AEROPLANE

DATABASE

17 IN-DEPTH PAGES

ROLLS-ROYCE MERLIN

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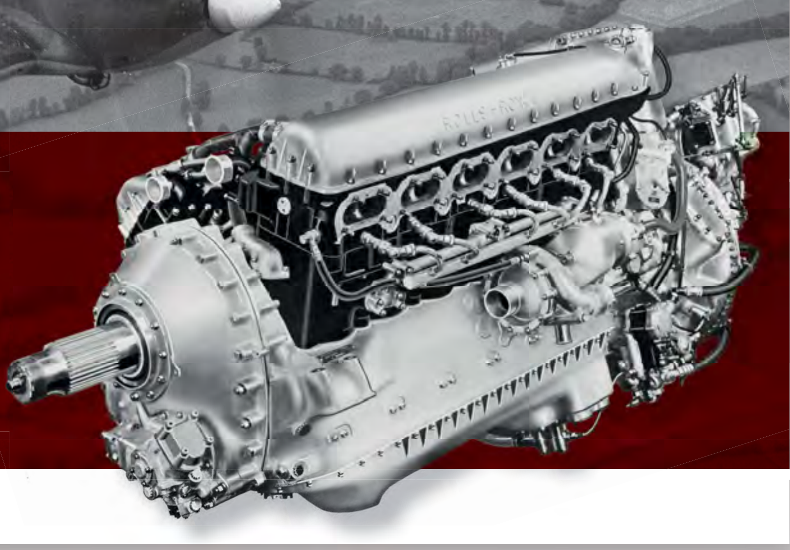
A Merlin-engined trio from the RAF's Empire Central Flying School at Hullavington in 1942: Hurricane I Z4791 leads Spitfire IIas P7882 and P7926. *AEROPLANE*

- The Merlin's sometimes difficult birth
- How Rolls-Royce kept the Merlin relevant
- Classic wartime cutaway from *The Aeroplane*



How Rolls-Royce made history

ABOVE: Spitfire Is undergoing final assembly at Eastleigh, with a number of Merlin IIs in the foreground awaiting installation to other airframes. AEROPLANE

The Rolls-Royce Merlin is, by any reckoning, one of the great aero engines of all time, and is certainly the most famous British aero engine ever. Produced in greater numbers than any other engine of the Second World War, its variants powered front-line aircraft from the first to the last day of the conflict. Yet in many ways the Merlin's success was as much a testament to Rolls-Royce's persistence as it was to the engine's inherent excellence. The great motoring journalist L. J. K. Setright was even more forthright: he called it a "triumph of development over design."

Compared to — for example — Roy Fedden's sleeve-valve radials, Frank Halford's fearsomely complex Sabre, or even Rolls-Royce's more exotic designs such as the Vulture and Crecy, the Merlin was perhaps technically conservative. It underwent at least three major mechanical redesigns to counteract what were, at the time, serious flaws. But it was designed and developed in a period when advances in fuels and supercharging meant a basically sound design could see huge increases in power, given suitable development. And Rolls-Royce's engineers were masters of the kind of development work that would ensure reliability in the face of dramatic power increases. Over its life the Merlin's power more than doubled; power at altitude nearly tripled, and, as Rolls-Royce's historian Ian Lloyd put it, "the skies of Britain and Europe reverberated to the deep throb of more than a million Merlin horsepower."

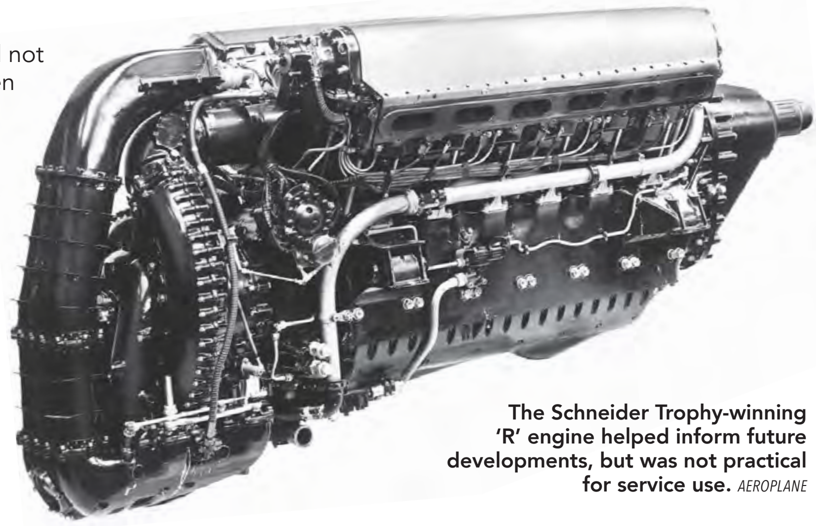
Sir Henry Royce had favoured liquid-cooled V12 engines since the First World War, but the firm's post-war designs were mainly used in larger aircraft. In 1912 Royce had suffered a collapse in health, attributed to his workaholic personality and poor diet. He underwent a major operation, his doctors giving him months to live. Advised to avoid Derby's industrial atmosphere, he split his time between villas in the south of France and West Wittering on the South Coast. Here, with a small design staff, including his assistant A. G. Elliott, he designed his new engines, and oversaw the work at Derby from afar. Letters, telegrams, and nervous draughtsmen bearing drawings for inspection headed back and forth, as Royce insisted on personal approval of even minor details.

