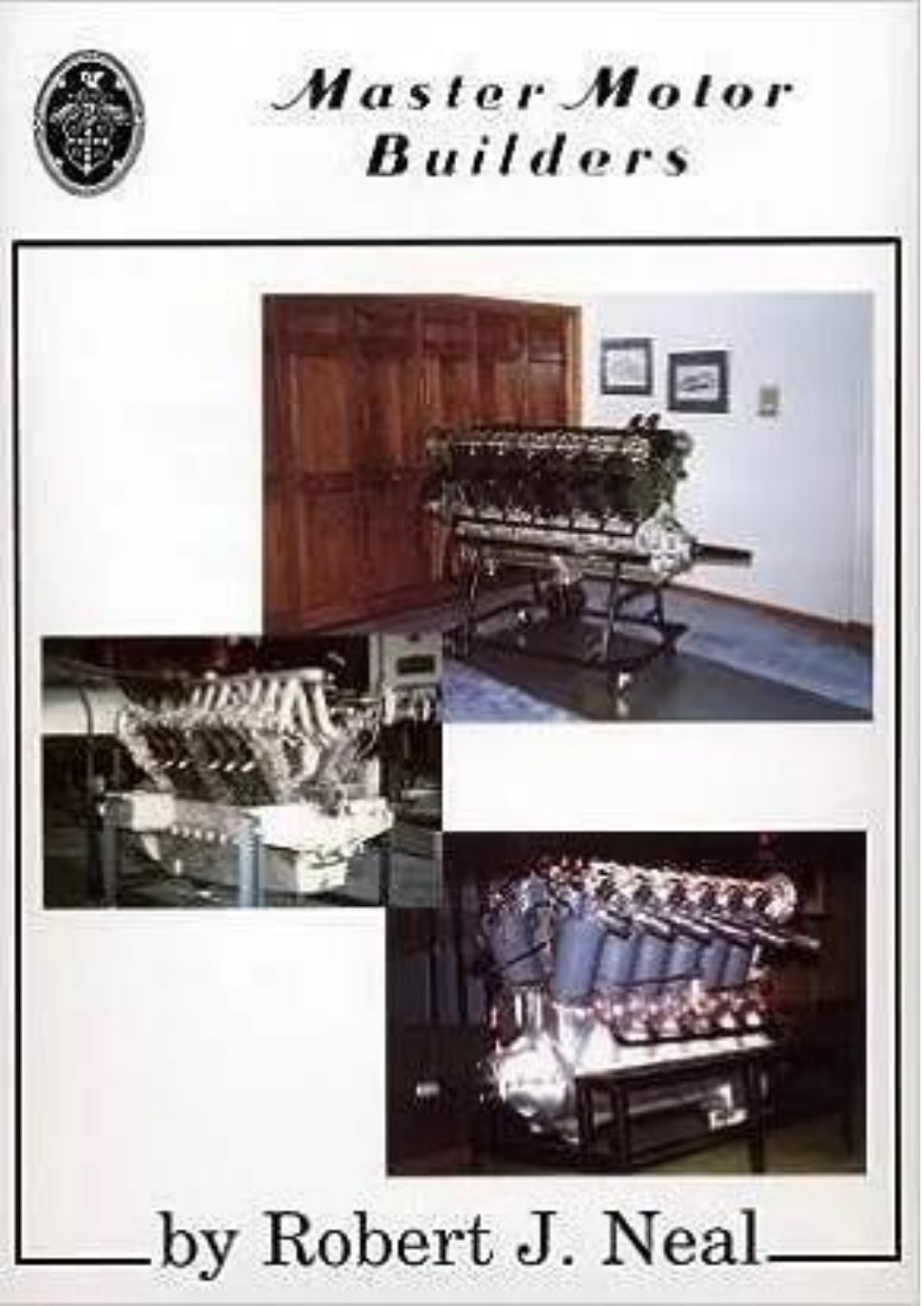


<u>Above</u>: comparison of first- and third-angle projections showing that related parts in the views are closer in third-angle

"…Packard also needed to figure-out how to obtain (or create) fasteners that used British thread standards - some of which had been further modified by Rolls-Royce to meet specific needs…"

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The Beginning of the Beginning



"…As Robert J. Neal writes in 'Master Motor Builders,' a tome documenting Packard's non-automotive engines: 'This was but the beginning of a monumental task of redesigning an engine which was not originally designed for mass production so that it could indeed be made by American mass-production methods and so that it could be fitted with American fittings and accessories as mentioned above [for example, carburetors, fuel pumps, generators and so on] or British accessories and fittings, depending upon which government the engine was intended for'…"

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Reverse Engineering

"…Neal also notes that 'the British did not specify tolerances and fits and Packard had to take parts from an existing engine and make measurements to determine these specifications as best as they could, using engineering judgement where necessary'…"

autoweek.com

Faster and Cheaper

"…This notion is also reflected in the March 1946 issue of FLYING magazine, which includes a retrospective on the powerplant by Paul H. Becker titled 'Mass Producing the Merlin'…"

autoweek.com

"…'It took the war to prove that the aircraft engine is not that complicated micro-micro-inch construction problem peace-time talk has made. It is larger, lighter-per-horsepower and has more parts than the automobile engine. But it can be made with the same ease, relatively cheaply and on a similar assembly line . . . The secret of this low-cost, high-production manufacturing is the assembly line. Rolls-Royce manufact-ures a 'fitter's' engine with parts being brought to the unit under construction on a bench. If the part doesn't fit, it is machined until it does meet required specifications . . . An American assembly line reverses this procedure. A conveyor belt brings the engine to the parts which always fit for by American methods all parts are made so precisely that they are always interchangeable'…"

autoweek.com

Automobile Engineers took a British hand-built engine and, using U.S. assembly-line techniques, constructed it faster and cheaper

***FLYING,* March 1946**

RE: introduction to an article written by *Paul H. Becker* entitled: "Mass-Producing the Merlin"



"IT took the war to prove that the aircraft engine is not that complicated micro-micro-inch construction problem peace-time talk has made it. It is larger, lighter-per-horsepower and has more parts than the automobile engine. But it can be made with the same ease, relatively cheaply and on a similar assembly line…"

***FLYING,* March 1946**

"…The Packard Motor Car Company was the first automobile manufacturer to prove this. In two years Packard made on its assembly line as many engines as British manufacturers could make in eight years. The engine, of course, was the Rolls-Royce Merlin…"

***FLYING*, March 1946**

"…Modified to fit U.S. requirements, the Merlin plans were turned over to the Packard Company in September, 1940, with an initial order for 9,000 units - 6,000 for the British, the balance for the AAF…"

***FLYING,* March 1946**

"…Although no figures are available, it was estimated that by British methods, a Merlin engine was costing perhaps $25,-000 crated for shipment. What Packard charged for their first engines is not known, but at the end of the war the auto-mobile company was manufacturing a Merlin far more com-plex than the original product for about $12,000…"
***FLYING,* March 1946**

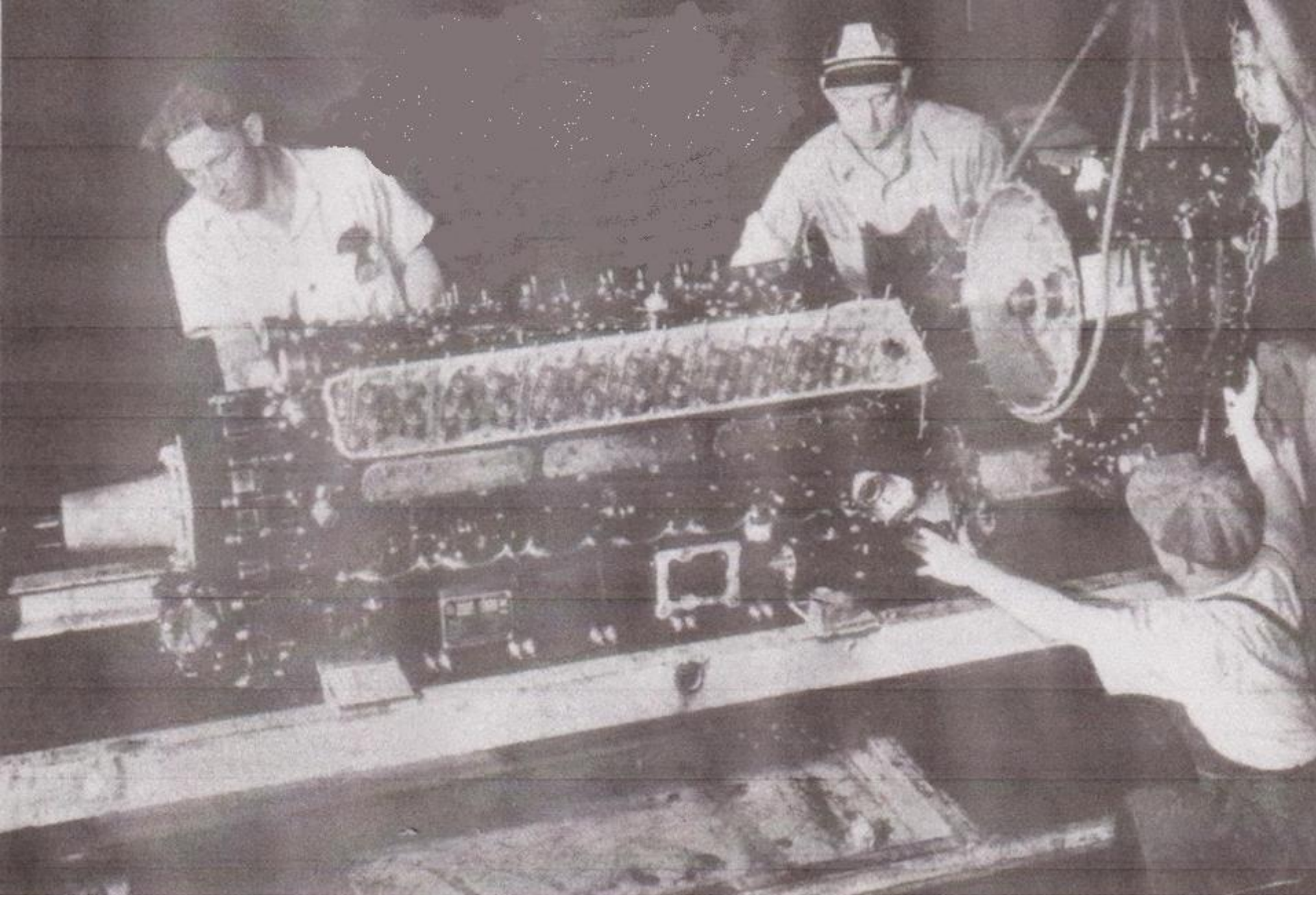
"…The secret of this low-cost, high-production manufacturing is the assembly line. Rolls-Royce manufactures a 'fitter's' engine with parts being brought to the unit under construction on a bench. If the part doesn't fit, it is machined until it does meet required specifications…"

***FLYING*, March 1946**



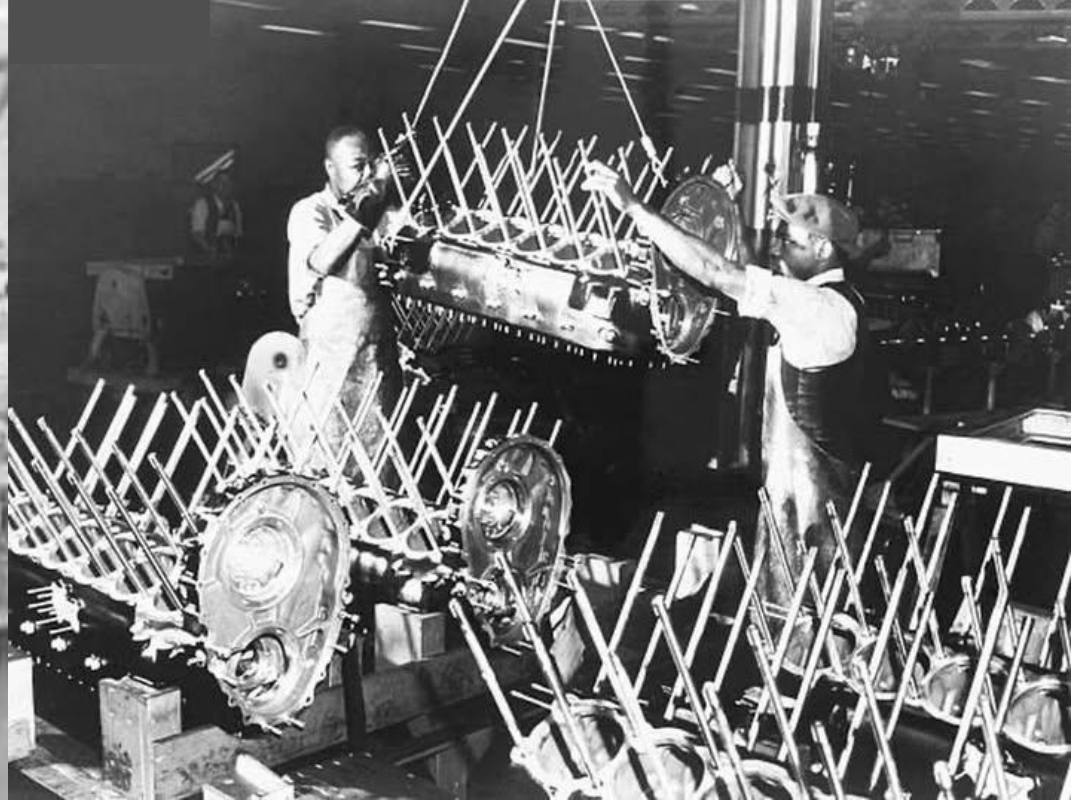
"…An American assembly line reverses this procedure. A conveyor belt brings the engine to the parts which always fit, for by American methods all parts are made so precisely that they are always interchangeable…"

***FLYING*, March 1946**



<u>Caption</u>: “Workers attach supercharger to Merlin. American precision methods make assembly line techniques possible – every part must fit”





"…Packard entered the Merlin contract amid much headshaking by those who believed that production of aircraft engines was an undertaking for specialized companies. Packard's Engineers, however, concluded that the fundamental problems in the design, development and production of automobile and aircraft engines were pretty similar…"

***FLYING,* March 1946**

<u>Left</u>: caption: "General view of engine assembly line, Packard plant, Detroit, Michigan"

<u>Right</u>: caption: "Two assembly line workers assemble Rolls-Royce engines at the Packard Motor Car Company in Detroit, Michigan, Jan. 1943"

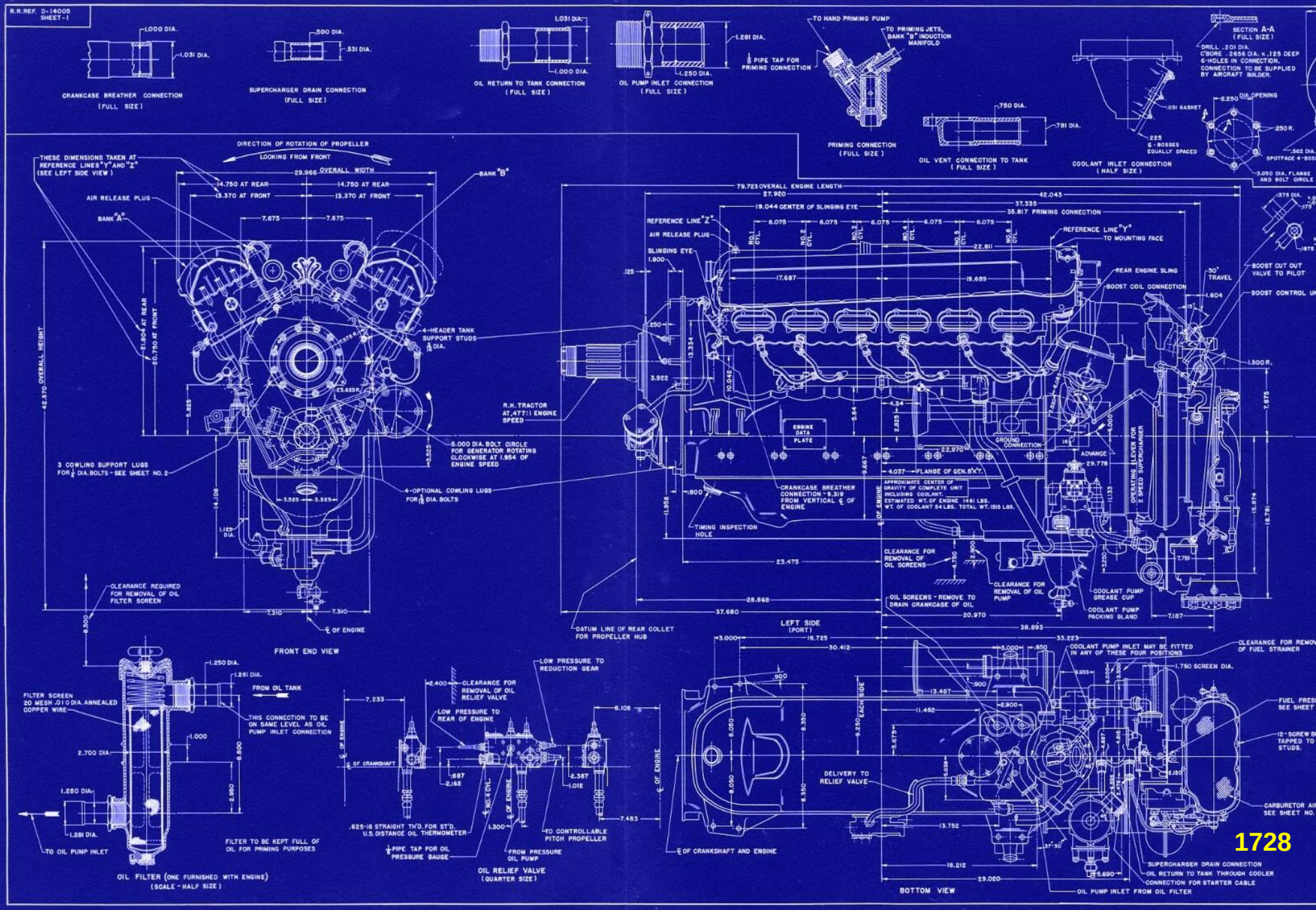
"…The operating parts of the Merlin were found to be no more accurate than corresponding automobile engine parts. Where the automobile engine designer was highly cost-conscious, the aircraft engine designer was extremely weight-conscious. But the accuracy achieved painstakingly by the latter had been accomplished by the former as a natural result of the automobile industry's insistence upon complete interchangeability and on avoidance of all expensive selective fitting practices…"

***FLYING*, March 1946**

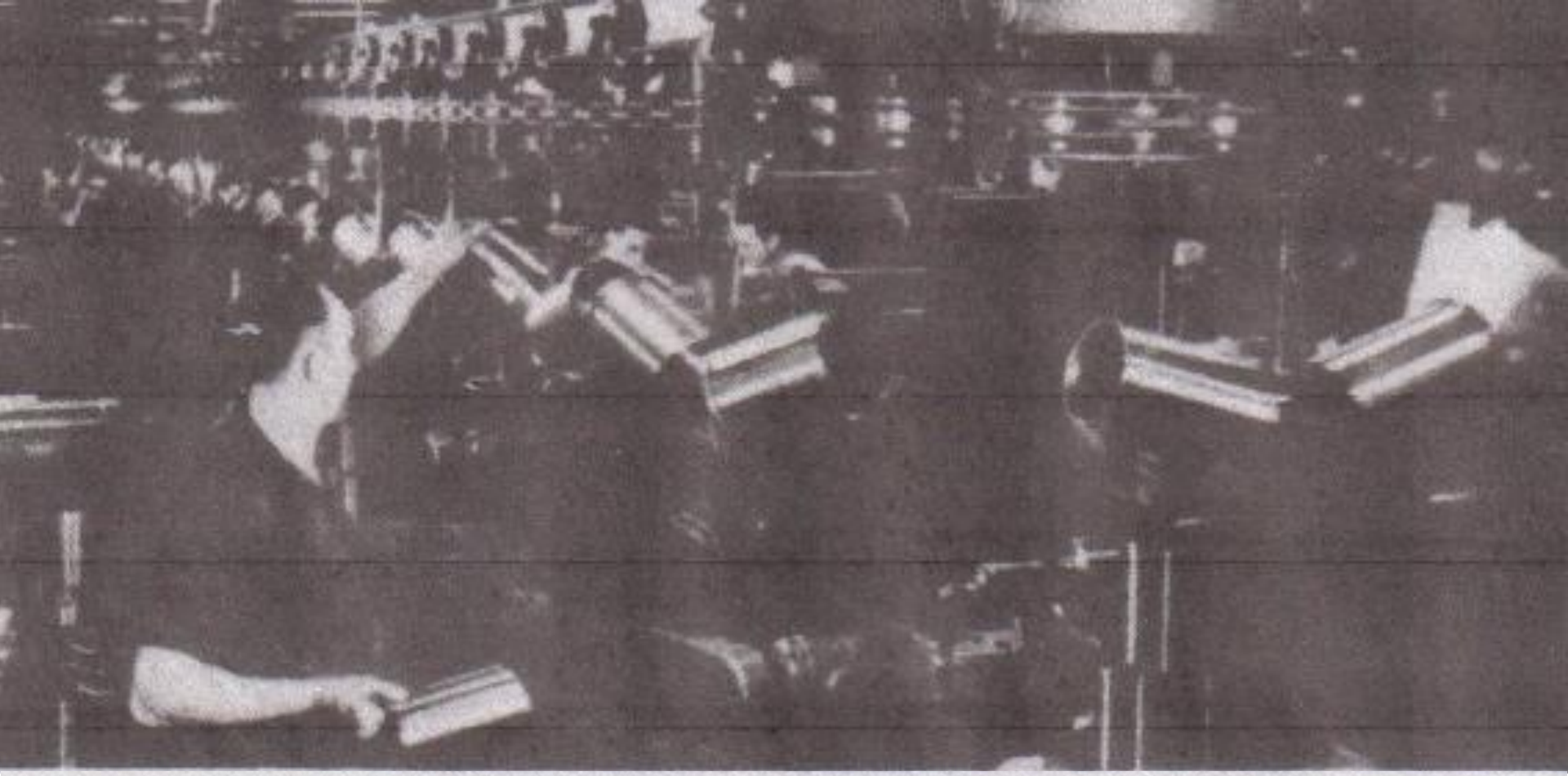
"…Packard's Engineers were not too familiar with the reactions of some of the highly-stressed materials used in aircraft engines. But, after experimentation, they agreed that, with few exceptions, the methods of producing mechanical fits would be the same for the Merlin as those with which they had become familiar in the manufacture of automobile engines…"

***FLYING,* March 1946**

"…Since the British use the third-angle projection, it was necessary to re-draw every one of the 2,500 Rolls-Royce 'left-handed' prints and to substitute American nomenclature or run the risk of producing an engine that would run in the wrong direction. Some 75 men were busy for four months making 125,000 blueprints covering 720,000 square-feet of paper…"
***FLYING,* March 1946**


R.R.REF. D-14005 SHEET-1
1.000 DIA.
1.031 DIA.
CRANKCASE BREATHER CONNECTION (FULL SIZE)
.500 DIA.
.531 DIA.
SUPERCHARGER DRAIN CONNECTION (FULL SIZE)
1.031 DIA.
1.000 DIA.
OIL RETURN TO TANK CONNECTION (FULL SIZE)
1.281 DIA.
1.250 DIA.
OIL PUMP INLET CONNECTION (FULL SIZE)
TO HAND PRIMING PUMP
TO PRIMING JETS, BANK "B" INDUCTION MANIFOLD
⅜ PIPE TAP FOR PRIMING CONNECTION
PRIMING CONNECTION (FULL SIZE)
.750 DIA.
.781 DIA.
OIL VENT CONNECTION TO TANK (FULL SIZE)
SECTION A-A (FULL SIZE)
DRILL .201 DIA. C'BORE .265 DIA. x .125 DEEP 6-HOLES IN CONNECTION. CONNECTION TO BE SUPPLIED BY AIRCRAFT BUILDER.
.031 GASKET
22½° 6-BOSSES EQUALLY SPACED
2.250 DIA. OPENING
.250 R.
.562 DIA. SPOTFACE 4-BOSSES
3.050 DIA. FLANGE AND BOLT CIRCLE
COOLANT INLET CONNECTION (HALF SIZE)
THESE DIMENSIONS TAKEN AT REFERENCE LINES "Y" AND "Z" (SEE LEFT SIDE VIEW)
DIRECTION OF ROTATION OF PROPELLER LOOKING FROM FRONT
29.966 OVERALL WIDTH
14.750 AT REAR
13.370 AT FRONT
BANK "B"
BANK "A"
AIR RELEASE PLUG
7.675
42.570 OVERALL HEIGHT
21.600 AT REAR
20.750 AT FRONT
4-HEADER TANK SUPPORT STUDS ⅜ DIA.
R.H. TRACTOR AT 477:1 ENGINE SPEED
5.000 DIA. BOLT CIRCLE FOR GENERATOR ROTATING CLOCKWISE AT 1.954 OF ENGINE SPEED
3 COWLING SUPPORT LUGS FOR ⅜ DIA. BOLTS - SEE SHEET NO. 2
4-OPTIONAL COWLING LUGS FOR ⅜ DIA. BOLTS
1.125 DIA.
3.525
CLEARANCE REQUIRED FOR REMOVAL OF OIL FILTER SCREEN
8.500
2.310
7.310
℄ OF ENGINE
FRONT END VIEW
79.723 OVERALL ENGINE LENGTH
27.920
19.044 CENTER OF SLINGING EYE
42.043
37.335
35.817 PRIMING CONNECTION
REFERENCE LINE "Z"
REFERENCE LINE "Y" TO MOUNTING FACE
AIR RELEASE PLUG
SLINGING EYE
1.800
.125
6.075
NO.1 CYL.
NO.2 CYL.
NO.3 CYL.
NO.4 CYL.
NO.5 CYL.
NO.6 CYL.
22.811
17.687
19.689
REAR ENGINE SLING
BOOST COIL CONNECTION
30° TRAVEL
1.604
BOOST CUT OUT VALVE TO PILOT
BOOST CONTROL UN
.375 DIA.
.175
1.875
1.500 R.
13.334
3.922
10.042
5.64
2.825
ENGINE DATA PLATE
GROUND CONNECTION
22.970
4.000
16°
ADVANCE 29.778
OPERATING LEVER FOR 2 SPEED SUPERCHARGER
7.975
15.874
18.781
7.781
4.037 FLANGE OF GEN. 8 K.Y.
CRANKCASE BREATHER CONNECTION - 9.319 FROM VERTICAL ℄ OF ENGINE
APPROXIMATE CENTER OF GRAVITY OF COMPLETE UNIT INCLUDING COOLANT. ESTIMATED WT. OF ENGINE (46) LBS. WT. OF COOLANT 54 LBS. TOTAL WT. (515 LBS.
℄ OF ENGINE
11.958
.800
TIMING INSPECTION HOLE
CLEARANCE FOR REMOVAL OF OIL SCREENS
1.750
2.900
23.475
28.868
37.680
CLEARANCE FOR REMOVAL OF OIL PUMP
OIL SCREENS - REMOVE TO DRAIN CRANKCASE OF OIL
COOLANT PUMP GREASE CUP
COOLANT PUMP PACKING GLAND
7.187
20.970
38.893
DATUM LINE OF REAR COLLET FOR PROPELLER HUB
LEFT SIDE (PORT)
16.725
30.412
3.000
33.223
.650
COOLANT PUMP INLET MAY BE FITTED IN ANY OF THESE FOUR POSITIONS
CLEARANCE FOR REMOVAL OF FUEL STRAINER
1.750 SCREEN DIA.
FUEL PRES SEE SHEET
12-SCREW B TAPPED TO STUDS.
CARBURETOR AI SEE SHEET NO.
.900
13.487
11.462
2.900
9.250 EACH SIDE
8.050
8.350
5.675
DELIVERY TO RELIEF VALVE
13.752
37.30
18.212
29.020
3.690
SUPERCHARGER DRAIN CONNECTION
OIL RETURN TO TANK THROUGH COOLER
CONNECTION FOR STARTER CABLE
OIL PUMP INLET FROM OIL FILTER
BOTTOM VIEW
FILTER SCREEN 20 MESH .010 DIA. ANNEALED COPPER WIRE
1.250 DIA.
1.281 DIA.
FROM OIL TANK
THIS CONNECTION TO BE ON SAME LEVEL AS OIL PUMP INLET CONNECTION
1.000
2.700 DIA.
6.800
2.950
TO OIL PUMP INLET
FILTER TO BE KEPT FULL OF OIL FOR PRIMING PURPOSES
OIL FILTER (ONE FURNISHED WITH ENGINE) (SCALE - HALF SIZE)
7.233
2.400
CLEARANCE FOR REMOVAL OF OIL RELIEF VALVE
LOW PRESSURE TO REAR OF ENGINE
℄ OF ENGINE
℄ OF CRANKSHAFT
.687
2.162
2.387
.012
NO.4 CYL.
1.300
.625-18 STRAIGHT THD. FOR ST'D. U.S. DISTANCE OIL THERMOMETER
PIPE TAP FOR OIL PRESSURE GAUGE
FROM PRESSURE OIL PUMP
LOW PRESSURE TO REDUCTION GEAR
8.108
TO CONTROLLABLE PITCH PROPELLER
7.483
OIL RELIEF VALVE (QUARTER SIZE)
℄ OF CRANKSHAFT AND ENGINE
1728

"…As soon as the first drawings were approved, they were released to the production men and work began on the manufacture of jigs, fixtures and machine tools. Contrary to popular belief, very few of the machine tools used to build automobiles were convertible for use on aircraft engine work…"
***FLYING,* March 1946**



Even sub-assemblies were finished on assembly lines. Here several hundred feet of cylinder liners travel on overhead conveyor line to various machining departments.

"…Production experts found that the Merlin had 1,978 different part numbers - exclusive of the carburetor, boost-control, magneto and ignition harness, which were all purchased from outside firms as complete subassemblies…"

1730

***FLYING,* March 1946**

"…Three thousand-five hundred seventy-five machine tools were required and contracts were let throughout the country…"

***FLYING*, March 1946**

"…The need for this special equipment can be seen from just one example: the crankcase upper on the Merlin requires 77 machines performing 108 operations for completion…"
***FLYING*, March 1946**



"…There are a total of 14,000 pieces in the Merlin, while a whole Packard automobile only 7,140 pieces. Machining only the major parts of the Rolls-Royce engine required upward of 80,000 operations: on many parts the limit must be held to 0.0002 in. Packard found that machining a complete Merlin connecting rod required 31 standard hours of work, as against a half-hour for a similar car engine rod…"

***FLYING*, March 1946**

"…There were, naturally, other differences. Machining the Merlin cylinder block required 110 hours, where a car block requires only five; the Merlin's crankshaft must be machined for 49 hours, while the automobile crankshaft requires 4.5 hours…"

***FLYING*, March 1946**

"…Packard decided to apply typical automotive assembly line techniques to the job. The first continuous assembly line for aircraft engines was set-up, consisting of a long main production line fed transversely by continuous subassembly lines, with the main line power-operated and ending at a test stand…"

***FLYING,* March 1946**

"…The continuous assembly line was also introduced to expedite the teardown and rebuild of engines after the 'green run' on the test stand…"

***FLYING*, March 1946**



A "U" line was designed by Packard engineers for disassembly, inspection and reassembly following Merlin's initial test run. Successive parts taken off engine were passed across to meet same engine block at proper reassembly stations on other side of "U."

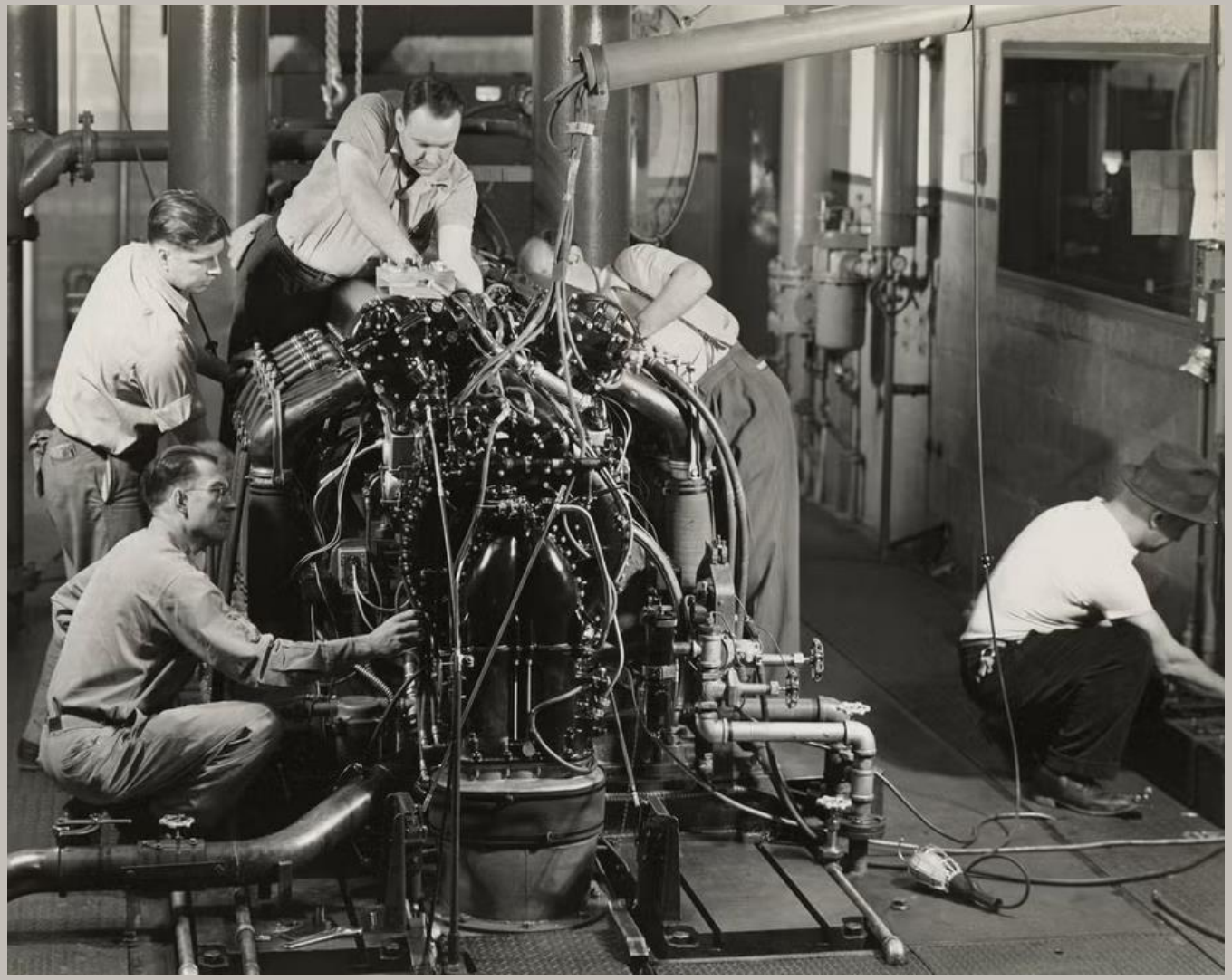
"…After test operation, the engine is washed and started along a U-shaped disassembly and rebuild line. The ignition harness is removed, cleaned, inspected and passed along the open-end of the 'U' to meet the same engine from which it was removed, becoming the last part to be re-assembled on the engine…"

***FLYING,* March 1946**

"…In the same manner, the other parts and subassemblies are removed and each passes through the hands of the dis-semblers, inspectors and assemblers while journeying along the transverse lines between the two prongs of the 'U.' The crankcase passes around the closed-end of the 'U,' is clean-ed and inspected then starts up the assembly side, acquiring its parts back in the proper order…"

***FLYING,* March 1946**

"…Packard found that this method of tear-down and re-assembly could be followed in a minimum amount of space and that new employees could be taught the requirements of one detailed job on the 'U' line in a comparatively little time…"
***FLYING,* March 1946**



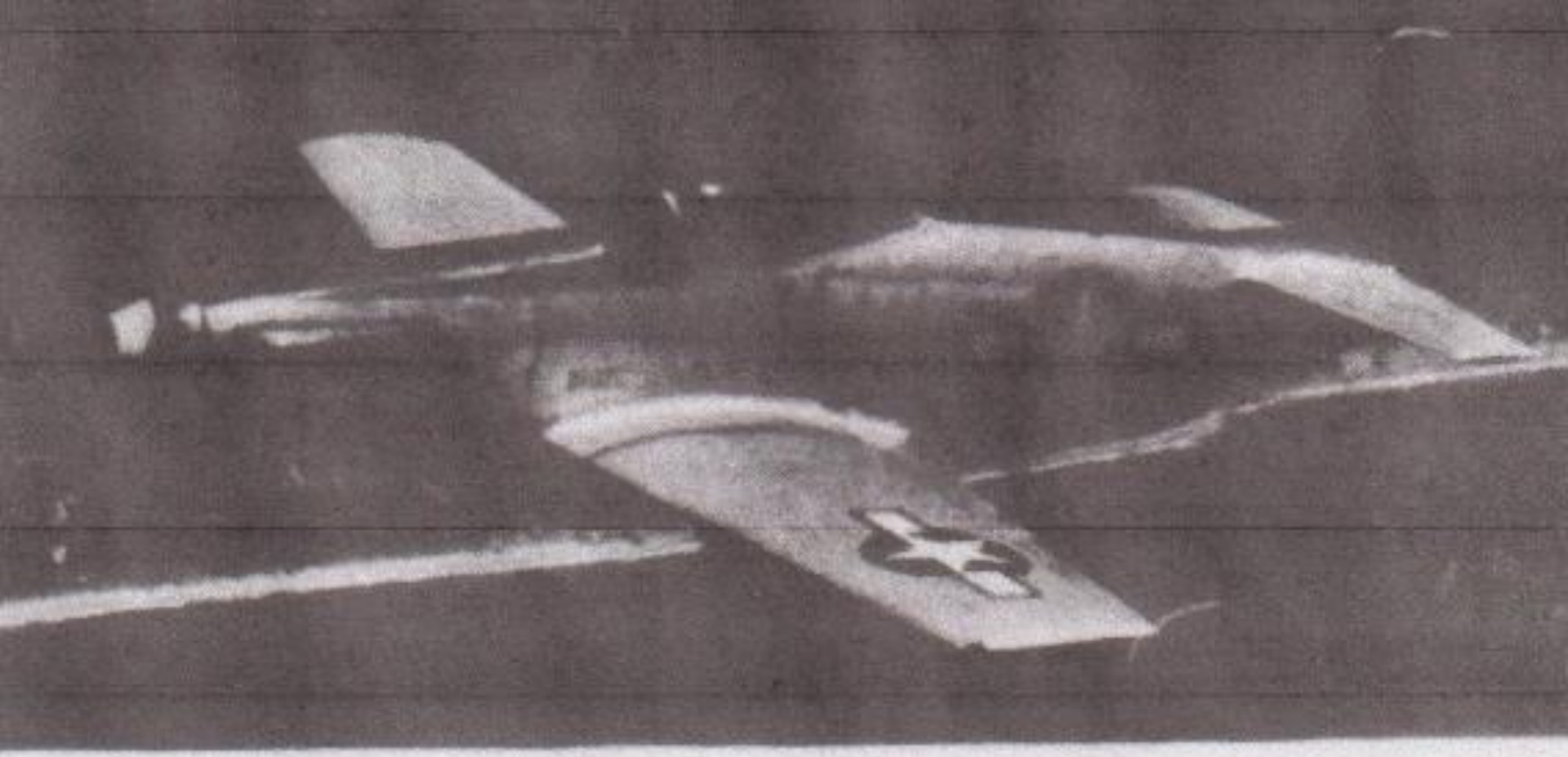
1740

"…Development ran a race with production and through a series of engineering alterations which often numbered as high as 400 per-month, the engine was refined into a power-plant more powerful and versatile than any other in the Allied armory…"

***FLYING*, March 1946**

"…For the British, Packard used the Merlin Model XX as the basic engine and from it progressively developed 13 models. For the AAF, Packard used the Merlin Model 60 as the basic unit and developed 10 models…"

***FLYING*, March 1946**



Using British-designed Merlin engine as manufactured by U. S. methods, North American Mustang set cross-country records. British took most of Packard-built Merlins.

"…Improvements developed jointly by Packard and British Engineers raised the Merlin's ceiling to over 40,000-feet and its horsepower to more than 2,000, an increase of 50 per cent since the first Packard-built Merlin was produced…"

***FLYING,* March 1946**

"…Through hundreds of engineering changes production was simplified, costs lowered, time saved and the efficiency of the product improved. One such change, an improved camshaft drive originated by Packard reduces by 21 the number of parts and aids materially in servicing engines in the field…"

***FLYING*, March 1946**

"…These production and engineering changes did much to increase manufacturing efficiency as completed engines began to roll-off the final assembly line at a rate of $1,000-worth a minute…"

***FLYING*, March 1946**

"…This is the second time that Packard's two top men turned to aircraft engine production during a war. In 1918, Packard President (now board Chairman) Alvan Macauley and Col. J.G. Vincent, Vice President in-charge of engineering, were instrumental in the design and subsequent development of the old Liberty XII engine…"

***FLYING*, March 1946**

"…Macauley and Vincent were joined by George T. Christopher (successor to Macauley as Packard President) in the World War II job of taking the British 'fitter's' engine and mass-producing it faster and cheaper than the British dreamed possible."

***FLYING,* March 1946**

Adaptive Mass Production

"…Packard's assembly line was undeniably cutting-edge. It probably helped that America was not at war when ground was broken for it - and anyway, the threat of Axis bombers flying to the Midwest to flatten it was somewhat less than the chances of the Luftwaffe raining fire on the manufacturing plants of the Midlands…"

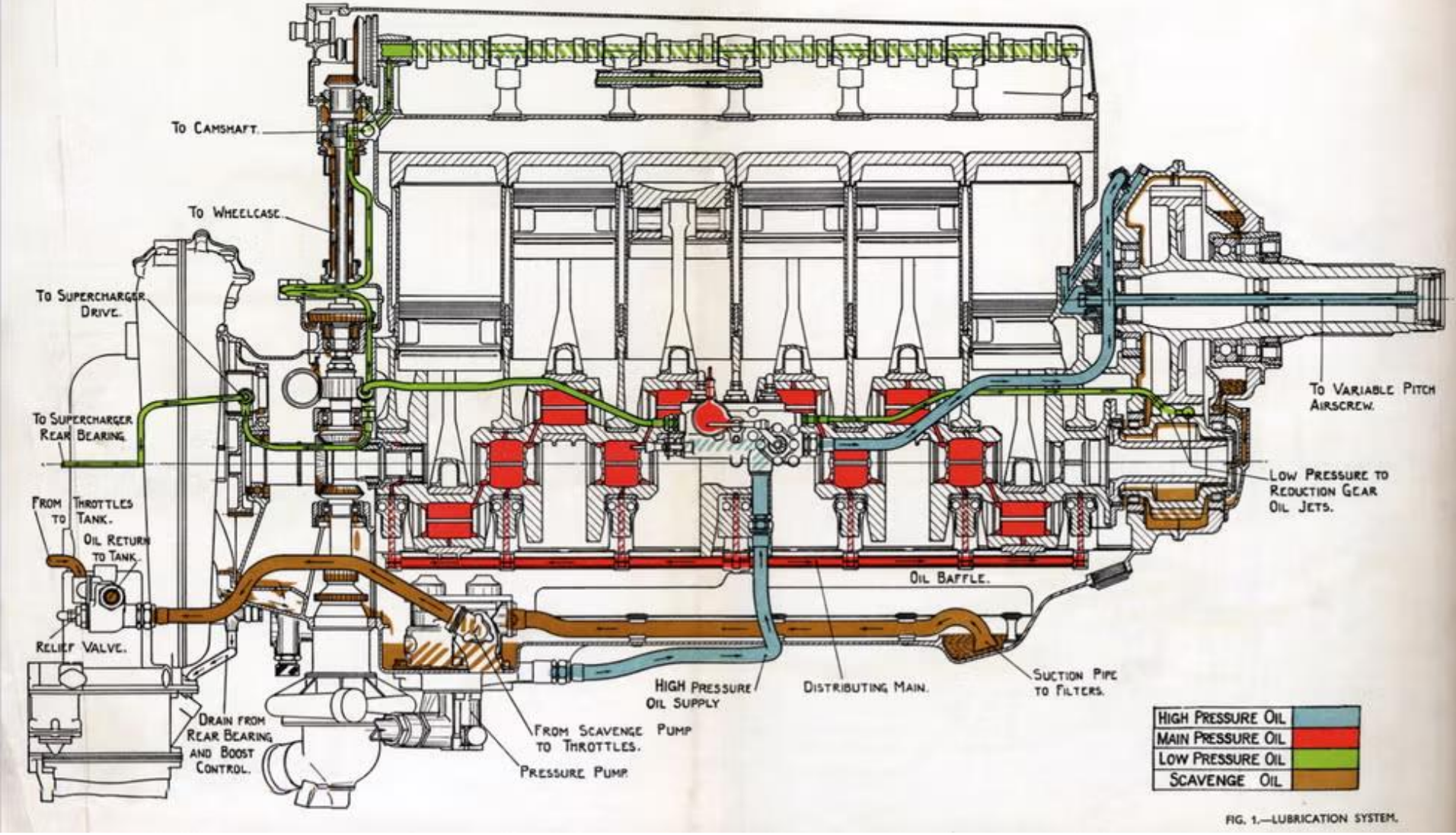
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<u>Caption</u>: “Packard constructed the buildings shown in the foreground of this photo for military engine production. Interestingly, while much of the company’s plant lies in ruins, these structures are still in use today.” 1750

"…All of this seems to back-up the claim that Packard went its own way when building the Merlin, at least when it came to tolerances. This is a little misleading: The Merlin II Service Manual, released May 1938, lists exacting fits and tolerances for the engine and every subsystem on it…"

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<u>Caption</u>: "An illustration of the Rolls-Royce Merlin V-12's lubrication system, pulled from a Merlin II service manual originally published in 1938"

Manufacturing Methodology

"…Did Rolls-Royce simply forget to include this vital information when it handed Ford, and then Packard, stacks of documentation two years later? It beggars belief. Neal and others must be referring to the fit and tolerances of the parts produced rather than as-installed - a distinction that will make more sense as we explore Rolls-Royce's pre-war manufacturing methods…"

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"…In any case, Packard's version of the Merlin XX, which the Detroit automaker dubbed the V-1650-1, was ready to run by August 1941. It did feature a number of improvements over the British-built Merlins such as a two-piece cylinder block. Some of these improvements were developed by Packard Engineers in an effort to make the complex engine easier and quicker to build in quantity. Others, however, like the two-piece block, were actually designed by Rolls-Royce and not yet implemented in production…"

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"…And to give a sense of how thoroughly this largely parallel, if somewhat staggered, transatlantic development effort has clouded the record, Neal states that Packard modified the design two-piece block to better facilitate production; when Rolls-Royce eventually implemented a slightly different two-part block, Packard subsequently adopted the Rolls-Royce design. Simple!..."

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<u>Caption</u>: "A Merlin cylinder block assembly scene at a Rolls-Royce factory. It's not quite as modern as Packard's facility, but nor is a collection of craftsmen's benches"

War Footing

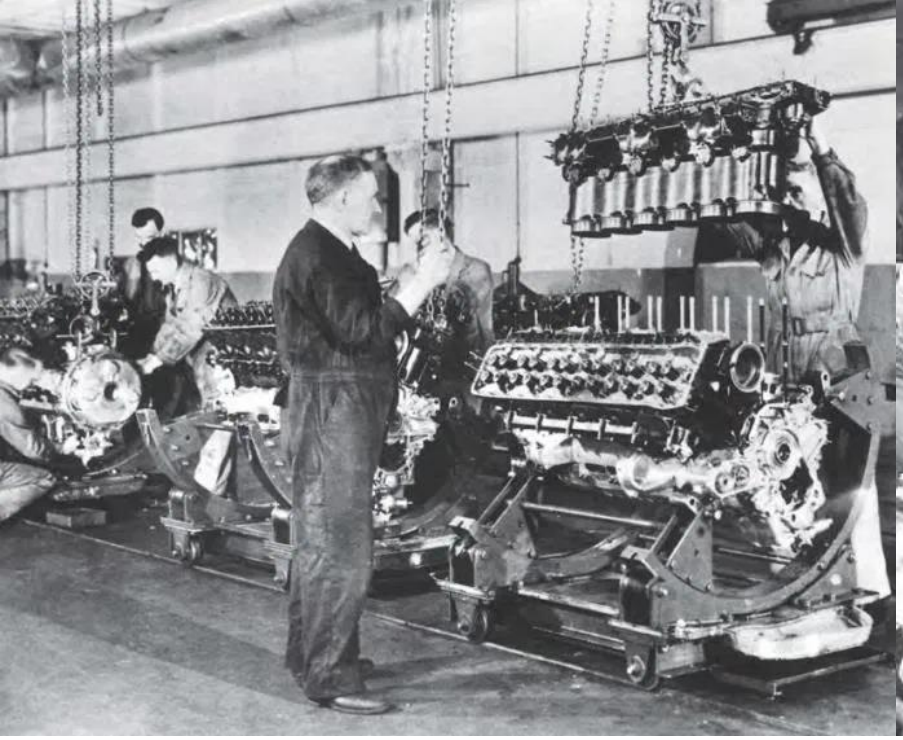
"…Following the attack on Pearl Harbor in December 1941, and the United States' declaration of war on the Axis powers, civilian automobile production quickly ceased; by early 1942, Packard was free to focus all of its effort on military engine production…"

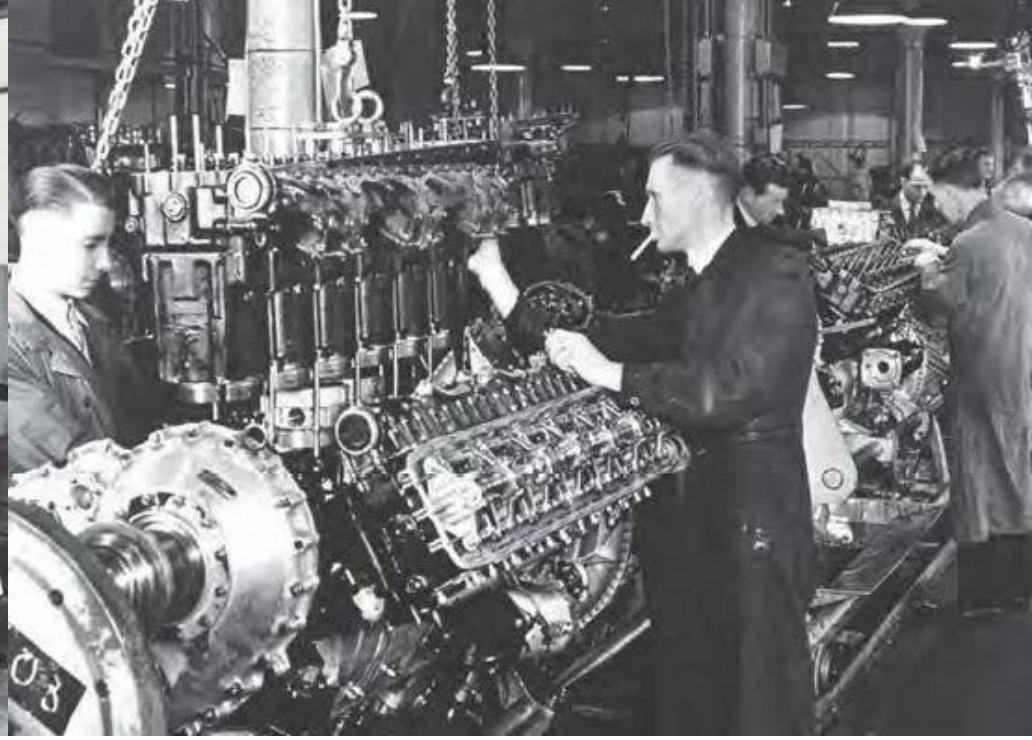
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This 1942 Packard Eight Clipper Special was the last car to leave the company's production line before it fully switched over to military engine production.

Ford of Britain



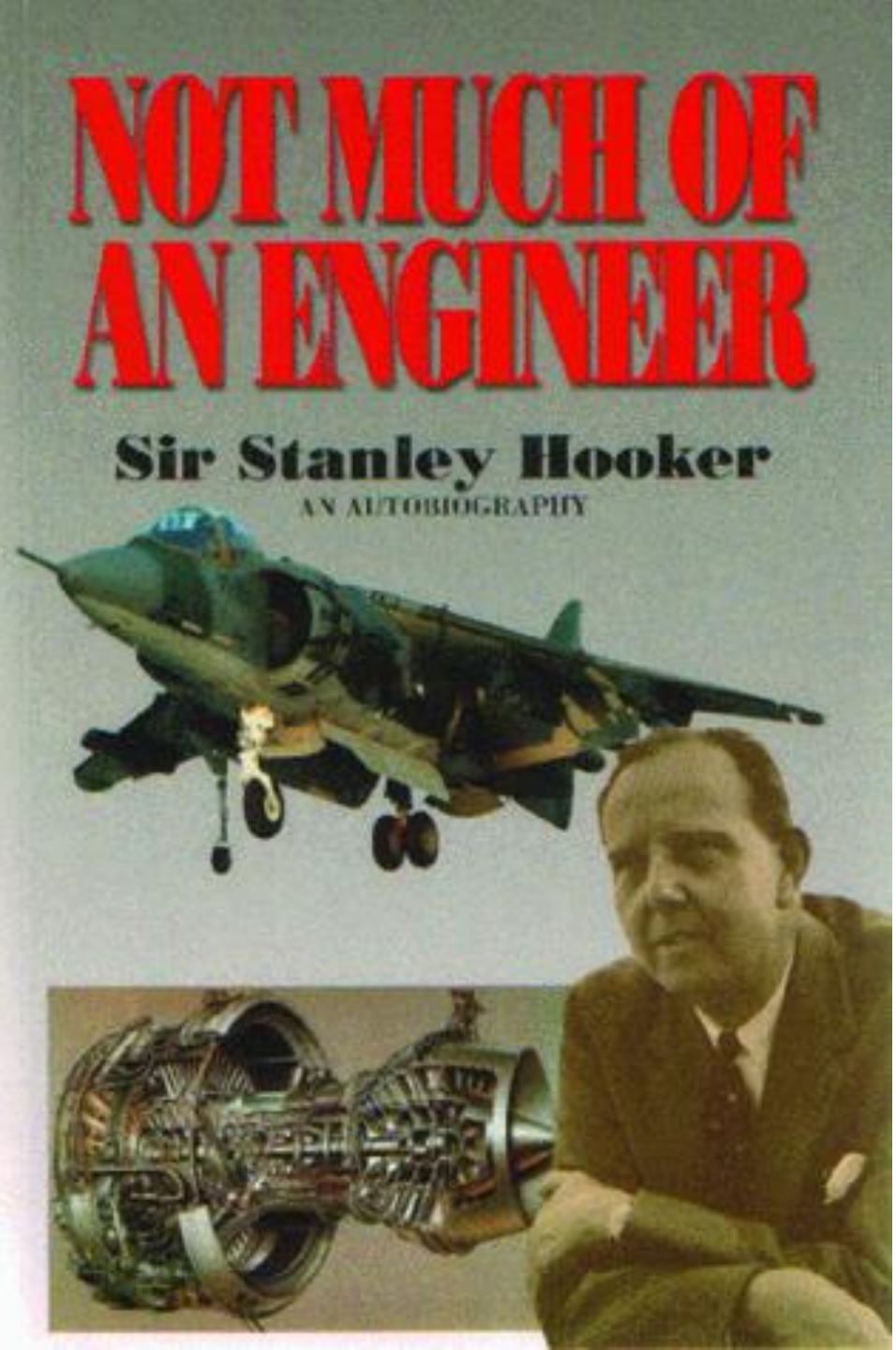


"…If there's a key to understanding Rolls-Royce's Merlin manufacturing tolerances, or the asserted lack thereof, it might be Ford - Ford of Britain, that is. British Merlins were eventually built at a quartet of facilities: Rolls-Royce Derby, plus two Rolls-Royce 'shadow factories' at Crewe (currently Bentley's works) and Glasgow (twice the size of Crewe, its foundry provided castings for the other operations) and a Ford factory in Manchester…"

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<u>Left</u>: caption: "Work underway at Ford's Trafford Park shadow factory in Manchester"

<u>Right</u>: caption: "Merlins on the line in Nottingham"



"…That last factory began churning out engines in mid-1941, but not before Ford, like Packard, overcame a few hurdles. Stanley Hooker's autobiography, 'Not Much of an Engineer,' deals mostly with his work on Rolls-Royce jet engines. But its section on Merlin development, the superchargers of which Hooker played a role in developing, is illuminating…"

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"…'In my enthusiasm, I considered that Rolls-Royce designs were the ne plus ultra, until the Ford Motor Co. in Britain was invited to manufacture the Merlin in the early days of the war. A number of Ford Engineers arrived in Derby and spent some months examining and familiarizing themselves with the drawings and manufacturing methods. One day their Chief Engineer appeared in (Merlin development head Cyril Lovesey's) office, which I was then sharing, and said, 'You know, we can't make the Merlin to these drawings.' 'I replied loftily, 'I suppose that is because the drawing tolerances are too difficult for you and you can't achieve the accuracy.' 'On the contrary,' he replied, 'the tolerances are far too wide for us. We make motor cars far more accurately than this. Every part on our car engines has to be interchangeable with the same part on any other engine and hence, all parts have to be made with extreme accuracy, far closer than you use. That is the only way we can achieve mass production'…"

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1763

"…A Rolls-Royce automobile engine may well have run better and smoother and have been assembled with tighter tolerances than a comparable Ford motor. But that's only because the company employed tradesmen who could fit the parts. Rolls-Royce was crafting Swiss watches; Ford was cranking out Timexes. And sometimes, the occasion calls for a Timex…"

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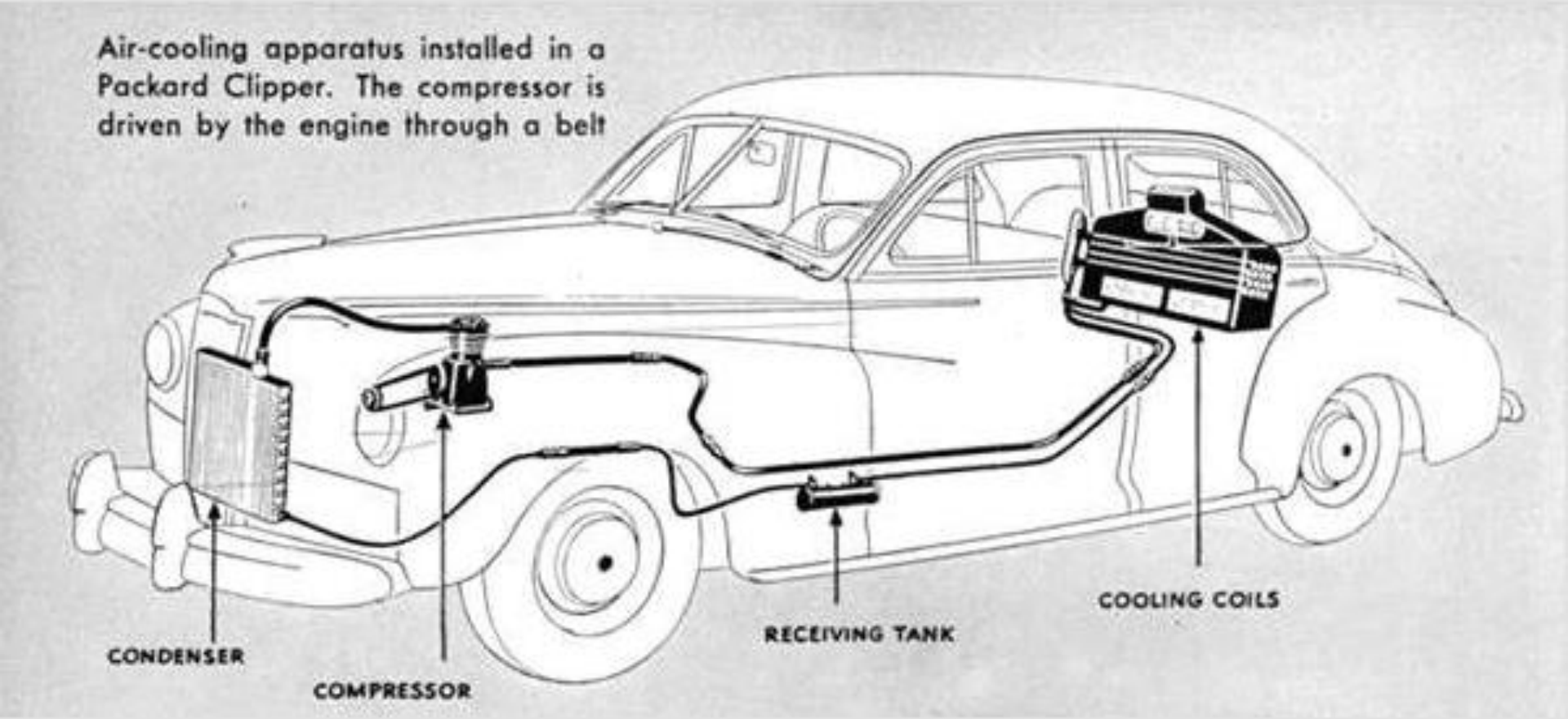
Quality vs. Quantity



"…This was only sustainable because Rolls-Royce cars were fantastically expensive and its production was tiny. For some perspective here, note that total Rolls-Royce automobile production from 1936-1939 totaled 6,244 (and that includes 3,824 units of 20/25 production, which spanned 19-29-1937…"

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<u>Left</u>: the Rolls-Royce Phantom III was produced from 1936 to 1939



"…Packard sold 98,000 units <u>in 1940 alone</u>. It may have been a luxury automaker, but it was clearly operating at a scale that dwarfed Rolls-Royce - and it achieved those production figures by embracing mechanized product-on…"

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<u>Above</u>: in 1940, the Packard Motor Car Co. was the first U.S. auto manufacturer to offer air-conditioning as a factory option

"…When it came time to build the V-1650, Packard was in an almost indisputably better place to build it in quantity than Rolls-Royce was when it began developing the Merlin in the early to mid-1930s. And a large part of that was Packard's ability to use modern industrial processes to create low-tolerance, highly interchangeable parts…"

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<u>Caption</u>: “A scene from the Packard Merlin assembly line showing crank-shaft production. The Detroit automaker was well-equipped to put the complex V-12 aero-engine into mass production, but Rolls-Royce also employed modern production techniques at its three Merlin-building facilities.”

"…The mistake here, and the foundation of the file-to-fit Rolls-Royce Merlin idea, is likely in conflating early engines, which were built in relatively limited quantities throughout the early to mid-1930s, with the mighty (and mightily improved) mass-produced Merlins that emerged as the war progressed…"

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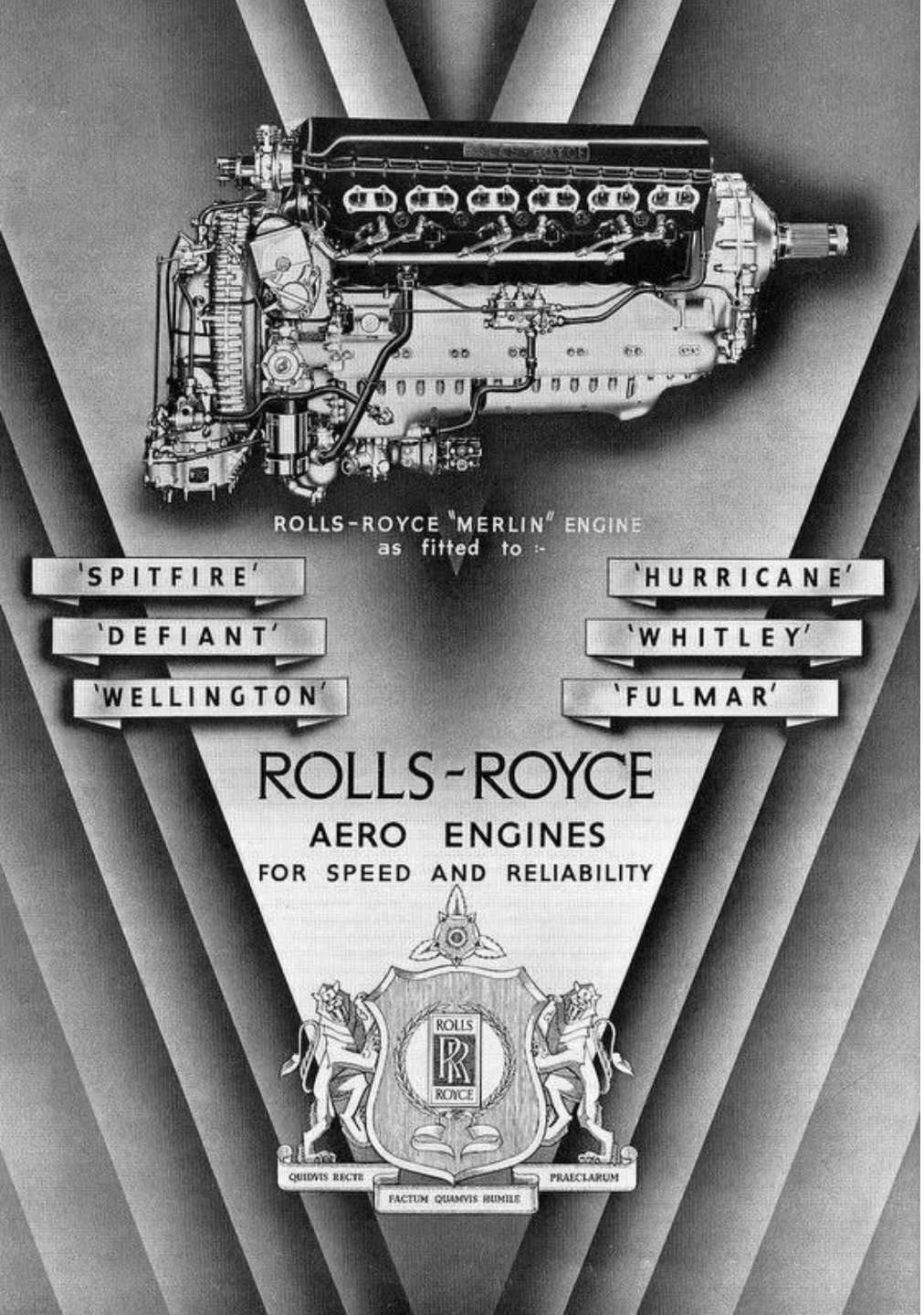
Then & Now

"…The initial Merlin engines may well have had a large number of hand-fitted components; the first generations, after all, were borderline-experimental. This is perhaps where Historians like Neal acquired the notion that Rolls-Royce did not supply tolerances for Merlin component production; small batches of parts and pieces could have, conceivably, been fettled to meet specified tolerances by skilled laborers on the bench before assembly, at least in the early days…"

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Head Count

"…Of the total of 168,068 Merlin variants built, Packard produced 55,523. Rolls-Royce did even better at 82,117 (32,377 at Derby, 26,065 at Crewe and 23,675 at Glasgow) and Ford of Britain ultimately built 30,428 at its Manchester facility (Note: these numbers vary slightly depending on the source)…"
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"…Rolls-Royce did not manage its incredible overall production numbers - again, greater than th-ose achieved by Packard, albeit at multiple plants - by adhering to its prewar manufacturing methods: It did so by mechanizing. Its factor-ies may not have looked exactly like the clean, ultra-modern Merlin production facility Packard const-ructed at its East Grand Boule-vard plant, but the storied mar-que, or at least the aircraft engine-building portion of it, evolved to meet the demands of wartime. And that meant taking the crafts-man out of the equation to what-ever extent possible - or in other words, embracing mass production…"

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1775

"…As Harvey-Bailey writes in 'The Merlin in Perspective:' 'Prior to the War the majority of operations in aero manufacture, build and test had been skilled in both a Trade Union and actual sense. In Derby, after almost a quarter-of-a-century of the business growing-up with the workforce, the true skills had become ingrained and many vital bits of knowledge were almost part of the atmosphere in which people work and often not formally documented. With the development of the new factories, men and women had to be trained to make and repair aero-engines in areas where the skills were not endemic. Union rules and demarcations had to be eased by dilution agreements and such were the aptitudes of the British that all over the country the so-called butchers, bakers and candlestick makers and their wives and girlfriends increased the trickle of engines to a river of power'…"

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1776

Depends on Who You Ask

"…So where does that leave us? Like so many historical yarns, the idea that American know-how was able to build a better Merlin (either through greater precision or some degree of calculated, mass-producible impression, depending on whom you ask) than Rolls-Royce is hard to dispel out-of-hand. But it's even tougher to prove conclusively, especially (as Neal notes, regretfully, in 'Master Motor Builders') given that so many Packard records were destroyed when the company folded…"

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"…If there's any truth underlying the mythos, it's likely to be in the somewhat incongruous comparison of the early Rolls-Royce Merlins and later mass-produced American Merlins - and it would still hold true if you stacked the earlier engines up against those Rolls-Royce itself would construct in great quantities once it began employing unskilled labor and modern production methods. Remember, Packard, and for that matter Ford of Britain, were able to jump more or less into mass production of the Merlin, while Rolls-Royce took the engine from a blank sheet of paper to eventual mass production at its three facilities…"

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Of Inestimable Value

1780

"…Owing to variations in development programs, the varied aircraft they powered and the different mission profiles they fulfilled, it is difficult to compare Packard and British-built Merlins directly to determine if one was in fact 'better.' Harvey-Bailey's assessment seems to reflect the consensus: 'At Squadron level there were times when there were fortuitous variations in reliability either way but when dealing with large numbers of engines at Group or Command level there was good consistency in results between British and Packard engines. The 60,000 engines produced by Packard for the RAF and USAAF were of inestimable value'…"

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An Engine for the Ages

1782



"…Ultimately, workers on both sides of the Atlantic were able to build an engine for the ages, flown to victory in all of the major theaters of combat. In the legend of the Merlin, any theorized variation in fit and tolerances cannot be more than a very tiny footnote."

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Left: this classic 1939 British poster celebrates fifty years of British aviation design and aircraft production, as the topless English lady looks to the beginning of her dark war-torn future. The next five war years would bring together the development of British and American aircraft and aero-engines until the end of the hostilities, in May 1945.

Part 15

A Tough Act to Follow

Introducing the Griffon

36.7 Litre 12-Cylinder Engine: Liquid Cooling: Compact Supercharger: A New System of Carburetion

***FLIGHT,* March 9, 1944**

RE: introduction to an article entitled: "New Rolls-Royce Griffon"

All in the Family

"IT is now permissible to reveal that yet another Rolls-Royce engine is in operational service with the RAF…"
***FLIGHT,* March 9, 1944**

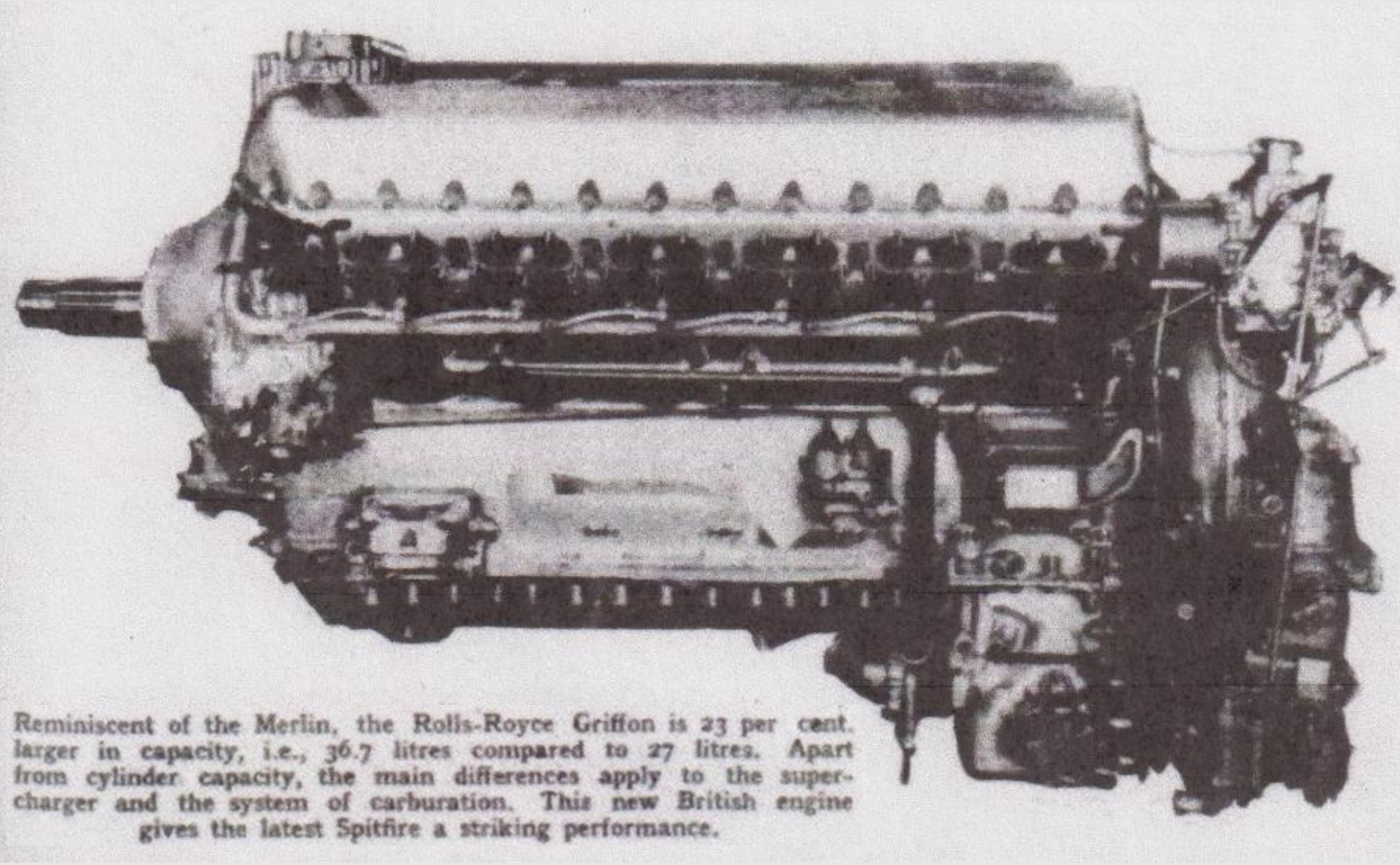
"…Known as the 'Griffon,' the new engine is a twelve-cylinder, liquid-cooled Vee-type and is in the 2,000-hp class. This new bird-of-prey which follows the Hawk, Falcon and Eagle of the First World War, already, by its amazing performance, has become a worthy contemporary of the Merlin - incidentally a bird of the Falcon family…"

***FLIGHT,* March 9, 1944**

Good Genes

"…The Griffon is larger than the Merlin, having a cylinder bore and stroke of 6.0 by 6.6 inches respectively, which give it a capacity of 36.7 litres against 27 liters of the Merlin, that is, a 23 per cent increase…"

***FLIGHT,* March 9, 1944**



Reminiscent of the Merlin, the Rolls-Royce Griffon is 23 per cent. larger in capacity, i.e., 36.7 litres compared to 27 litres. Apart from cylinder capacity, the main differences apply to the supercharger and the system of carburation. This new British engine gives the latest Spitfire a striking performance.

"…Although an entirely new product, it is of the same cylinder arrangement and dimensions as the 'R' type Rolls-Royce which won the Schneider Trophy in 1931. The experience gained with that engine, coupled with the Merlin engine which is produced so successfully in its thousands, has enabled Rolls-Royce Engineers to evolve a unit already proved in reliability and high power generation…"

***FLIGHT,* March 9, 1944**

"…In this connection, it may be recalled that the 'R' type engine of 1930 still remains the outstanding engine of all-time. Produced especially for this comparatively short-distance, it completed a one-hour endurance test without the slightest trouble, developing 2,350-bhp for a total weight of 1,630 lbs. or 11 oz. per-bhp. Its normal speed was 3,200 rpm…"

***FLIGHT,* March 9, 1944**

"…Later, the 'R' engine was used in a successful attack upon the world's speed air record. With Flt. Lt. Stainforth at the helm, the record figure of 408 mph was attained. At one period the engine held the world's land, water and air speed records…"

***FLIGHT,* March 9, 1944**

The March of Time

"…Naturally, production-type engines from which reliable service is demanded over lengthy periods could not, at that time, be expected to attain such astounding figures, but the march of time and progress of recent years in supercharger design, metallurgical problems and fuel have served to eliminate, one-by-one, the obstacles in the way…"

***FLIGHT,* March 9, 1944**

Perfect Fit

"…As fitted to the Spitfire, the Griffon engine has a two-speed mechanically driven supercharger of the same general type as that fitted to the Merlin XX engine which gives it an outstanding performance; not only at low altitudes, but also at heights between 15,000 and 25,000 ft., in which region very many combats take place…"

***FLIGHT,* March 9, 1944**

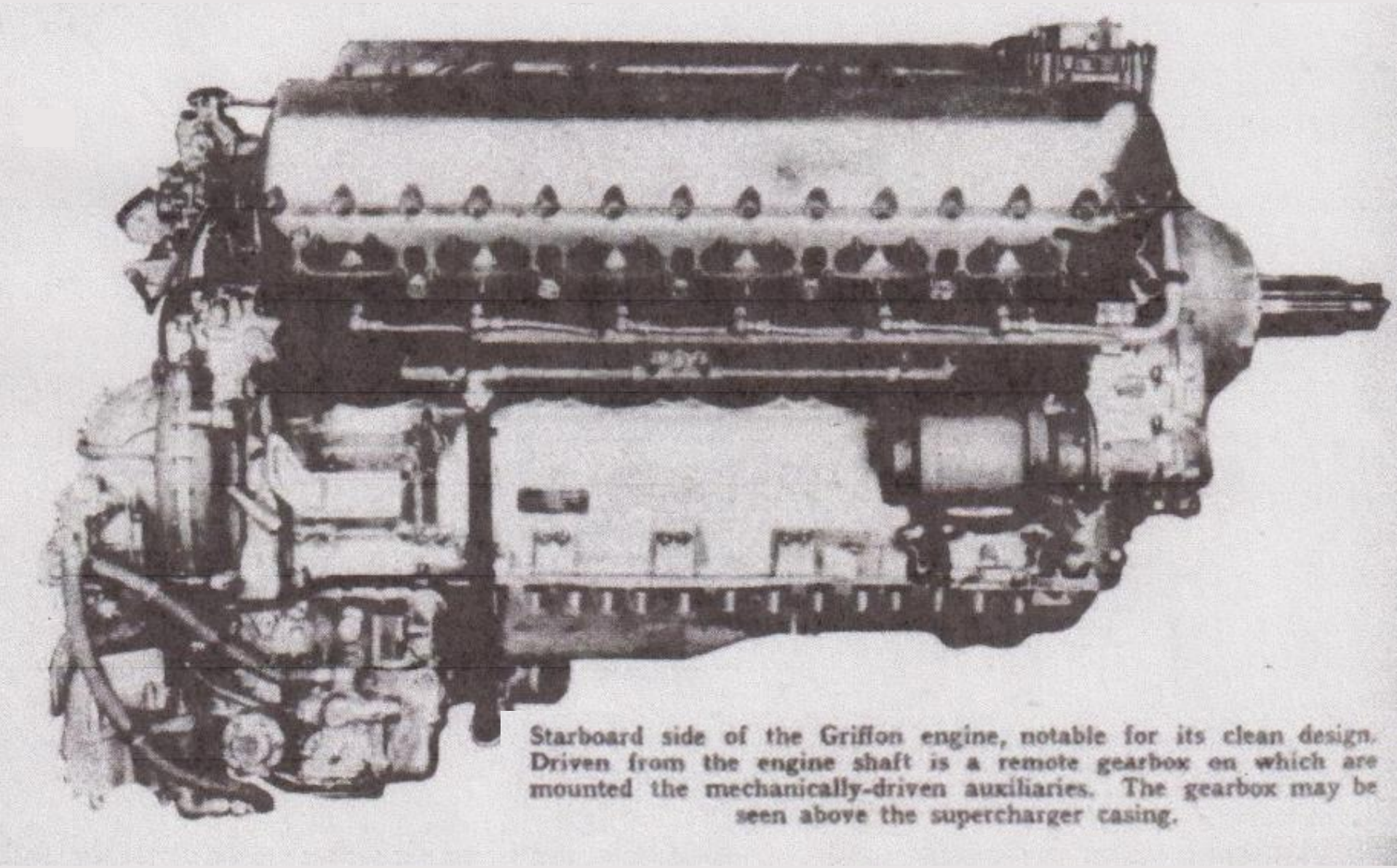
Auxiliary Drives

"…An interesting feature of the Griffon, not usually found on engines in fighter aircraft, is the provision of a remote gear box; shaft-driven from the engine, on which are mounted the mechanically driven accessories required to operate the retractable undercarriage, the wheel brakes and wing flaps, blind-flying instrument panel and the generator for the wireless installation…"

***FLIGHT,* March 9, 1944**

"…Normally these accessories are mounted on the engine wherever arrangements can be made to drive them, but it will be obvious that the provision of an independent gear box makes for simplification of engine and accessory installation and their subsequent maintenance…"

***FLIGHT,* March 9, 1944**



Starboard side of the Griffon engine, notable for its clean design. Driven from the engine shaft is a remote gearbox on which are mounted the mechanically-driven auxiliaries. The gearbox may be seen above the supercharger casing.

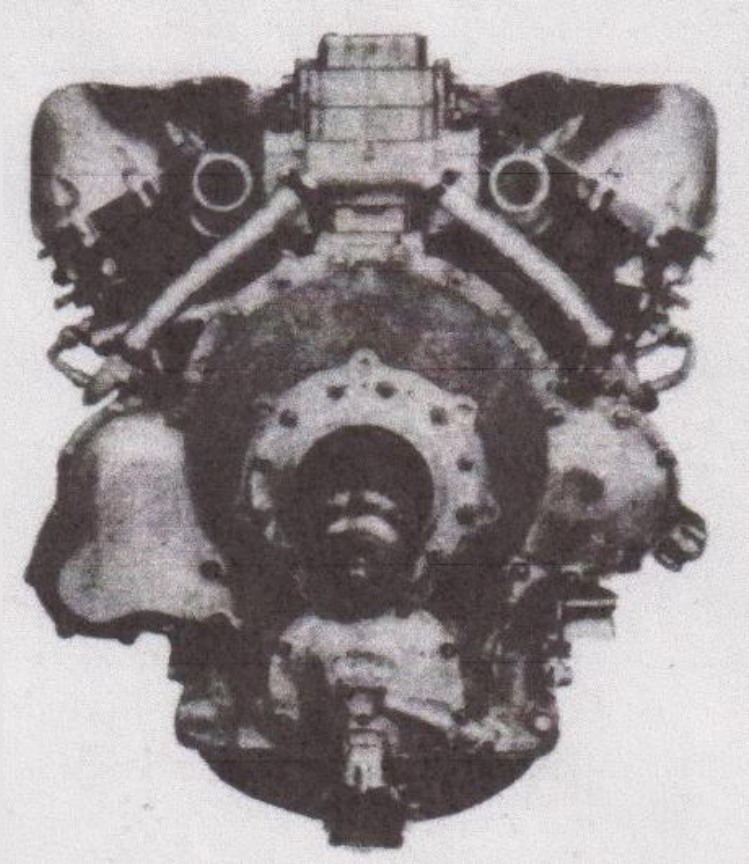
Accumulated Experience

"…It will thus be appreciated that the newest British aircraft engine is neither a modification of the racing engine nor a st-epped-up Merlin. Rather it should be described as an engine representing the accumulated experience of two of the most notable aero-engines the world has known…"

***FLIGHT,* March 9, 1944**

Small, But Mighty

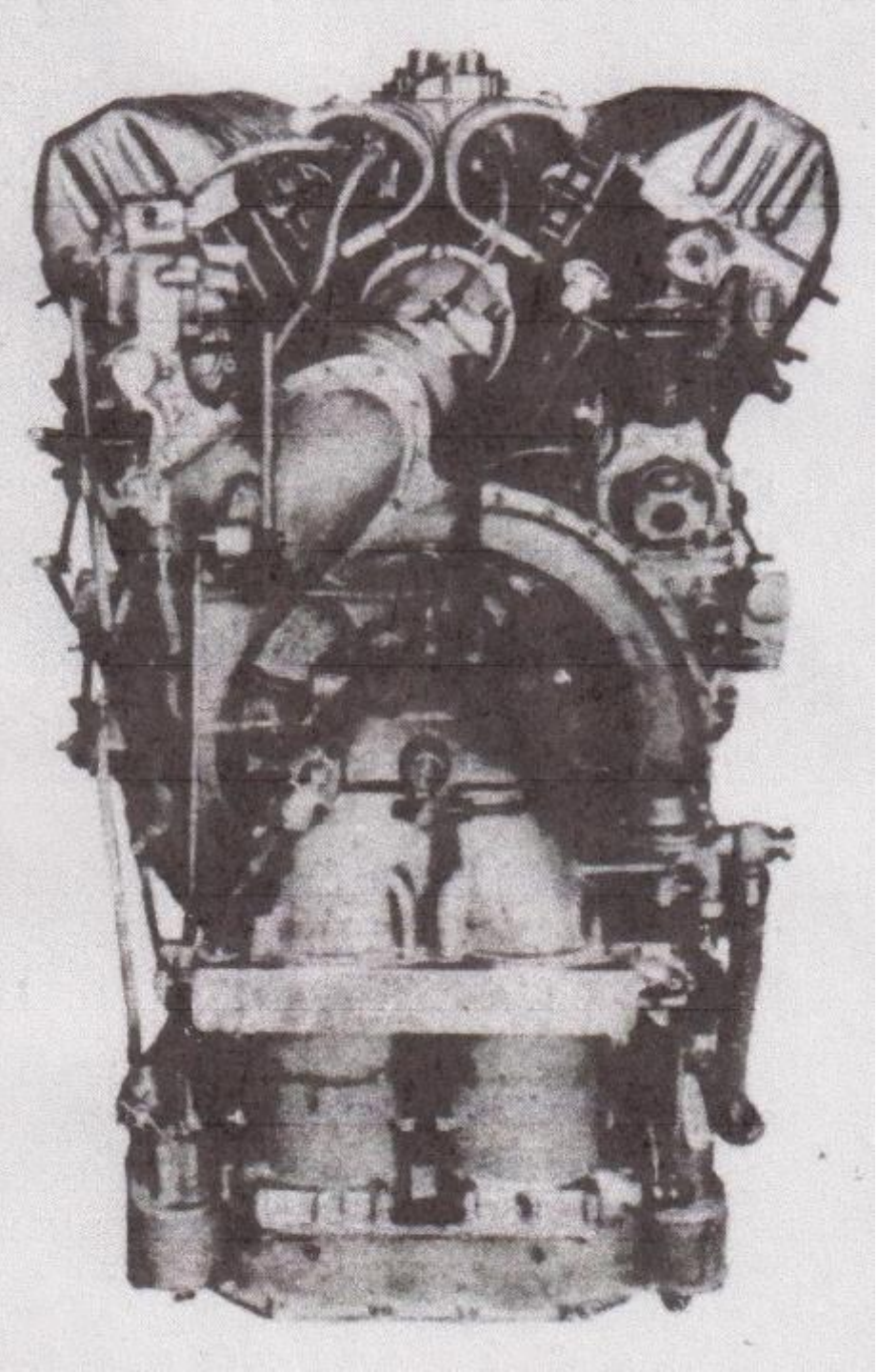
"…The choice of cylinder arrangement and size from the 'R' engine must have been a happy one for the purpose of producing immense power from an engine of small overall dimensions, whilst prolonged experience with the Merlin assisted materially in providing the enduring qualities so important a problem with an engine of high power and light weight…"
***FLIGHT,* March 9, 1944**



"…The new Griffon is a masterpiece of compact design; indeed, it is extremely difficult to determine immediately whether the latest Spitfire has a Griffon or a Merlin engine, for the reason that it has been found possible; notwithstanding the increased cylinder dimensions and power, to apply the engine without structural alterations to the airframe…"

***FLIGHT,* March 9, 1944**

Caption: "Another view demonstrating the extraordinary compactness of the design. Its very small frontal area is a great advantage in fighter aircraft. The reduction gear is an improvement on the Merlin."