Whatever the difficulties of this manner of working, after the First World War Derby expanded its design team. In 1921 Arthur J. Rowledge, who was Napier's chief engine designer and had just come up with the Napier Lion broad-arrow W12 engine, joined Rolls-Royce. His first job was to redesign the Condor engine, and the resulting Condor III incorporated features that were to become standard for Rolls-Royce production engines for the next two decades: two inlet and two outlet valves per cylinder, fork-and-blade connecting rods, and spur reduction gear. Unfortunately for Rolls-Royce, the company became involved in a dispute with Lord Trenchard over engine production. To ensure production capacity in the event of future conflict, the Air Ministry had decided that all future engines for the RAF should be able to be manufactured under licence by the car industry. Rolls-Royce was adamant and explained it had never licensed its designs, as it could not guarantee the

ABOVE: Ernest Hives, head of Rolls-Royce's experimental department and later general works manager.

quality of engines it did not manufacture itself. When the report reached Trenchard, he scrawled "no more Condors!" in the margin.

What brought Rolls-Royce back into the Air Ministry's fold was a rival engine — not one from a local competitor, but from overseas. This was the revolutionary Curtiss D-12. In this V12 water-cooled engine, each bank of six cylinders was a single-casting aluminium casting. Previously, individual steel cylinders were screwed into the crankcase, and a separate coolant water jacket fitted around the cylinders. The Curtiss's 'monobloc' construction was both lighter and more rigid, allowing for a more powerful engine. Inspired by its use in the Curtiss CR-3 Schneider Trophy-winning aircraft of 1923, two years later Sir Richard Fairey designed his private-venture Fox bomber around the D-12, allegedly personally importing the prototype's engine, stowing it in his cabin on board a trans-Atlantic liner. The Fox, a streamlined biplane, was faster than any RAF fighter, and Trenchard immediately ordered a squadron for the RAF. Though Fairey imported the first 50 engines required, he sought a manufacturing licence for the D-12.



The Schneider Trophy-winning 'R' engine helped inform future developments, but was not practical for service use. *AEROPLANE*

Stung by the American engine's superiority, and unwilling to support another aero engine manufacturer, the Air Ministry looked for an existing engine company willing to build a comparable design. With its experience of liquid-cooled V12s, Rolls-Royce was an obvious choice.

> "Rolls-Royce were masters of the kind of development work that would ensure reliability in the face of dramatic power increases"

The head of the company's experimental department, Ernest Hives, was eager to expand the firm's aeronautical business and accepted the challenge, especially as Rowledge and Royce had already begun the design of the FX, an engine along similar lines. The resulting Kestrel incorporated one-piece castings for the cylinder blocks and heads, and many of the refinements applied to the Condor III. Early Kestrel prototypes used 'dry' cylinder liners screwed directly into the castings (aluminium engine blocks needed steel sleeves, or liners, to resist wear from the engine pistons), but cooling problems forced a change to 'wet' liners. In these, coolant passed directly along the outside of the cylinder sleeve, giving better cooling, but the liners carried greater stress. As a consequence, the Kestrel was always susceptible to coolant leaks into the cylinders.

This issue aside, the Kestrel was enormously successful, with 4,750 being built from 1927 to 1940. Power rose from 450hp in the Kestrel I to 695hp in the Kestrel V, later marks taking advantage of higher-octane fuel ratings to push power to more than 700hp. The engine probably saved Rolls-Royce's aeronautical business. In the wake of the Condor licensing dispute, its share of the market had fallen from 25 per cent in 1925 to 11 per cent in 1929.