"…One of the illustrations shows that the design of the supercharger and the system of carburation has been considerably amended and made still more compact…"

***FLIGHT,* March 9, 1944**

Caption: "Supercharger end of the new Griffon – the largest of the Rolls-Royce range. Its compact design will be appreciated."

"…The engine, too, reveals that two-stage supercharging is not employed on this particular example, as there are no signs of an intercooler…"

***FLIGHT,* March 9, 1944**

A Notable Advance

"…In these days when high-powered units are so badly needed, the advent of the Rolls-Royce Griffon marks a notable advance in aero-engine design."

***FLIGHT,* March 9, 1944**

R-R’s Latest

Review of the Latest Rolls-Royce Piston Engine: Classic Orthodoxy of Design: Highest Specific Powers Yet Achieved
***FLIGHT,* September 20, 1945**
RE: introduction to an article entitled: "Rolls-Royce Griffon (65)"

First Impressions

"WHEN confronted with the Rolls-Royce Griffon for the first time, the facile result of an initial rapid appraisal is that the engine is nothing much more than a scaled-up Merlin and, although there is doubtless a certain amount of justification for this view, it is not wholly accurate…."

***FLIGHT,* September 20, 1945**

In it’s Own Right

"…In actual fact, as one's investigations progress, the impression is steadily strengthened that, far from being merely a scale-up of an existing engine, the Griffon is an entirely new engine in its own right…"

***FLIGHT,* September 20, 1945**

Hazard the Assumption

"…It would, however, probably be pretty accurate to hazard the assumption that the Griffon was born of a desire to re-design the Merlin; eliminating all the snags and, at the same time, increase the capacity to meet the imminent demand for a larger engine whilst retaining the smallest overall dimensions possible…"

***FLIGHT,* September 20, 1945**

By Comparison

"…How well the men of Derby have succeeded in doing what they set-out to do may be appreciated in part by a comparison of overall dimensions as between Griffon and Merlin, together with the respective swept volumes and piston areas…"

***FLIGHT,* September 20, 1945**

"…In overall length the Griffon 65 is 81 in., three inches longer than the 78 in. of the equivalent Merlin, the 66; overall heights are respectively: Griffon, 45 in. and Merlin 43.675 in. whilst the overall widths are; Griffon 29.5 in. and Merlin 29.825 in…"

***FLIGHT,* September 20, 1945**

On the Face of It

"…It would seem 'well-nigh impossible, on the face of it, that with such similarity of overall dimensions in two engines of the same basic type, the swept volume of one should be 35.9 per cent larger than that of the other. Such, however, is the case. Piston area of the Griffon is 23 per cent greater than that of the Merlin, this having been achieved by increasing the cylinder bore to 6.0 in.: a figure which is just about verging on the optimum limit…"

***FLIGHT,* September 20, 1945**

20/20 Foresight

"…In view of this, one is led to wonder what form the Griffon's successor will take; the useful limit of piston diameter having been reached, one is forced to the conclusion that any larger capacity piston engine that Rolls have in mind to follow the Griffon will, of necessity, have more cylinders. It is an interesting speculation which naturally, and on precedent, takes it for granted that Derby do intend to produce a new and bigger orthodox engine…"

***FLIGHT,* September 20, 1945**

Influence of the Racing “Buzzard”

1828

"…Before going on to deal with the Griffon, a word should be said on the prevalent and somewhat erroneous assumption that the engine is a counterpart of the famous 'R' special Buzzard racing engine which secured the Schneider Trophy for England in 1929 and 1931 and established a World's Speed Record…"

***FLIGHT,* September 20, 1945**

Apples and Oranges

"…Certainly, the bore and stroke size are the same and so is the fundamental layout of the engine - but there the similarity ends…"

***FLIGHT,* September 20, 1945**

Lessons Learned

"…It can truthfully be said that the lessons learned on the 'R' engine have had their influence on all the subsequent Rolls engines, but equally, the knowledge gained in the Merlin has resulted in the refinements which distinguish the Griffon…"
***FLIGHT,* September 20, 1945**

In Particular

"…The one particular feature which the Griffon owes directly to the 'R' is the crankshaft, for the amount of development put into this member on the racing engine virtually paved the way towards making the Griffon a success from the very beginning of its life…"

***FLIGHT,* September 20, 1945**

Meeting the Need

"…It is not, perhaps, generally known that the Griffon was originally developed primarily to meet the Fleet Air Arm's specific needs - low-altitude power, ease-of-service, reliability etc…"

***FLIGHT,* September 20, 1945**

"…In the early days of the war, the Griffon was rather displaced by the Vulture until the latter was discarded, then the Griffon was resurrected as the need for a larger engine than the Merlin was again realized as a necessity…"

***FLIGHT,* September 20, 1945**

Squashing the Opposition

"…The various marks of Merlin Spitfires were capable of handling enemy aircraft at height, but when the Fw-190 was derated to give maximum performance low-down we were somewhat pressed. A quick decision was reached to put the Griffon II into some Spitfire VIII's, which then became the Mark XII; these were built in limited numbers, but effectively squashed the opposition…"

***FLIGHT,* September 20, 1945**

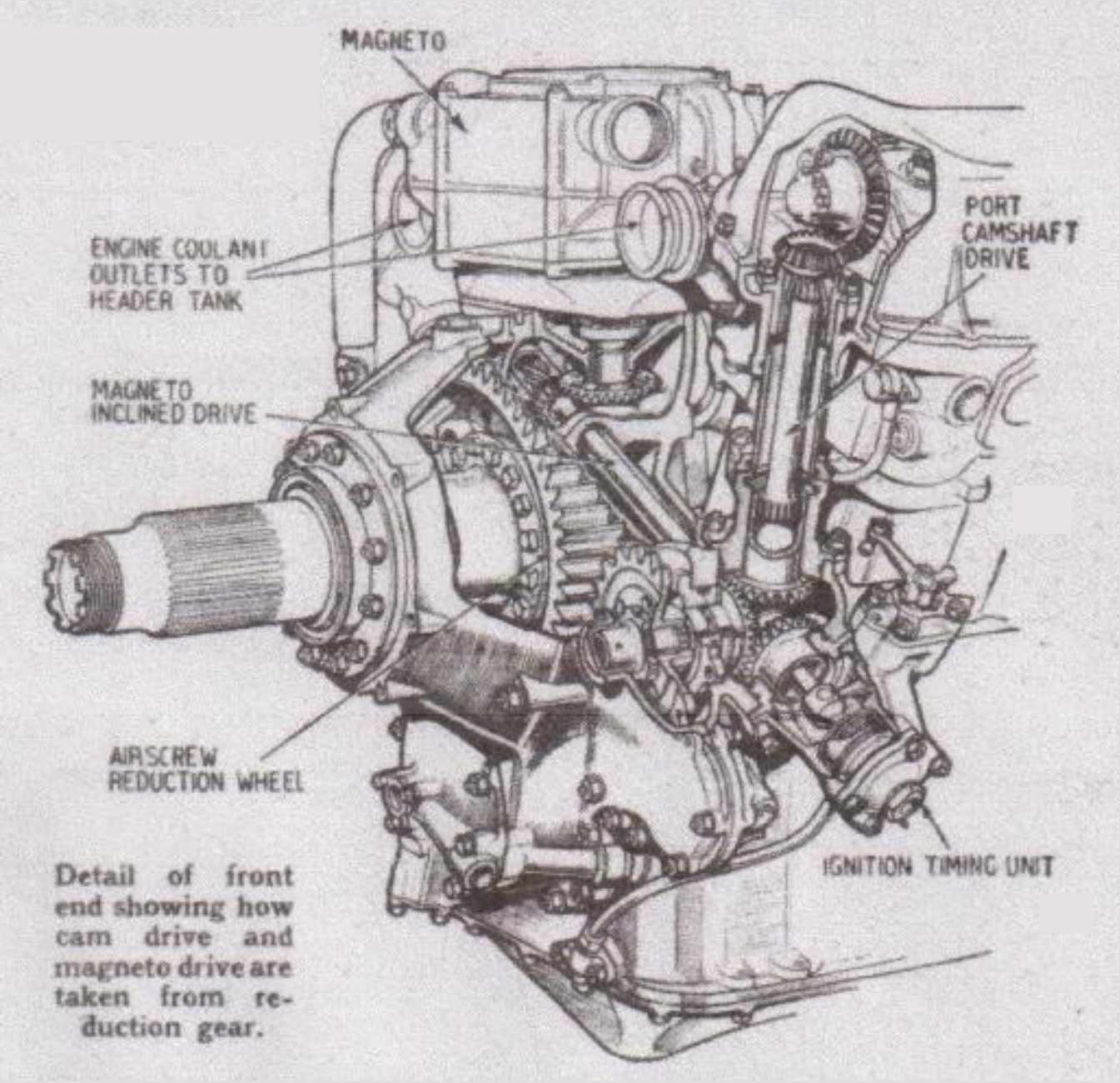
FAA and RAF Requirements

"…These models of the Griffon were all fitted with single-stage, two-speed blowers and this basic type has progressed for Fleet Air Arm use (vide the Fairey Firefly), whilst the special needs of the RAF have been met by the two-speed, two-stage engine for high-altitude use expected, the Griffon owes a fair amount to Merlin development, but what is peculiarly interesting is that various practices initially proved on the Griffon have been incorporated in the later Merlins…"

***FLIGHT,* September 20, 1945**

Similar, But Different

"….Basically the engine is, of course, on the same lines as the Merlin, although the detail design is new pretty well throughout. One of the most important innovations is in taking the cam- and mag-drives from the front. This was decided upon in order to relieve the valve operation from as much variation as possible: by interpolating a semi-floating coupling between the crankshaft and the driving wheel of the reduction gearing and, in addition, by taking the cam drives from the airscrew-driving gear, angular variations in crankshaft speed are greatly reduced in their transmission to the camshafts…"
***FLIGHT,* September 20, 1945**



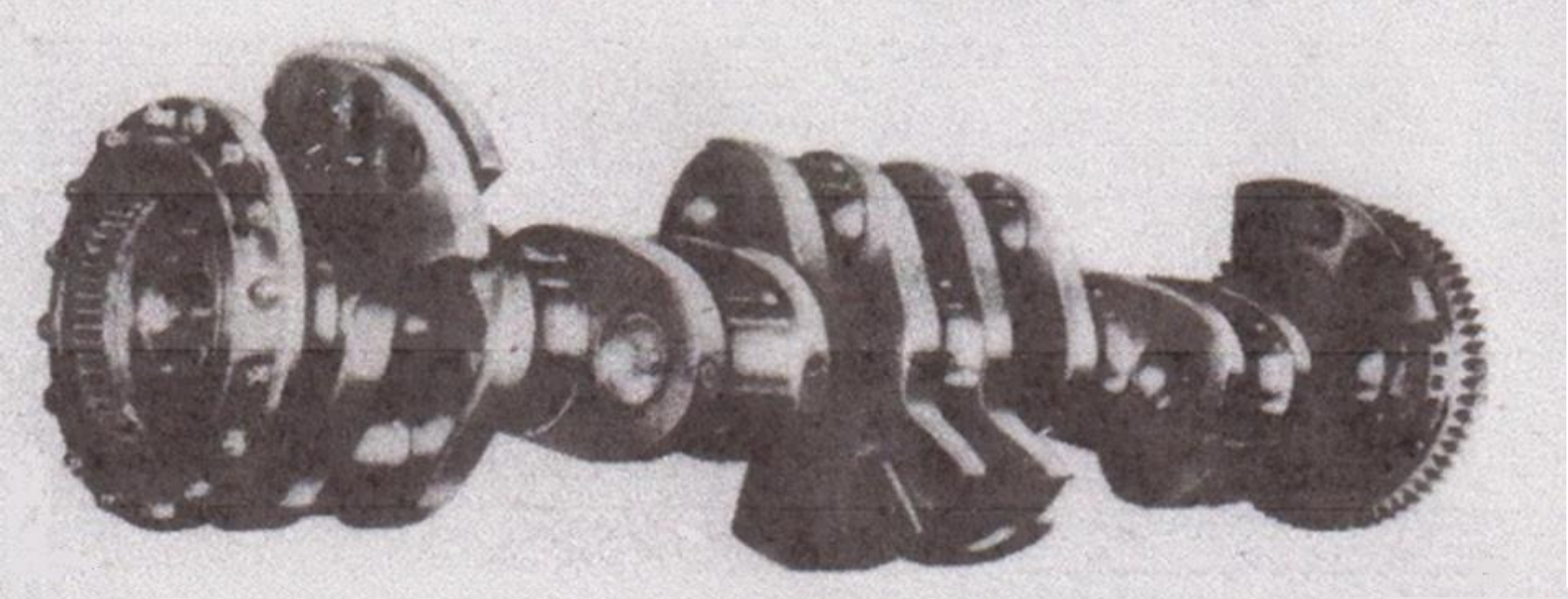
Detail of front end showing how cam drive and magneto drive are taken from reduction gear.

Advantage: Griffon

"…Further, air-screw inertia results in a reasonably constant rate of rpm and, to top-off the advantages, the front drive allo-ws a comparatively shorter overall length which, in turn, per-mits the larger and more powerful engine to go into existing fighters…"

***FLIGHT,* September 20, 1945**

An Interesting Component



Three-quarter front view of crankshaft with semi-floating toothed annulus in front coupling. Note the detachable counterweights on crank throws.

"…Whilst on the subject of the crankshaft, we might as well deal with that interesting component. It is, of course, machined all over from a forged billet; and is fully counter-balanced, the front throw of No. 1, both throws of No. 4 and the rear throw of No. 6 bearings each having a separate balance weight bolted to them…"

1849

***FLIGHT,* September 20, 1945**

"…Vibratory troubles in the crankshaft have been very few, but a pointer to the Derby standard is that the firing order geography was selected to give optimum crankshaft harmonics…"

***FLIGHT,* September 20, 1945**

Crankshaft Lubrication

"…Perhaps the most-novel feature of the crank assembly is that the main bearings and big ends are all lubricated from the hollow interior of the shaft. This scheme, though novel, is by no means new, Rolls having first tried it years ago; however, the Griffon is the first Rolls engine in which it has become practice…"

***FLIGHT,* September 20, 1945**

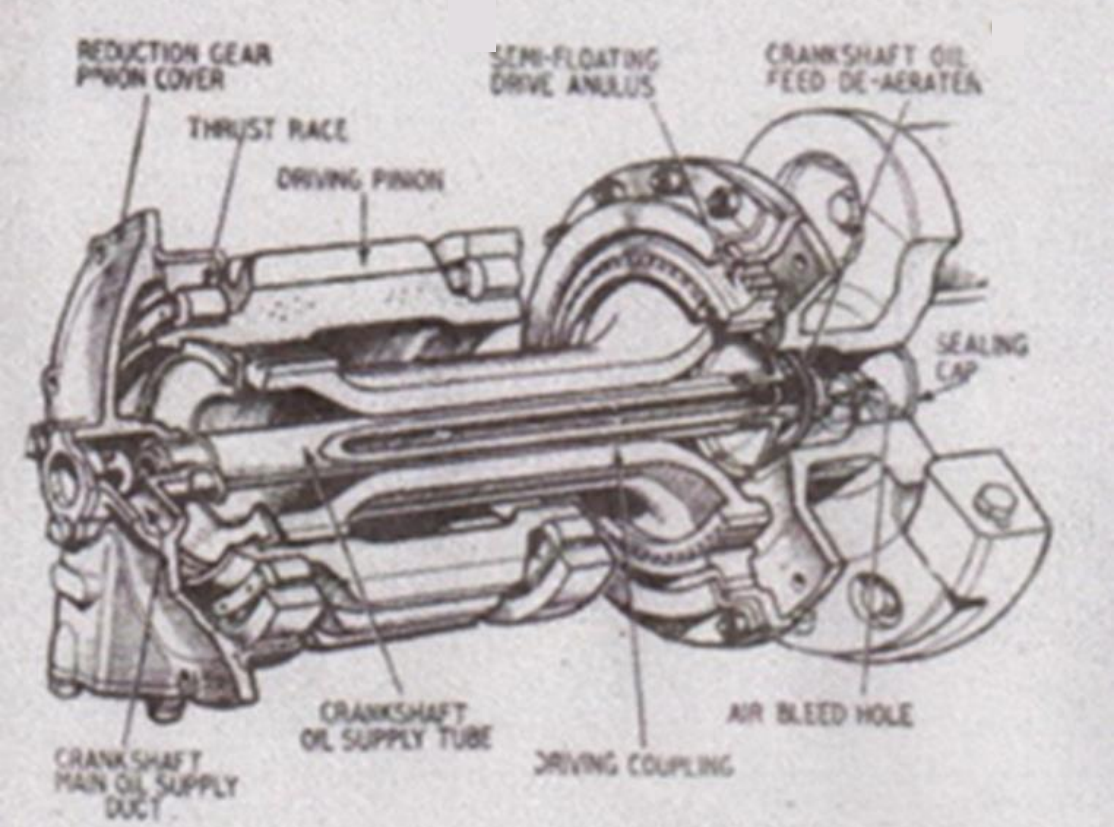
"…Feed is into each end of the shaft and, in addition to the system pressure, shaft rotation provides a 'built-in' centrifuge. A great advantage of the system is that the amount of oil supplied to each bearing is not influenced by relative shaft/bearing movement. In addition, each main journal has internal standpipes which act as sludge traps as well as permitting, by a variation in their diameter, a means of metering or controlling the amount of oil supplied to any particular bearing…"

***FLIGHT,* September 20, 1945**

An Interesting Feature

"…Another interesting feature of the crankshaft is that it is rigidly connected neither to the front nor the rear driven members…"

***FLIGHT,* September 20, 1945**



Three-quarter front view of semi-floating coupling between crankshaft and reduction gear.

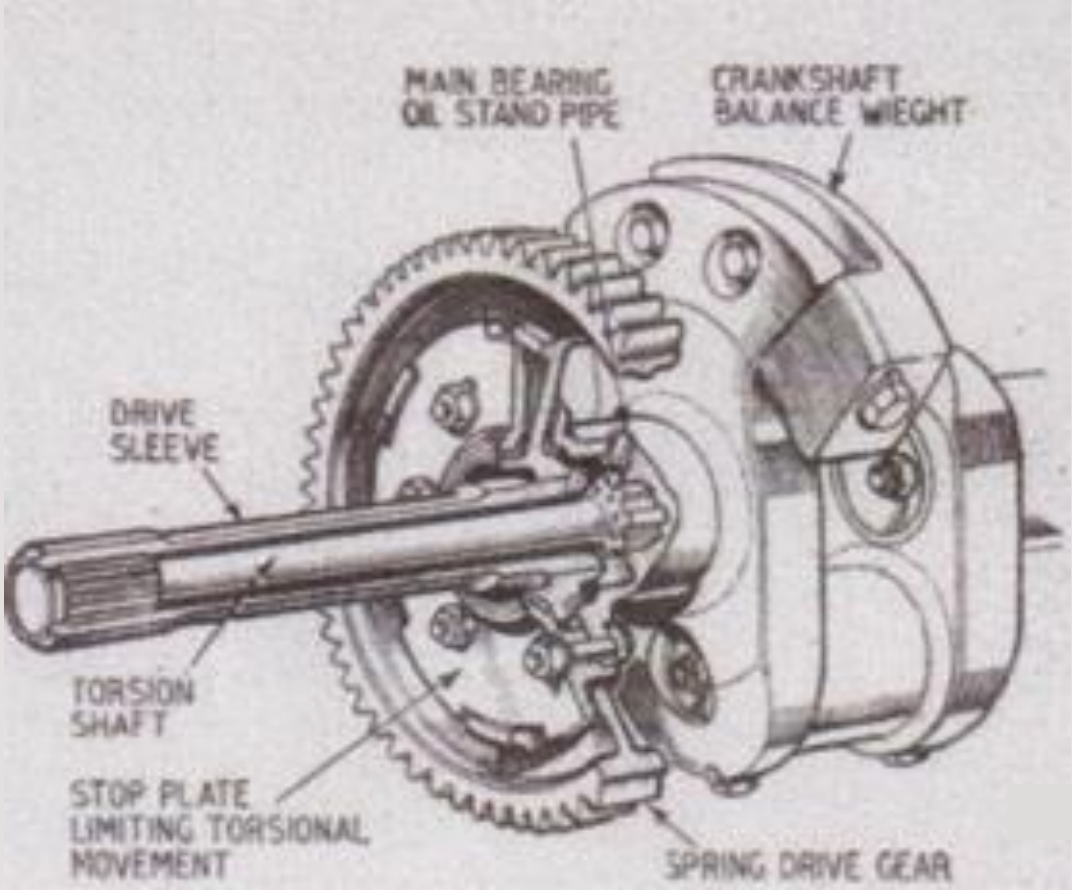
"…At the front-end an internally toothed annulus is bolted on, this meshing with and housing a semi-floating ring which itself is internally splined to a coupling shaft. The latter is splined at its front-end to the driving wheel of the reduction gear so that this mechanism is partly relieved from crankshaft rotational variations and totally relieved from end-float effects…"

1856

***FLIGHT,* September 20, 1945**

"…Going to the other end of the shaft, we encounter the beautifully neat torsional spring-drive coupling, the purpose of which is to relieve the crankshaft from impeller inertia…"
***FLIGHT,* September 20, 1945**

"…When the throttle is opened quickly, the 'fly-wheel' inertia of the impellers does not allow them to be accelerated as quickly as is the crankshaft by the pistons and the resulting lag engenders a tendency to twist the crankshaft. Again, when the throttle is rapidly closed the impellers try to overrun the crankshaft with reversed, but similar, twisting effect…"
***FLIGHT,* September 20, 1945**



Three-quarter rear detail of torsion spring drive coupling at rear end of crankshaft.

"…To relieve the shaft from these embarrassments, a spring-drive is embodied between shaft and impellers, which absorbs the initial shock loading resulting from the inertia. The coaxial shaft and sleeve which, splined together, form the springing member, are shown in a detail drawing…"

1859

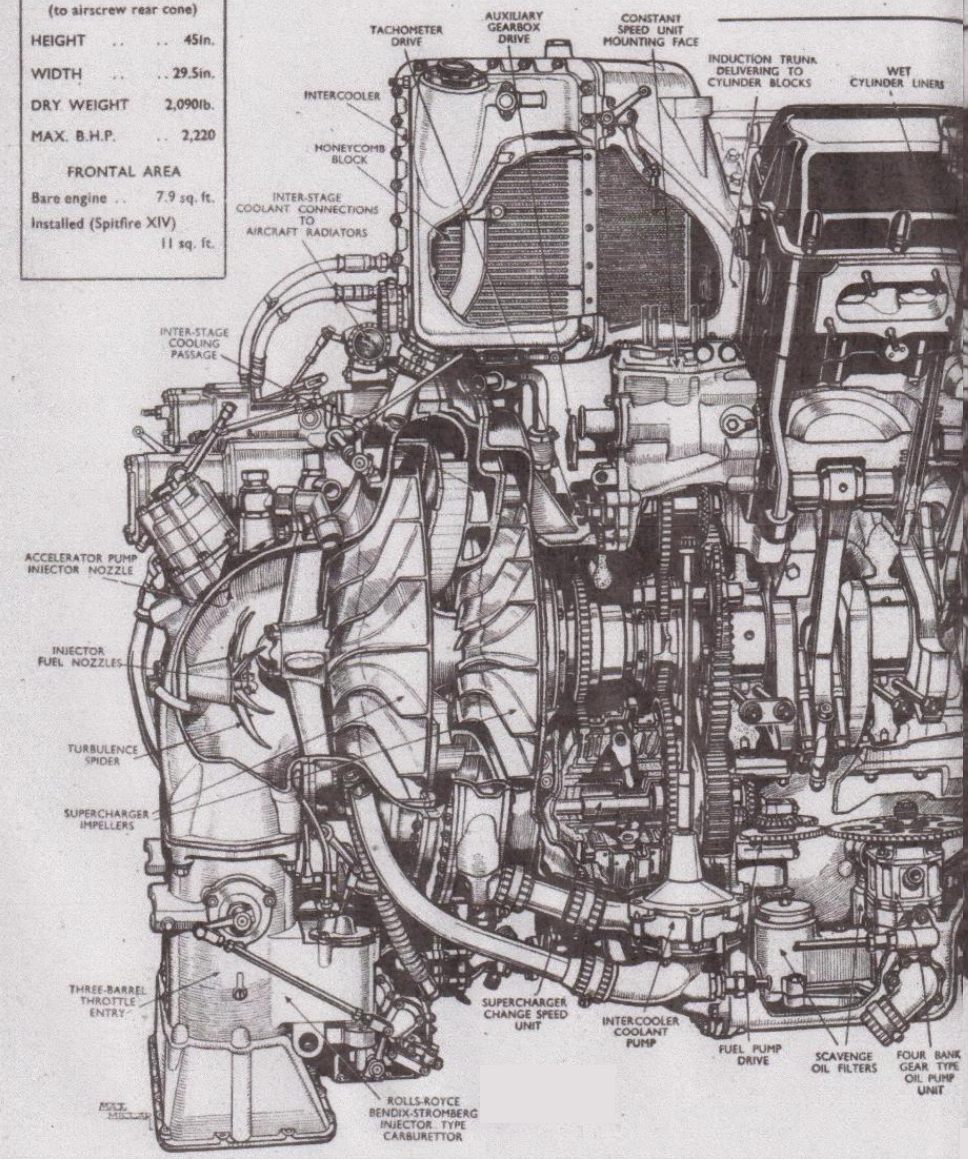
***FLIGHT,* September 20, 1945**

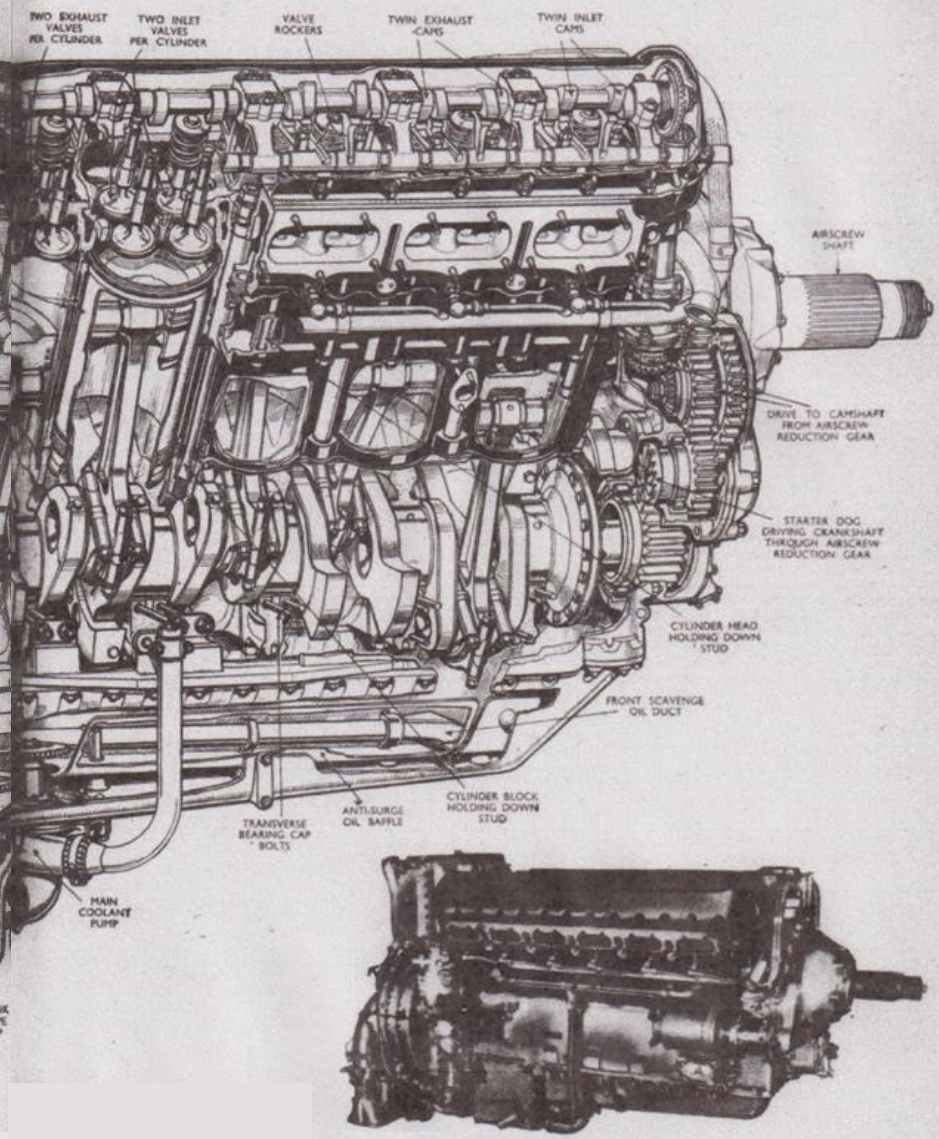
Compact Drives

"…There is not such a number of gears at the rear-end of the Griffon as is found in the Merlin, the front-end cam-drive arrangements, etc., being the cause; nevertheless, there is still a goodly number of wheels, bearings and shafts at the back of the Griffon and to attempt to describe these individually would, as well as being tedious, serve no worthwhile function. They can almost all be traced in the Max Millar drawing and other details; however, it is worthy of emphasis that the nesting of this mass of drives is as compact and neat as the highest order of mechanical design ingenuity can make it…"
***FLIGHT,* September 20, 1945**

ROLLS-ROYCE GRIFFON (65) ENGINE

LENGTH (to airscrew rear cone)	81in.
HEIGHT	45in.
WIDTH	29.5in.
DRY WEIGHT	2,090lb.
MAX. B.H.P.	2,220
FRONTAL AREA	
Bare engine	7.9 sq. ft.
Installed (Spitfire XIV)	11 sq. ft.





1862

way can the amazing compactness of this
ew on the right and the drawing and so

This special copyright *Flight* drawing by Max Millar lays bare the component arrangement and structural design of the engine. In no beautiful piece of work be illustrated more effectively, and, further to emphasise this point, the reader may refer between the exte follow the disposition of the various units.

Classic Orthodoxy of Design

"…In the title sub-heading of this article are the words 'Classic Orthodoxy of Design,' and in the Griffon probably more than in any other Rolls engine is this trait manifest. There is nothing about the engine which is awfully cunning or 'super new.' It is the epitome of plain, straightforward simplicity of design, which is carried to the absolute of logical conclusion…"

***FLIGHT,* September 20, 1945**

By Way of Lineage

"…It is for this reason, almost undoubtedly, that the Griffon carries further the standard set by the Merlin as being the highest performance engine in existence, for other engines of similar power are larger or, if of the same size, are lower powered. Such a feature, when coupled to great reliability, cannot well be achieved by 'mushroom' methods - it comes only by way of lineage of thoroughbreds born: of painstaking care and unrivalled experience. It is on this foundation that the name Rolls-Royce rests so securely…"

***FLIGHT,* September 20, 1945**

Crankcase

"…The main body of the Griffon is not unlike the later Merlins in that it has a light-alloy pentagonal-section crankcase, the lower-half of which is a dry sump housing the oil-pressure and scavenge pumps with their filters in a well at the rear-end. A baffle plate is also embodied in the lower-half case to restrict oil surge and prevent excessive breathing under negative-G accelerations…"

***FLIGHT,* September 20, 1945**

Cylinders

"…Cylinders are floating wet liners fitted in light alloy jacketing blocks, the compressive stress due to the holding-down studs being taken by the jacket. The liners are chromium plated in the bores for about 2-1/2 inches down from the head as an anti-wear measure, it being in this area that maximum wear from corrosion and great temperatures occurs…"
***FLIGHT,* September 20, 1945**

"…A flange is incorporated round the head of the liner and, with aluminum sealing rings above and below, is nipped between the cylinder head and jacketing block. Thus, all thermal expansion and contraction of the liner takes place relative to the lower-end…"

***FLIGHT,* September 20, 1945**

"…This fashion of nipping the liners at the top means that, when tightened-down, there is a gap of 0.15 in. between adjacent faces of the cylinder-head block and the jacketing block which, until one knows the reason, looks very queer…"
***FLIGHT,* September 20, 1945**

"…To prevent excessive cantilever loading on the joints adj-acent to the end studs when at normal running temperatures, flat steel plates are interposed at each end of the cylinder bank between head and jacket, these plates transmitting the load as the engine warms-up…"

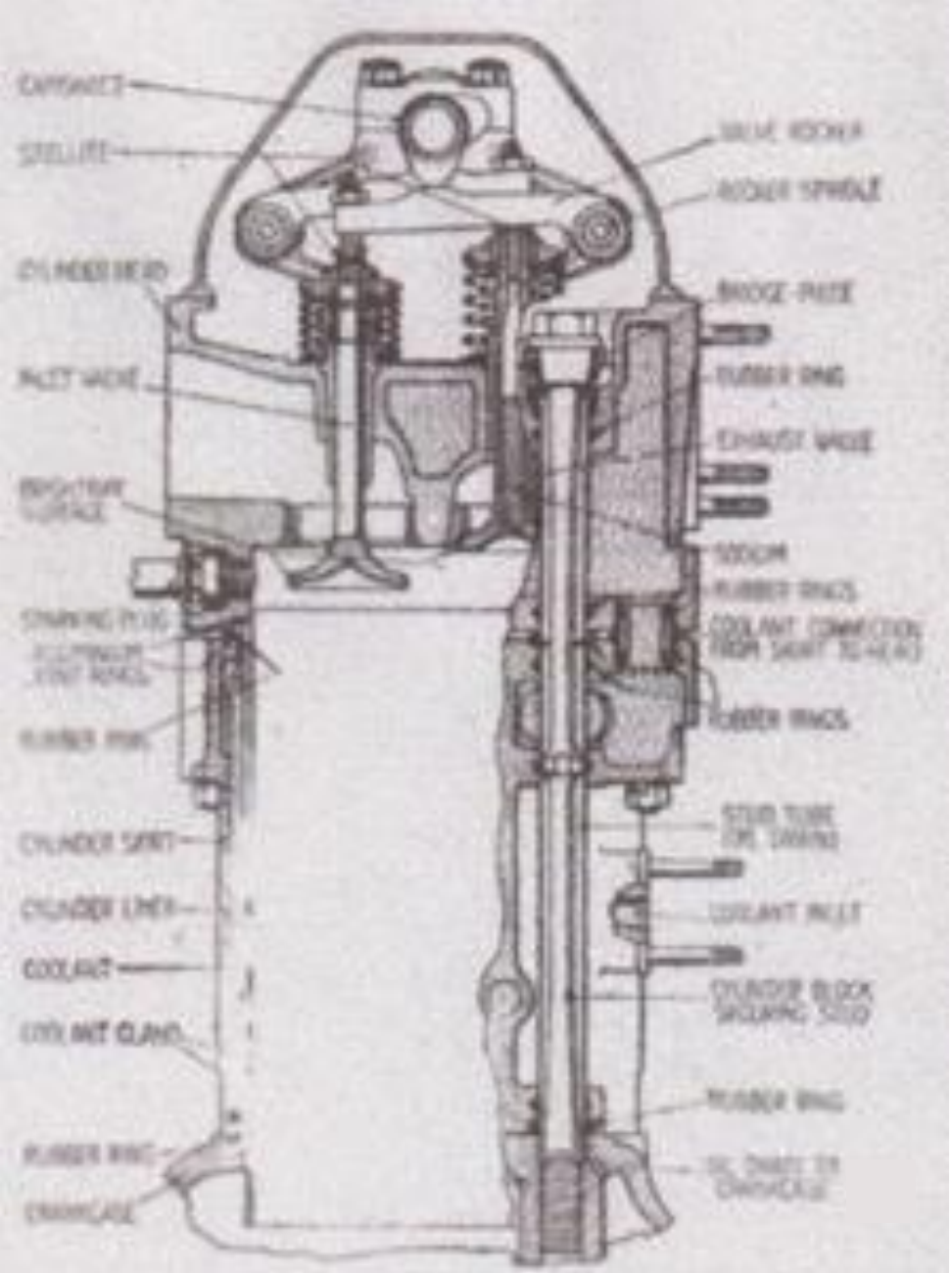
***FLIGHT,* September 20, 1945**

Combustion Chambers

"…Combustion chambers are machined all over and are quite orthodox in shape. Valve seats are shrunk-in inserts and the porting passages are scurfed - very smoothly indeed on the inlet side (as is to be expected), but fairly roughly on the exhaust side. The valves have Brightray seat facings and, whilst the inlet valves have extended guides, the exhaust valves are partially filled in the stems with metallic sodium…"

***FLIGHT,* September 20, 1945**

Valve Gear



ection through cylinder and head illustrating simple valve gear and large coolant areas.

"…Rocker gear is very similar in design to that of the Merlin, the central camshaft operating the two rows of valves through cantilever rocker arms. The cams themselves are of reasonably quick-lift profile and are designed to give harmonic negative acceleration. Two springs per-valve are employed, of opposite helix and differing periodicity, the latter being an anti-surge measure…"

***FLIGHT,* Sept. 20, 1945**

1877

Ignition System

"…The ignition system of the Griffon is well worthy of attention, not so much as a but in view of the unusual timing arrangement and very efficient magneto…"

***FLIGHT,* September 20, 1945**

"…This is a BTH duplex type which runs at half engine speed, being driven through bevel gears from an inclined shaft taken from the base of the port bank camshaft drive. The timing arrangement is 'built-in' to the inclined shaft and comprises a hydraulic ram, at the base of the shaft, subject under control to engine oil-pressure which is used to alter, as required, the linear position of the inclined shaft…"

***FLIGHT,* September 20, 1945**

"…At the top-end, the shaft is helically splined to the mag-driving bevel so that linear motion of the shaft will, via the helical splines, cause a change in the relative positions of the cam and rocker pad in the magneto to achieve the desired timing - i.e., the cam is caused to strike the pad at an earlier or later point of crank angle…"

***FLIGHT,* September 20, 1945**

"…Additionally, as the power input to change the timing is provided by oil-pressure, the pilot's control loading is extremely light; in fact the only load is that needed to operate a small pilot valve to regulate oil flow to the ram…"
***FLIGHT,* September 20, 1945**

Power Lever Control System

"…Mention of pilot's controls leads one naturally to consideration of what, in the writer's opinion, is most aptly called the 'power lever control' system. Briefly, what this means is that, instead of the normal cockpit arrangement comprising separate throttle and airscrew or, rather, rpm controls, a single 'power' lever is fitted which governs the boost, rpm and ignition…"

***FLIGHT,* September 20, 1945**

"…Maximum performance (that is, max. rpm and max. boost) is obtained at full forward movement of the single power lever and at intermediate positions of the lever suitable combinations of boost and rpm are obtained for various other flight conditions…"

***FLIGHT,* September 20, 1945**

Override Essential

"…There is little doubt that this scheme is a most useful one in that it relieves the pilot from responsibility in ensuring that the engine is always operating under the best conditions. However, it is rather essential that an override control be fitted to allow normal separate settings of boost and rpm when required - for example, when landing or in combat…"

***FLIGHT,* September 20, 1945**

"…The Griffon is provided with an override lever for these particular functions and there is every reason to suppose that, despite the innate conservatism of pilots, nothing but advantage can result from the use of the power lever control…"

***FLIGHT,* September 20, 1945**

Boost Regulation

"…Further, to ensure the most advantageous and safe operation of the engine, a boost regulator unit is fitted, the purpose of which is to restrict boost-pressure below full-throttle height to a safe maximum…"

***FLIGHT,* September 20, 1945**

"…As may be realized, although the maximum boost-pressure of the Griffon 65 is nominally 21 lbs./sq. in., the blower is capable of delivering nearly twice this pressure at low altitudes and in order that the pilot can slam forward the lever to obtain maximum power without having to worry about the safe boost limit and to save the possibility of the engine from disintegration with expensive noises, a regulator unit is installed which limits the delivery below throttle height for whatever boost is being used in the appropriate gear…"

***FLIGHT,* September 20, 1945**

"…The regulator comprises an aneroid-controlled relay piston linked to the throttle butterflies by a differential gearing to shut-off the degree of throttle opening as necessary. The relay piston is subject to the differentials of blower intake and delivery pressures so that if, for example, combat climb is required from the ground up, as altitude is gained the aneroid capsule tasting the boost will move a piston valve to admit the pressure difference across the blower to the relay piston to open the throttle progressively and maintain boost up to full-throttle height…"

***FLIGHT,* September 20, 1945**

Powers and Future Use

"…Whilst on the question of powers it is noteworthy that the continuous cruising powers of the Griffon 65 are well over 1,000-hp from sea-level up to over 30,000 ft. Compare this with the original Merlin at the outbreak of war which had a maximum SL power of 880-hp (at 6-1/4 lbs. boost) rising to 990 at 12,250 ft., the maximum rated height…"

***FLIGHT,* September 20, 1945**

"…Although the Merlin is such a magnificent engine - the outstanding engine of all time - as an alternative for future airliners it would surely be sensible to install a de-rated Griffon to give similar performance more economically and, at the same time, gain all the benefits of advanced development. It is not without significance that the Griffon is one of the very, very few engines ever to have succeeded to general service without experiencing modifications necessitating grounding…"

***FLIGHT,* September 20, 1945**

"…There is, too, a good deal of advantage the Griffon has over the Merlin on the subject of servicing and maintenance…"
***FLIGHT,* September 20, 1945**

"…We have mentioned that the maximum boost of the Griffon 65 is 21 lbs./sq. in., but there are other models in existence which have been passed for 25 lbs./sq. in. maximum boost (with 100/150 grade fuel) and the maximum powers in the respective moderate and full supercharge gears have thus been stepped up to: MS, 2,375-bhp at 1,250 ft. and FS, 2,140-bhp at 15,500 ft…"

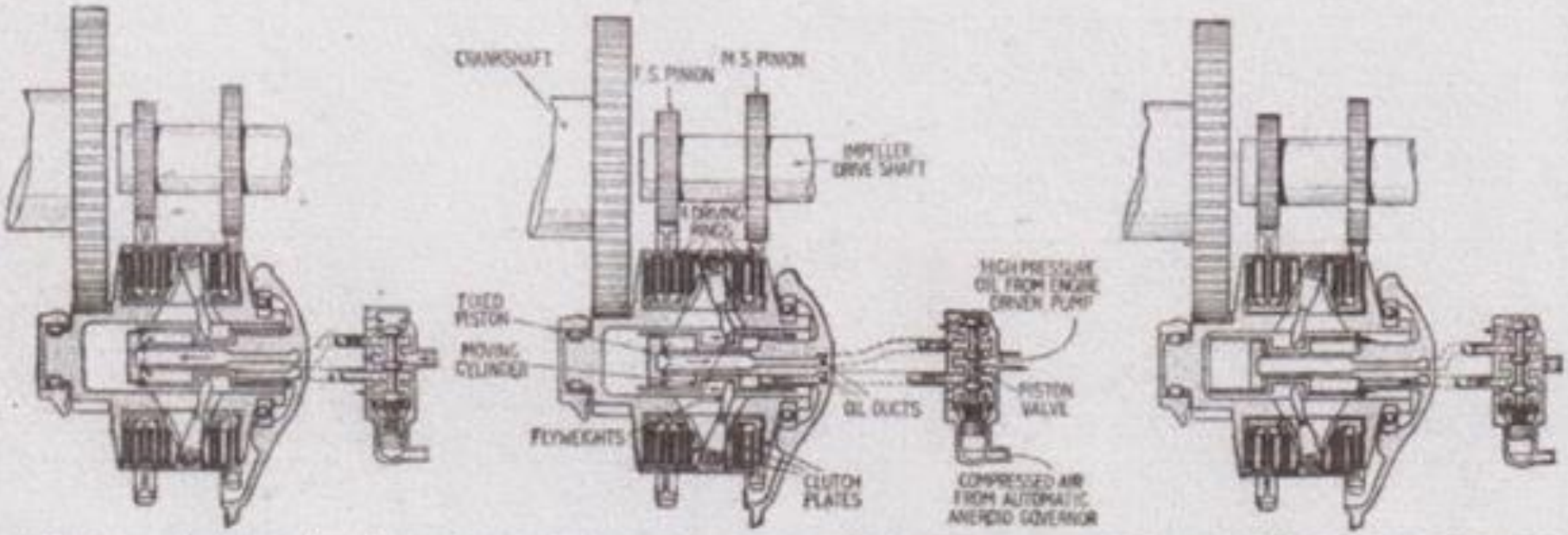
***FLIGHT,* September 20, 1945**

Supercharger

1898

"…The very high output of the engine would not be possible without the two-speed two-stage supercharger which, although of greater capacity, seems to be smaller than that of the equivalent Merlin; nevertheless, a price of no less than 600-hp is paid in driving the supercharger and, even more amazing, this power is transmitted through relatively small friction clutches in the speed change unit…"

***FLIGHT,* September 20, 1945**



Diagrammatic illustration of supercharger change-speed unit showing (left) MS gear engaged; (centre) changing from MS to FS gear; and (right) FS gear engaged.

"…A driving wheel on the spring-drive coupling at the rear of the crankshaft meshes with a hollow layshaft in the change-speed unit, this layshaft housing a stationary piston and sliding cylinder assembly. Mounted on the layshaft are a series of clutch plates and driving rings on each side of a driving member in which are pivoted six flyweights; the clutches on the crankshaft-side of the central weights are for full supercharge drive (FS), whilst those on the impeller-side of the weights are for moderate supercharge (MS), the respective clutches transmitting the drive through gears which mesh with pinions on the impeller shaft…" 1900

***FLIGHT,* September 20, 1945**

"…When, for example, MS drive is in operation, the flyweights are held inclined rearwards by centrifugal force to engage the clutch plates of the MS gear and, as the FS clutches are disengaged and doing no work, the driving gears can both be in constant mesh with the impeller pinions…"

***FLIGHT,* September 20, 1945**

Automatic Blower Gear Change

"…If the aircraft climbs into an altitude range where FS gear is required, the change of speed is effected automatically by a selector mechanism which actuates a piston valve so that oil delivered by the special pump in the crankcase is directed to the appropriate side of the change-speed unit piston. The pressure exerted against the piston reacts on the cylinder causing it to move and by so doing, push the flyweights away from the MS clutches towards the FS clutches; as the weights move beyond the neutral plane centrifugal force again takes hold and forces them to engage the FS clutches which there-upon transmit the drive through the high-speed FS gear…"
***FLIGHT,* September 20, 1945**

"…The automatic selector mechanism which effects the blower speed change comprises an aneroid capsule which operates a micro-switch to open a valve in the aircraft's air supply and so pass compressed-air to a ram on the end of the piston valve which directs the distribution of oil to the change-speed unit. However, the pilot is provided with a change-speed switch to bypass the aneroid and thus permit a change in blower speed for emergency use, to allow of retaining low gear for formation flying, or to allow of ground testing…"

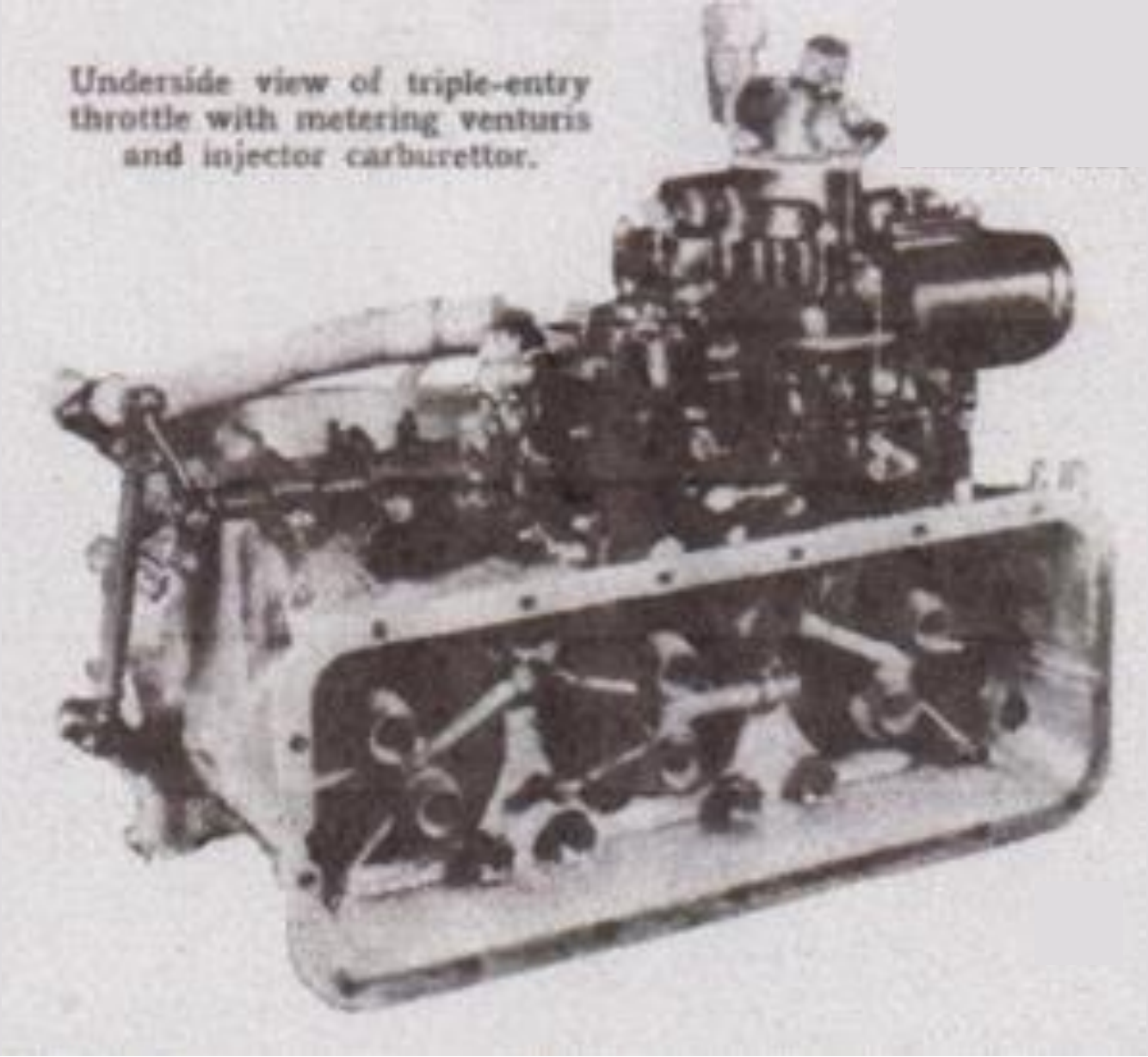
***FLIGHT,* September 20, 1945**

"…In order that no ill effects result from small axial movement as between the driving gears of the speed-change unit and also to preclude the effects of an over-hung drive, the respective drive pinions on the impeller shaft are not integral. In point-of-fact, only the MS pinion is mounted on the impeller shaft itself; the FS pinion being supported in a housing around the spring-drive sleeve, with a bell coupling separating the pinions and splined to each…"

***FLIGHT,* September 20, 1945**

Carburetion

1906

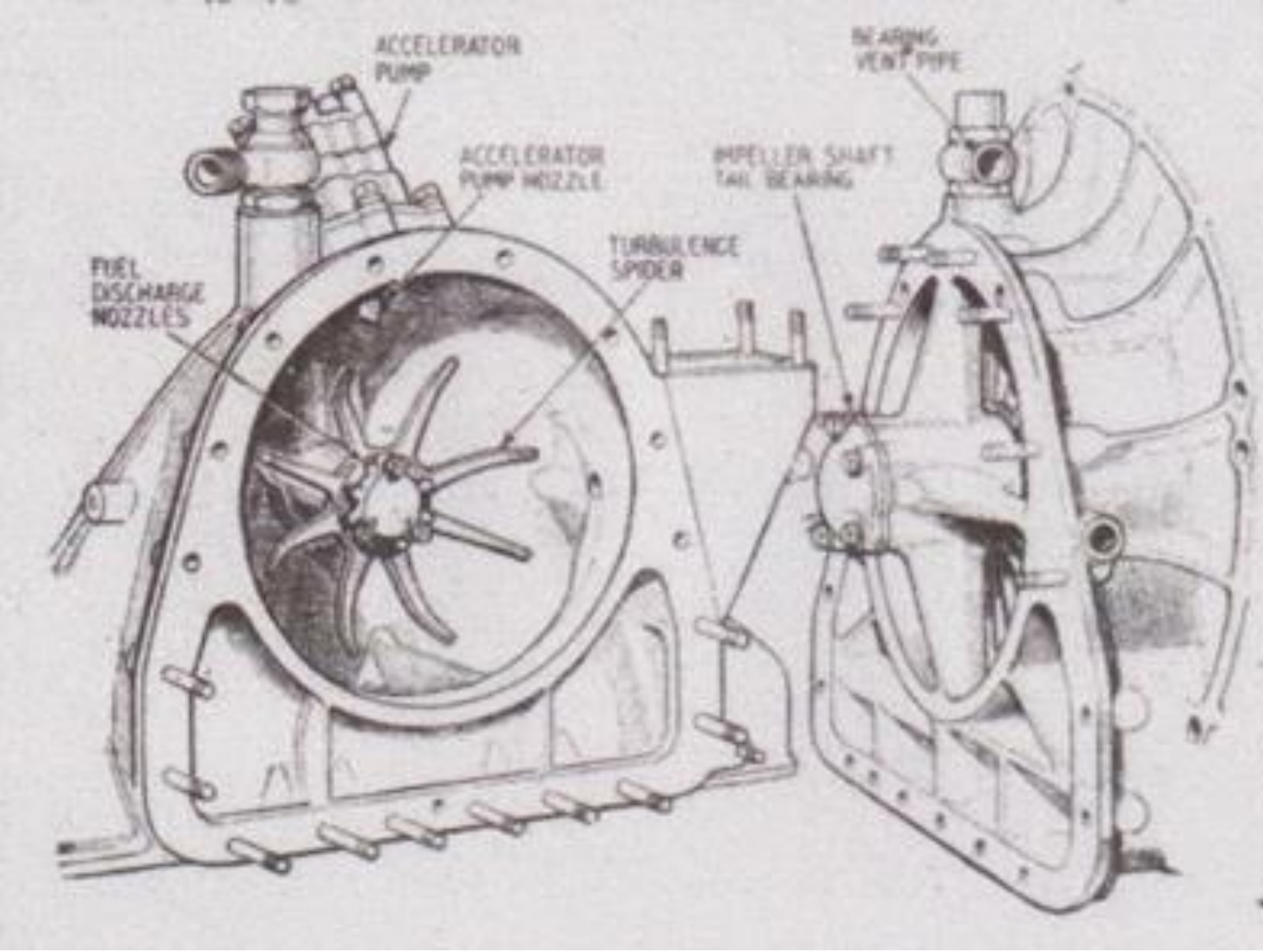


"…Induction is updraught through a triple-barrel throttle in the mouths of which are the venturis for fuel metering balance…" 1907

***FLIGHT,* September 20, 1945**

"…The carburetor is a Rolls-Royce modification of the Bendix-Stromberg metering injector, and supplies a governed measure of fuel to a series of discharge nozzles arranged in a 'hub' from which project eight 'spokes.' On the downstream side of these is created a depression or turbulent area into which the fuel nozzles discharge and from here the mixture is taken straight into the eye of the first-stage impeller. Rectifying and diffuser vanes are interposed between the first and second impellers and in this interstage area the blower casing is cooled by its own little coolant system…"

***FLIGHT,* September 20, 1945**



Induction throat to impellers showing turbulence spider with fuel nozzles.

"…From the second-stage impeller the charge is passed through a further diffuser ring and so to the volume delivering to the intercooler. An accelerator pump is located in the updraft throat between the nozzle spider and the impeller eye and discharges through a single nozzle…" 1909

***FLIGHT,* September 20, 1945**

"…The interstage impeller case cooling has the effect of increasing the charge density as an intermediate measure and by so doing, increases the capacity efficiency of the second stage. This principle lies behind the use of the main intercooler, for an increase in charge density for a given volume enhances the volumetric efficiency and although this leads to a large flow through the carburetor and, thus, a higher consumption relative to the power increase, the step-up in consumption is well worthwhile…"

***FLIGHT,* September 20, 1945**

For the Future

"…For the future, Rolls-Royce have evolved a metering pump to supplant the present system and it also seems likely that water/methanol injection will be introduced before very long, not necessarily only as an emergency measure but as a normal running condition. Direct injection to individual cylinders will also, without doubt, eventually be incorporated…"

***FLIGHT,* September 20, 1945**

Never Before Known

1913

"…There is this to be said for the new metering pump: it is an extraordinarily simple unit of great reliability and meters so accurately throughout the whole performance range that it is not too much of an exaggeration to state that flights could be planned to within a half-gallon of fuel endurance. With this is naturally linked a control and pre-knowledge of specific consumption such as has never before been known."

***FLIGHT,* September 20, 1945**

Griffon Specifications

LEADING PARTICULARS

Type	.. Pressure liquid-cooled, in-line 60 deg. V.
No. of cylinders	.. 12, arranged in two monobloc banks of six with detachable heads.
Bore and stroke	.. 6.0in. × 6.6in.
Unit capacity ..	.. 186.6 cu. in.
Total swept volume	.. 2,239 cu. in. (36.7 litres).
Reduction gear	.. Direct spur gear—Ratio: 0.5102 : 1.
Rotation	.. Left-hand tractor.
Airscrew shaft size	.. No. 5 S.B.A.C. Standard.
Valve type ..	.. Poppet—exhaust valves sodium cooled.
No. of valves/cylinder	.. Four, quadrantly disposed.
Supercharger ..	.. Centrifugal two-speed two-stage with inter-cooler.
Carburettor ..	.. Rolls-Royce Bendix-Stromberg pressure injection type 9T/40/1 triple-entry up-draught.
Magneto	.. B.T.H. C.S.H. 12-125/3 duplex type with integral distributors.
Plug positions ..	.. Two/cyl. diametrically opposite and radially disposed one each to inlet and exhaust sides.
Firing order ..	.. (P = port; S = starboard) 1S, 4P, 3S, 2P, 5S, 1P, 6S, 3P, 4S, 5P, 2S, 6P.
Ignition timing ..	.. Fully advanced: Inlet plugs 45 deg. before T.D.C. Exhaust plugs 51 deg. before T.D.C. Fully retarded: Inlet plugs 10 deg. before T.D.C. Exhaust plugs 16 deg. before T.D.C.
Crankshaft type	.. Counterbalanced six throw.

1916

BEARINGS

Main bearing diameters	3.75in.
Main bearing areas	Centre, 5.45 sq. in. Ends and inters, 5.12 sq. in.
Big-end diameter	Fork rods, 3.10in.; plain rods, 3.773in.
Big-end areas	Fork rods, 6.28 sq. in.; plain rods, 2.61 sq. in.
Gudgeon diameter	1.50in.
Total gudgeon bearing area	6.83 sq. in.
Rod/gudgeon bearing area	2.976 sq. in.
Piston/gudgeon bearing area	3.854 sq. in.
Con. rod length, centre to centre	10.65in.
Ratio of con. rod length to stroke	1.614 : 1 $\frac{L}{R} = 3.228$.
Max. angularity of con. rod	18 deg.
Cam base circle dia.	1.150in.
Cam major axis length	1.5308in.
Valve lift	0.570in.

WEIGHT

Power/weight ratio ..	0.941 lb./b.h.p.
Weight/sq. in. piston area	6.159 lb.
Max. mean piston speed	3,025 ft./min.
Weight of piston and rod ass'y/cyl. ..	12.23 lb.

1918

ASPIRATION

Valve timing	Inlet opens 24 deg. before T.D.C.; closes 44 deg. after B.D.C. Exhaust opens 64 deg. before B.D.C.; closes 4 deg. after T.D.C.
Inlet port area (valve throat)	5.54 sq. in./cyl.
Exhaust port area (valve throat)	4.12 sq. in./cyl.
Piston area to inlet valve area ratio ..	5.103 : 1
Piston area to exhaust valve area ratio ..	6.867 : 1.
Ratio of piston area to frontal area	0.298 : 1.
Cylinder compression ratio	6 : 1.
Max. internal compression ratio of blower ..	5.3 : 1.
Impeller diameters ..	1st stage, 13.4in.; 2nd stage, 11.3in.
M.S. gear ratio	5.84 : 1.
F.S. gear ratio ..	7.58 : 1.
Equivalent tip speeds ..	M.S. cruising, 1,071 ft./sec.; M.S. max. power, 1,228 ft./sec. F.S. cruising, 1,391 ft./sec.; F.S. max. power, 1,594 ft./sec.
Eye area of 1st impeller ..	56.1 sq. in. free, 40.5 sq. in., restricted by tail bearing support.
Rich mixture ratio ..	11 : 1 by weight.
Weak mixture ratio ..	14 : 1 by weight.

1919

POWER

Max. boost pressure ..	21 lb./sq. in.
Max. cruising boost pressure	7 lb./sq. in.
Max. b.h.p.	2,220.
Max. r.p.m.	2,750.
Cruise r.p.m.	2,400.
Max. b.m.e.p.	256 lb./sq. in.
Altitude to which 1 ata. manifold pressure is maintained	39,500ft. in F.S. gear.
Power/cu. in. swept volume	0.992 h.p.
Power/litre ..	60.5 h.p.
Power/sq. in. piston area	6.54 h.p.
Power/sq. ft. frontal area	281 h.p.
Power ratio/sq. in. piston area to sq. in. frontal area	3.35 : 1.

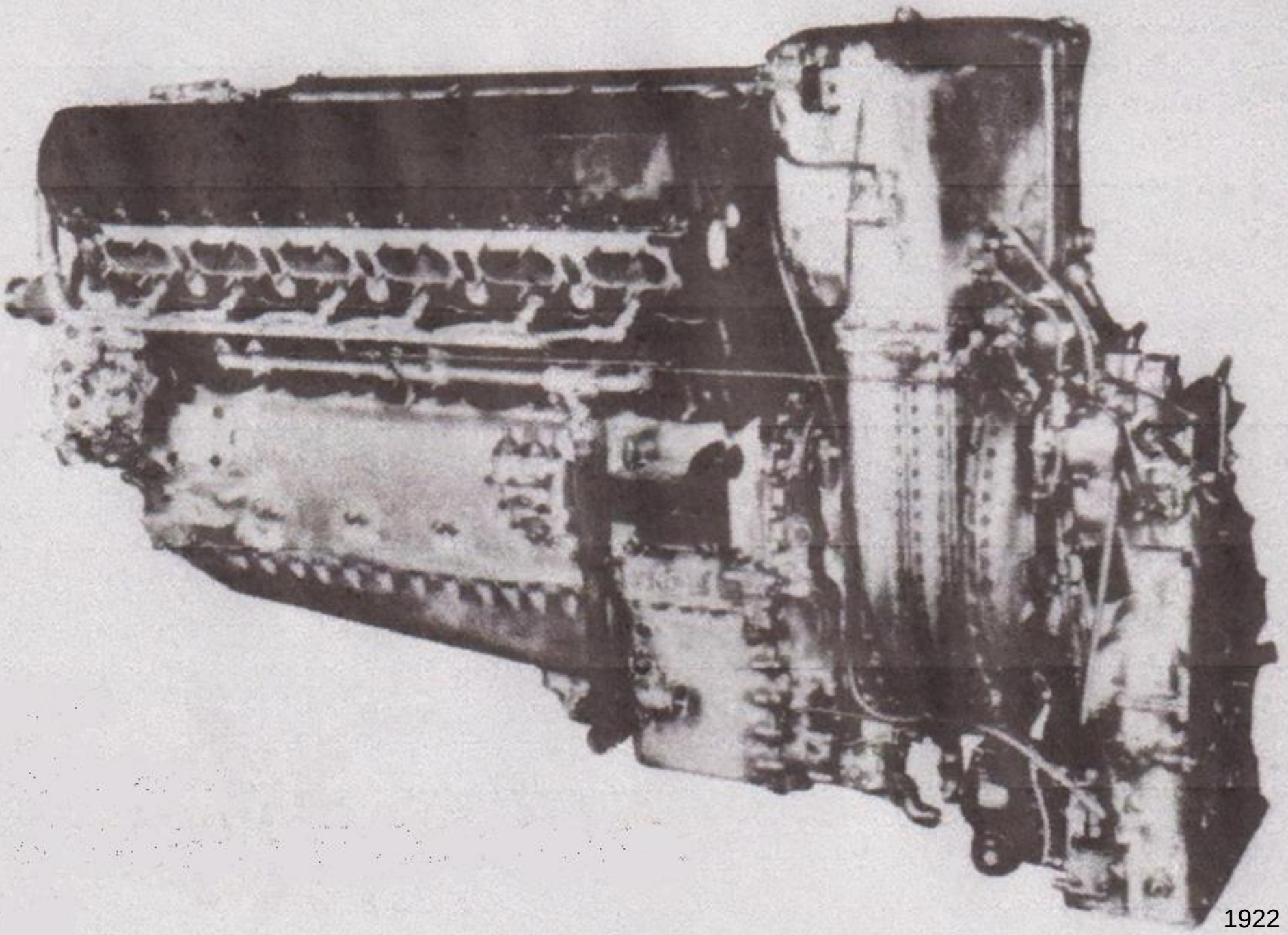
1920

AUXILIARY DRIVES

Auxiliary drive speeds (ratio relative to crankshaft)—

Tachometer	0.250 : 1.	
Gearbox input	0.984 : 1	(Accessory drive faces; hydraulic pump, electric generator, air compressor, vacuum pump).
Magneto	0.50 : 1.	
C.S.U.	0.82 : 1.	
Fuel pump	0.887 : 1.	
Oil pumps	0.984 : 1.	
Engine coolant pump	1.793 : 1.	
Inter-cooler coolant pump	1.799 : 1.	
Starter	1 : 1.	
Type of starter	Coffman combustion type L5.	

1921



1922

Part 16

“Spitfireness”

1923

Fear No Evil

1924

A few weeks back, the hugely admirable John Mollison posted a new *Old Guys & Their Airplanes* clip to accompany his finished illustration of F/L John Wilkinson's Spitfire Mk.XIV
airscapemag.com
RE: introduction to an article entitled: "Flying the Fourteen"



"I will fear no evil..."
Supermarine Spitfire Mk XIV as flown by
F/L John F. Wilkinson
41 Squadron, Royal Air Force

©john mellison

A Pilot's POV

1927

“PERHAPS I should have that the other way around . . . Anyway, John’s post, clip and artwork reminded me that I had a pilot’s review of the XIV in my collection and it seemed appropriate to share it…”

airscapemag.com

1928

Born-to-Kill

1929



"…Unlike a lot of Spitfire fans, the Griffon-engined Marks are by far my favorite. There is no apology about them - they are pointed and purposeful. Much as the Me-262 puts me in mind of a shark, the late model Spitfires look like a knife. No one ever wrote 'Born-to-Kill' on the side of a Spitfire XIV. There was no need…"

airscapemag.com

<u>Caption</u>: "The first Spitfire Mark XIVe, RB140, on a test-flight after engine modifications. The aircraft served with RAF No. 610 Squadron from April 6, 1944, but was destroyed in a landing accident on October 30th."

Impressions

1931

"…The following piece dates from mid-1945, when 'Indicator' recorded his impressions of the Spitfire XIV for FLIGHT magazine. His report appeared on newsstands on August 16th, the day after Japan's surrender and 20 months after XIV had entered service…"

airscapemag.com

Ever Young

1933

A Few Impressions of One of the Later Spitfire Marks: The War's Ever-Young Veteran: Maintaining Consistent Handling Qualities With Quantity Production

***FLIGHT,* August 16, 1945**

RE: introduction to an article written by "Indicator" entitled: "Flying the Spitfire XIV"

War Dividend

1935

"ALTHOUGH the impetus of war has probably had a more marked effect on aeronautical than on any other engineering development, it is as well, sometimes, to remember that this impetus has merely hurried progress - and that not always in the right direction. Because more concentrated effort and expenditure has been possible progress, at least along certain lines, has been more rapid than it would otherwise have been…"

***FLIGHT,* August 16, 1945**

In Due Course

1937

"…Some of the best and most useful types were largely or entirely developed during the years of peace and, though it is not suggested that the likelihood of war did not accelerate progress, the basic knowledge was available and this knowledge would undoubtedly have been applied to the design of civil and military types in due course…"

***FLIGHT,* August 16, 1945**

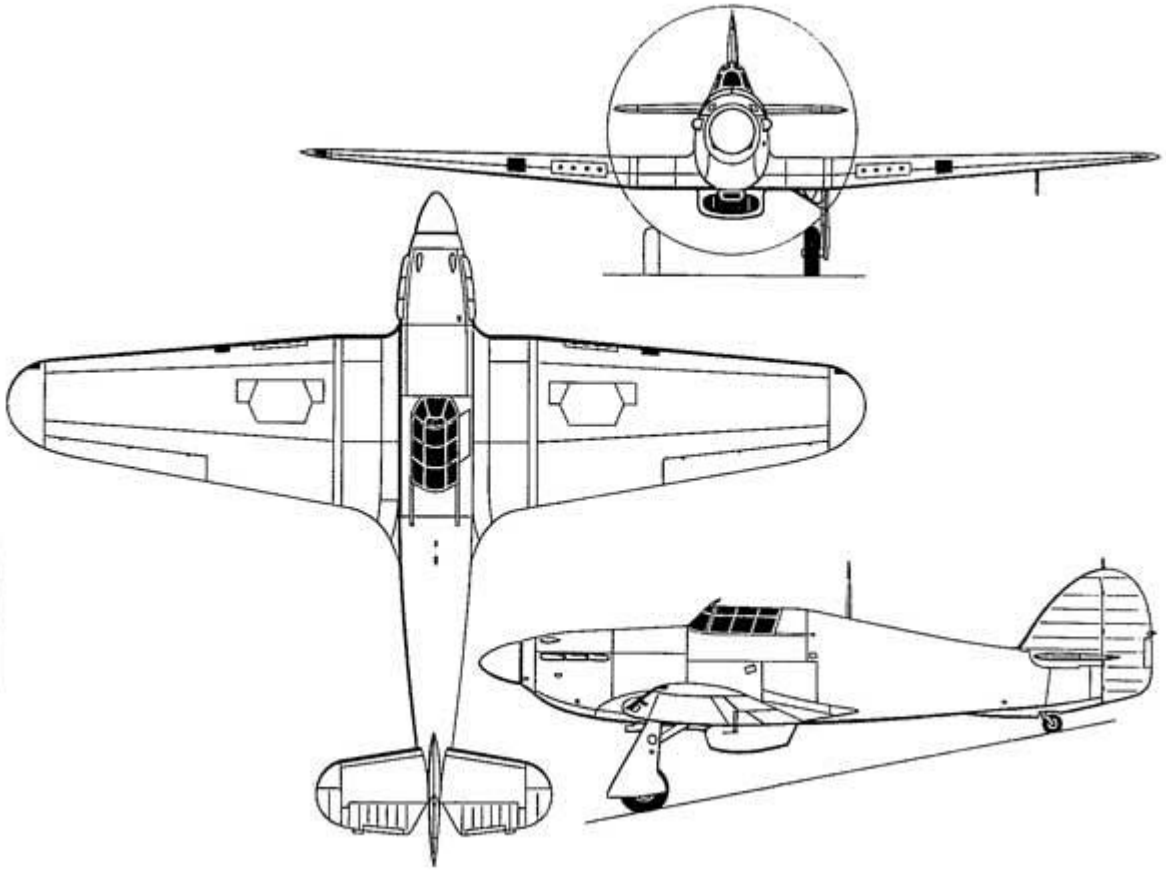
1938

Before the War

1939

"…Without delving deeply into the history of the different firms and of the persons concerned with these firms, it would be impossible to produce an accurate list of outstanding military aircraft which were actually planned, and even experimentally flown, before the outbreak of war, but a few can safely be mentioned…"

***FLIGHT,* August 16, 1945**



Length: 31 ft 5in
Height: 13 ft 1in
Weight: 74901b.
Wingspan: 40ft
Wing area: 257.6 sq ft
Engine: 1030hp Rolls-Royce Merlin III liquid-cooled V12.

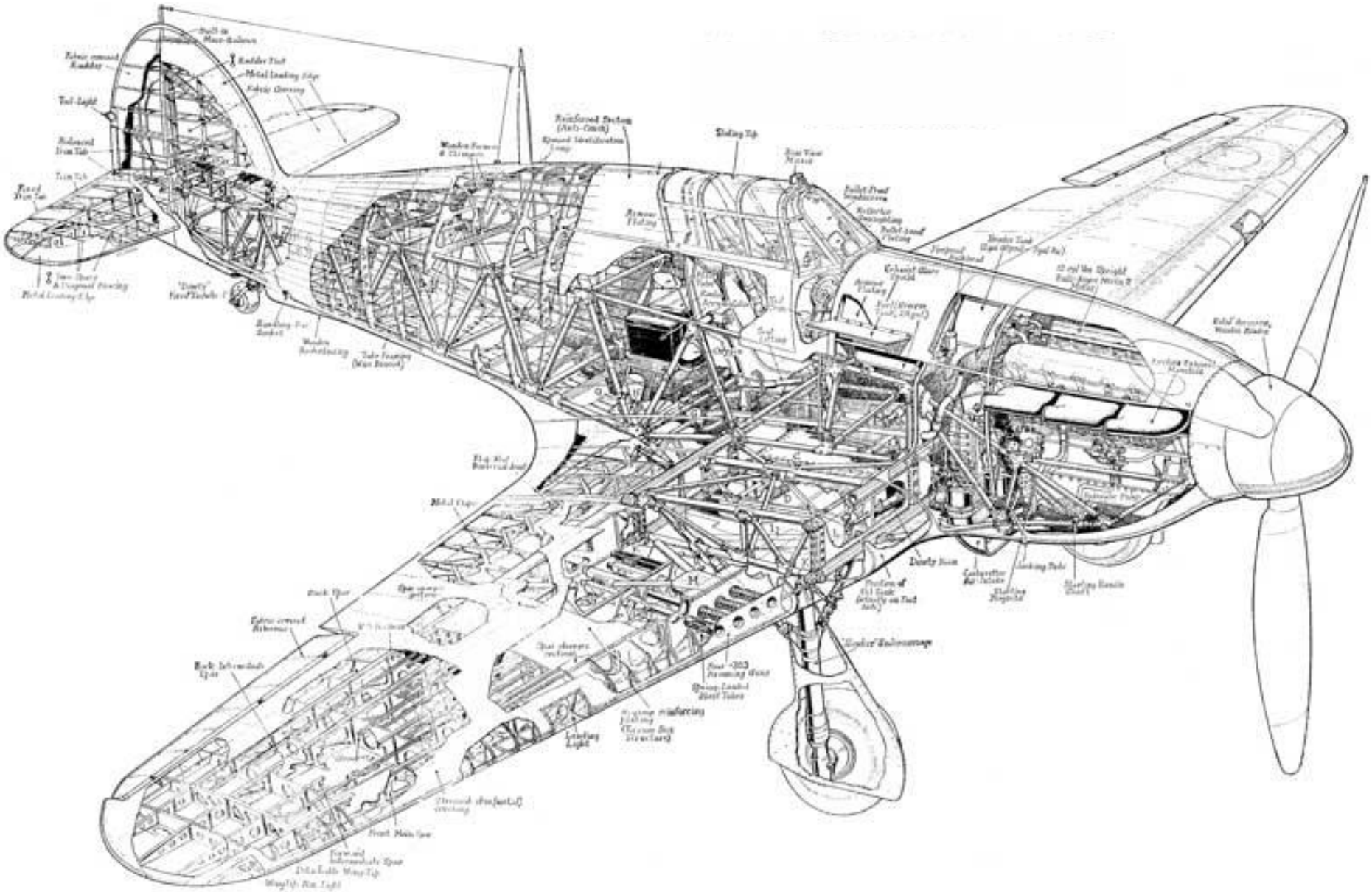
Performance
Max speed: 322mph.
Ceiling: 34000 ft
Range: 505 miles
Armament
Eight 0.303in Browning machine guns.

"…From the point-of-view of British survival, the most important, of course, were the Hurricane and Spitfire. The former, I believe, is still doing good work in the Far East, though, after an almost incredible lease-of-life when loaded with cannons, bombs, rockets and extra tanks, it can now be considered as obsolescent…"

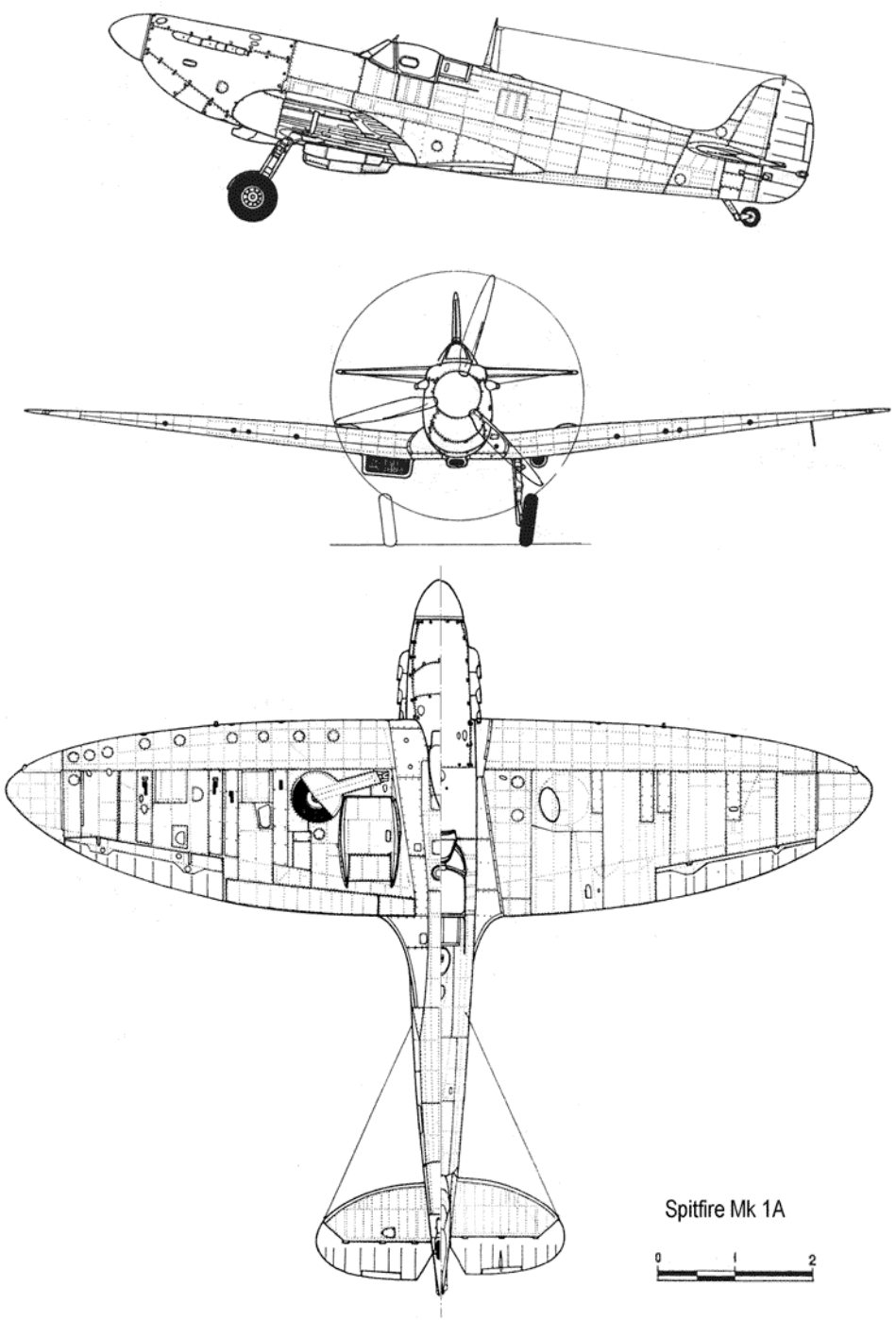
***FLIGHT,* August 16, 1945**

1941

<u>Caption</u>: "Specifications for the Hawker Hurricane"



1942

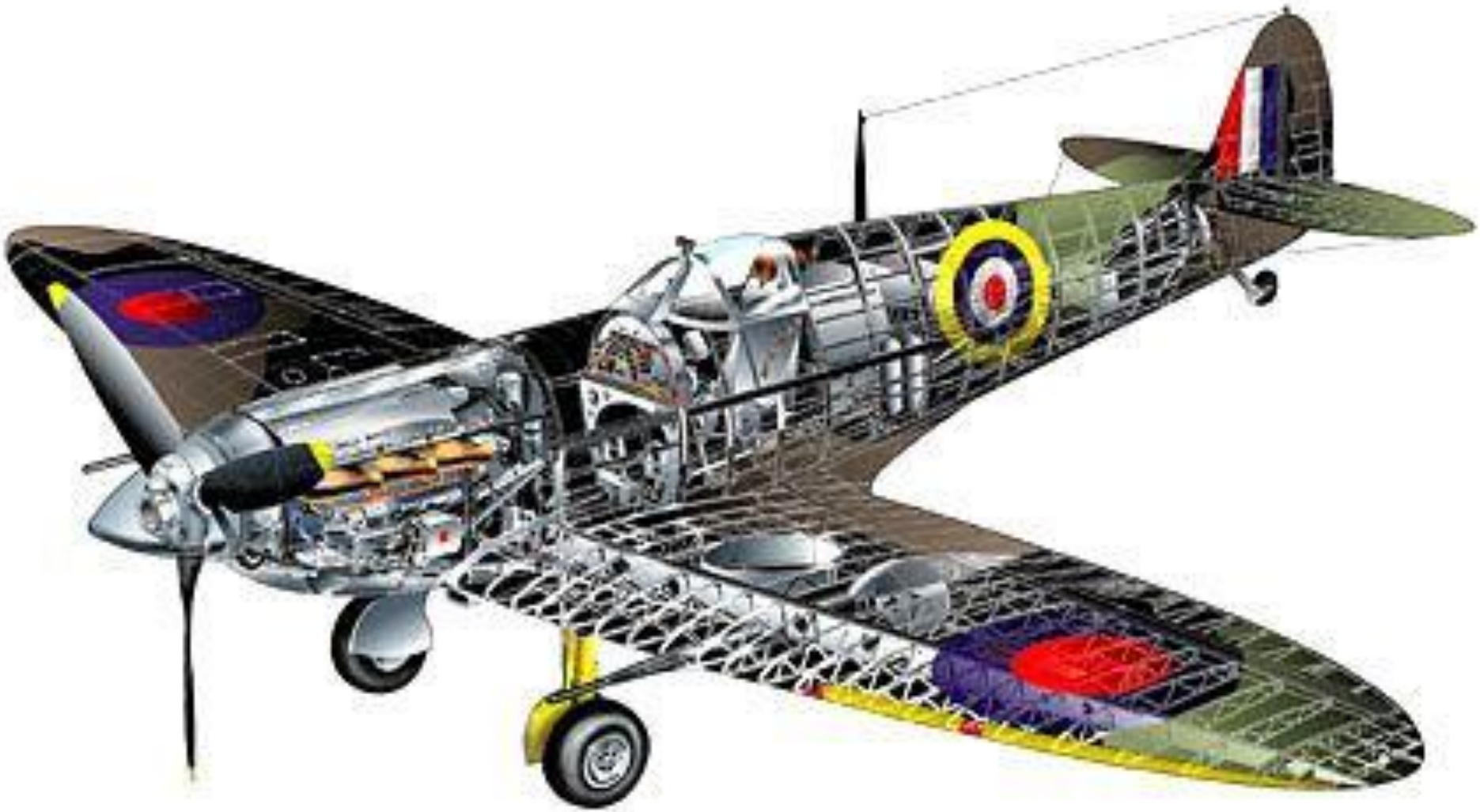


"…The latter, in vastly different form, but basically the Spitfire of 1938, is still going as strongly as ever. With twice its original power and nearly twice its early performance, it has lost few, if any, of its original favorable flying characteristics…"

***FLIGHT,* August 16, 1945**

Caption: "Supermarine Spitfire I: Initial production version, built to Specification 16/36; first contract placed June 3, 1936. First aircraft flown May 14, 1938 with 1,030-hp Merlin II; Merlin III introduced at 175th aircraft. Entered service Aug. 1938. Nine squadrons operational by Sept. 1939, with ten more by mid-1940. Designation Supermarine Spitfire IA adopted retrospectively in 1940 after 30 aircraft designated Supermarine Spitfire IB when fitted with two Hispano 20mm canon each in place of four of the machine guns."

1943



1944



Supermarine Spitfire Mk.I

1945






"…Among the few other aircraft which, I believe, were flying before the European war and which were still being used in basically the same form for front-line operations at its termination, are the Douglas Boston (an outstandingly good aircraft from the handling point-of-view), the Junkers 88 and, if one can allow such extreme changes as have been made in layout and armament, the Boeing Fortress. But the Spitfire holds a big lead in length of active service on any…"

***FLIGHT,* August 16, 1945**

RE: the Douglas A-20 Havoc was an American light bomber, attack aircraft, night-intruder, night-fighter and reconnaissance aircraft. The bomber served with the RAF under the service name "Boston."