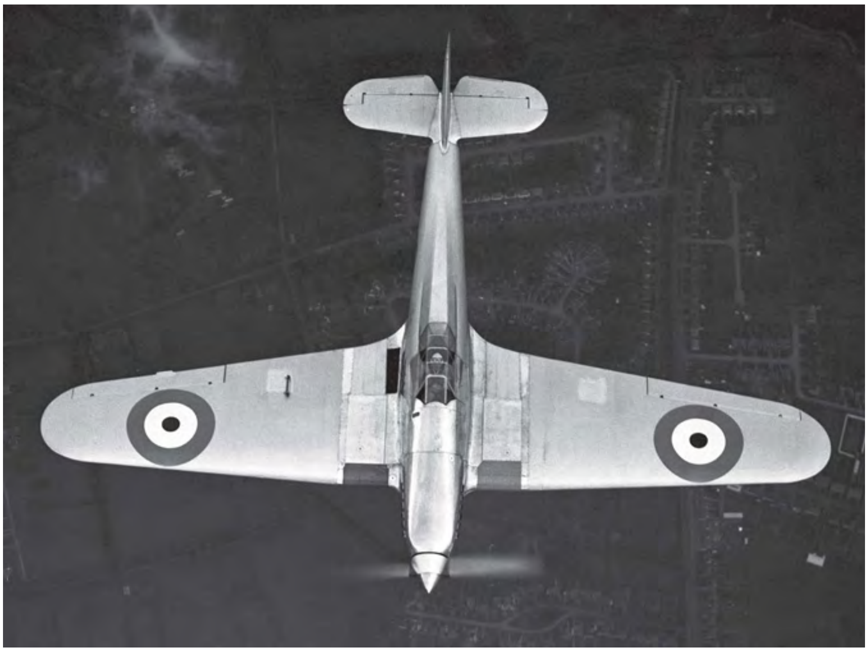
The Kestrel was Rolls-Royce's first engine to use sea-level supercharger boost to increase power. In this it was assisted by the fact that the company employed probably the world's leading supercharger expert, James Ellor. He had worked in the Royal Aircraft Establishment's engine department since before the First World War, and was apparently being headhunted by a US engine firm. Civil service pay scales meant that the RAE could not match their salary offers, so, attempting to keep Ellor's expertise in the UK, the Air Ministry suggested that Rolls-Royce employ him. He joined the company in 1927, and was responsible for the Kestrel, 'R' and Merlin superchargers.

Rolls-Royce's second boost came in the form of the Supermarine S6. In 1927, Reginald Mitchell's S5 monoplane had won the Schneider Trophy, its 890hp Napier Lion powering it to victory. As a result of the growing expense of developing a Schneider competitor, the participating nations agreed to switch to a biennial contest; competitors would have to be ready for September 1929. At the Air Ministry, Maj George Bulman, in charge of aero engine development, considered his options: either continue with the Lion, which would require the introduction of supercharging, or go for an entirely new design.

Mitchell had already had discussions with Rolls-Royce to see how his S5 would have to be modified to incorporate a significantly heavier and more powerful engine, and though Bulman was aware going for a new engine was a gamble, he had faith in Rolls-Royce's design team. Rolls-Royce had recently type-tested its Buzzard or 'H' engine, essentially a scaled-up Kestrel with 70 per cent greater displacement.

Bulman asked his boss, the Air Member for Supply and Research AVM John Higgins, to hold a meeting with the Rolls-Royce chairman Basil Johnson. When he arrived, Bulman and Higgins were amazed that Johnson wanted to refuse the commission. He was worried that involvement in "sordid competition" would tarnish the firm's reputation for quality and perfection.

ABOVE: Two of the key figures behind what became the Merlin: Sir Henry Royce (right) and Supermarine's R. J. Mitchell. Of course, neither man would live to witness the full impact of the powerplant in operational use. *AEROPLANE*



ABOVE: The first Hurricane prototype, K5083, required three engine changes due to various problems with the Merlin. *AEROPLANE*
TOP RIGHT: Rolls-Royce-operated Hawker Hart K3036, in which the first PV12 test flight was made.
ABOVE RIGHT: A long-serving testbed was Rolls-Royce's Hawker Horsley S1436, here with a Merlin III. *AEROPLANE*

Knowing that, as he put it, "the firm's engineers were straining at the leash to go ahead", Bulman "blurted out in [his] fury a single word, unprintable in polite context". His boss "turned and looked at me for a long second, and then in a steely voice of real Air Marshal calibre said to our guest, 'Mr [Johnson], I order your firm to take on this job. We have complete faith in your technical team. The necessary arrangements will be made between our respective staffs. Good afternoon". Johnson — who was not to remain Rolls-Royce chairman for much longer — left with his tail between his legs, and as Bulman hurried to give the good news to Rowledge, Higgins thanked him "for summing up the discussion so succinctly"!

Sir Henry Royce is related as summing up his design philosophy as, "I invent nothing; inventors go broke". The Rolls-Royce designers decided that the best course of action would be to build on the 'H', itself a scaled-up Kestrel, in order to build a 'racing H', or 'R'. The 'R' was a supercharged engine of 6in bore by 6.6in stroke, with a compression ratio of 6:1. Starting in October 1928 and working day and night, Rolls-Royce had such an engine on test in three months. With the help of the Ethyl Export Corporation's fuel expert Rod Banks, it raised supercharger boost and engine power without encountering detonation by adding benzole and tetraethyl lead (TEL) to aviation fuel to raise the octane rating. In September 1929, the 'R' producing about 1,900hp, with the Supermarine S6 won the Schneider Trophy at a speed of 328.64mph.

For the 1931 attempt, the Rolls-Royce development engineers sought to increase the 'R's' power. This was achieved by raising the revs and supercharger boost, Rod Banks concocting a new 'witches' brew' by adding 10 per cent methanol to the previous fuel cocktail, allowing the engine to run at 3,200rpm and 2,350hp. If what comes up must go down, however, in engine terms what goes in must come out, and the prodigious heat output of the uprated 'R' required both a beefier cooling system, and the introduction of new technologies such as sodium-cooled exhaust valves, a first for Rolls-Royce. Having increased power to such a degree, almost every part of the engine required strengthening, and during the spring of 1931 the 'Derby hum' of the day-and-night development running was such that the mayor had to appeal to the patriotism of the city's citizens as they complained of lost sleep.