<u>Above</u>: (Left-to-right): Douglas Boston / Junkers 88 / Boeing B-17 Flying Fortress 1946

Different, But the Same

1947



"…Not that one would suggest for a moment that the Spitfire XIV is merely a Spitfire I with more power and equipment. Gradual detailed development has made it vastly different, but the 'shape,' structure and, most important of all, the handling qualities have remained much the same…"

***FLIGHT,* August 16, 1945**

1948

<u>Caption</u>: "Supermarine Spitfire Mk.I - starboard-side profile"

"…The pilot of the I or II might find the XIV something of a handful for a start with its long nose, increased power and greater all-up weight, but he would soon accustom himself to the differences and would recognize the essential 'Spitfire-ness' of the ensemble. A few circuits would convince him that its somewhat savage and purposeful look, in comparison with the concealing elegance of earlier Marks, is a camou-flage for a set of comparatively mild habits…"

***FLIGHT,* August 16, 1945**

"…Nevertheless, there might have been some justification for the renaming of the type with the introduction of the XIV. The additional power of the Griffon engine and the fact that it turns round the other way with a somewhat marked torque effect makes both this, and subsidiary Marks, 'feel' different - particularly while on and near the ground…"

***FLIGHT,* August 16, 1945**

"…The majority of pilots, as they climb out of their first XIV after a long experience of the earlier Marks, are inclined to say: 'Nice, fast, handleable flying machine - but it ain't a Spitfire no more…' Since Merlin-engined VIIIs, IXs and XIs were, and still are, in action on the fighting fronts, a change of name would still have left the Spitfire with the honor of being the war's ever-young veteran…"

***FLIGHT,* August 16, 1945**

Marks and Engines

1952

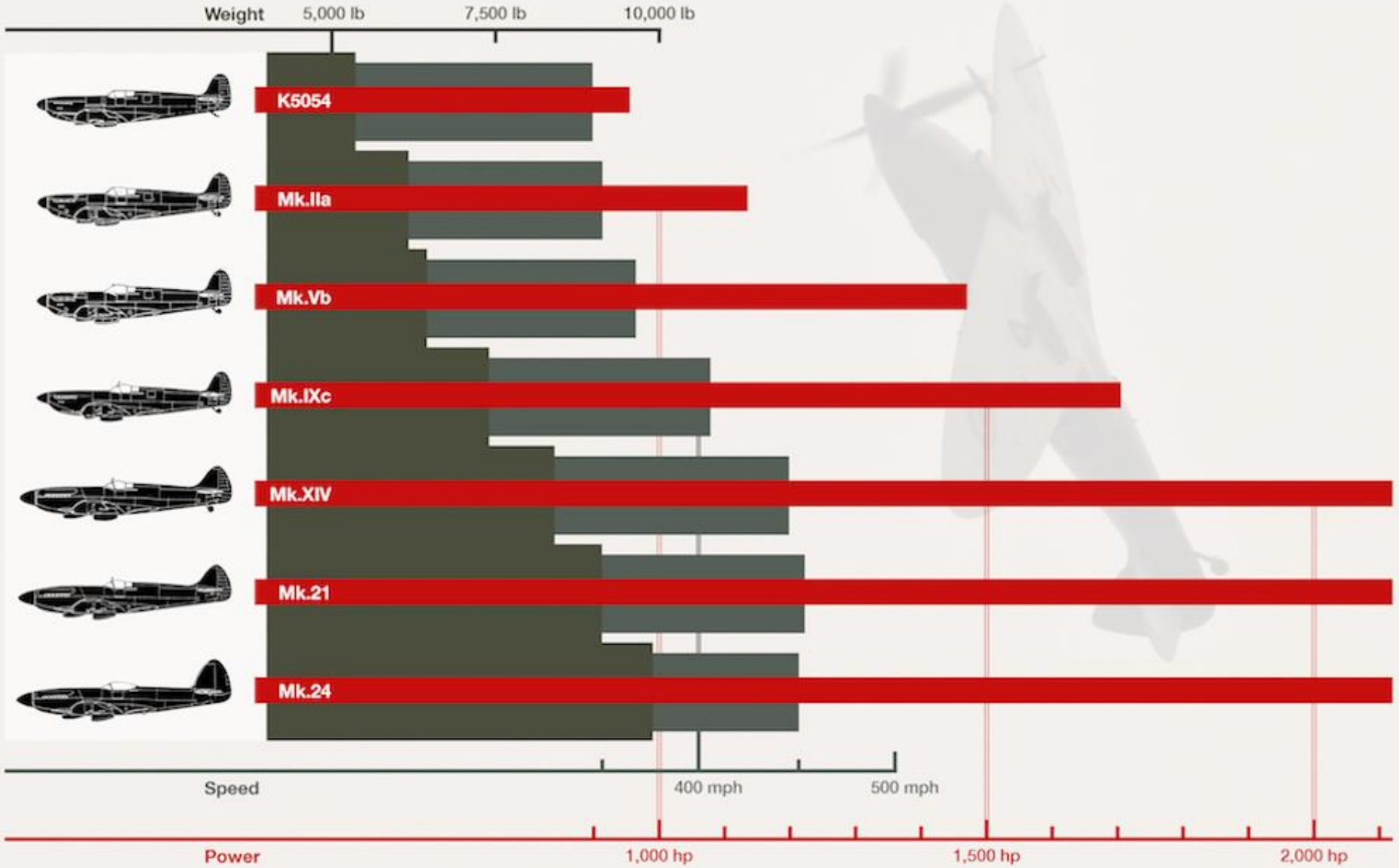
"…For the assistance of those who have no reason to be 'au fait' with the somewhat bewildering series of Marks in the Spitfire series - and for whom, perhaps, the use of Roman numerals involves a series of calculations rather after the manner of those needed in translating twenty-four-hour-clock times to ancient English - it might be as well to sort-out some of the later types in so far as the censor will permit…"

***FLIGHT,* August 16, 1945**

1953

"…Excluding the little-used or obsolescent Marks, the Seafire III, and the Spitfire V, VII, VIII, IX, XI and XVI are all Merlin-engined. Engine Mark numbers have reached such heights that the Roman method of numerology has had to be discontinued and we can say that they are powered, variously and according to their age and uses, with Merlin 45, 55, 61, 63, 64, 66, 70, 71 and 266 - which last is merely the Packard-built 66 fitted to the XVI and which, again, is merely a variation of the IX. The VII and XI are PRU types and the VIII is, curiously enough, an 'advanced' form of the IX, with retractable tail-wheel and various other refinements. The apparent numerical inconsistency was caused by production arrangements…"

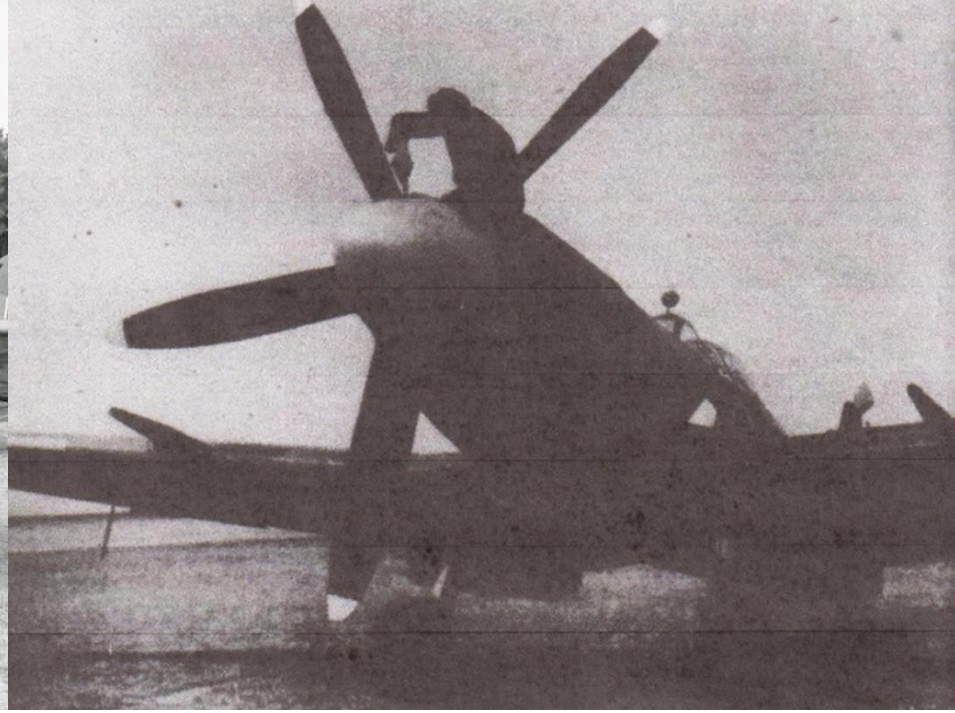
***FLIGHT,* August 16, 1945**



<u>Caption</u>: "Through its various marks, the family gained 100 mph, almost doubled in weight and more than doubled its horsepower. Starting with the XIV, the Griffon versions were a quantum jump."

1955





"…Of the Griffon-engined Marks, the first to appear was the XI - a low-level fighter with clipped wings. It has a four-bladed airscrew. Then there is the XIV, characterized by a five-blader and a long nose to accommodate the two-stage, two-speed blower and intercooler of the Griffon 65…"

***FLIGHT,* August 16, 1945**

Left: caption: "RAF No.91 Squadron ground crew attend to one of their Spitfire XIVs and its mighty Griffon at West Malling, Kent, in 1944"

Right: caption: "The closely cowled Rolls-Royce Griffon engine on the Spitfire XIV and its five-bladed Rotol airscrew"

1956


1957

"…So much for the history and development lesson…"
***FLIGHT,* August 16, 1945**

Paradigm Shift

1959



"…The XIV was a paradigm shift in the Spitfire lineage - arguably a new type, given the introduction of Rolls-Royce's 2,120-hp Griffon V-12 plus the major structural and aerodynamic changes it required…"

airscapemag.com

<u>Caption</u>: "Restored Spitfire F Mk.XIVc 'SM832', originally delivered in March 1945, she was sold to the Indian Air Force in 1947 and first restored in 1978"

1960

The Wing's the Thing

1961



"…But, as the saying goes around Spitfires, 'the wing is the thing' and the XIV used the same elliptical wing as its forbears, despite the ever-increasing weight and power. And, as 'Indicator' found, that wing ensured the ferocious 'new' fighter remained very much one of the family . . . "

airscapemag.com

<u>Caption</u>: "Spitfire F Mark XIV, RB159 DW-D being flown by Squadron Leader R.A. Newbury of 610 Squadron RAF. The 'F's were dogfighters, with their elliptical wingtips clipped to improve roll response."

1962

Part 17

UPP

1963

Interchangeability

1964

Interchangeability of Engine Type and Position: Wartime Measure Applied to Civil Transports: Provision Against Climatic Extremes

***FLIGHT,* February 13, 1947**

RE: introduction to an article entitled: “Universal Power Plants”

1965

Head Start

1966

"SOME of the highly accelerated development work carried out by the British aircraft industry working at wartime pressure produced results in military aircraft which are well ahead of present civil practices…"

***FLIGHT,* February 13, 1947**

Playing Catch-up

1968

"…In some cases we have now, so to speak, to catch-up with ourselves and fill-in the intermediate stages. There were, however, many other wartime developments which could be applied at once and almost directly to civil aircraft. The Universal Power Plant is one example…"

***FLIGHT,* February 13, 1947**

Advantage: UPP

"…Most people will know, in general terms, the purpose of the Universal Power Plant, but they may not know of the many advantages it now offers for civil aircraft…"

***FLIGHT,* February 13, 1947**

Third Stage

1972

"…At one time, in pre-war days, the engine manufacturer produced 'an engine' and the airframe designer arranged for it to be wrapped-up and attached at some convenient point on the airframe. During the late 1930s 'power units' were proposed and the first examples produced. This meant that an engine with mounting and cowlings was assembled as a unit from bulkhead forward and presented to the airframe manufacturer for installation, pick-up points and connections having previously been settled. The introduction of the Universal Power Plant was a logical and timely third stage…"

***FLIGHT,* February 13, 1947**

The Changing Times

1974

"…Only ten years ago engines were comparatively simple and free from 'extras,' but while the basic structure of a Merlin 620 differs little in layout or appearance from the first Merlin or, in fact, from the early unsupercharged Kestrel, a great difference can now be seen, particularly at the breathing-end where an injection carburetor, a massive supercharger unit with intercooler and a cluster of accessories and controls have been added. The main components of the in-line engine are now barely visible, beneath all this equipment which goes to make-up a modern engine…"

***FLIGHT,* February 13, 1947**

"…Installation design quickly became a job for the specialist and the transformation of an engine into a self-contained power unit the work of a department equal in status to those producing the engine and the airframe…"

***FLIGHT,* February 13, 1947**

Rough Start

1977

"…The first application of the UPP was to the Avro Lincoln. Very little adverse criticism was ever heard of the Lancaster from which it was developed, but one weakness, from the points-of-view of production and maintenance, concerned the Merlin power units…"

***FLIGHT,* February 13, 1947**

"…The four units for a single aircraft were not interchangeable between nacelle positions and the different marks of power units were not interchangeable between aircraft. In addition, the double-curvature panels were not easy to produce and were prone to distortion in service…"

***FLIGHT,* February 13, 1947**

"…Finally, the many different accessories for each of the four power units were directly mounted on the engine and therefore, all had to be disconnected and reconnected for an engine change. As would be expected, engine changes were fairly frequent on operational bombers…"

***FLIGHT,* February 13, 1947**

Outcome

1981

"…The outcome then of a requirement felt by all aircraft and engine manufacturers and, in the particular case of the Rolls-Royce and A.V. Roe Companies, a result of experience with the Lancaster was the development of the Universal Power Plant for the Lincoln…"

***FLIGHT,* February 13, 1947**



"…Attachment points are spaced on a standard bulkhead to dimensions settled by the SBAC and accessories are driven from a separate gear box. With the minimum of labor, Merlin units can be changed and port and starboard, inboard and outboard installations are all interchangeable..."

***FLIGHT,* February 13, 1947**

<u>Caption</u>: "All four Merlin 620 powerplants are interchangeable on the Avro Tudors. Four-bladed airscrews are used for this installation."

1983



An interesting example of interchangeability is provided by this Lancaster test bed with Tudor power plants inboard and D.C.4M power plants outboard.

"…In unusual circumstances, to quote the special case of a Lancaster in use as a flying test-bed, four different marks of Merlin engine could be fitted in any of the four positions; single- or two-stage Griffons could be substituted for the Merlins or, finally, radial engines in the same group, conforming to S.B.A.C. dimensions, could be installed…"

***FLIGHT,* February 13, 1947**

1984

UPP Installations

1985

"…Rolls-Royce engines supplied as Universal Power Plants and the aircraft for which they are intended are as follows:

Merlin 65, 68 and 85	..	Lincoln I and II.
.. 100 Series (102)	..	Civil prototype engine for Tudor I.
.. 600 Series (620)	..	Canadian Douglas D.C.4M.
.. .. . (621)	..	Avro Tudor I and II.
Griffon 11, 2-speed	..	Experimental.
.. 61 and 62, 2-speed, 2-stage	..	..

Main features of the UPP may be listed as follows:

(a) Circular cowling which is acceptable to all aircraft manufacturers, and which is built-up from single-curvature panels, easy to produce and fit.

(b) Separate gear box for accessories installed in the aircraft independent of the engine.

(c) Standardized bulkhead diameter and pick-up points.

***FLIGHT,* February 13, 1947**

The Canadian - built Skymaster with Rolls-Royce Merlin 621s has a considerably improved performance. The slight taper of the power plant cowling can be seen.



1987

"…In addition to the main provision of interchangeability between all nacelle positions, the UPP is particularly clean aerodynamically in that all intakes, radiators, air filters and exhaust systems are contained within the cowling. It also lends itself very well to armored protection and exhaust-flame damping for military installations and the side panels can be used as maintenance platforms…"

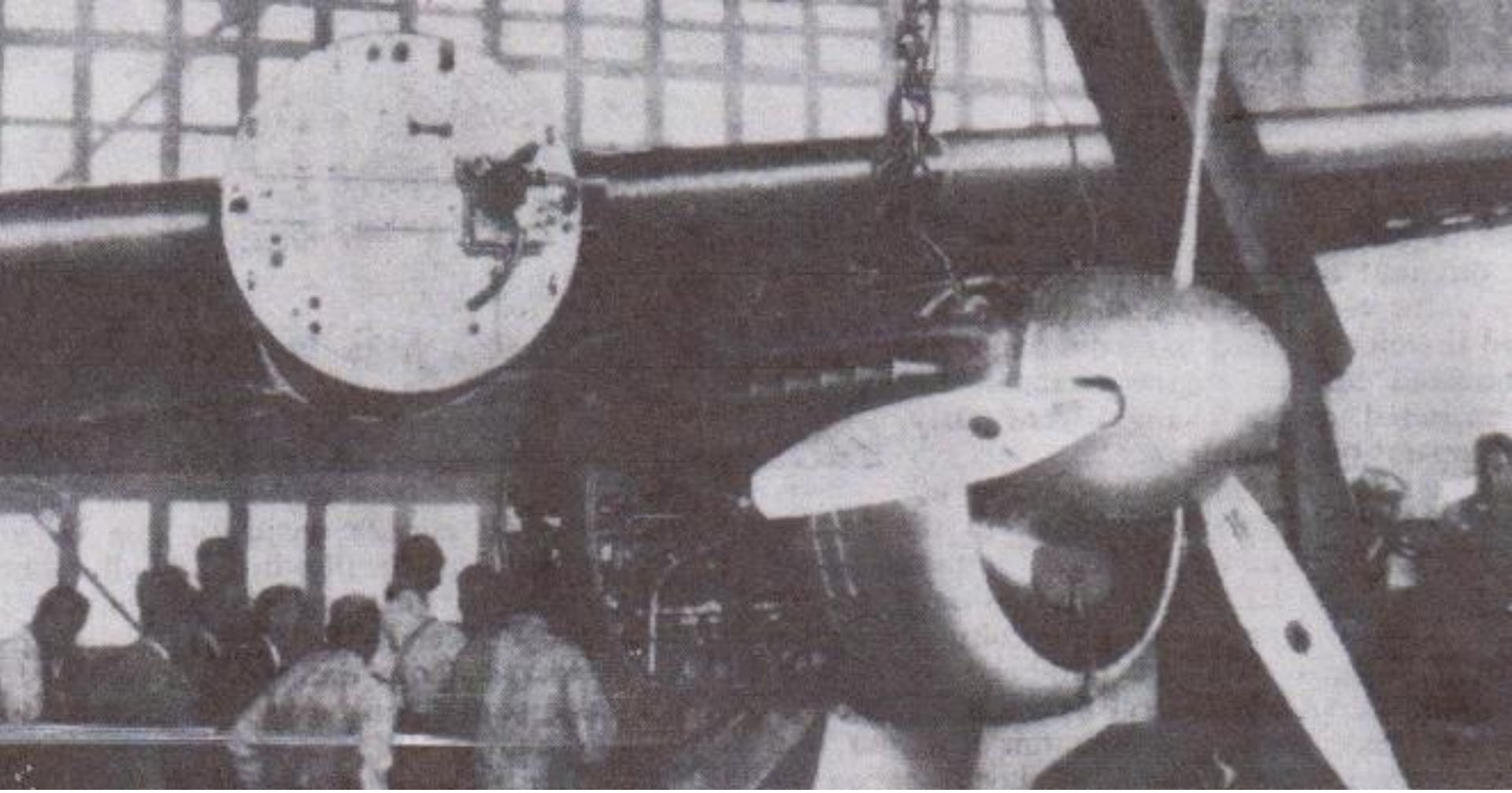
***FLIGHT,* February 13, 1947**

"…There are certain slight drawbacks, but, as with almost every unit of an aircraft, there must be some compromise. For the Merlin, the UPP diameter is unnecessarily big, first, because of the size of the bulkhead required for the inboard powerplant at the rear of which is the undercarriage assembly and, secondly, because it must be able to accommodate radial engines…"

***FLIGHT,* February 13, 1947**

"…Again, the requisite quantity of fire-extinguisher fluid is larger with the pressure cowling type of powerplant because of the large air-flow over the engine - a measure to meet the exhaust flame damping requirements of the military power unit…"

***FLIGHT,* February 13, 1947**

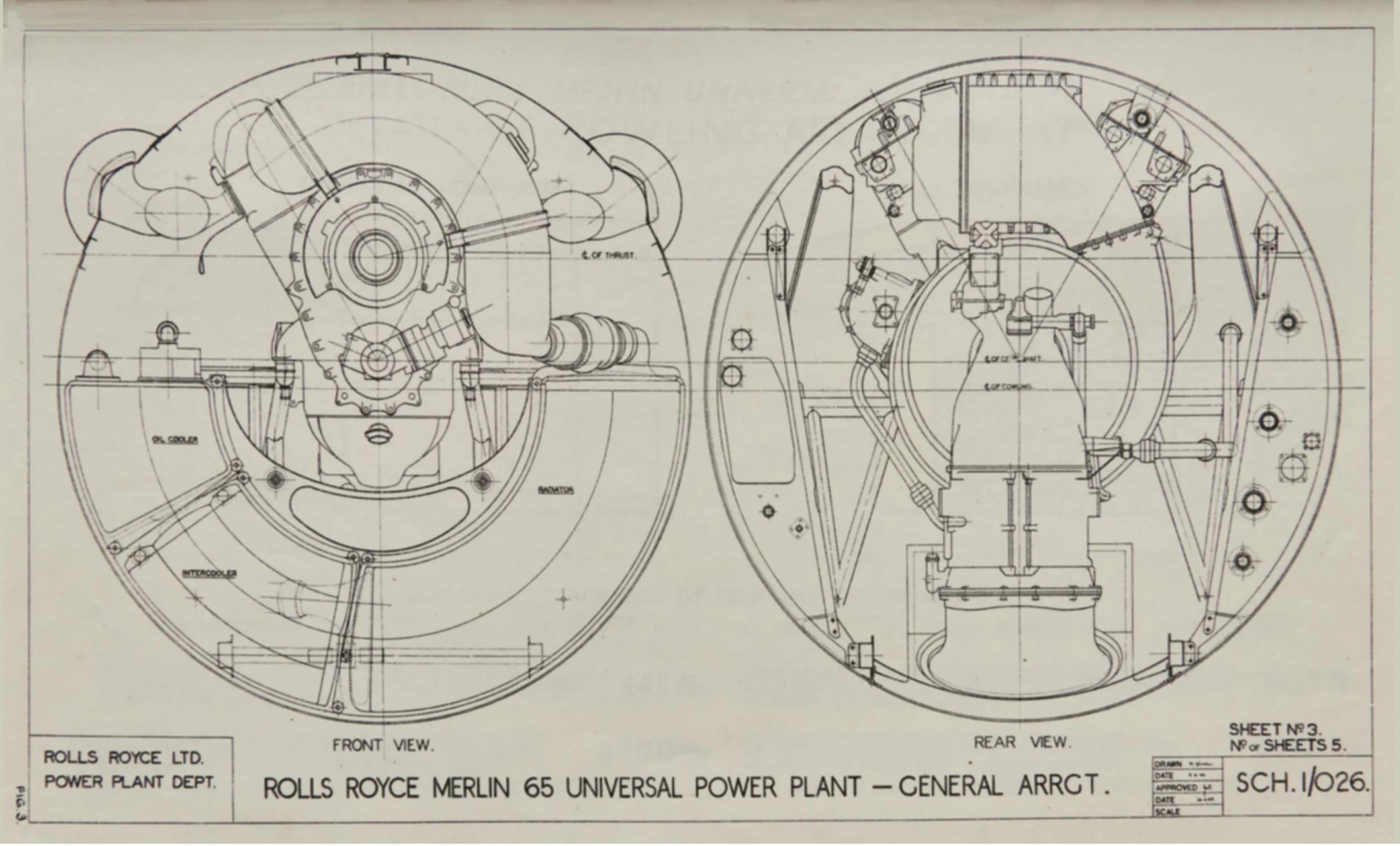


"…It should be made clear that, although the Merlin 620 powerplants for the D.C.4Ms are of UPP type, there are certain distinct differences…"

***FLIGHT,* February 13, 1947**

<u>Caption</u>: "Technicians confer as a Merlin 621 is hoisted-up to its D.C.4M bulkhead"

1991



"…The diameter of the standard cowling is 56 in., while that for the D.C.-4M has to taper from 60 in., the size of the original Douglas bulkhead, down to the standard 56 in. at the front former ring…"

***FLIGHT,* February 13, 1947**

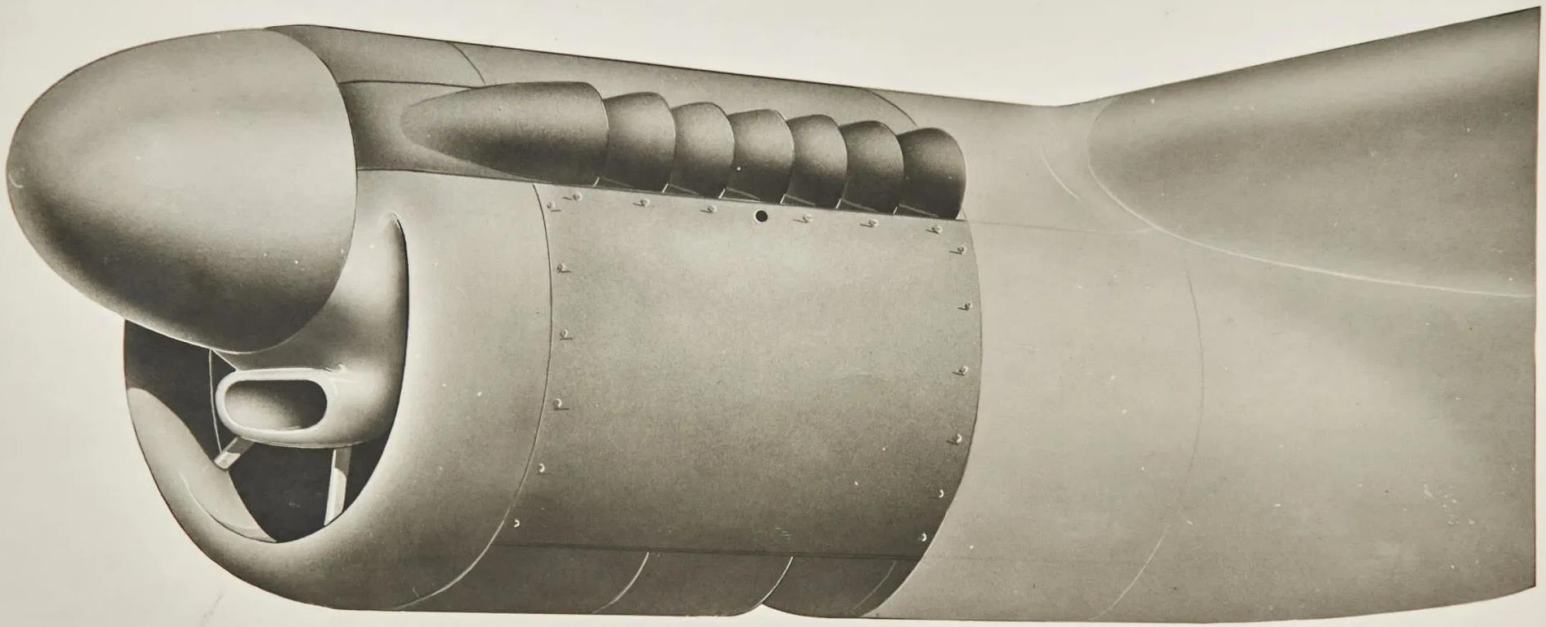
1992

<u>Caption</u>: "A drawing showing the UPP's front and back elevations"

"…Other differences include the employment of electric actuators in place of pneumatic ones and the provision of a second air-exit flap to enable the exhaust cowling louvres to be deleted…"

***FLIGHT,* February 13, 1947**

Equipment Complete



ROLLS ROYCE UNIVERSAL POWER PLANT INSTALLED

"…D.C.4M Powerplants are very thoroughly prepared to meet extremes of climate and the size and elaborate equipment of the installation can be said to be commensurate with the services provided…"

***FLIGHT,* February 13, 1947**

1995

<u>Caption</u>: "A period illustration depicting the UPP installation"

"…To gain a true picture, a visit to the Rolls-Royce flight-development and testing establishment at Hucknall would be required. It must suffice here to say that every detail has been developed and tested in the various sections of the Experimental Department where rigs have been devised to investigate the behavior of all systems and structures under the most arduous conditions before incorporating them in the powerplant…"

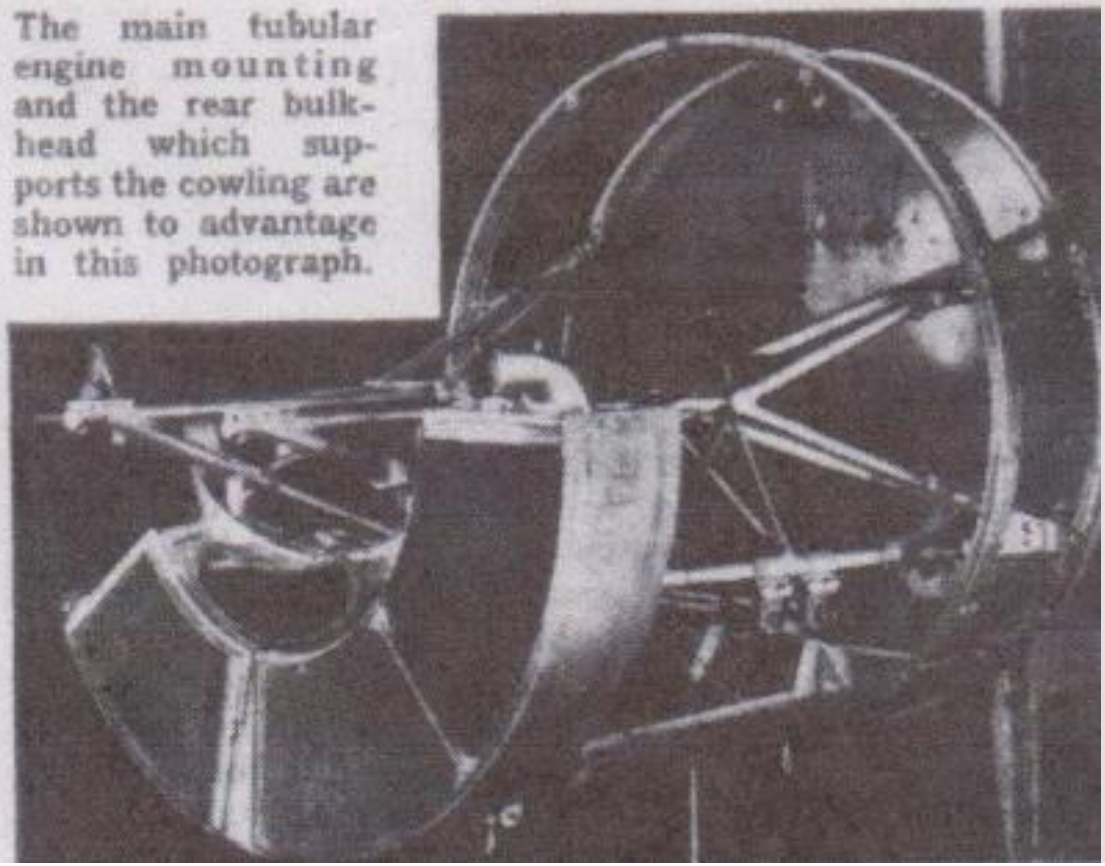
***FLIGHT,* February 13, 1947**

"…The Rolls-Royce Company does not hesitate to check and test proprietary equipment used on their civil powerplants and at all times to give advice to the manufacturers. The company accepts responsibility for the whole powerplant and rightly points-out that the reliability or, more particularly, serviceability of a powerplant, depends on the trouble-free operation of each component…"

***FLIGHT,* February 13, 1947**

Structures and Systems

"…So far, these powerplants have been described in general terms as a Merlin engine with circular cowling, standardized attachment points and a remote gear box for accessories. Details of its various structures and systems follow…"
***FLIGHT,* February 13, 1947**

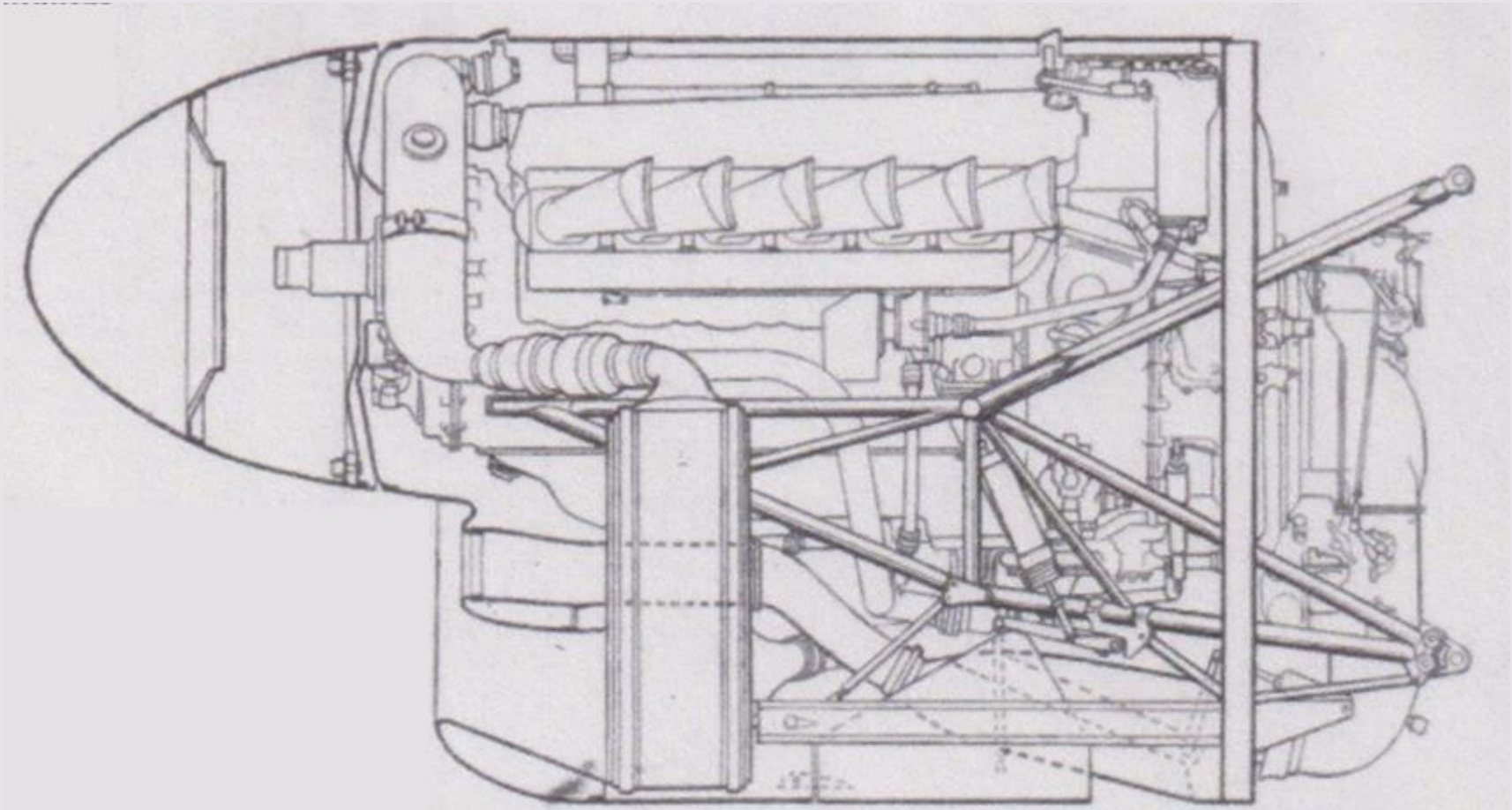


The main tubular engine mounting and the rear bulkhead which supports the cowling are shown to advantage in this photograph.

"…A rigid triangulated engine support of welded steel tubes forms the backbone of the whole powerplant. The engine is carried on four feet, of which the front two are secured by fitted bolts and the rear two by bolts which permit movement for thermal expansion. From the forward-end of the mounting is slung the beam which supports the radiators…"

2000

***FLIGHT,* February 13, 1947**



Installation drawing of the Merlin Universal Power Plant. The engine mounting, and the cooling and air-intake systems, have been accentuated.

"…Much interesting information was brought to light during wartime investigation of engine vibration. Fractures of radiators and exhaust stubs were traced to this cause and cured, in the main by redesign of mountings. The introduction of rubber mountings for radiators has increased their life tenfold…"

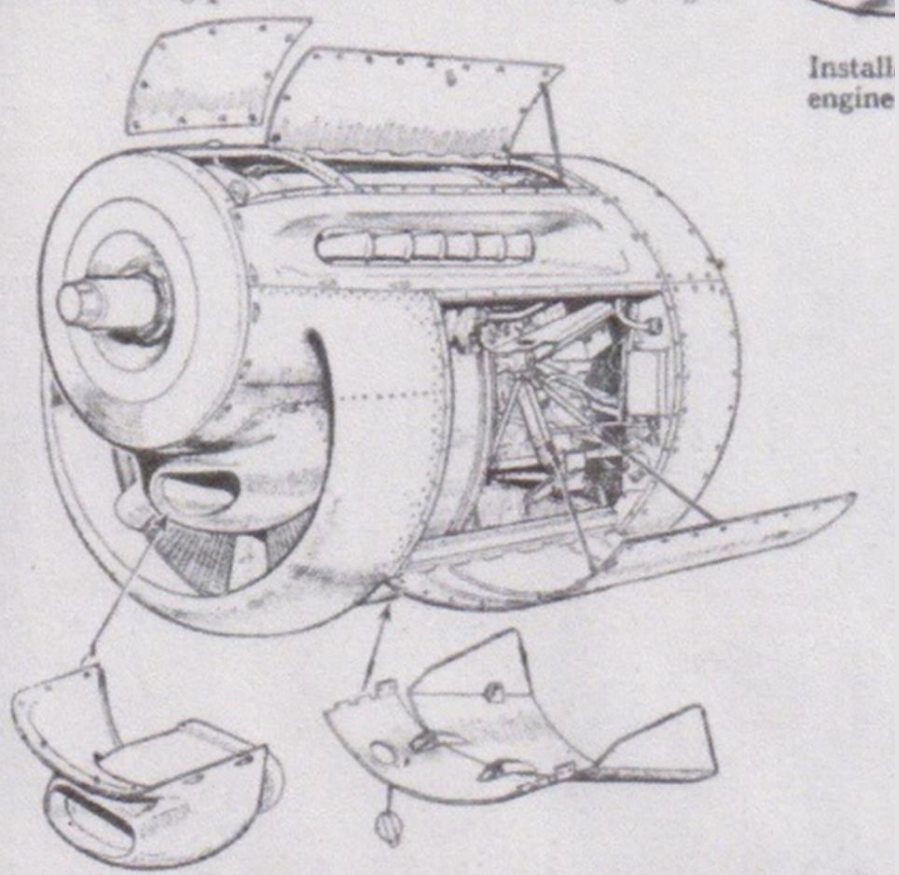
***FLIGHT,* February 13, 1947**

"…In America, incidentally, a civil aircraft cannot be granted a C of A until the whole airframe has been vibration tested. There has been no similar regulation in this country. It is understood that when the Lincoln was first tested with three-bladed airscrews, excessive vibration occurred and desynchronization between engines and air-frame was required. Four-bladed airscrews, in this case, effected a cure. A slight cropping of the airscrew blades removed a similar trouble in Mosquitoes…"

***FLIGHT,* February 13, 1947**

"…Recent strain-gauge measurements of the engine mounting have shown that the strength safety factor is considerably over the accepted figure. Work is now proceeding on a structure of reduced weight…"

***FLIGHT,* February 13, 1947**



Install
engine

U.P.P. top cowling panels are hinged to give access for inspection and the large side panels can be used as maintenance platforms. The air-intake fairing and exhaust flap are shown separately.