> "The Merlin is sometimes called a derivative of the 'R', but although it drew on the racing engine it was smaller and used different construction"

As is now well-known, in September 1931 the updated Supermarine S6B won the Schneider Trophy outright for Britain at a speed of 340.08mph. Later that month it attempted the world absolute speed record. For this Banks concocted a brew of 60 per cent methanol, 30 per cent benzole and 10 per cent acetone, with 4.2cc of tetraethyl lead per gallon. Dissolving paint and tank sealing compounds and causing spark plug leading, this was even less suitable an everyday fuel than that used for the Schneider Trophy, but it was only needed for a short run. Adding some 250hp of extra power, the S6B smashed the 400mph barrier — and the record — at 407.5mph.

Though the 'R' was phenomenally successful, it was not a practical service engine. By the early 1930s it was clear to Rolls-Royce both that the RAF would be needing an engine more powerful than the Kestrel, and that the technologies used for the 'R' were one way of achieving this. The resultant engine was the PV12, soon to be named the Merlin.

The Merlin is sometimes described as being a derivative of the 'R', but though it drew on much of the development experience from the racing engine, it was much smaller and used different construction. As the name implied, the PV12 was a private venture without an Air Ministry contract, but it was not quite the gamble that is sometimes suggested. The Rolls-Royce company historian called it a "courageous decision", but if the firm still produced only 315 engines in 1931 and the same again in 1932, this was up from a mere

35 in 1929, and was a measure of the Kestrel's considerable success.

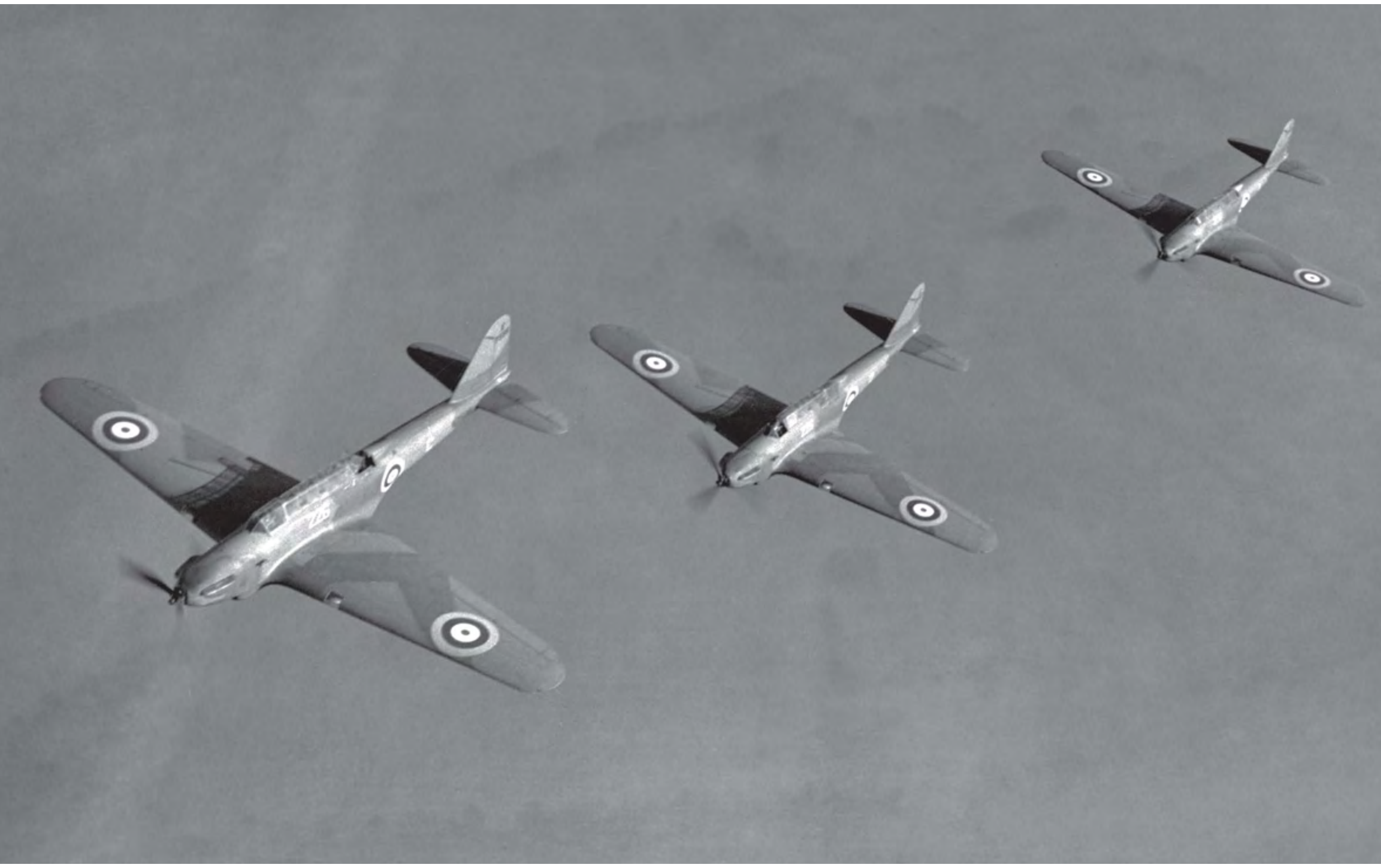
In addition, in the inter-war period the Air Ministry's Directorate of Technical Development worked closely with engine manufacturers, and it was understood that promising engines would soon gain the support of the Ministry. Bulman was happy to let Rolls-Royce start work on the PV12, knowing that he would be able to put development funds towards it in due course. Indeed, the earliest flight tests of the Merlin were covered by a Ministry contract.