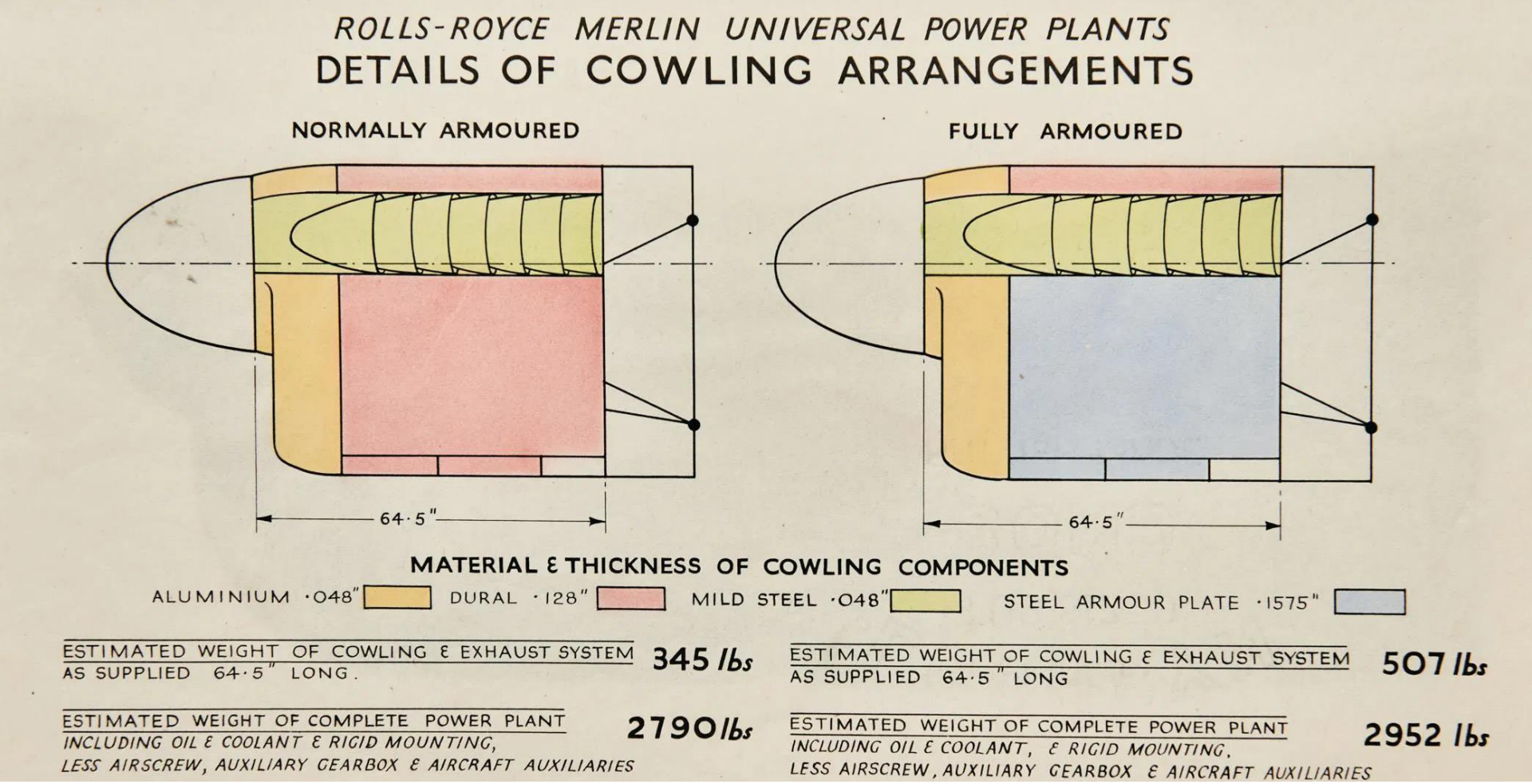
"…The main supports for the cowling are a channel-section ring at the rear and a flexible light-metal diaphragm mounted on the engine reduction gear casing in front. Top panels open like a car bonnet and side panels hinge down to form servicing platforms. The rear cowling ring is small pressure-tight panels aft of the cowling ring…"

2005

***FLIGHT,* February 13, 1947**

"…Additional sections are the radiator intake scoop which carries the air-intake fairing and the lower panel carrying hinges for the cooling flap…"

***FLIGHT,* February 13, 1947**



"…Side, top and bottom panels are made of 10 SWG Duralumin sheet which, incidentally, is sufficient to give some protection against small-arms fire and shrapnel. Full armor for military installations calls for the use of 4mm armor plate with a weight increase of about 1600 lbs. per powerplant…"

***FLIGHT*, February 13, 1947** 2007

Caption: "Armored plating options for the UPP"

"…The main induction-air intake is placed below the spinner in a forward-facing position, taking full advantage of ram. A duct leads the air back to the supercharger intake and embodied in the system are a hot-air intake and an air filter…"
***FLIGHT,* February 13, 1947**

"…A two-position forward-facing flap valve has been let into the duct at the point where it passes behind the radiators. With flap in the up position, hot air passing through the radiators is drawn into the engine and, with the pressure cowling outlet closed, an intake temperature rise of 65-deg. C is possible in conditions of extreme cold…"

***FLIGHT,* February 13, 1947**

"…Air filtration is desirable on transport aircraft, particularly those serving countries with dry climates, in order to avoid the need for engine changes before the established overhaul period…"

***FLIGHT,* February 13, 1947**

"…With the increase of rated altitudes the question of how to house a cleaner large enough not to impair performance at operating height has become a considerable problem. It has been met on the UPP by arranging to bypass the filter after the aircraft has left the ground…"

***FLIGHT,* February 13, 1947**

"…A cleaner box assembly is interposed between intake duct and supercharger, and the filter element lies roughly horizontally in it. This element is hinged at this rear-end and, on the ground, is swung upwards into filtering position. When it is swung down again after the aircraft has left the ground, the greater portion of sand or dust is shaken from it and lost through holes provided…"

***FLIGHT,* February 13, 1947**

"…The filter can be linked-up with the undercarriage of the aircraft so that it moves to the bypass position as the wheels fold-up. On the D.C.4M, installation of the filter box assembly has been removed and a collector box or trap for drain pipes etc. has been added in place of external outlets…"

***FLIGHT,* February 13, 1947**

Radiators

"…It is in the arrangement of radiators that the main visible difference between the UPP and earlier Merlin power units is seen…"

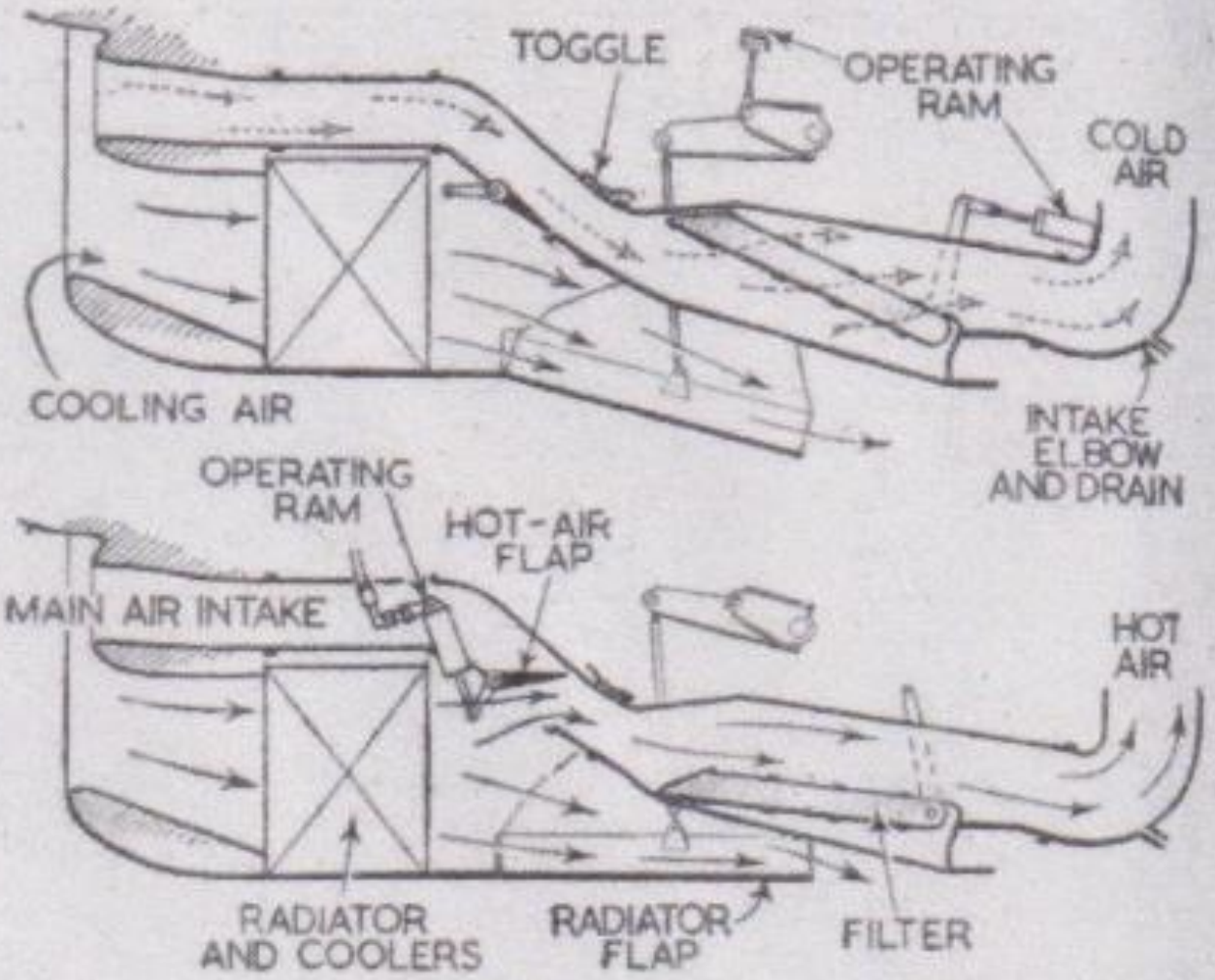
***FLIGHT,* February 13, 1947**

"…The three side-by-side segments of the semi-circular UPP assembly are, port-to-starboard, main coolant radiator, inter-cooler and oil radiators. Their respective areas are 2.75 sq. ft, 1.27 sq. ft. and 0.75 sq. ft. The three are supported from a beam attached through flexible rubber mountings to the en-gine cradle…"

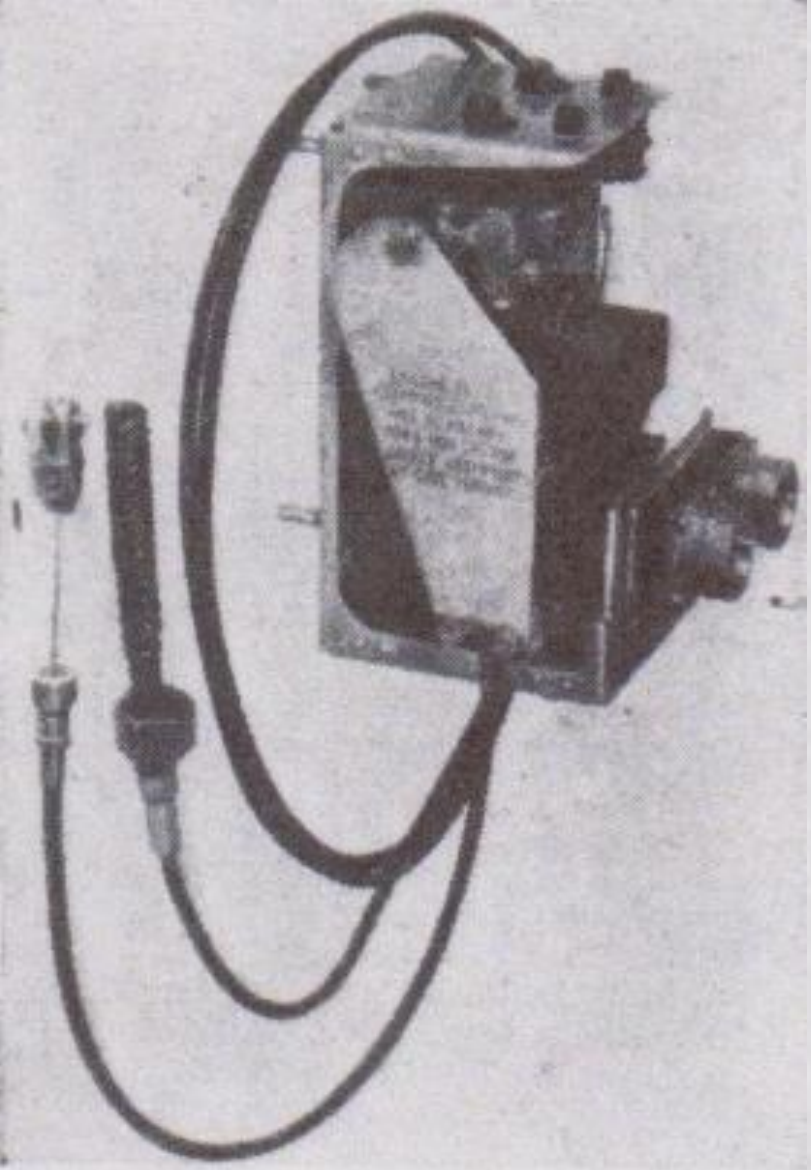
***FLIGHT,* February 13, 1947**

"…Air enters through the forward scoop, passes through the radiators and into the pressure cowling and is exhausted round the exhaust stubs and through a flap-controlled outlet below. This flap is operated by what is known as an 'inching' control and for the normal range of working positions its positioning is automatic…"

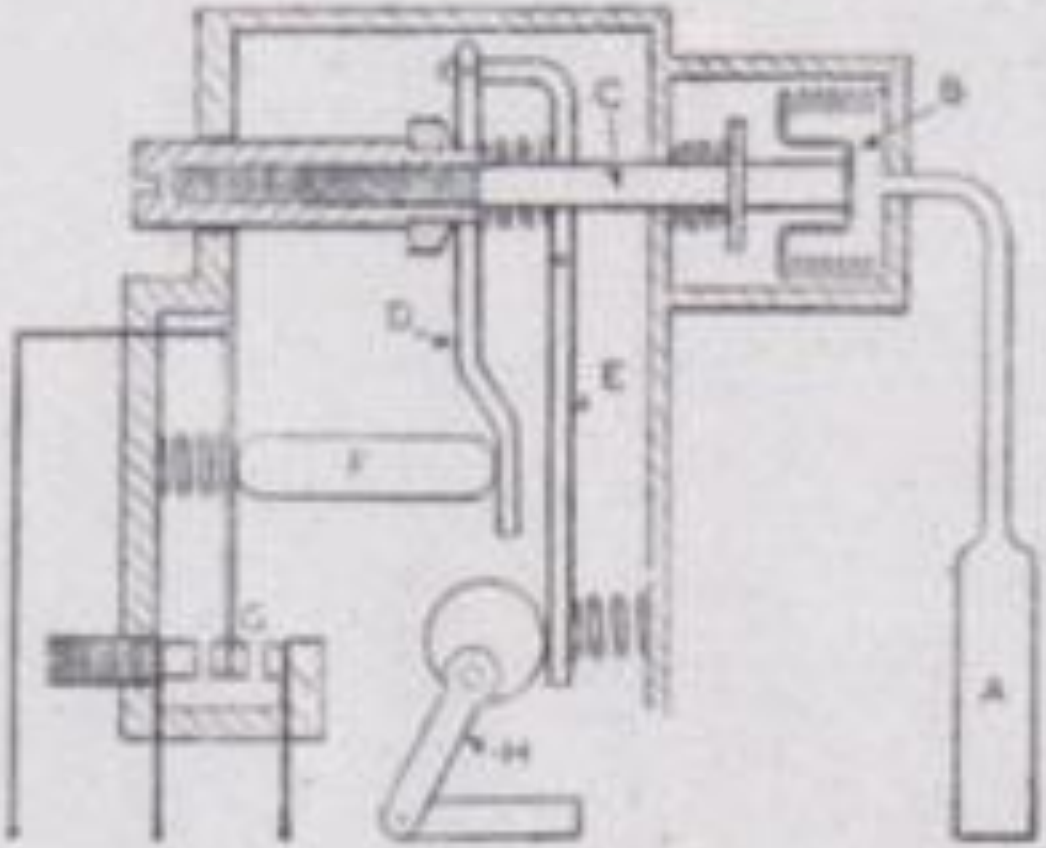
***FLIGHT,* February 13, 1947**



Details of the hot and cold air intake and air filter systems are shown in these diagrams. The air flow through the radiators and out through the main outlet flap is also indicated.



The radiator flap "inching" control unit. The phial for the header tank and the Bowden cable for the follow-up lever are also shown.



The inching control thermal switch in diagrammatic form. A phial ; B bellows. C, D and F transmit movement of the bellows to double contact switch G. H follow-up arm and cam responding to flap movement. E lever transmitting cam movement via D and F to break circuit at G.

2019

"…From normal 'operating closed' to 'fully closed' position it is manually controlled (except on the D.C.4M which is automatic over the whole range). The system also has an automatic emergency override control and in the event of component failure, a serviceable trailing position is assumed by the flap…"

***FLIGHT,* February 13, 1947**

"…The 'inching control,' developed by Teddington Controls, Ltd., is applicable to coolant; oil or cabin air systems and in this particular case holds the Merlin coolant temperature between low and high limits of 105 and 125 deg. C. It represents an advance over bypass thermostats in several respects and provides much closer control than the earlier two-position 'open and normal' type radiator flap controls…"

***FLIGHT,* February 13, 1947**

"…Unlike previous systems, the 'inching control' (so-called because it is capable of 'inching' or moving the air outlet flap in a large number of steps) permits the maintenance of a temperature balance for engine heat output, so providing a flap position of minimum drag for particular running conditions…"

***FLIGHT,* February 13, 1947**

"…A later refinement is the provision for 'step inching,' that is, limitation of flap response to that induced by a suitable predetermined change in temperature, generally about one-degree C, thus reducing wear-and-tear in the actuating mechanism…"

***FLIGHT,* February 13, 1947**

"…In the D.C.4M the inching control unit or thermal switch is located on an anti-vibration mounting. A phial is let into the header tank and the follow-up arm is connected with the air outlet through a Bowden cable. Very briefly the principle is that in response to changes in coolant temperature, bellows operate a switch arm opening or closing one or other of two electric circuits. These, through either an electric screw or pneumatic actuator, cause the flap to open or close with rise or fall in temperature. The movement of the flap is transmitted back to the thermal switch via the follow-up lever so as to neutralize the movement of the switch arm occasioned by the original change in temperature…"

***FLIGHT,* February 13, 1947**

"…Methods and materials of radiator construction have undergone a number of changes during the last few years. It is interesting that the practices employed in America differ considerably from those in this country. Rolls-Royce Engineers are investigating further alternatives…"

***FLIGHT,* February 13, 1947**

"…Incidentally, radiators and cooling were the first installation problems tackled by the company on the formation of the Flight Experimental Establishment at Hucknall…"

***FLIGHT,* February 13, 1947**

"…The main changeover during the war was from honey-comb to secondary surface (fin and tube) construction and it resulted in greatly simplified production and startling reductions in price…"

***FLIGHT,* February 13, 1947**

"…Difference of materials is, of course, responsible for some of the change in price. In this country copper and 50:50 solder are still the principal ingredients. America and France, however, favor aluminum. American practice is to expand extruded aluminum tubes into header plates, while in France a secret brazing process has been developed in conjunction with drawn tubes. Several methods are used in this country, based on copper tubes and dipping methods. One technique is to apply a 1/2 thou. silver skin and then to heat the block in an inert atmosphere…"

***FLIGHT,* February 13, 1947**

"…Some corrosion troubles have been experienced with aluminum radiators used with glycol. A solution may be a completely aluminum system, i.e., aluminum pipes, header tank etc., in that the electrical potential between copper and aluminum gives high corrosion rates…"

***FLIGHT,* February 13, 1947**

"…In commercial-type aircraft cost and weight are particularly important and the use of aluminum might result in a major weight saving over existing types of radiator…"
***FLIGHT,* February 13, 1947**

"…Honeycomb construction permits a saving in weight, but the liquid content is high, the weight of water per-square-foot of the frontal area being in the ratio of 15 lbs.-to-5 lbs. for the secondary-surface type with its small passages…"
***FLIGHT,* February 13, 1947**

"…Oil coolers are mostly of the honeycomb type because of the low viscosity of the fluid and the next stage will probably be a change to aluminum construction. Intercoolers are similar in construction to the main coolant radiators, but brazing is usually employed in place of solder because of the higher temperatures and pressures…"

***FLIGHT,* February 13, 1947**

"…One source of trouble experienced due to bad design of an oil system is frothing. A 'hot pot' must be able to separate up to 100 per cent of air from the oil for on the dive or climb, either the front or rear scavenge pump intake in the engine will be clear of oil. There is normally about 20 per cent of air by volume on the pressure delivery side of the system…"
***FLIGHT,* February 13, 1947**

"…A greater problem is to make provision for the enormous rise in pressure on starting at sub-zero temperatures. From a normal scavenge pressure of about 20 lbs./sq. in, it may rise momentarily to 200, which is at least 100 lbs. higher than the average oil cooler is built to withstand. The present control valves prove inadequate in extreme cold and surge valves are now being fitted for countries in which sub-zero starts might be made…"

***FLIGHT,* February 13, 1947**

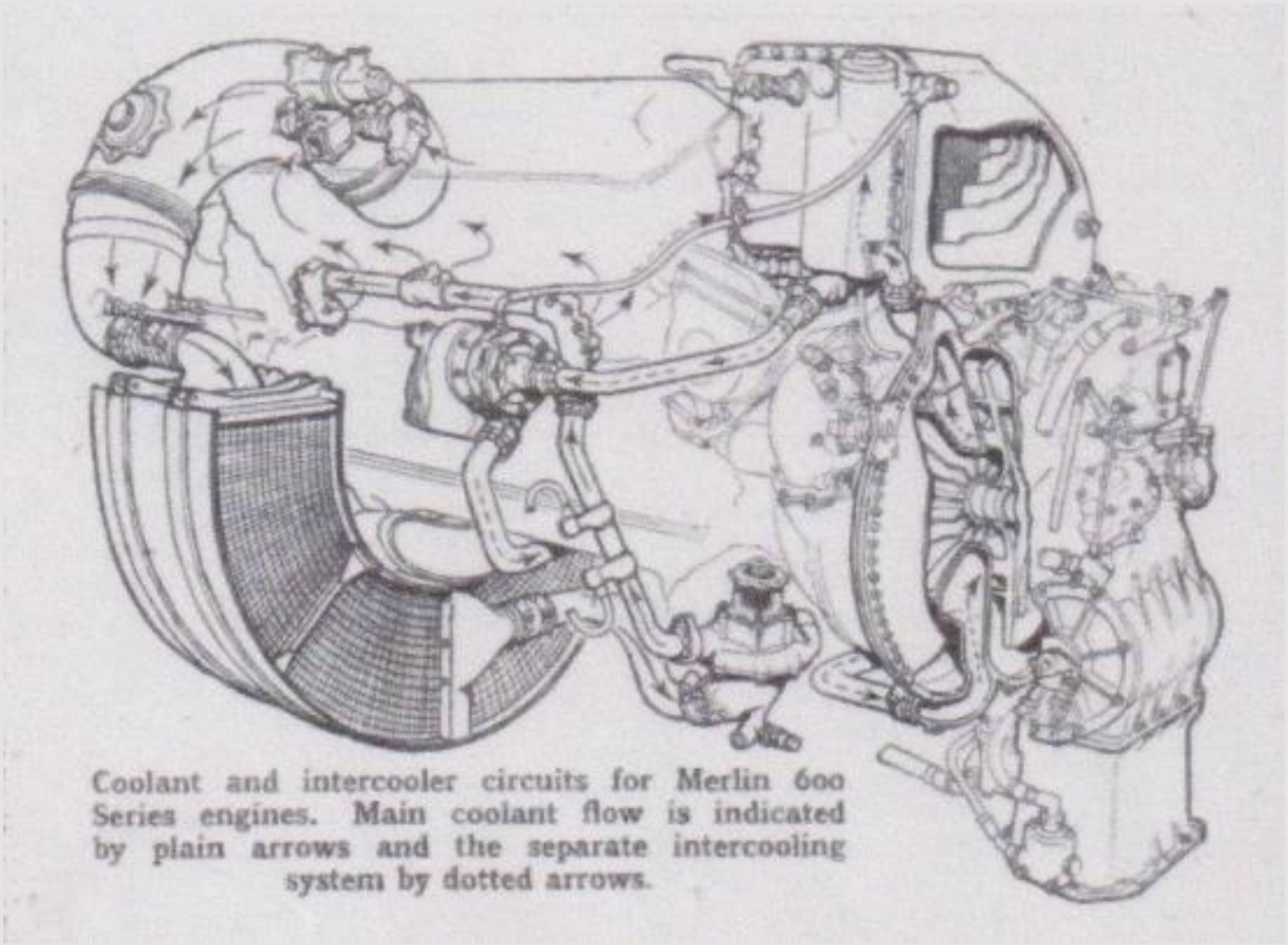
"…The header tank for the coolant system is somewhat smaller than in earlier installations and carries a thermostatic relief valve and a quick-release filler cap. Because a considerable pressure exists in the system at higher temperatures, this cap is designed to prohibit removal under conditions that might be dangerous to the Service Engineer…"

***FLIGHT,* February 13, 1947**

"…A 30:70 per cent ethylene-glycol water mixture is used in normal climatic conditions and separate systems with separate engine-driven circulating pumps are used for main cooling and for the intercooler…"

***FLIGHT,* February 13, 1947**

"…Civil Merlin installations have in the cockpit low-flow indicators which include warning lights automatically switched on should leakage or pump failure reduce the capacity or circulation of engine coolant to a dangerously low level…"
***FLIGHT,* February 13, 1947**

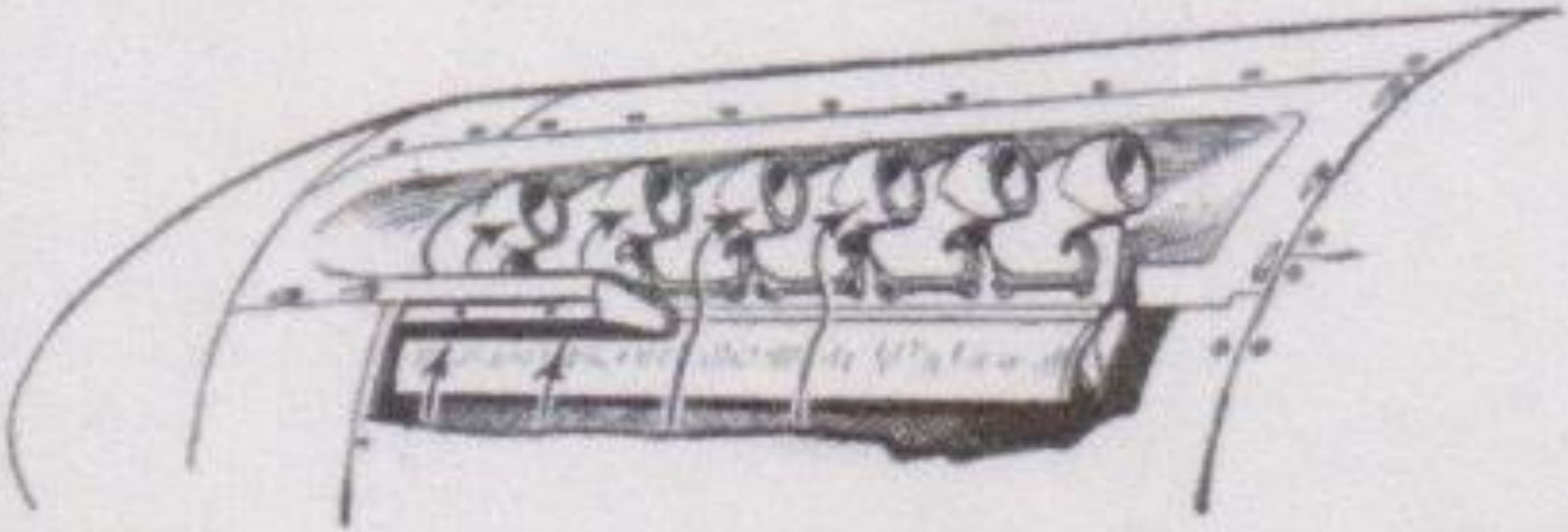


Coolant and intercooler circuits for Merlin 600 Series engines. Main coolant flow is indicated by plain arrows and the separate intercooling system by dotted arrows.

"…Rolls-Royce are now tackling the problem of pipes and hoses and the design of connections which are thought to be in need of improvement to keep pace with other components. A satisfactory all-metal flexible pipe with screwed connection is one of the aims…"

***FLIGHT,* February 13, 1947**

Exhaust System



Louvred ejector type exhaust stubs. Air flow from the pressure cowling is indicated by the arrows.

"…For the original UPP as fitted to the Linclon night bomber, exhaust flame damping was essential and, as has been mentioned, the air-cooled manifolds and fishtails, which project independently from the cylinder blocks into the two louvred exhaust panels, are very efficient in this matter…"

2041

***FLIGHT,* February 13, 1947**

"…The exhausts terminate in curved fishtails with gin slits. Flame damping is achieved in this manner with minimum loss of power due to back pressure, but at the expense of some exhaust thrust…"

***FLIGHT,* February 13, 1947**

"…On civil installations the fishtails were replaced by round stubs to regain thrust, but they proved to be noisy. The answer to the silencing problem may be long pipes carried below the wing and acceptance of loss of thrust and increase of weight, although on the D.C.4M this is impracticable because of the engine position in relation to the leading edge. A modified fishtail may still be used for this installation…"

***FLIGHT,* February 13, 1947**

"…Since a fuel supply failure may stop an engine even more quickly than a mechanical failure, Rolls-Royce have made themselves responsible for testing the whole fuel systems except for the tanks. As with other services; tanks, pumps, filters, lines and cocks are all assembled as an installation on a test rig and fuel supply is checked in all attitudes and under extreme conditions of temperature and pressure…"

***FLIGHT,* February 13, 1947**

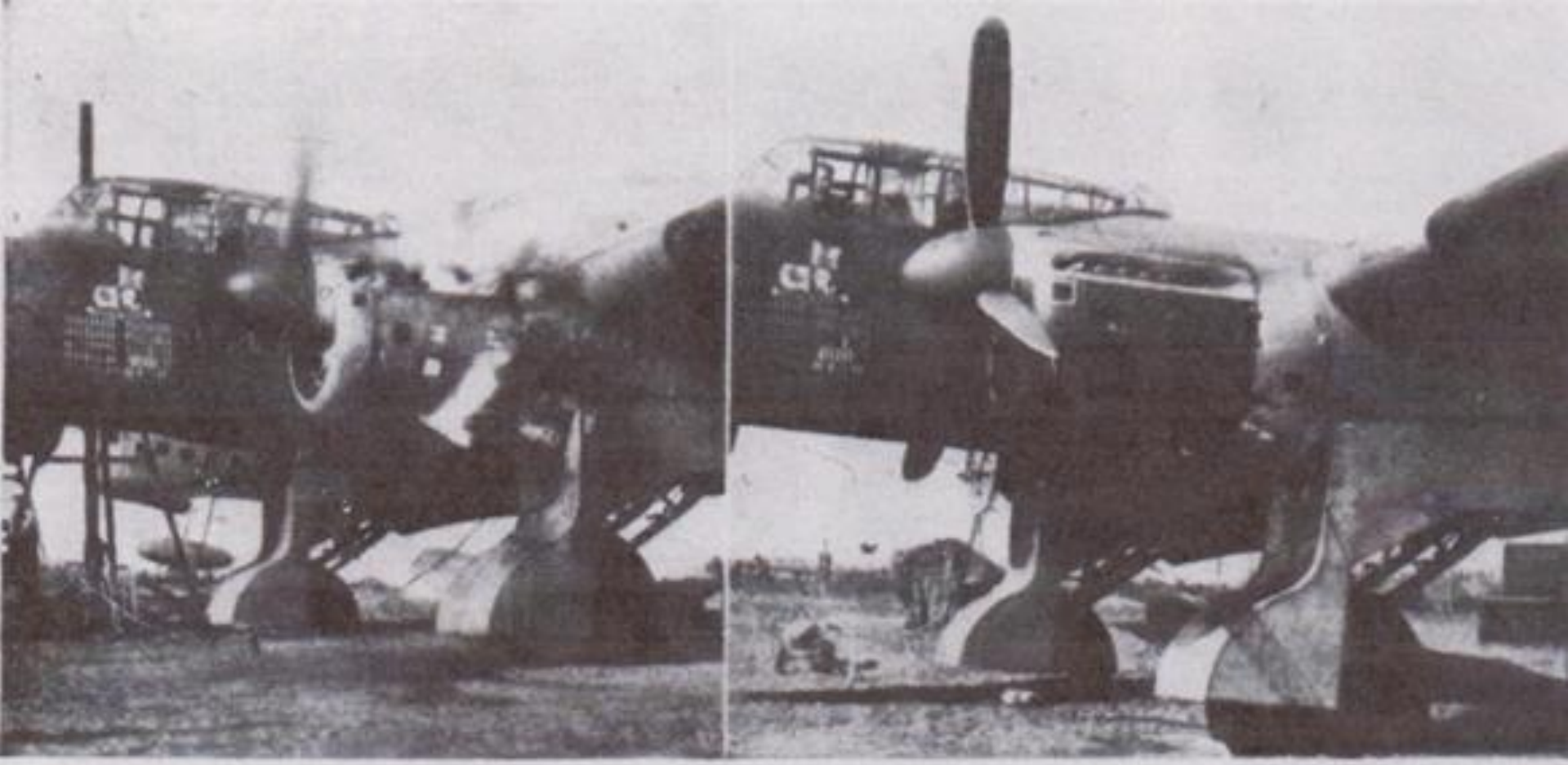
Fire Extinguishing

"…Rolls-Royce, Ltd., have made a special study of fire prevention and extinguishing and all civil powerplants now meet world requirements…"

***FLIGHT,* February 13, 1947**

"…A multi-bottle system of spray nozzles at strategic points around the engine have proved satisfactory on many full-scale tests conducted at Hucknall…"

***FLIGHT,* February 13, 1947**



A retired operational Lancaster is used to test fire extinguishing systems. (Left) A fire is caused in an engine running at full speed and with the slipstream of another Lancaster, standing immediately in front, passing over it. (Right) A few seconds later the airscrew is feathered and the fire successfully extinguished.

"…Accompanying illustrations give a good idea of such a test in progress, although the second Lancaster, standing just in front of the burning engine and providing slipstream from its engines at full throttle, is not shown…"

***FLIGHT,* February 13, 1947**



<u>Caption</u>: “A prototype UPP during fire suppression testing on the adapted wing bulkhead of Lancaster EE134 ca. 1944. The former bomber was modified at Hucknall to take the civil version of the Merlin on its in-board port and both bulkheads of its starboard wings.”

"…Several important changes have taken place among the minor components of the powerplants and in some instances, these must also be mentioned as differences between the D.C.4M and Tudor plants…"

***FLIGHT,* February 13, 1947**

"…First, the actuators on the D.C.4M are all of the Rotax and Miles electric screw type because the Canadians believe these are better suited to operation in extreme cold. Engineers at Hucknall support this contention, but believe that the alternative electro-pneumatic rams can be made satisfactory for very low temperatures with the use of suitable natural rubber…"

***FLIGHT,* February 13, 1947**

"…TCA require their D.C.4Ms to operate at -40 deg. C and synthetic rubber washers become hard and may cause air leaks at less than -30 deg. C. Electric screw actuators are somewhat heavier than pneumatic ones and must be covered by safety devices to provide automatic opening or closing as appropriate in the event of failure…"

***FLIGHT,* February 13, 1947**

"…Another Canadian modification is the fitting of stainless-steel pipes in place of copper ones, which might eventually fatigue and crack. In addition, all plants are to have new semi-rigid ignition conduits of nickel-plated steel. These will give better protection against oil, moisture and vibration and will improve the appearance considerably…"

***FLIGHT,* February 13, 1947**

"…With oil absorption and fire risks in mind, a new type of flexible pipe is being used which is rubber-covered and asbe-stos-lagged…"

***FLIGHT,* February 13, 1947**

"…A small engine modification which gives much improved accessibility is the side-mounting for the airscrew CSU. An additional advantage of this modification is that it permits the use of a simple rod control in place of a remote system…"
***FLIGHT,* February 13, 1947**

"…The foregoing description will, it is hoped, have indicated something of the enormous amount of thought and research which goes into. the preparation of a modern Universal Power Plant. As a result, engines are equipped to meet almost every climatic emergency and are capable of very long running periods before overhaul, followed by only a few hours of aircraft unserviceability for powerplant change…"

***FLIGHT,* February 13, 1947**

DATA SUMMARY

	Merlin 61	Merlin 620	Merlin 621 (D.C.4M)
Engine weight (net dry)	1,700 lb.	1,740 lb	1,740 lb
Take-off power	1,725 b.h.p.	1,725 b.h.p.	1,725 b.h.p.
Max. cruising (at 23,500 ft. consumption 98 g.p.h.)	1,160 b.h.p.	1,160 b.h.p.	1,160 b.h.p.
Power plant weight	2,790 lb	2,806 lb	2,830 lb
Diameter	55.8 in	55.8 in	60 — 55.8 in (tapering)
Length overall	83.5 in	83.5 in	84.35 in

"…The overhaul period for the Merlin engine varies according to the air service on which it is used and a representative figure is 650 to 750 hours. Many of the accessories and services now have overhaul periods upwards of 1,500 hours."

2057

***FLIGHT,* February 13, 1947**

Part 18

Hucknall

An Intriguing Tale

Concluding his examination of Hucknall's Flight Test Establishment, Nigel Gibson opens his father Colin's scrapbooks and photo albums to reveal the intriguing tale of Rolls-Royce's Universal Power Plant

***key.aero,* July 30, 2022**

RE: introduction to an article written by *Nigel Gibson* entitled: "The Fascinating Story of Rolls-Royce's UNIVERSAL POWER PLANT"

Only One Thing

"FOR a Rolls-Royce Aero-Engineer of a certain age, the acronym 'UPP' means only one thing, the Universal Power Plant…"

***key.aero*, July 30, 2022**

Bolt-on/Bolt-off

"…This was an idea researched by Rolls-Royce - a wing-mounted assembly that could incorporate all the main ancillary components and systems needed to support an aero-engine. It was essentially a bolt-on/bolt-off assembly allowing for rapid powerplant repair or replacement and crucially, could be used on both civil and military aircraft of many different types…"

***key.aero,* July 30, 2022**

FTE



"…The concept was developed and tested exclusively at Hucknall in Nottinghamshire…"

***key.aero,* July 30, 2022**

<u>Caption</u>: "The Hucknall flight-line in 1938. Left-to-right: Fairey Battle prototype K7572, Hawker Horsley S1436, Whitney Straight G-AEUZ, Heinkel He 70 G-ADZF, and Hawker Fury K3586 with two Harts, K2969 and K3036. The first indoor test-bed buildings can seen in the background."

"…Born from hours of rigorous testing in the air and on the ground, it was started by the team that would become the Rolls-Royce Hucknall Flight Test Establishment (FTE), under the personal direction of Ernest Hives, the visionary Engineer who had originally suggested the idea…"

***key.aero,* July 30, 2022**

RE*: Ernest Hives* (1886-1965) was a motoring pioneer, magazine proprietor, influential parliamentarian and devoted R-R owner. As well, he was a pivotal figure in the early days of R-R, driving R-R's success in the great motor trials of the early 20th century, before becoming Chairman of the Board in 1950.

Exponential Growth



"…Over the course of 87 years, the Rolls-Royce site at Hucknall grew with an ever-expanding remit. From just two hangars and a shared grass airfield, it eventually incorporated nine hangars, 11 outdoor test-beds, numerous indoor test rigs, two Wing Hangars, an X-ray rig and a cold room…"
***key.aero,* July 30, 2022**

<u>Above</u>: Hucknall airfield (right). By 1956, the RAF had moved out of the airfield (the grass airfield had proved unsuitable for regular operation of jet aircraft). To bring all flight-testing back to Hucknall, a 6K foot-long by 150 foot-wide tarmac runway was completed in late 1955.

"…It was also home to wind and fire tunnels, experimental and design drawing offices, a fire station, factory buildings, a 7,000 yd. runway with its own air traffic control tower and even its own leisure facility and sports ground…"

***key.aero,* July 30, 2022**



<u>Caption</u>: “An early aerial shot of the Hucknall Flight Test Establishment. Left of the central fence line is RAF Hucknall.”

2071



"…In 1950, Hives was made a Lord in recognition of his services to the nation. That year the company hosted a garden party and a dinner in his honor. The Chairman's report paid special tribute to Hives and his achievements: 'In the King's Birthday Honors List, Hs [Hives – all Rolls-Royce Managers were given an abbreviation based on letters in their name] was raised to the peerage in recognition of his services to the nation and will take the title of Lord Hives (1st Baron Hives of Duffield). Hs joined the firm in 1908 as an ordinary worker, but it was not long before he was recognized as a person of great ability and when an experimental section was formed, he was the one chosen to take charge. This section soon developed into a department, with Hs at the helm'…"

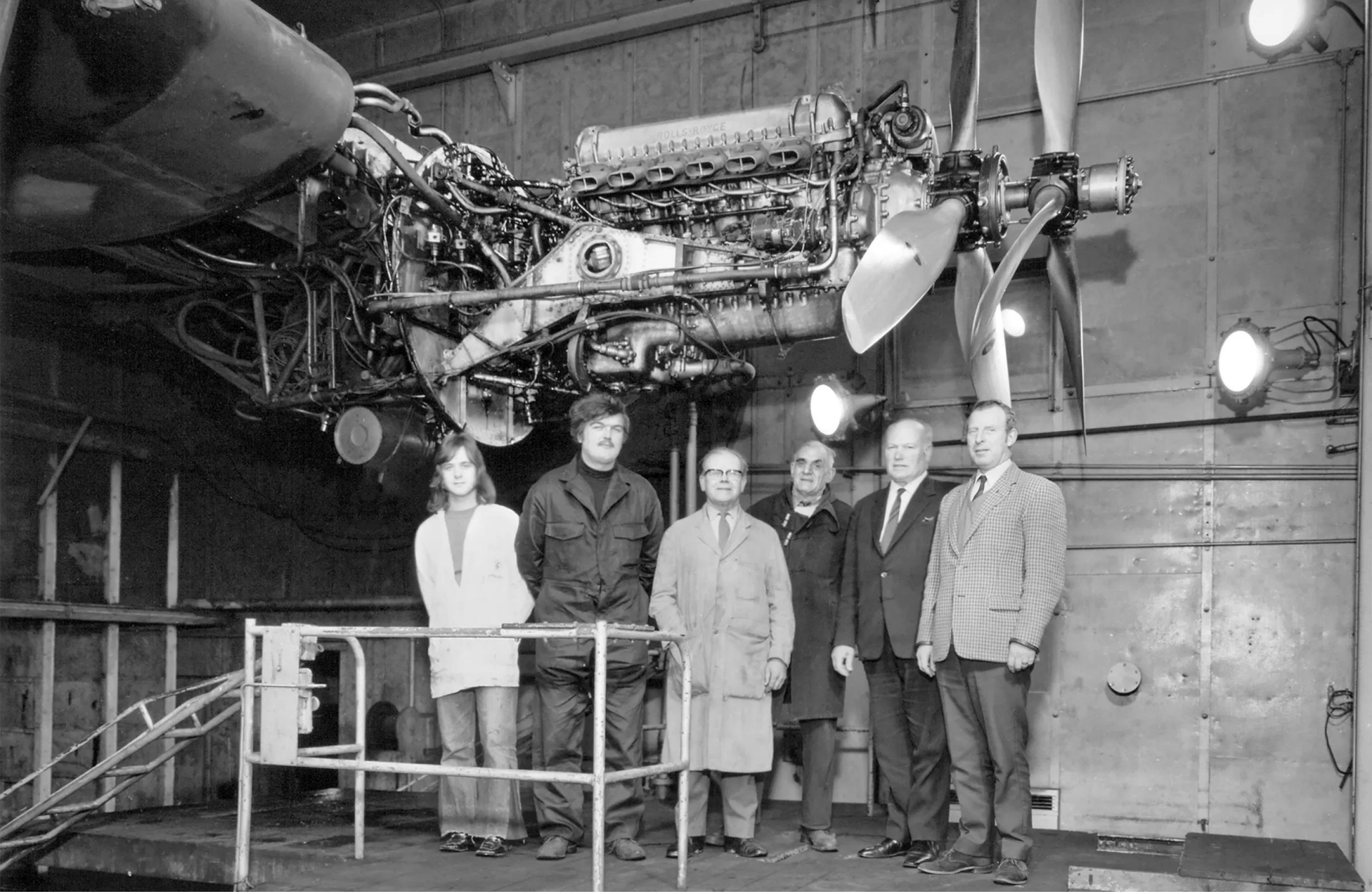
***key.aero,* July 30, 2022**

<u>Caption</u>: "R-R's Ernest Hives"

Changing Fortunes

"…Inevitably, times change. All test flying from the site ended in 1972 and subsequently many of the Hucknall hangars were altered or adapted for other uses by the company. In more recent years, the site has understandably seen many alterations, largely due to changes in the industry, with government regulations and fluctuating market forces causing it to slowly contract…"

***key.aero,* July 30, 2022**



<u>Caption</u>: “A quiet commemoration is held on the last day of testing in February 1972. The team stands proudly in front of the Shackleton’s contra-rotating props and Griffon engine RG30SMS. “

"…A new housing estate now stands on the site of the original World War One aerodrome landing site and much of the 1950s runway and control tower has gone. The large paddock for the outdoor test-beds finally fell silent in 2008 and now hosts an industrial park…"

***key.aero,* July 30, 2022**

"…As a tribute to its past, new roads carry the names of some of the early FTE pioneers: Dorey Way, Shepherd Street and Lovesey Avenue. Finally, a new primary school has been named the 'Flying High Academy,' to honor the department's memory and achievements…"

***key.aero,* July 30, 2022**



<u>Caption</u>: "Rolls-Royce's first three salaried test pilots, Ronnie Shepherd, Ronnie Harker and Harvey Heyworth seen here with Hucknall managers in front of a Fairey Battle"

TMR



"…The two Wing Hangars still stand proudly at the rear of the site, just yards from where the famous 'Thrust Measuring Rig' (popularly known as 'the flying bedstead') made its first vertical leap into the air using Rolls-Royce jet power, giving Hucknall another world first…"

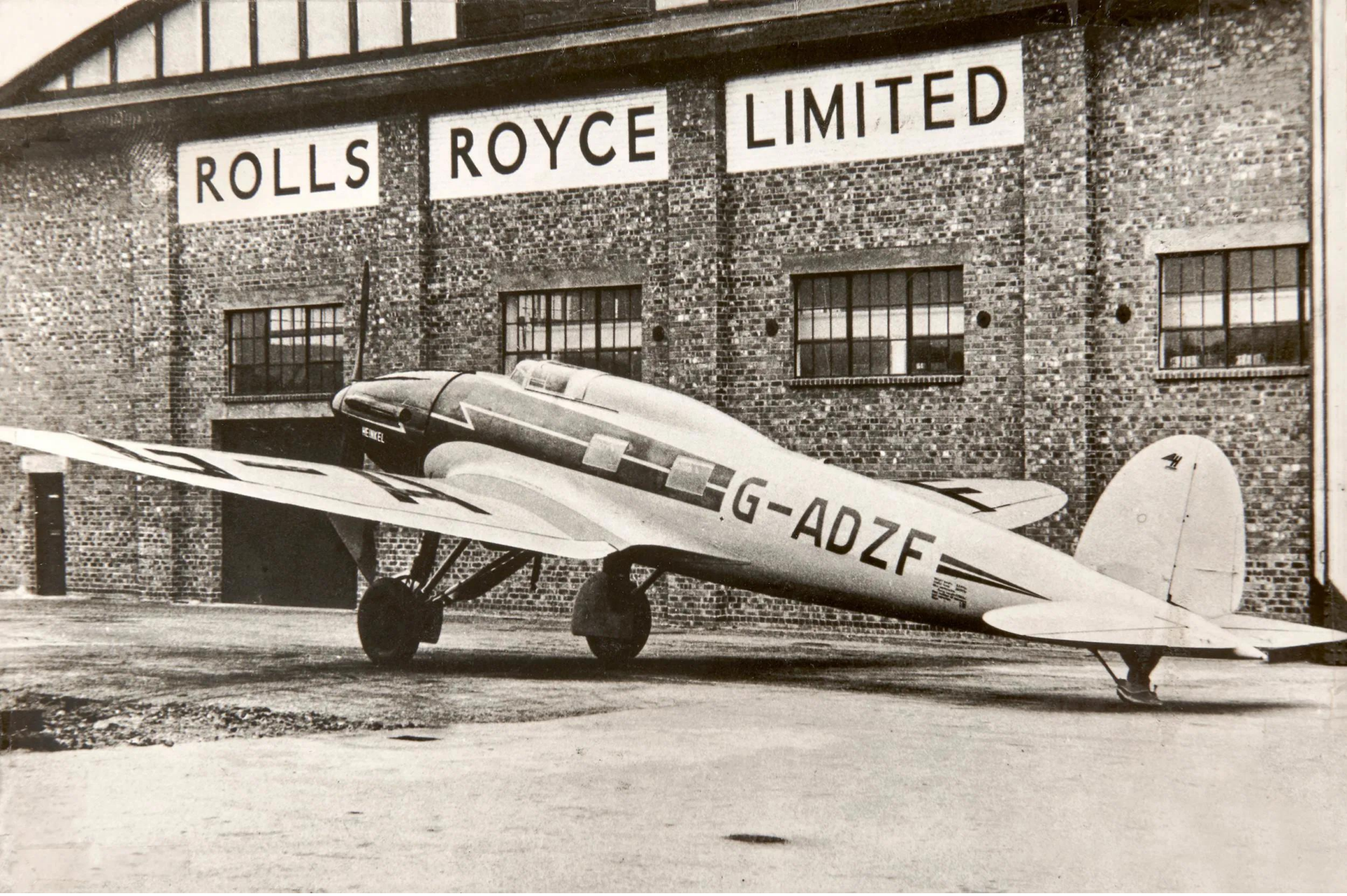
***key.aero,* July 30, 2022**

Above: on August 19, 1953, a prototype of the very first Vertical Take-off and Landing (VTOL) aircraft made its maiden flight at Hucknall Aerodrome. The pioneering and experimental aircraft (officially known as the Rolls-Royce *Thrust Measuring Rig* (TMR) was the first of its kind.