Approving the PV12's development in October 1932 was one of the last decisions Henry Royce made, sketching a preliminary design with a stroke of 6in and a bore of 5.4in. The design followed existing Rolls-Royce practice: a supercharged 60° liquid-cooled monobloc V12, with wet cylinder liners, four sodium-cooled valves per cylinder, and fork-and-blade connecting rods. To ensure rigidity and strength for an engine whose potential power was in excess of 1,000hp, the cylinder blocks were cast integral with the upper crankcase, with cylinder head castings being screwed down onto the blocks. Six months later Royce was dead, and he was succeeded as chief engineer by A. G. Elliott.

The first PV12 prototype ran on the bench in October 1933, passing a type test the following July. The inaugural flight test was made in Hawker Hart K3036 on 21 February 1935. Two prototype engines were built, and during development minor changes were made, such as switching from helical to spur reduction gears. More serious troubles were encountered with the large crankcase and cylinder block castings. Despite Rolls-Royce's foundry expertise, they were susceptible to cracking, and large components were expensive to repair. The evaporative engine cooling system proved troublesome and prone to leaks.

The first engine to carry the Merlin name may in fact have been one of the design concepts discarded for the PV12: an inverted V12. A mock-up was built, but after consideration of the pros and cons it was decided to continue with a conventional V12 layout. The mock-up, however, was on display at the Rolls-Royce factory when a delegation of German engineers visited, and reportedly took a close interest in the design. The big Daimler-Benz and Junkers Jumo V12s developed for the Second World War were all inverted V12s. Though the German engineers could weigh up the configuration's advantages and disadvantages as well as could Rolls-Royce's, did the sight of the mock-up maybe tip the balance in favour of the inverted design?

In any case, for the next PV12 variant, now called the Merlin B, Elliott introduced some changes of his own. The original PV12 prototypes, like the Kestrel, Buzzard and 'R' before them, used a plain flat cylinder head, which allowed for easy valve placement. Elliott, however, had become convinced of the advantages of a 'ramp' head; this more complex shape supposedly improved combustion by creating turbulence in the cylinder, giving better mixing of the fuel and inlet air. Elliott had long been a proponent of such a head, arguing that single-cylinder tests of the design showed clear benefits. Perhaps, now he was out of Royce's shadow, he also saw a chance to try out some of his own ideas? However, once Merlin B running started in February 1935 it became clear that the advantages were proving elusive if not



ABOVE: The first Merlin-powered aircraft to enter RAF service was the Fairey Battle light bomber. Photographed in 1937, these examples are from Nos 105 and 226 Squadrons. *AEROPLANE*

An instrumented external Merlin test rig at Rolls-Royce's Hucknall, Nottinghamshire-based experimental department. AEROPLANE

imaginary. It produced less power, was more susceptible to detonation, and suffered from problems with burning of the exhaust ports.

Continued cracking of the cylinder block led to a redesign for the next model, the Merlin C. This effectively sliced the troublesome large casting into three, with the cylinder blocks separated from the upper crankcase. While this solved the cracking problem, the ramp head continued to give trouble, and, in the words of engine historian Graham White, the Merlin entered "the nadir of its development". The Merlin C failed its civilian (50-hour) type test, and the decision was made to switch the cooling system from water to ethylene glycol. Though water has a greater specific heat, glycol has a higher boiling point. Developing 890hp, Merlin Cs did power the prototypes of both the Spitfire and the Hurricane, though presumably their designers had a certain amount of trepidation in using a non-type-tested engine for their aircraft. Indeed, the Hurricane prototype's engine had to be changed three times because of cracking and coolant leaks.

Rolls-Royce's development engineers tried their best to salvage the ramp head, changing the location of the spark plugs and the head's layout, but were only marginally successful. The Merlin E's revised heads allowed this engine to pass a civilian type test in December 1935 at 890hp, but in March 1936 it failed the 100-hour military test. It still had problems with exhaust valve burning. With minor modifications it was developed into the Merlin F, which passed a reduced military type test, allowing for the replacement of valves, in November 1936. By this point the pressures of rearmament had caused the Air Ministry to order the Merlin F into production as the Merlin I.

> "The Merlin C failed its civilian 50-hour type test, and the decision was made to switch the cooling system from water to ethylene glycol"

Some 172 engines were built, mainly for Fairey Battles. Though unreliable, at 1,030hp they were the most powerful engines the RAF had available.

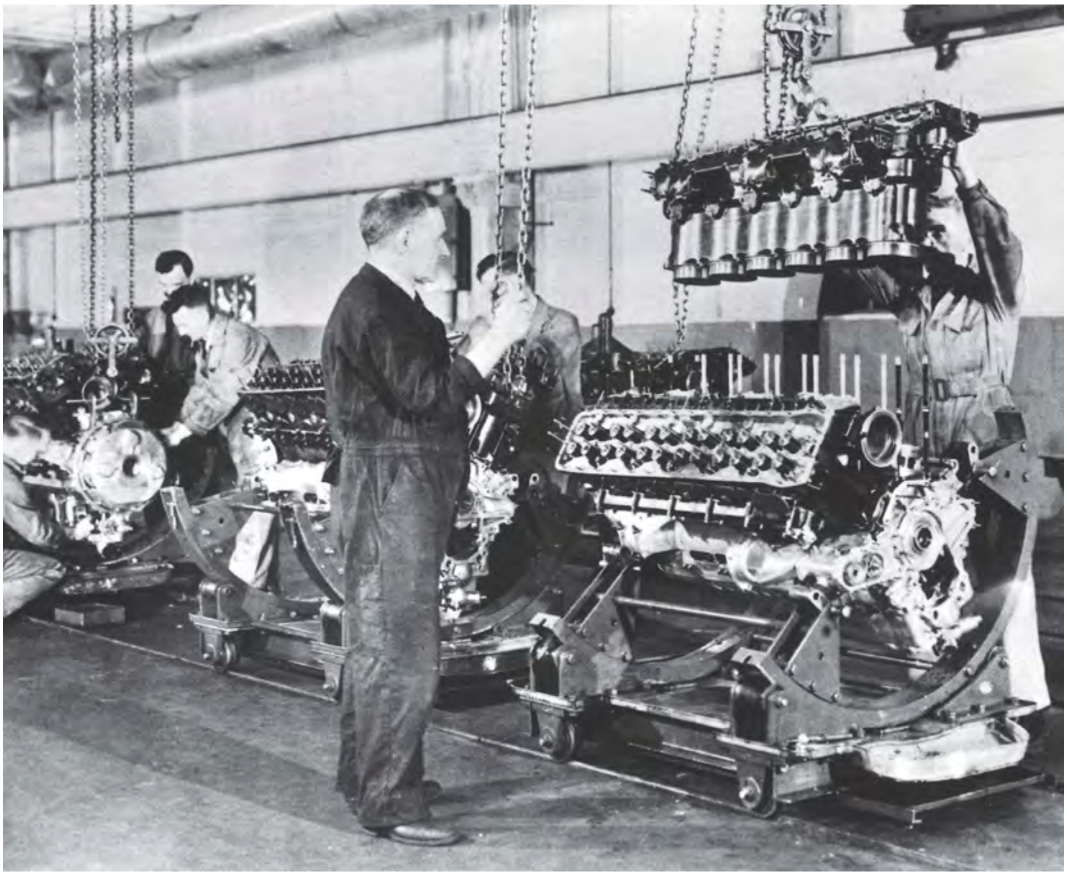
Elliott had come to the conclusion that the ramp head was not going to be suitable for a production engine, and had tested the Merlin G. This used what was effectively a scaled-up Kestrel block, with a conventional flat-head combustion chamber and the cylinder heads cast integral to the cylinder blocks. Though it was no more powerful than the Merlin F, it was significantly more reliable, passing a type test in October 1936 and entering production the following year as the Merlin II. More than 1,000 Merlin IIs were built by 1939, and, along with the Merlin III (a model with only minor differences), it was the engine that powered the RAF's Spitfires and Hurricanes in the Battle of Britain.

One major advantage that the RAF had was the introduction of 100-octane fuel. This allowed an increase in maximum supercharger boost from +6.25 to +9, increasing power from 1,030 to 1,160hp. By mid-1940 the Merlin III had been cleared for five-minute emergency power at +12 boost, giving 1,310hp at 3,000rpm.

Many factories built the Merlin

By the mid-1930s, it was becoming clear that the growth of airframe and aero engine production required by the RAF's expansion schemes would far outstrip the capacity of existing manufacturers. The solution was for the government to pay for 'shadow' production capacity, mostly in the automotive industry. A 1934 government analysis of Kestrel production capacity concluded that it would be insufficient in wartime. The suggested remedy was an 'educational' shadow scheme, with Rolls-Royce teaching Humber how to build Kestrels. However, as with Condor production, Rolls-Royce was reluctant to share its secrets. It instead decided to increase the capacity of its Derby factory, as well as sub-contracting more work.