For Posterity

"…Dating from 1944 and remaining close to original condition, the Wing Hangars were listed Grade 2 by Historic England in 2018. They provide a permanent home to the Hucknall branch of the Rolls-Royce Heritage Trust, used by members since 1983…"

***key.aero,* July 30, 2022**



<u>Caption</u>: “Heinkel He 70 G-ADZF alongside the Rolls-Royce Belfast hangars at Hucknall in March 1936”

Storytelling



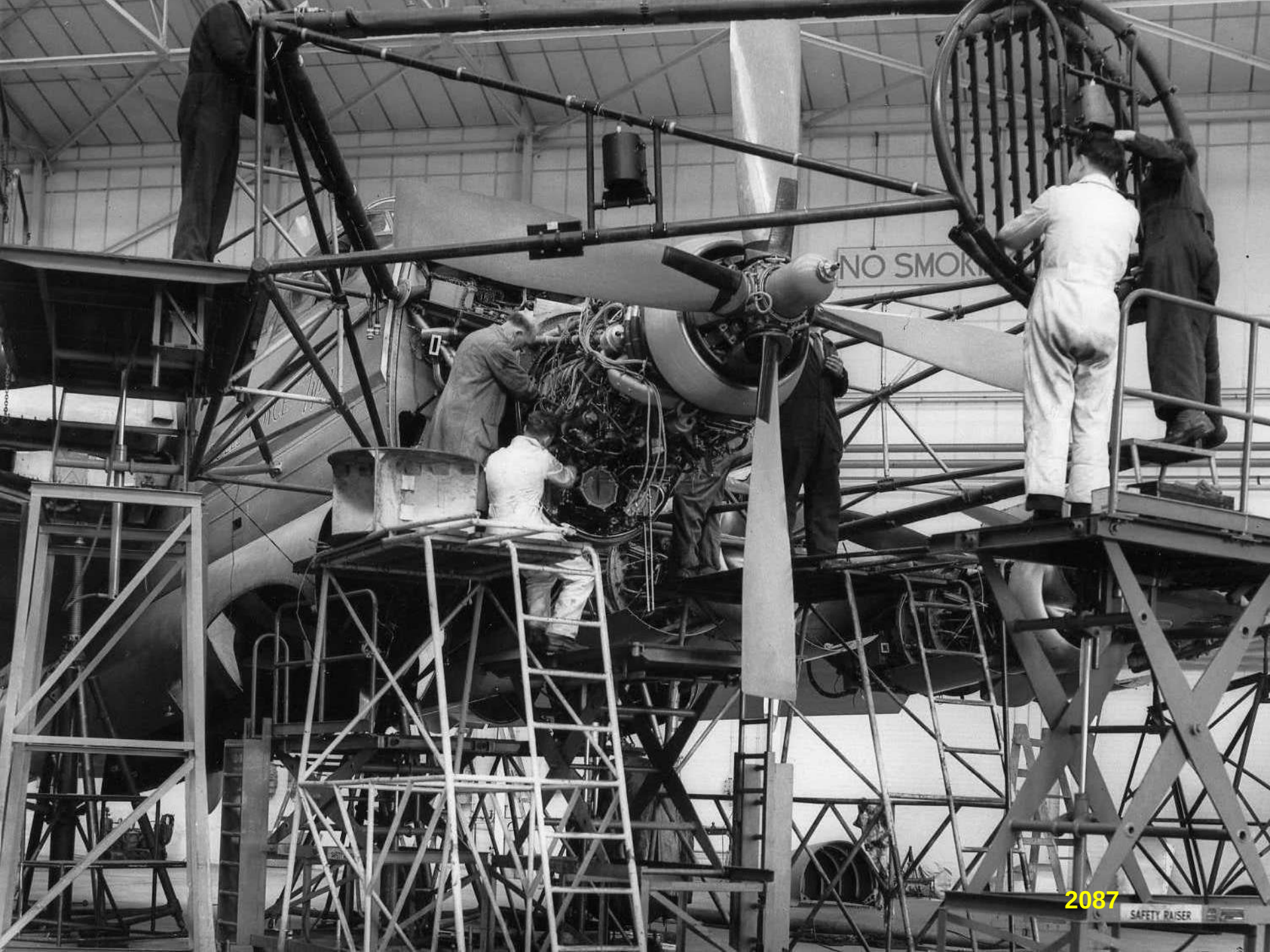
"…Over four decades, these retired Aero-Engineers and volunteers have created a wonderful museum telling Hucknall's FTE story, containing a workshop to restore engines, model test aircraft displays, an exhibit space and an extensive document archive, which traces the history of the establishment back to its earliest incarnations…"

***key.aero,* July 30, 2022**

RE: opening in January 1934, the R-R FTE went on to lead the world in the flight development of aero-engines for the next 30 years, contributing significantly to the "golden years" of British aviation



The museum is housed in the Hucknall Wing Hangar (above), a rare 20th century Grade 2 listed industrial building, originally constructed in 1944. It was built to provide dedicated ground test facilities for ongoing Merlin and Griffon engine development. The building consists of two test hangars, originally with an aircraft wing section suspended in each. Both hangars are joined by a central blockhouse which provided test control facilities. Engines would be mounted on the articulating wing section for testing in an identical manner to a service aircraft installation, enabling a full range of simulated engine stress tests to be carried out.


NO SMOK
2087
SAFETY RAISER

Visitors can see exhibits relating to both the flight-testing th-at took place at the largely secret Rolls-Royce Hucknall Flight Test Establishment from 1934 to 1971 and the equally import-ant specialist ground testing that continued at Hucknall up until the early 2000s.

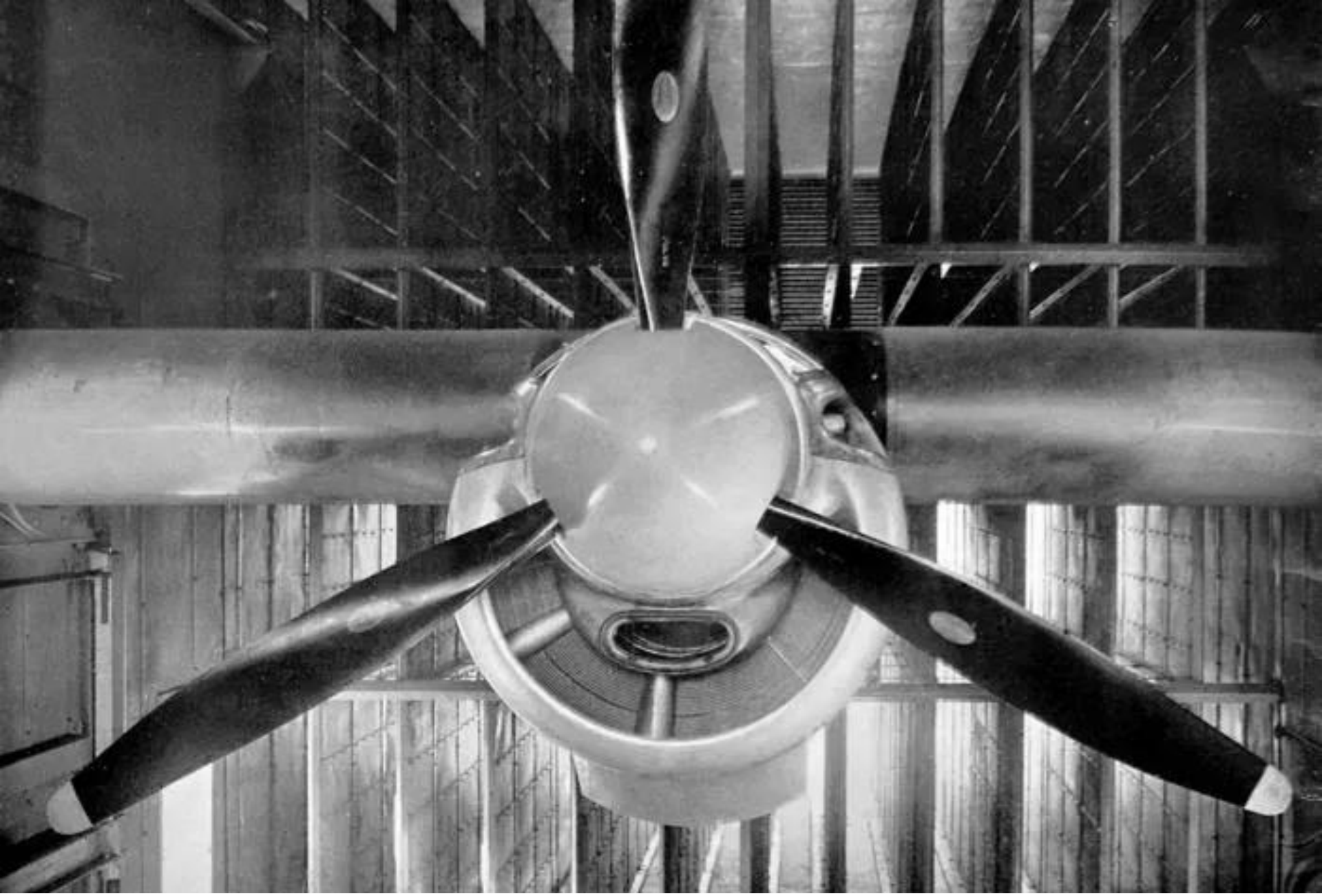


2089

Forward Thinking

"…The two Wing Hangars were originally purpose-built for Hives' team to develop his Universal Power Plant idea. They each supported a Lancaster wing section and single engine bulkhead, to accept the annular (circular) and fully cowled Merlin and Griffon powerplants…"

***key.aero,* July 30, 2022**

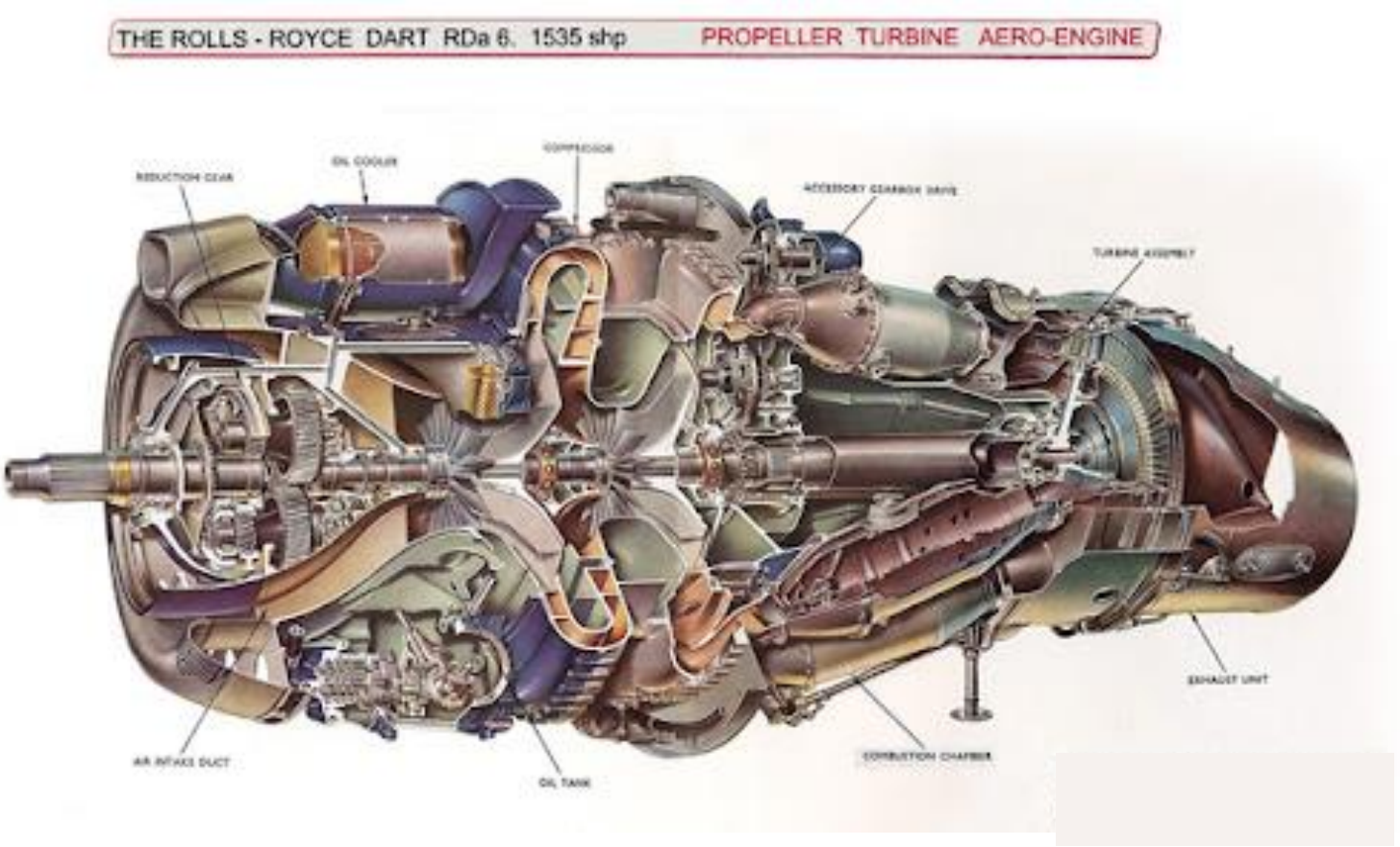


<u>Caption</u>: "The DC-4M Merlin powerplant on the Lancaster wing section with floor-to-ceiling acoustic baffles behind it, ca. 1944"

Peace Dividend

"…These were being tested in readiness for the anticipated expansion of global air traffic, for both cargo and passengers, which the company knew peace would bring…"
***key.aero,* July 30, 2022**

Enter the Jet Age



"…As the jet engine quickly gained precedence, one of the test cells was converted to develop the Dart turboprop and then the Conway, which pioneered the twin shaft bypass turbofan engine, another first for the company and the grandfather of all the modern bypass engines in airline service today…"

***key.aero,* July 30, 2022**

RE: the R-R RB.53 Dart was a turboprop engine designed and manufactured by Rolls-Royce Ltd. First run in 1946, it powered the Vickers Viscount on its maiden flight in 1948.



Prototype Viscount c/n 1 G-AHRF on its maiden flight 16 July 1946

2097

Trouble-free

500 Hours of Simulated Operational Conditions Completed Without Trouble

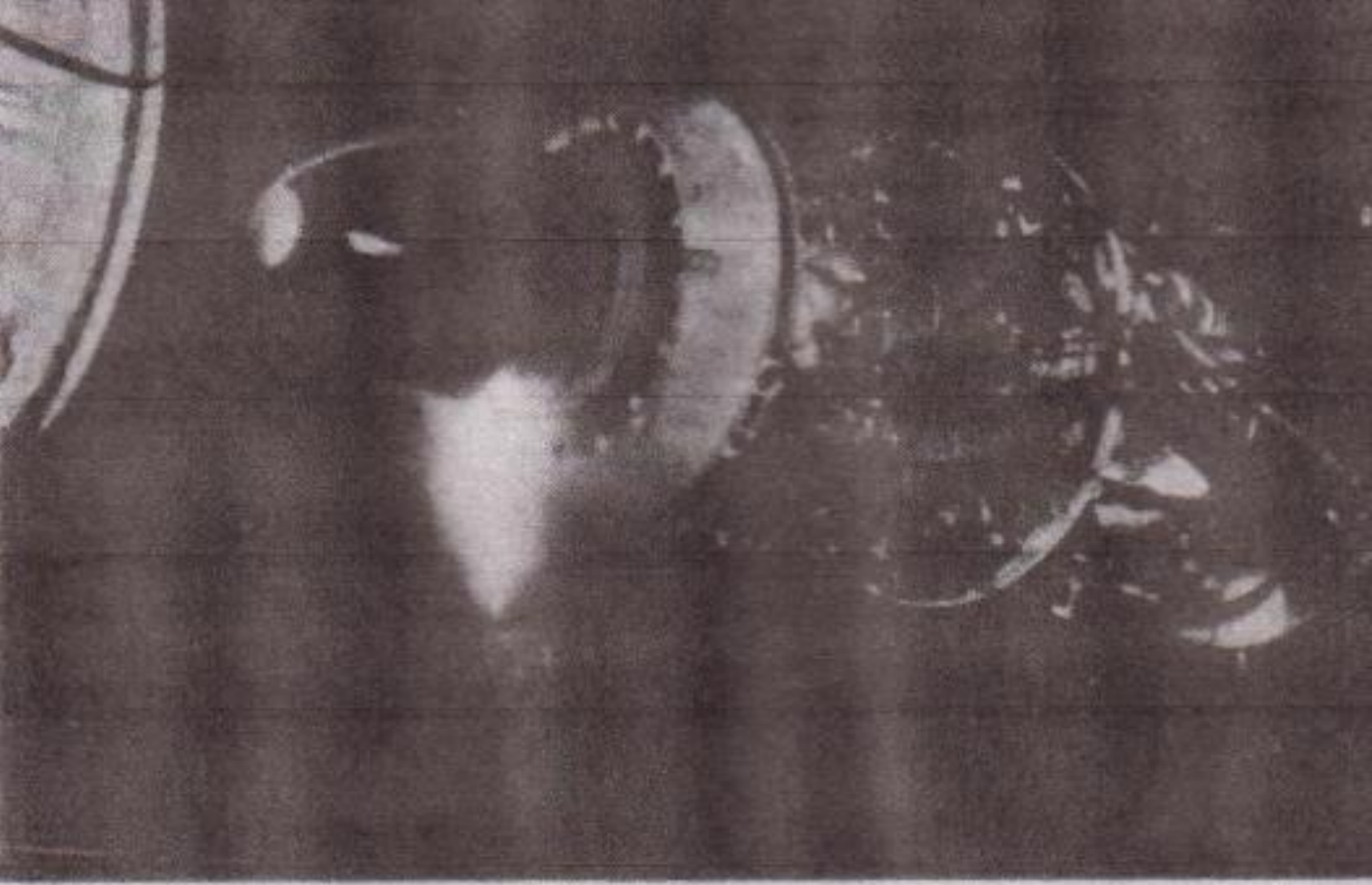
***FLIGHT,* August 31, 1951**

RE: introduction to an article entitled: “Dart Endurance Test”

Most Satisfying

"THE news that the Rolls-Royce Dart turboprop has successfully completed a 500-hour endurance test some twelve months before the Viscount is expected to go into regular service is most satisfying…"

***FLIGHT,* August 31, 1951**



A photograph taken when the Rolls-Royce endurance test was in progress and during one of the rain-injection periods.

Dart-Dakota Combination

"…British European Airways, who gained considerable experience with the prototype Viscount on the London-Paris and Edinburgh routes during the summer of 1950, now also have in regular freight service one Dart-powered Dakota, while another is due for delivery…"

***FLIGHT,* August 31, 1951**

"…This Dakota, which started its regular freight service to Hanover on August 15, 1951, will provide a wealth of information on handling and maintenance of the Dart turboprops. Eventually these aircraft are expected to be transferred to the longer route to Milan…"

***FLIGHT,* August 31, 1951**



Rolls-Royce Dart Turboprops
fitted to a BEA Air-Freight Dakota

"…The reason for the Dart-Dakota combination is to accumulate the maximum amount of information on the Dart prior to introducing the Viscount into regular service and it must be emphasized that BEA do not propose to modify existing Dakotas to include the Rolls-Royce Dart turboprop…"

***FLIGHT,* August 31, 1951**

Grounds for Believing

"…The 500-hour endurance test at Derby, together with the 5,000 total flying hours which have been accumulated, give good grounds for believing that when the Viscount is introduced into scheduled service the power units will be virtually trouble-free…"

***FLIGHT,* August 31, 1951**

"…The policy of developing and testing powerplants to this degree whenever possible is one of the factors which has given Rolls-Royce the reputation they hold throughout the world today…"

***FLIGHT,* August 31, 1951**

Civil Operation

"…The application of Rolls-Royce engines has not, of course, been restricted to military spheres alone. In fact, up to June 31, 1951, the two-stage Merlin had accumulated 1,169,000 engine hours and the single-stage unit no fewer than 2,615,000 hours in civil operation…"

***FLIGHT,* August 31, 1951**

"…In their participation in civil aviation, Rolls-Royce also offer to civilian operators a standard charge for major overhauls, based on the engine hours flown. Operators have found this service very useful and in the majority of cases competitive economically with their own maintenance facilities…"
***FLIGHT,* August 31, 1951**

"…A Rolls-Royce overhaul agreement is expected to be extended to the Dart following operational experience with the Viscounts…"

***FLIGHT,* August 31, 1951**



"…To summarize, it may be said that the 500-hour endurance test was completed most successfully and BEA will have not only the first turbo-prop to become available, but the finest that could have been chosen for the work."

***FLIGHT,* August 31, 1951**

<u>Caption</u>: "V.700 prototype Viscount c/n G-AMAV at the Farnborough Air Show

2115

The Chairman’s POV

"…An overview of the importance of Rolls-Royce testing within this period of British Cold War history is captured in the Chairman's statement of 1950: 'In the civil field there has been a steady development of the Merlin installations, of which the British Overseas Airways Corporation and Trans-Canada Air Lines now have substantial numbers in operation. Success in this field is measured by reliability and economy and the achievement of these goals in the high performance engine requires unremitting effort on the part of the design and development staff'…"

***key.aero,* July 30, 2022**

"…'There has been steady development in the Dart gas turbine propeller engine and the power rating of the engine specified for the Vickers Viscount shows a substantial increase since the prototype first flew. The reception which has been given this particular aeroplane by the various airlines throughout Europe, including Scandinavia, confirms the opinions which we had already formed regarding the high standards of passenger comfort made possible by the use of the gas turbine engine'…"

***key.aero,* July 30, 2022**

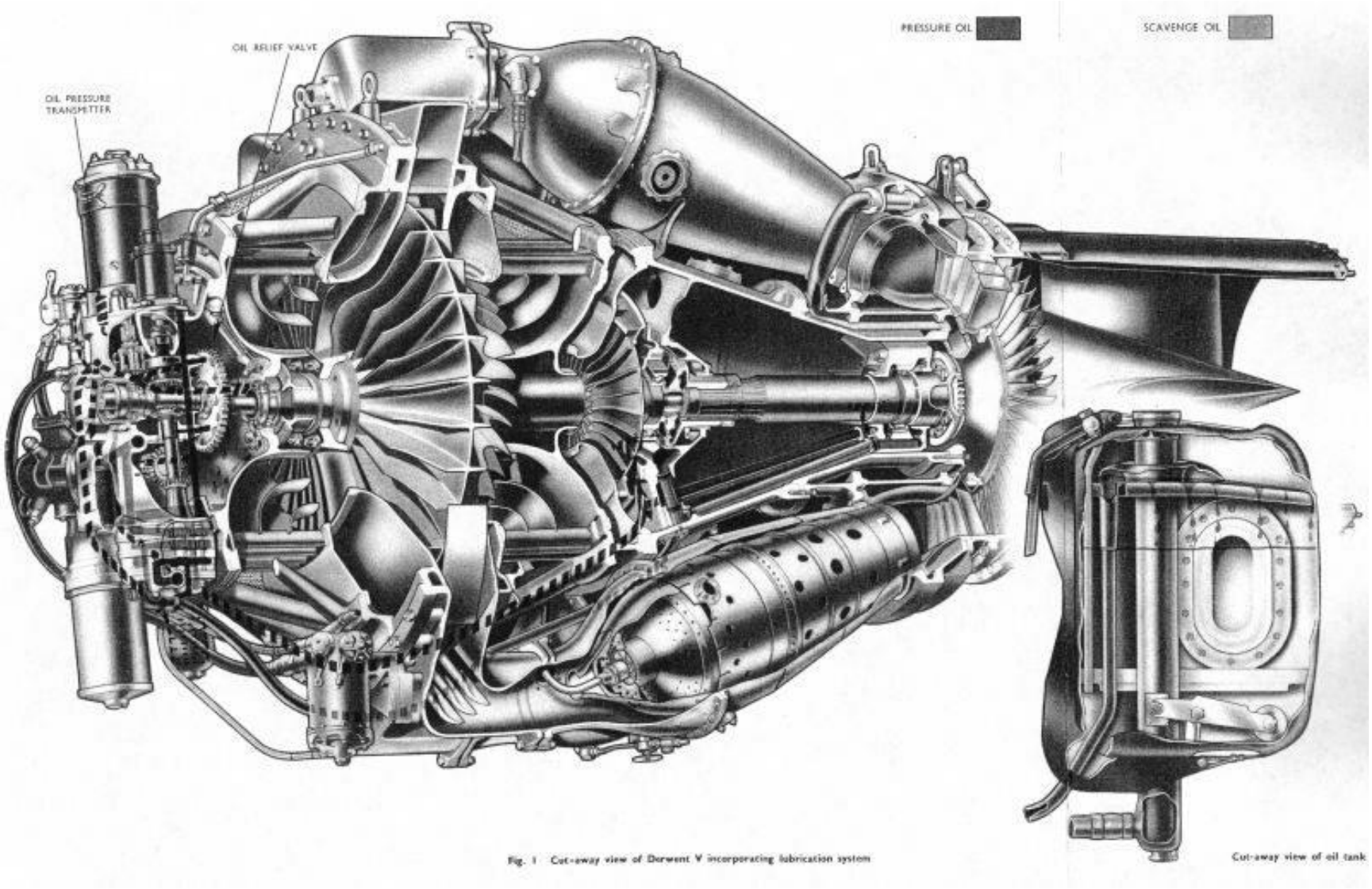
RE: Air France ordered 12 Dart-powered Vickers Viscount aircraft


AIR FRANCE
2119

"…'In the military field the outstanding event has been the performance of the Avon engine in the Canberra light bomber. There is no doubt that more will be heard of this particular aircraft and engine combination as it finds its way into service beside the Meteor aircraft which, with our Derwent engine, continues to serve not only the Royal Air Force but also Western Union Powers and other Allies in ever-increasing numbers'…"

***key.aero,* July 30, 2022**

RE: the R-R Derwent engine was a simple "Whittle-style" design that came into service at the end of WWII. Originally fitted to the Glouster Meteor aircraft, later surplus Derwents were used as runway de-icers.



Derwent Engine Schematic

"…'The complex nature of the new family of engines of which the Avon is the forerunner places a high premium on fundamental research and design facilities and it continues to be your company's policy to foster and strengthen these particular activities in parallel with the subsequent development work which follows the prototype stage. The rate of technical development has, until recently, presented problems to the production departments, but the last year has seen substantial progress in this field also'…"

***key.aero*, July 30, 2022**

"…'There is still scope for ingenuity if the production costs of the engines of the future are to stand comparison with those of the established piston engines'…"

***key.aero,* July 30, 2022**

World’s First

"…The world's first true Universal Power Plants flew from Hucknall installed on the modified outboard wing bulkheads of Lancaster R5849 with standard production Merlin 28s on the inboard bulkheads. After only 43 hours of testing, this aircraft was destroyed in a blaze - it landed safely with an engine fire, but could not be saved…"

***key.aero,* July 30, 2022**

"…To continue the test programme, Lancaster DV170 was similarly converted with standard 28s inboard and Merlin 65s, again fitted in the new circular UPPs on the outboard positions. It took to the air on August 24, 1943. By September 14 it had completed 117 hours of test flying, typically between ten and 12 hours in the air on each occasion. It was again altered, to accept the new powerplants in all four modified bulkheads. The inboard 28s were replaced with Merlin 38s, in annular powerplant cowlings and Merlin 85s in the same on the outboards…"

***key.aero,* July 30, 2022**



"…On November 3, 1943, Lancaster DV170 became the first aircraft to fly with all four engines configured with these new UPPs. In early 1944 the completion of a second flying test-bed came with the similarly configured Lancaster DV199. It also flew with a full set of UPPs on all four bulkhead positions, enabling flight testing of the Merlin 100 'Special.' DV199 was designated as the prototype Lancaster VI and could cruise 31 mph faster than a Lancaster III. Both the Hucknall Lancasters were the mainstays in UPP development…"

***key.aero,* July 30, 2022**

<u>Caption</u>: "Avro Lancaster DV170 sits at Hucknall with its four annular Universal Power Plants installed ready for flight-testing. A second Lancaster, DV199, was similarly converted to enhance the UPP test program, flying for the first time just one month after DV170."

Running in the family

"…My father, Colin Gibson, had followed both his brother Steve and his father Taylor (Ted) into the company at Hucknall. Starting his apprenticeship just one month after the Battle of Britain ended in November 1940, dad soon found himself in the Flight Department repairing the radiators and Merlins of battle-damaged Hurricanes and Spitfires. He even helped to rebuild a captured Messerschmitt Bf-109E to evaluate against the new Spitfire Mk.V. The German fighter is now on display at RAF Museum Hendon. Like his father before him, Colin also became a company Flight Test Observer and by 1944 was involved in the testing of the UPP, flying many hours in Lancaster DV199…"

***key.aero,* July 30, 2022**

Back on the Wing



"…Having been mothballed for many years, Number One Wing Hangar was temporarily recommissioned in the early 1970s on an emergency basis to extend the service life of the Griffon UPP-powered Avro Shackleton. A number of low cruise and certification tests had to be carried-out on the aging units…"

***key.aero,* July 30, 2022**

<u>Above</u>: the first Avro Shackleton was delivered to No. 120 Squadron RAF in March 1952 and by the end of 1952, seven more squadrons were operating the type. Maritime reconnaissance was a large part of the Shackleton's mission.

"…Number One Wing Hangar was ideally suited to this task as it still had a Lancaster wing section and UPP bulkhead in position - with a simple upgrade to the control panels it was a relatively straightforward proposition to bring it back on-line. The clock was effectively wound-back to the heyday of its wartime service…"

***key.aero,* July 30, 2022**



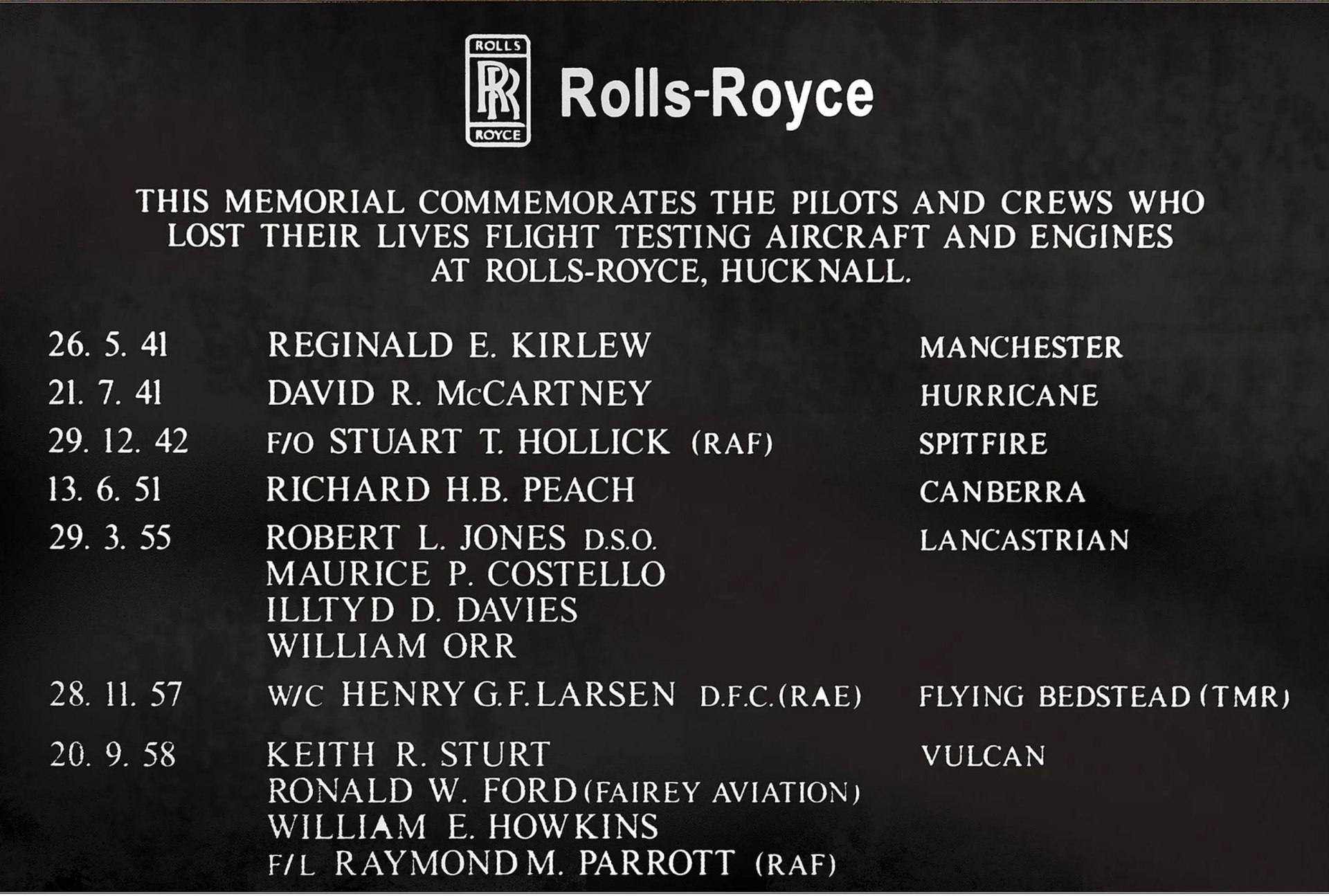
<u>Caption</u>: “The Shackleton-Griffon UPP engine undergoes testing in Number One Wing Hangar. The image shows the upgraded, part-digital dynamometer and test observer’s window in 1972.”

Gone, But Not Forgotten

"…With the successful test and certification program ending on February 29, 1972, my father - the obvious choice to over-see the initiative given his years of experience - brought the hangars' piston engine testing history to a final close…"
***key.aero,* July 30, 2022**

"…Just eight days later on March 8, all test flying from Hucknall ended – the VC10 RB211 flying test-bed program was transferred to Bristol…"

***key.aero,* July 30, 2022**



Caption: "Memorial plaque in the Wing Hangars to the Rolls-Royce crews who lost their lives flight testing at Hucknall"

A Proud Heritage

"…However, the old Wing Hangars survived, leaping into a new era. With the acoustic baffles and wing section removed, testing of a different nature began with the installation of the Large Wind Tunnel. This saw useful service in Number One until well into the mid-1990s, while in 1984 Number Two Wing Hangar became home to the Hucknall branch of the Rolls-Royce Heritage Trust. When the wind tunnel testing finally ceased, the trust was able to expand into Number One as well, giving the branch the splendid museum base it enjoys today…"

***key.aero,* July 30, 2022**

Testbed 80

"…In the summer of 2021, Rolls-Royce commissioned a brand new indoor test center at Derby named 80 Bed. This superb new facility boasts myriad capabilities that would at one time have been conducted on numerous separate out-door and indoor test-beds at Hucknall and other company sites now long-gone. It hosts all the most forward-thinking ideas for testing the new generation of jet and electric power-plants, heralding the dawn of a new era for civil aviation…"

***key.aero,* July 30, 2022**

RE: Testbed 80 was the result of a £90m investment by R-R and a three-year construction project. According to R-R CEO *Warren East,* the facility: "features the most advanced testing technology we have ever used," with cutting-edge systems to: "test engines to the limit, physically and digitally." Its internal chamber, where turbofans are tested, is 7,500m² in area, making it the largest indoor jet engine test facility ever built. Fittingly, Testbed 80 will play a major role in R-R's engine-development initiatives.





"…It is fascinating and indeed gratifying to see that all the principles and work of our predecessors, such as those used on Hives' UPP products, are still being applied today. The superb Derby base should serve the company well into the second half of the 21st century…"

***key.aero*, July 30, 2022**


Testbed 80
2143

Museum of Achievements

"…The Wing Hangars themselves still contain many original period features, fittings and equipment; in particular an impressive control/observer's room with a stunning period analogue test dynamometer around a Crittall observing window. This dates back to jet engine trials of the early 1950s…"
***key.aero,* July 30, 2022**

"…The Hucknall Flight Test Museum Charity was established there in 2018 to celebrate the incredible contribution made to aviation by the FTE, with the aim of formally opening the Wing Hangar museum to the public. Plans for renovation, plus new exhibits with an additional building or extension, car parking and community facilities are being discussed with the relevant authorities. Prior to the pandemic, it was possible to visit the site via pre-arrangement, but the attraction remains closed at the time of writing…"

***key.aero*, July 30, 2022**

"…Still owned by the company, the Wing Hangars are an historic and very important last piece of company wartime history and can trace their lineage through their builder, Ernest Hives, to Henry Royce himself…"

***key.aero,* July 30, 2022**

"…They effectively bridge the period between pre-war piston engine development and the postwar expansion of jet propulsion…"

***key.aero,* July 30, 2022**

"…They stand as a great monument to those two visionary men and indeed all who worked in the FTE…"

***key.aero,* July 30, 2022**

Their Legacy

"…It's tempting to conclude by considering the site's wider impact. In 1942, through its chief services liaison pilot Ronnie Harker, Rolls-Royce gave the world what is widely considered to be the finest piston-engined fighter of World War Two, the Merlin-powered North American P-51 Mustang. Ronnie opened the way for U.S.-based Packard to be granted the only overseas license to build the engine. These were then fitted to Mustangs – to stunning effect…"

***key.aero,* July 30, 2022**



"…With British Merlins becoming scarcer, Packard-built versions now proliferate in the heritage and restoration sector. One wonders how many of these magnificent aircraft would be flying today if Rolls-Royce and the Air Ministry had not granted Packard that license. And would it be so easy for modern-day small businesses to remanufacture Merlin spares from original drawings, using new technologies and modern materials?..."

***key.aero,* July 30, 2022**

<u>Caption</u>: "A P-51 Mustang fighter - the most storied fighter plane of WWII - and powered by the Rolls-Royce designed Merlin V-12. Of the 150,000 Merlin engines built in World War II, Packard built 55,000. It was Packard who figured-out how to mass produce this complex engine which has over 14,000 parts."

"…Whatever the truth, I think most would agree that the work ethic and example of sheer determination in the face of adversity, set by Royce, Hives and his flight-test team, is something for all to be proud of."

***key.aero,* July 30, 2022**

Part 19

The Civil Merlin

Call on Canadair

BOAC Fleet on the Stocks at Montreal
***FLIGHT,* February 24, 1949**
RE: introduction to an article written by *H.F. King,* MBE, entitled: "A Call on Canadair – Part I"

Under Construction

"TO inspect production of Canadair Fours under construction for BOAC I left London Airport in Constellation Bedford on the night of Sunday, February 13th…"

FLIGHT, **February 24, 1949**



Canadair and B.O.A.C. officials in conclave at Cartierville, Montreal. Mr. Emmert, vice-president of Canadair, is at the head of the table and Mr. Strawson, B.O.A.C.'s senior plant representative, is in the centre of the nearer group

"…Early next morning we were out at Cartierville, where the Canadair plants are located, to meet Mr. H. Oliver West (President of the company), T.J. Emmert (Vice-President), R. A. Neale (Vice-President, Manufacturing), K.G. Smith (Chief Project Engineer) and J.G. Barker (Comptroller). This meeting served to acquaint us with, or remind us of, certain facts concerning the production of the B0AC Canadairs and in view of their significance, these will be set-down in advance of personal impressions…"

2159

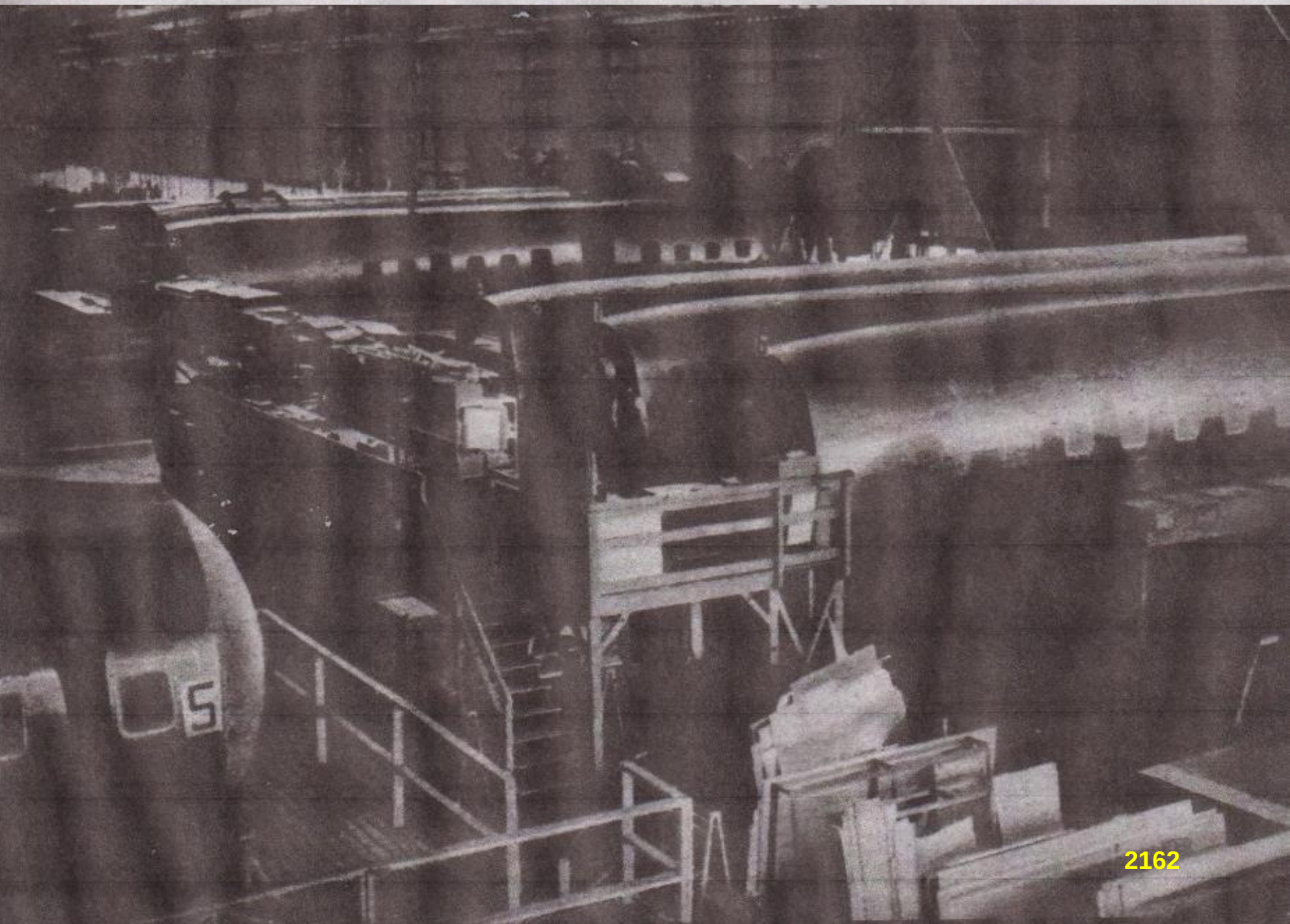
FLIGHT, **February 24, 1949**

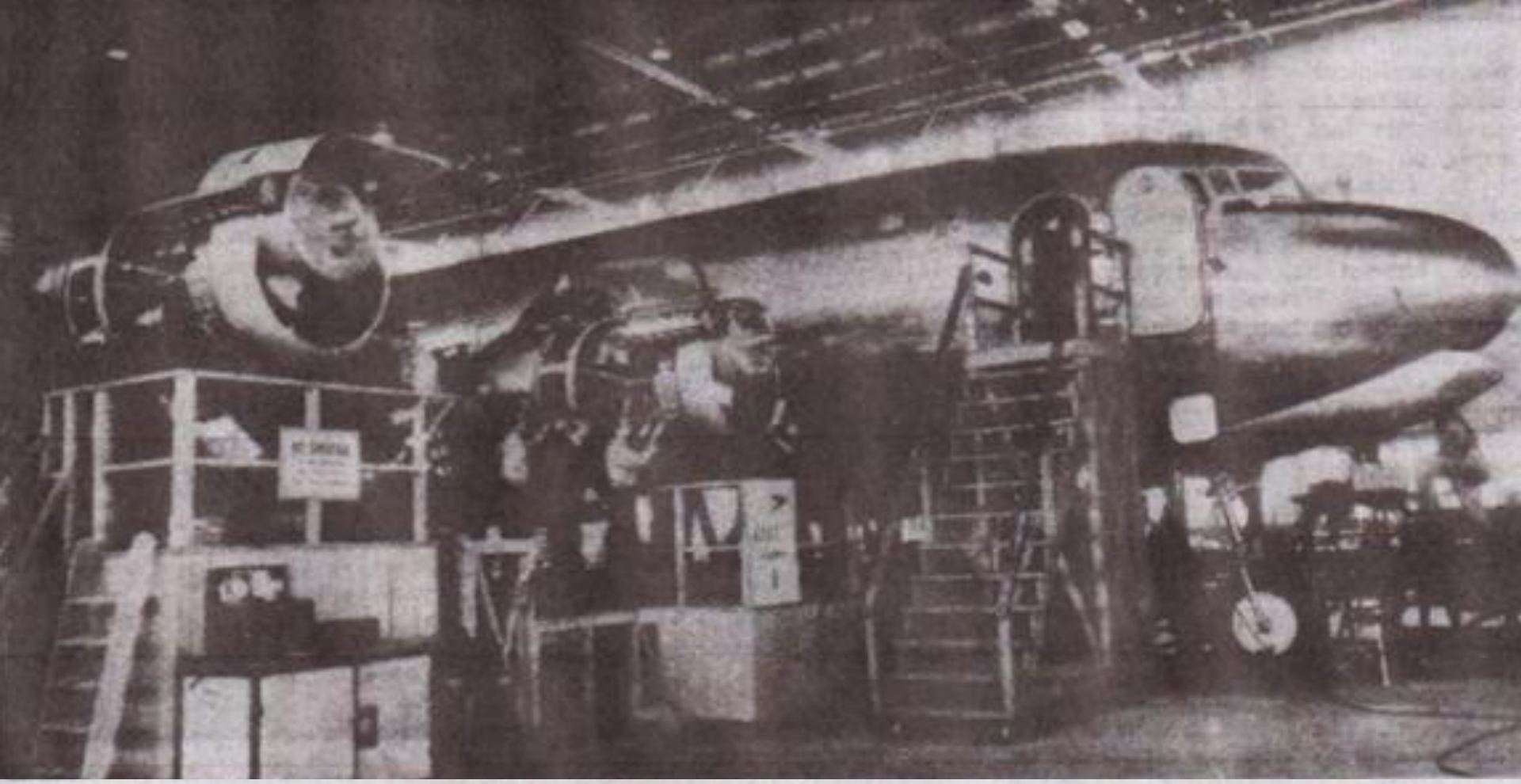
"…It was startling, I must confess, to be reminded that the first letter of intent covering the construction of Canadair Fours was signed as recently as July 24th last year. Thereupon, Canadair opened negotiations for definitive contracts and such specification changes as might be required. The 'specs' were completed on September 30th and the contracts signed, providing for delivery of the first aircraft in the eighth month from September 30th - that is, by May 30th this year…"
***FLIGHT,* February 24, 1949**

"…The first five of twenty-six Canadair (twenty-two for BOAC; four for Canadian Pacific Airlines) are now on the final assembly line and major sub-assemblies are well ahead of time estimates…"

***FLIGHT,* February 24, 1949**

Major fuselage sections in an advanced state, prior to being incorporated in B.O.A.C. machines on the final assembly line.