Even more change was afoot. The head of the experimental department, Ernest Hives, was appointed general works manager at the end of 1936, and was convinced of the need for Rolls-Royce's working practices to change. After analysing the company's operations, he submitted a report to the board in January 1937. It made sobering reading, pointing out that current profits were essentially based entirely on military rearmament contracts, and masked the fact that production costs were disproportionate. Rolls-Royce's legendarily skilled employees were compensating for the fact that equipment and working practices were outmoded. There were almost as many hand-workers as machinists, whereas modern factory practice was to have between six and eight machine-workers to every hand-worker. Cost control was deemed inadequate, and the design staff organisation was hampered by having been set up to deal with Henry Royce's 'in absentia' personal oversight of all major projects.



Work under way at Ford's Trafford Park shadow factory in Manchester. KEY COLLECTION

> "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"

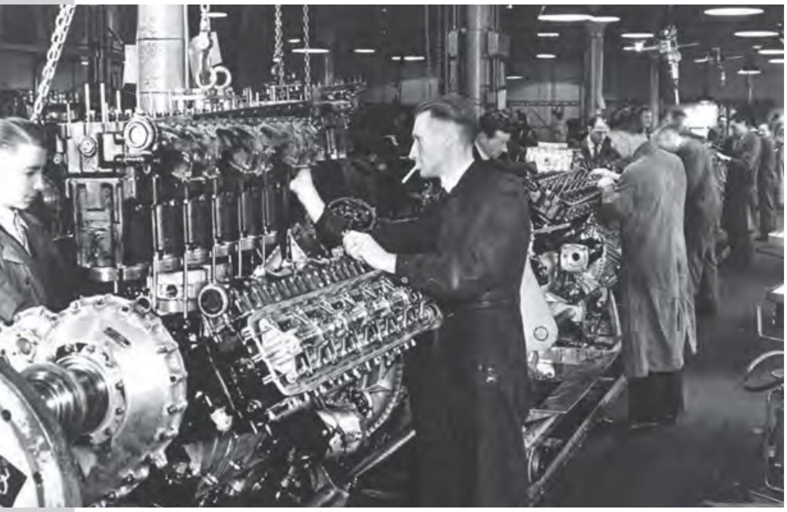
With the support of the board, Hives swiftly made wholesale changes to Rolls-Royce's operations and factory layout. Though it was not without the inevitable snags, by the end of 1937 the company's production potential was looking a great deal healthier, especially as, with the abandonment of the ramp head Merlin, the worst of the engine's development woes were behind it.

As noted previously, Rolls-Royce had 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 programmes more room would be required. The company decided to operate its own shadow factories, building one in Crewe and one in Hillington, a suburb of Glasgow.

Shadow factories were designed for mass production and a high degree of machine tooling, using a large proportion of unskilled or semi-skilled labour. As a result, their output was fairly inflexible — making design changes required re-tooling and re-jigging. Rolls-Royce operated a three-tier system: Glasgow (and later other licence factories) only manufactured major variants in large numbers; Derby became, in Hives' words, "a huge development factory rather than a manufacturing plant", and Crewe was somewhere between the two.

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. Rolls-Royce's policy of apprenticeships and highly skilled labour turned out to have the unforeseen advantage that it could promote a nucleus of skilled staff from Derby to act as overseers in both its shadow factories, transferring production knowhow.

Rolls-Royce chose Crewe for its first shadow factory because of its good road and rail links to Derby. Construction began in July



Merlins on the line in Nottingham. Rolls-Royce learned much about modern production techniques during the 1930s. *AEROPLANE*

1938, and an astonishing five months later the first Merlins were coming off the production line. Glasgow was selected because it was becoming hard to find engineering workers in the Midlands, and providing suitable housing for those who had been employed at Crewe was a problem; while housing was being built, employees had to be billeted with local households.

Construction of the Hillington factory began in June 1939, and was able to draw on the experience gained in setting up Crewe. The first buildings were occupied in October of that year, and engines started coming off the line in November 1940, though the plant had been providing parts for work undertaken at Derby and Crewe before then. However, despite high unemployment in the Glasgow engineering industries during the depression, the demands of rearmament as well as conscription into the armed forces meant that finding suitably skilled workers was a problem. Hilllington was designed to be mostly self-sufficient, relying far less on sub-contracting than Crewe or Derby, and so needed skilled foundry workers as well as machinists. Shaped by the brutal unemployment of the 1930s, many of the workers who could be found were considered militant by the management, and despite being a factory intended to use large amounts of unskilled labour there were constant disputes about who should be allowed to work on which machines. Nonetheless, by June 1941 Hillington was producing 200 engines a month, and by March 1942 more than 400 a month were rolling off the line.

The Air Ministry had decided by November 1939 that the demands of wartime — in particular those of the multi-engined bomber programmes — would require engine production even in excess of what the Crewe and Glasgow factories could provide. Air Marshal Wilfred Freeman, the air member for development and production, enquired of the Ford UK chairman Sir Percival Perry whether he would be willing to produce Merlins. In a follow-up meeting with Perry and his general manager Rowland Smith, Smith agreed that Ford could, though his estimate of the cost to build and equip a shadow factory for the desired rate of 400 engines a month was £7 million, equivalent to hundreds of millions of pounds today. Remarkably, the actual cost was some £6.6 million. Freeman felt the matter was urgent enough to sidestep the usual procedures and sent George Bulman to the Treasury to get approval, which he received within about five minutes of his arrival!