"B.O.A.C. Number 1", with its four Rolls-Royce Merlin 626s installed, at the head of Canadair's final assembly line.

"…BOAC Number 1 - started only 97 normal working days before our visit - has its Merlins installed and is expected to fly before the end of February and there is good reason to believe that this machine will be delivered to England many weeks ahead of contract…"

2163

FLIGHT, **February 24, 1949**

"…The order should be completed several months in advance of requirements and it is hoped at Canadair that this performance will attract additional orders. These, obviously, must soon be placed if the production flow is not to be interrupted and the company has sales representatives in many parts of the world. Talks have already taken place in Australia, New Zealand, South Africa and Italy. Such is the production position that as many as twenty additional 'Fours' are confidently offered by Canadair for delivery this year…"

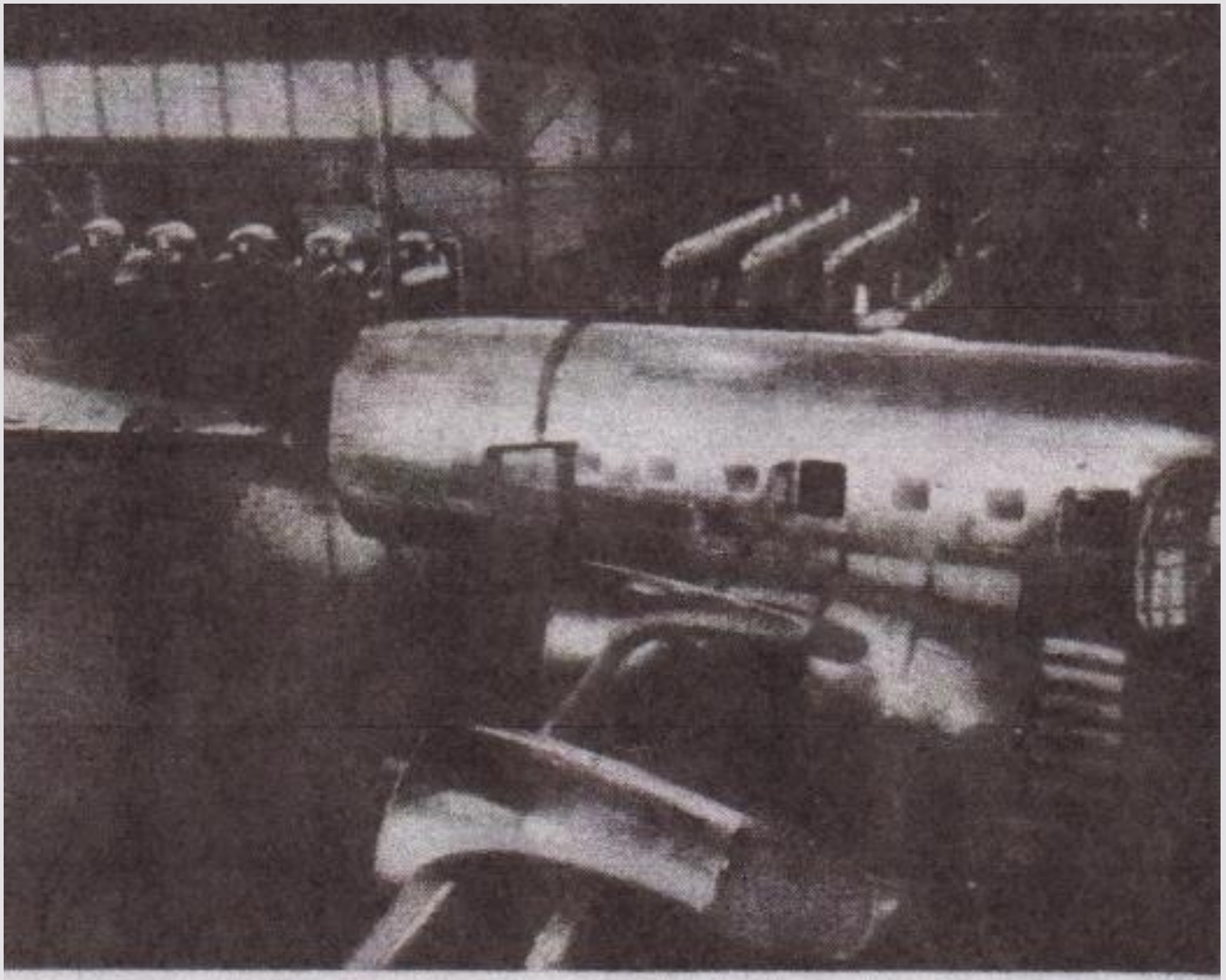
***FLIGHT,* February 24, 1949**

In the Shops

"…So that we might see for ourselves: how the line stands, Mr. West and Mr. Emmert conducted us to the factory. Here, sure enough, was No. 1, with its four Merlin 626s in-place and cowled and de-icer and undercarriage tests underway…"
***FLIGHT,* February 24, 1949**

"…When we ourselves saw it, No. 1 was at Station 2, the first position on the line being occupied by an unpressurized North Star of the RCAF - one of 20 supplied - in for overhaul. Close on the tail of No. 1, the second machine was seen to be far advanced, though without engines; No: 3 was likewise engineless and awaited outer mainplanes; No. 4 was wanting its nose and Nos. 5, 6 and 7 were sufficiently advanced to be recognizable…"

FLIGHT, **February 24, 1949**



As "B.O.A.C. Number 5" takes form on the final assembly line, its nose section, on the end of its own line, is seen to be ready for it

Meeting the Requirements

"…Some minor rearrangement of the pilots' cockpit was a BOAC requirement; engine instruments have been re-grouped; torquemeter and power meters are fitted and the pedestal adapted for control of the braking airscrews, with which the Merlin 626-1 engines of the BOAC machines are fitted…"

FLIGHT, **February 24, 1949**

"…When the throttles are closed beyond the neutral position, the pitch reverses for braking and means are provided to prevent selection of reverse pitch until weight is on either the nosewheel or one of the main twin-wheel assemblies…"
FLIGHT, **February 24, 1949**

"…The first few of the BOAC aircraft will be delivered with the present exhaust system, i.e., Canadair Lincoln-type manifolds on the inboard bank of each engine and Rolls-Royce stubs on the outer banks…"

FLIGHT, **February 24, 1949**

Cross-over System

"…Somewhere along the production line the new Rolls-Royce cross-over system will be introduced. Total enclosure within the cowling may confer some slight aerodynamic advantage. For take-off the cross-over pipes, which carry the exhaust of the inboard cylinder banks across the engines to exhaust on the outboard side, will be bypassed…"

FLIGHT, **February 24, 1949**

"…Cruising, with the cross-over system in operation, the BOAC Canadairs should be appreciably quieter than present machines of the type and the extra weight will be more than compensated by new aluminum radiators…"

FLIGHT, **February 24, 1949**

Merlin 626

"…The Merlin 626 as supplied for BOAC has 0.42:1 reduction gearing; 14 lbs. maximum continuous boost; 20.5 lbs. take-off boost and a full-intercooling scheme whereby for take-off and climb not only the ordinary intercooler matrix is used but a second matrix, which has hitherto served solely as a charge-heater…"

FLIGHT, **February 24, 1949**

"…An effective increase in power rating is afforded by the lower charge temperature under the critical conditions of take-off and landing…"

FLIGHT, **February 24, 1949**

"…The Merlins now operate for 800-hours between overhauls at a cost-per-hp claimed to be as low as for any air-cooled commercial engine of comparable output. Powerplants are quickly interchangeable between all four nacelle positions."
***FLIGHT,* February 24, 1949**

Cartierville

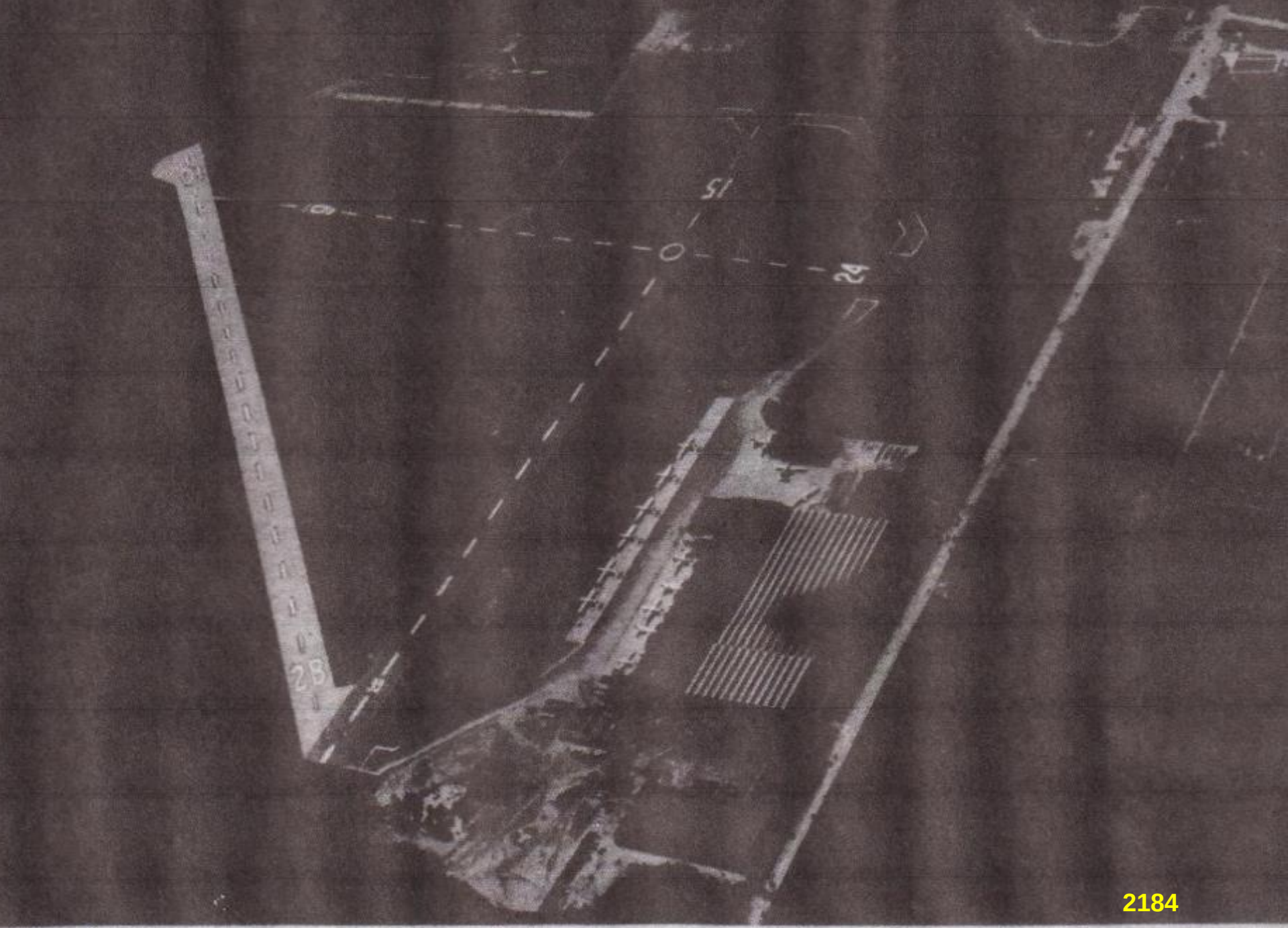
At Cartierville: Home on a TCA Northstar
***FLIGHT,* March 3, 1949**
RE: introduction to an article written by *H.F. King,* MBE, entitled: "A Call on Canadair – Part ll"

"HAVING duly inspected BOAC's 'No. 1' Canadair Four, we toured the main plant, where these aircraft are in production…"

FLIGHT, **March 3, 1949**

"…There are, it should be explained, two separate Canadair factories on Cartierville Airport, Montreal, the second being the old Noorduyn plant - or most of it - which, when taken over, brought Canadair's total floor space to a-million-and-a-half square-feet. In this secondary plant ex-military aircraft - principally Dakotas - are converted for civil use. More than 317 have been delivered to customers…"

***FLIGHT,* March 3, 1949**



2184

rtierville Airport, near Montreal, showing the main Canadair plant in the foreground and the smaller plant across the airfield.

"…The main plant is beautifully laid-out, warm and, of course, very completely jigged. To these factors, to a vigorous management and to employees who put in a full day's work for a full day's pay, may be attributed Canadair's productivity…"
***FLIGHT,* March 3, 1949**

"…Construction of the various components is carefully synchronized thus, the wing, fuselage, tail unit, etc. of, say, No. 11, are equally far advanced. Each day the Industrial Engineering Department distributes a very neat little plan of the works, indicating precisely how production stands. A glance shows, for instance, how many nosepieces, door-jambs, or cockpit enclosures are in Department 23 for pressure test; how tank tests are progressing in Department 19 and which fuselage has reached the joining jig in Department 16…"

FLIGHT, **March 3, 1949**

Performance Data

"…The latest performance data, applicable to the Canadair Four with Merlin 626-18, delivering 1,760-hp for take-off, include a CAA take-off field length of 5,650 ft. at a gross weight of 82,000 lbs. At an average weight of 70,000 lbs., using maximum economical cruising power, the speed is 325 mph at 25,000 ft. and at levels of this order TCA pilots delight in drawing ahead of Constellations. With full available tankage the range is 3,880 miles and payloads of up to 16,000 lbs. are possible, depending upon interior layout and range…"

FLIGHT, **March 3, 1949**

Making an Impression

"…We left Cartierville genuinely impressed by Canadair's achievement. There has been, and doubtless still is, considerable resentment in some quarters that the BOAC have spread across the world that Canadair was unequal to the task. The foregoing may serve to show that if the performance of the Canadair Fours on the Empire routes is worthy of the manner in which the machines were built the order will have been amply justified…"

***FLIGHT,* March 3, 1949**

Return Trip

"…The TCA Canadair in which we were returning was noisier than most because the inboard cylinder bank of No. 1 engine was fitted with an old type of manifold and as I myself was seated on the port-side by an emergency exit, I was probably more affected by noise than other passengers…"

FLIGHT, **March 3, 1949**



"…Reassurance was forthcoming from Mr. J.D. Pearson, Rolls-Royce General Sales and Service Manager, who made a most welcome appearance at my elbow en route for Goose Bay, that the final exhaust system to be fitted on the BOAC machines will effect a very real improvement…"

***FLIGHT,* March 3, 1949**

<u>Caption</u>: "The BOAC machine will be similar to that shown, but will eventually have enclosed 'cross-over' manifolds"

"…Our flight plan called for a constant indicated air speed of 165 mph (190 mph true) with the Merlins delivering 840-hp apiece and we had a stiff wind in our favor . . . There remained only a brief pause at Prestwick and a two-hour flight to London Airport to conclude our return in an aircraft of which Canada may well be proud."

***FLIGHT,* March 3, 1949**

Less Noise, More Power

Details of the Merlin Cross-over Exhaust System: Less Noise Yet More Power

***FLIGHT,* February 29, 1952**

RE: introduction to an article entitled: “Quieter Argonaut”

Cross-over

"FIRST announced some months ago, the Cross-over Exhaust System developed for the Merlin TML powerplant by Rolls-Royce, Ltd., is now entering BOAC service - in particular, all four engines of the Argonaut 'Atalanta,' in which H.M. The Queen recently flew to Kenya and back, were fitted with it…"

***FLIGHT,* February 29, 1952**

Problems & Solutions

"…Both Rolls-Royce and BOAC have long appreciated the fact that the Argonaut (Canadair DC-4M) could well be made a quieter aircraft; to do so, however, and lose nothing in the way of performance, was a much greater problem and Rolls-Royce have spent a considerable period in finding the best solution…"

***FLIGHT,* February 29, 1952**

A Win-Win Situation

"…It must therefore be with some gratification that they can now announce the development of this new exhaust system which, while effecting a marked reduction in noise level, improves performance…"

***FLIGHT,* February 29, 1952**

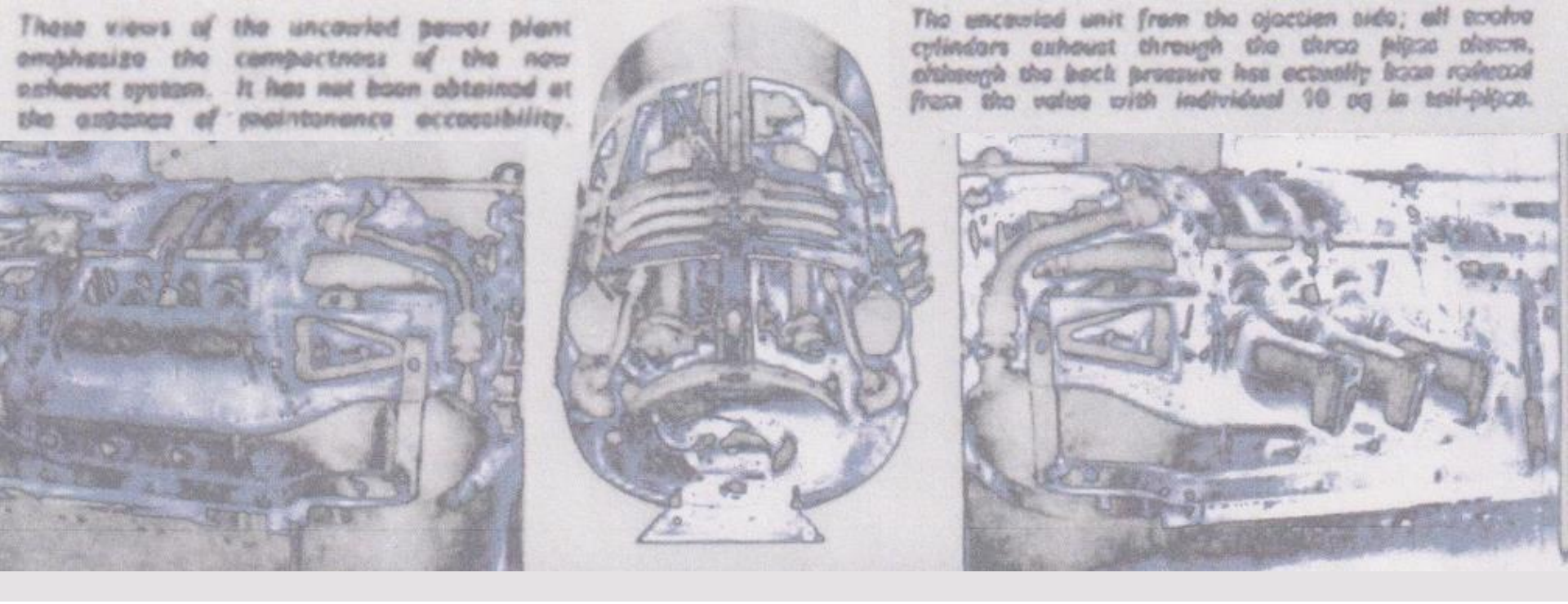
Merlin TMO

"…BOAC recently afforded us the opportunity of examining this new powerplant - re-designated Merlin TMO - at London Airport, and the accompanying photographs show the system to good advantage…"

***FLIGHT,* February 29, 1952**

"…Beside each cylinder bank and suspended from a sub-frame off the main bulkhead, is a cylindrical manifold into which the adjacent cylinders exhaust via ball-jointed stubs. The two manifolds of each powerplant are symmetrically connected by three stainless-steel pipes which carry the exhaust from the inner bank of each engine over to the outer manifold; final release to atmosphere is made through three stubs ejecting on the outer side of each cowling…"

***FLIGHT,* February 29, 1952**



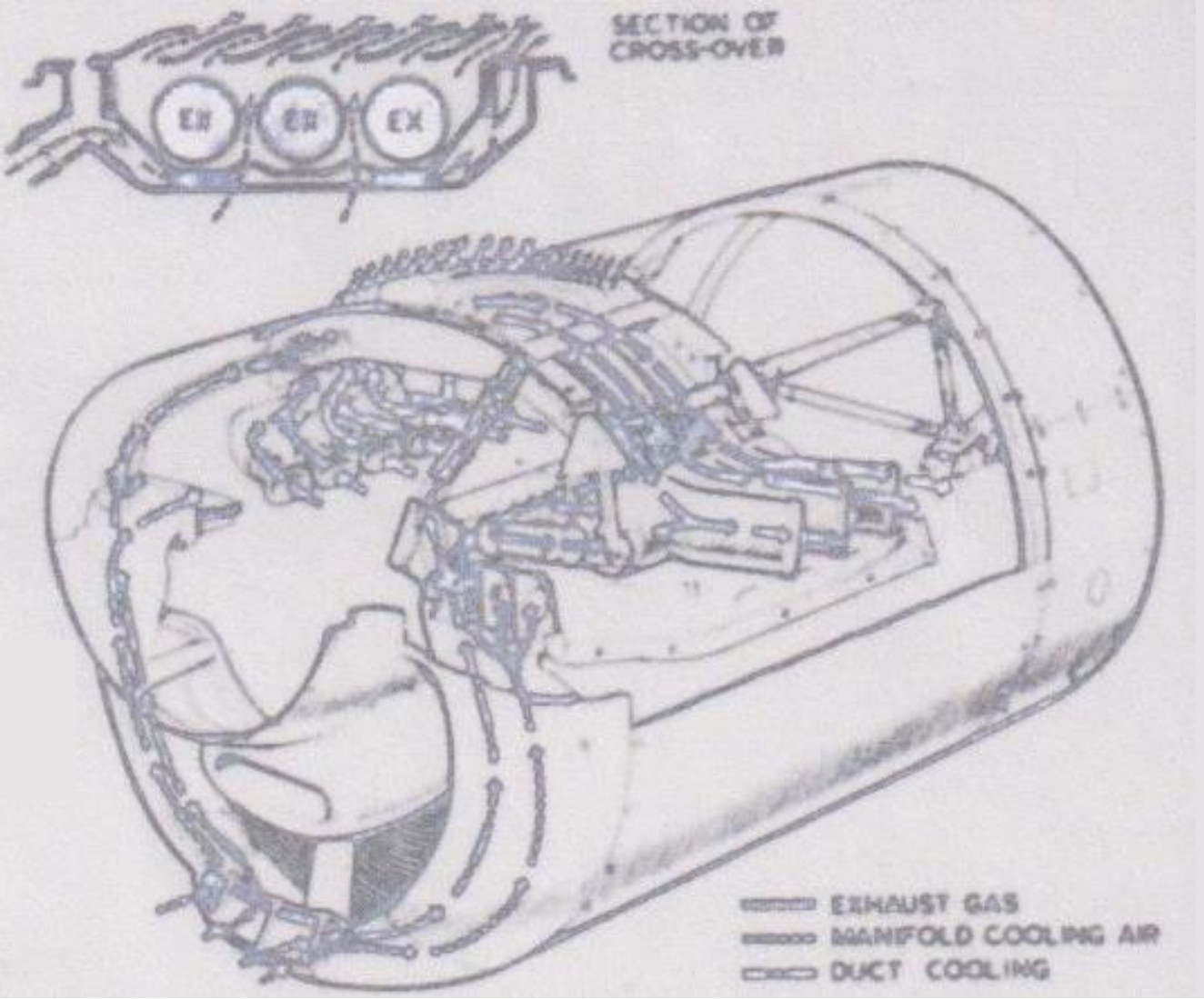
"…Beside each cylinder bank and suspended from a sub-frame off the main bulkhead, is a cylindrical manifold into which the adjacent cylinders exhaust via ball-jointed stubs. The two manifolds of each power plant are symmetrically connected by three stainless-steel pipes which carry the exhaust from the inner bank of each engine over to the outer manifold; final release to atmosphere is made through three stubs ejecting on the outer side of each cowling…"

2206

***FLIGHT,* February 29, 1952**

"…The manifolds and primary exhaust stubs are made of Inconel and are designed to be free from stresses arising from engine vibration while affording the clearest possible gas path. The system is cooled by air drawn in at an intake placed centrally on the lower lip of the main radiator intake. This position receives the full benefit of both airscrew slip-stream and ram air and results in effective cooling under all conditions…"

***FLIGHT,* February 29, 1952**



"…From the new intake the flow is divided, one stream cooling the primary stubs and the adjacent ignition harnesses, while the other passes over the connecting pipes; both exhaust from herringbone-shaped louvres above the cowling…"

***FLIGHT,* February 29, 1952**

"…The Cross-over modification also involves replacement of the existing main coolant radiator by a unit made entirely of light alloy, while a new circular brass oil-cooler is also specified…"

***FLIGHT,* February 29, 1952**



Surrounding the inner Merlin 724s of *Arcturus,* the new cowling looks even cleaner than the original pattern. The blanked-off inner side (above) gives the impression that "something is missing," while the larger photograph enables a comparison with the original powerplant installation to be made.



"…The modified powerplant is interchangeable port and starboard by fitting the appropriate ejector-stubs to the outer-side of the engine and the correctly handed blanking-plate on the fuselage-side. The new exhaust is completely interchangeable with the original system, the only parts affected being the valve rocker-box covers, ignition harness and fire extinguishers, all of which are supplied by Rolls-Royce in the modification kit…"

2210

***FLIGHT,* February 29, 1952**

Noise Reduction

"…The reduction in noise is achieved both by exhausting aw-ay from the fuselage - exhaust flow, incidentally, is entirely above the wing - and also by the mutual cancellation of many of the harmonic constituents of the noise spectrum…"
***FLIGHT,* February 29, 1952**

"…Throughout, close attention has been paid to providing unrestricted gas-flow and to reducing installation-drag; the result has been a back-pressure reduction giving an additional 38-bhp at maximum per-engine in comparison with the original Merlin TML while the cleaner installation results in a gain in TAS of some 5 kt. over the range of cruising speeds…"

***FLIGHT,* February 29, 1952**

"…The factors combine to increase the specific air range of the 'Argonaut' by some 4 per cent and to reduce the noise level by between 5 and 8 decibels; the greatest silencing effect is obtained in the higher frequencies, which are those most affecting passenger comfort…"

***FLIGHT,* February 29, 1952**

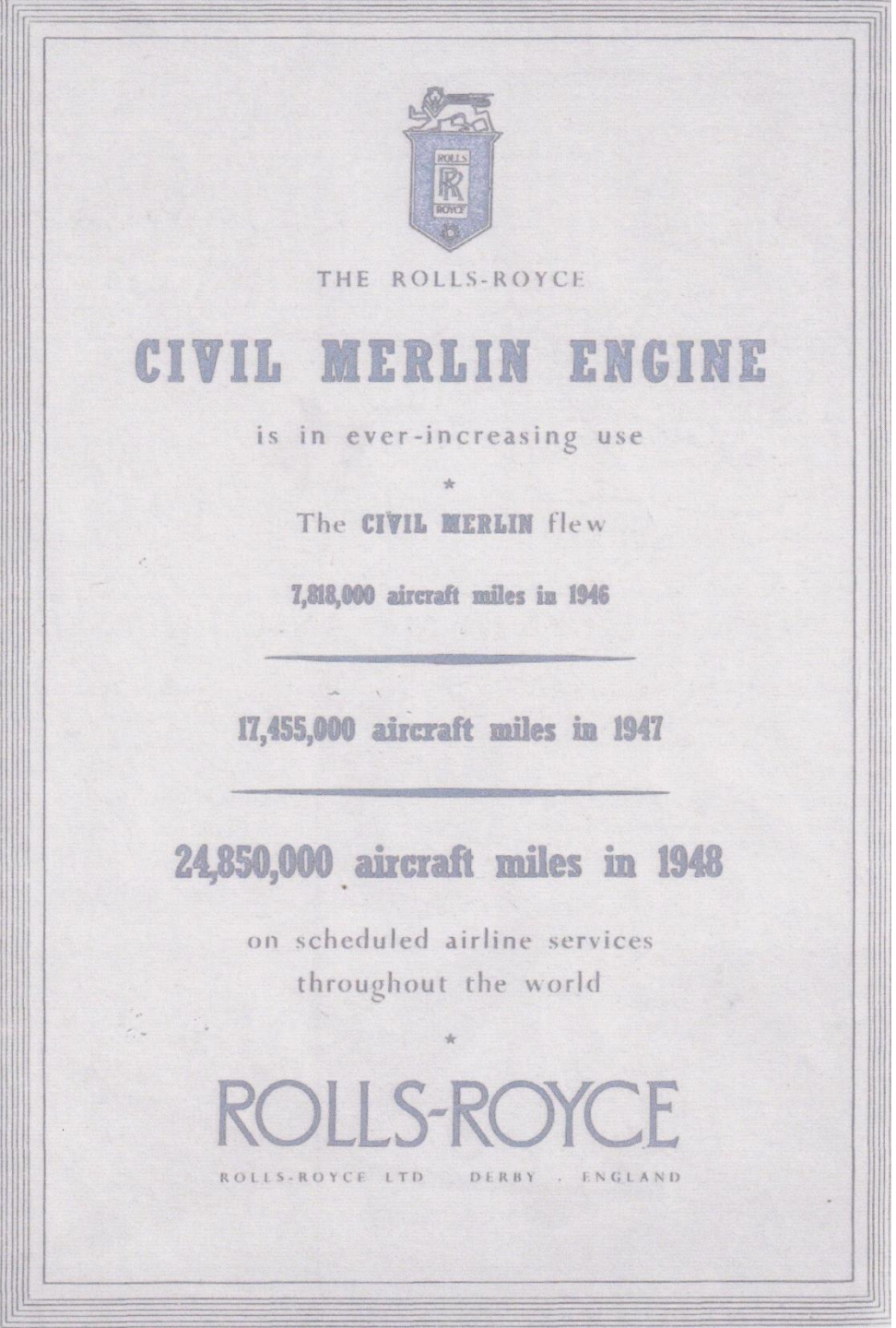
Pros & Cons

"…The penalties involved appear to be negligible; they comprise an increase in exhaust-system weight of 155 lbs. per-engine - largely offset by the saving of 106 lbs. made by the new light-alloy radiator and a slight increase in the time required for the inspection of tappets and valve gear; plug changes are unaffected…"

***FLIGHT,* February 29, 1952**

Inner & Outer

"…At present, 'Argonaut' powerplants are being sent to Rolls- Royce for modification as they become available. Apart from 'Atalanta,' only the inner engines are being converted to the Cross-over System in order to effect the maximum noise-reduction while maintaining aircraft hours at the highest level; when all the BOAC Argonaut fleet has been so treated, the aircraft will give up their outer power plants for modification until all TML Merlins have been modified to TMO standard…"
***FLIGHT,* February 29, 1952**



"…Because it must be integrated with aircraft schedules the complete process of modifying all 'Argonaut' powerplants is expected to take about a year."

***FLIGHT,* February 29, 1952**

Part 20

Quotable

The Driving Force



"It wasn't his sole responsibility, there were others in the team but he was definitely the driving force. He had the perception and he had the ability to motivate - his motto was 'Work 'til it hurts.'"

***Mick Whitehead,* R-R Derby Historian**

RE: the development and production of the Merlin was in large part due to R-R Chairman *Ernest Hives.* In 1936, with another war on the horizon, Hives became General Manager of the Nightingale Road Factory (above), where the Merlin engine was designed and developed.

"Beatrice Shilling is an inspiration to us all. Not only was she a first-class Engineer but she also loved speed and was fast on both two wheels and four. Miss Shilling should be celebrated and remembered for the incredible woman she was, and as an Engineer who made wartime pilots lives as safe as they could be when in battle."

***Mark Burnett,* Managing Director for *Burlen Ltd.,* which still manufactures and supplies S.U. carburetors**

RE: In 1940, 31yo *Beatrice Shilling* found a solution to a carburetor malfunction in the R-R Merlin III engines that were used in RAF Hurricane and Spitfire fighter aircraft. Shilling devised a preventative modification, retrofitted to all serving aircraft; a restrictor (or orifice plate) with a calibrated aperture in the center which was fitted to the fuel line before the carburetor. It limited the fuel flow to a volume only slightly less than the engine demanded at full power and, while it did not stop the momentary weak hesitation, it prevented the excruciatingly long 1.5-second cut. By 1941, the RAE had developed an anti-G modification which would become a standard feature of all new SU carburetors. However, Miss Shilling's restrictor was retained by many aircraft, depending on their role in combat.

"By the end of 1937 Rolls-Royce's production potential was much healthier, especially as the worst of the Merlin's woes were behind it"

***Ernest Hives* – R-R's General Works Manager**

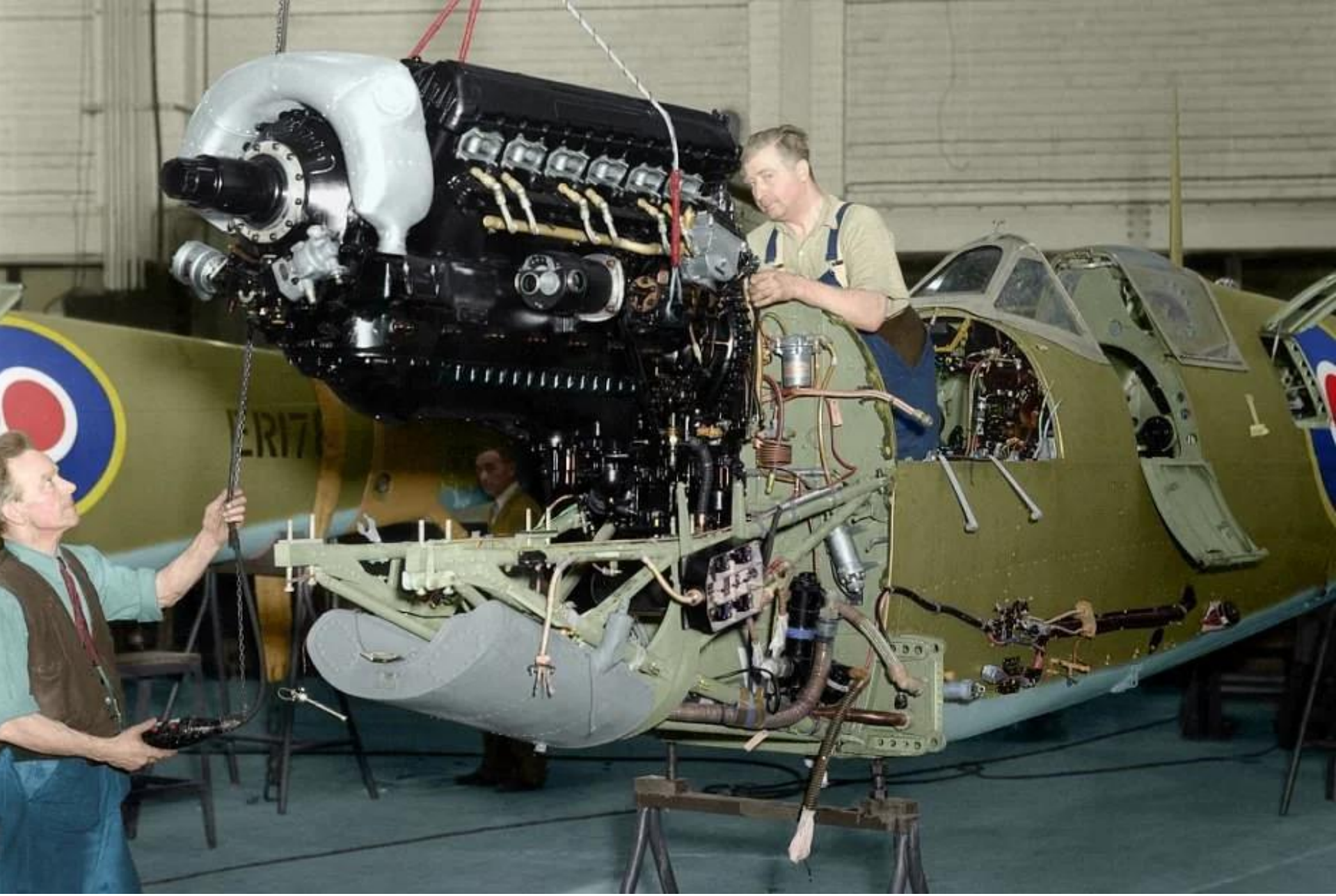
RE: appointed GM in 1936, Hives, with the support of the Board of Directors, made wholesale changes to R-R's operations and factory lay-out. Though it was not without snags, by the end of 1937 the company's production potential was looking a great deal healthier, especially as, with the abandonment of the ramp-head Merlin, the worst of the engine's development woes were behind it. R-R expanded its Derby factory to boost production; between 1935 and 1939 it increased floor space by nearly a third, to more than 1.1 million square-feet. However, it became clear that with the Air Ministry's planned engine production programs, more room would be required. R-R decided to operate its own shadow factories, building one in Crewe and another one in Hillington, a suburb of Glasgow.

A Test-Pilot’s Best Friend

"I learned to be meticulous in the matter of correct engine handling at all times and although I never hesitated to run a Merlin to the absolute limit of its capabilities, I was careful never to exceed those limits except when unavoidable. In return the engine hardly ever let me down and such total power failures as I experienced - and over the years inevitably there were many - were due as often as not to extraneous causes rather than to anything fundamental to the engine. The Merlin really was the pilot's friend."

***Jeffrey Quill,* Spitfire Chief Test Pilot**

RE: by wartime standards, the Merlin was a very reliable engine. The advantage of liquid-cooled engines (such as the Merlin) over radials was that the coolant provided a thermal mass to dump heat into. As a result, they could maintain emergency boost at higher levels and/or for longer than air-cooled engines. The downside was that leaks in the radiator system (i.e., from battle damage) would lead to a white stream of coolant evaporating off, a rise in cylinder temperatures and piston or head failures.



A Merlin engine being lowered into a Spitfire

Higher and Faster



"The Merlin was an amazing engine. It could be developed and adapted and when aircraft needed to go higher and faster, it could go higher and faster. It could be used in different ways and while it's most famous for aircraft like the Spitfire, Hurricane and Lancaster, it was used on both land in tanks and sea for fast patrol boats."

***Peter Collins,* R-R Head of Corporate Heritage**

<u>Caption</u>: "While used in various ways, the Merlin is mostly associated with the Spitfire"

The Hand of God



"The torque is unbelievable. It's like the hand of God is just pushing you."

Jay Leno

RE: an episode of *Jay Leno's Garage* featured a Merlin V-12 encased in a custom-built aluminum Rolls-Royce. Not requiring the additional complexity of a boost-fed motor, Leno opted to keep his V-12 naturally aspirated, limiting its output to only 1K-hp and 1,750 lb.-ft. of torque. Leno owned the car for nearly 30 years and its restoration took nearly that long to complete. It started life as just an engine; an original 1934 R-R chassis and a basic wooden body, so a good amount of custom work was needed to get it to its finish condition.

Looking Good

“The fact is simple. The Spitfire looked good. It was every bit as dashing as the young men who flew it and in flight it was as graceful as any bird. Its progress through the sky seemed effortless, as though it was simply riding the breeze and its Merlin engine was only there to provide a suitable sound-track. You had Mr. Churchill on the radio explaining that we’d never surrender and above you had the Spitfire and you couldn't help thinking: Yes, we can win this thing. Possibly, just possibly, the Spitfire is the greatest machine ever made.”

Jeremy Clarkson


MJ6
Spitfire Over London
2234

“The Few”

"…Never in the field of human conflict was so much owed by so many to so few…"

***Winston Churchill,* British Prime Minister**

RE: in the summer of 1940, the Battle of Britain took place in the skies over Southeast England. The aerial conflict between the RAF and the German Luftwaffe tested men and machines to their utmost. In an August 20, 1940, PM *Winston Churchill* paid tribute to the RAF squadrons which repelled the German invader in their R-R Merlin-powered Hurricanes and Spitfires.



<u>Above</u>: consisting of 2,945 aircrew, the RAF was joined by volunteers from 13 nations, some of whom had battle experience against the Luftwaffe in their own Air Forces. This international force became known as "The Few."

Excelsior

“Strive for perfection in everything. Take the best that exists and make it better. If it doesn’t exist, create it. Accept nothing nearly right or good enough.”

***Sir Frederick Henry Royce* (1863-1933)**


MERLIN
POWER