Ford decided its Dagenham factory could not be expanded to manage production on this scale, and chose to build a new facility on the Trafford Park industrial estate in Manchester. Because Rolls-Royce had no skilled workers to spare, having sent staff to establish the Crewe and Glasgow plants, Ford decided to send 190 of its workers to Derby to learn the manufacturing processes needed for a Merlin, in order to be able to set up the machine tools for a production line.

On arriving there, the Ford engineering team discovered that the Rolls-Royce drawings were unsuitable for the demands of Ford-style manufacturing: the tolerances were too wide to allow for the mass production of interchangeable parts. Having redrawn some 20,000 drawings to Ford's standards, the Trafford Park factory began construction in the spring of 1940, and the first engines were produced in May-June 1941, though the manufacture of parts for use on Crewe's production lines was under way by August 1940.

By the end of the war, Ford had produced some 30,000 Merlins, all twin-speed single-stage engines (initially Merlin XXs, later 22s and 24s) that were used mostly in bombers.

FRENCH MERLINS

During 1939 the French Air Ministry was seeking to supplement the output of the French aero engine industry, and asked Ford SAF, the French subsidiary of the Ford Motor Company, to negotiate a licence for Merlins with Rolls-Royce. Initial discussions were held in March 1939, when Ford SAF's managing director confided in the Rolls-Royce executive that his company was not really interested in making complete engines for some time, but that the Air Ministry's proposal was motivated largely by the need to satisfy political opinion in France.

The Ford subsidiary company Fordair was to handle production, with a new factory to be built in Bordeaux. This would not be ready before the spring of 1940, so initially Fordair was to be more of a repair and overhaul centre for Derby-built Merlins. Because of the difficulties Fordair had in finding machine tools and skilled staff, a team of engineers from the US parent company was sent to Derby, who analysed production requirements and ordered tooling in the US for shipment to Bordeaux. Unfortunately, in August 1939 the strongly isolationist Henry Ford had decided to stop work on any armament projects, and recalled the Detroit engineers. Without this assistance Fordair was overstretched, so discussions began about the production of engines from parts.

By the autumn, it was clear that, although Fordair had made some progress, production was unlikely to start before late 1940, due to a shortage of tooling and staff. Much intrigue seems to have surrounded the project at the French Air Ministry (as indeed was the case for much of France's nationalised aero industry), and the licence was finally cancelled in December 1939, with Fordair's Bordeaux factory being switched to the production of the simpler, if significantly less powerful, Hispano-Suiza V12 engine.

The Merlin was still, however, intended as the powerplant for a number of advanced French designs, including the Dewoitine D531 fighter and the Amiot 356 bomber, and the French Ministry placed orders for these engines in Derby. Rolls-Royce delivered 143 Merlins before the fall of France, but few — if any — made it into aircraft, and none of them into action.

THE PACKARD MERLIN

An early Packard V-1650 application was on the Curtiss P-40F. This is an 18th Fighter Group example named ***Destitute Prostitute.*** USAF

When Lord Beaverbrook took over the Ministry of Aircraft Production in May 1940, he 'raised the voltage' there, bringing his brand of whirlwind energy to bear. Though his influence was in many ways mixed — he inherited an organisation that was beginning to bear the fruits of the past three or four years' rearmament planning, and many of his schemes would have damaged long-term planning while bringing only minimal improvements in the short term — he did have a galvanising effect on many schemes. Rolls-Royce was able to gain approval for various repair schemes to keep up with Merlin demand: bullet holes were patched and repaired, cracked crankcases damaged in wheels-up landings had steel braces attached, and major components were salvaged wherever possible from damaged engines and used for new engines.

Among his ideas was to send sets of blueprints for British war materiel to the US with a view to securing their overseas production. These included drawings for the Merlin and Griffon engines. The Rolls-Royce management was unhappy about this, worrying, given Beaverbrook's buccaneering style, that he might trade away manufacturing licences for other concessions without regard to the company's rights. They were not entirely wrong — in June 1940 it was reported that Ford had been given a contract to manufacture 6,000 Merlins. Given the work already done by the Detroit engineers for the French Ford company, and that under way by Ford UK, this made some sense, but within hours of the announcement Henry Ford had decided that he would not provide war materiel to a belligerent party — only to the US government. The entreaties of his son Edsel, the Ford Motor Company's president, and US government officials proved futile, and the deal was cancelled.

Rolls-Royce's American representatives had been in discussion with US companies exploring the possibility of licensed production since 1938, though nothing had come of it. Derby's management had considered at the time that it would be more cost-effective to sub-contract the manufacture of parts, rather than complete engines. With the failure of the Ford production deal, the British Purchasing Commission turned to the Packard Motor Car Company. Packard was, like Rolls-Royce, a luxury car manufacturer, and was one of the few US companies that Henry Royce had respected.

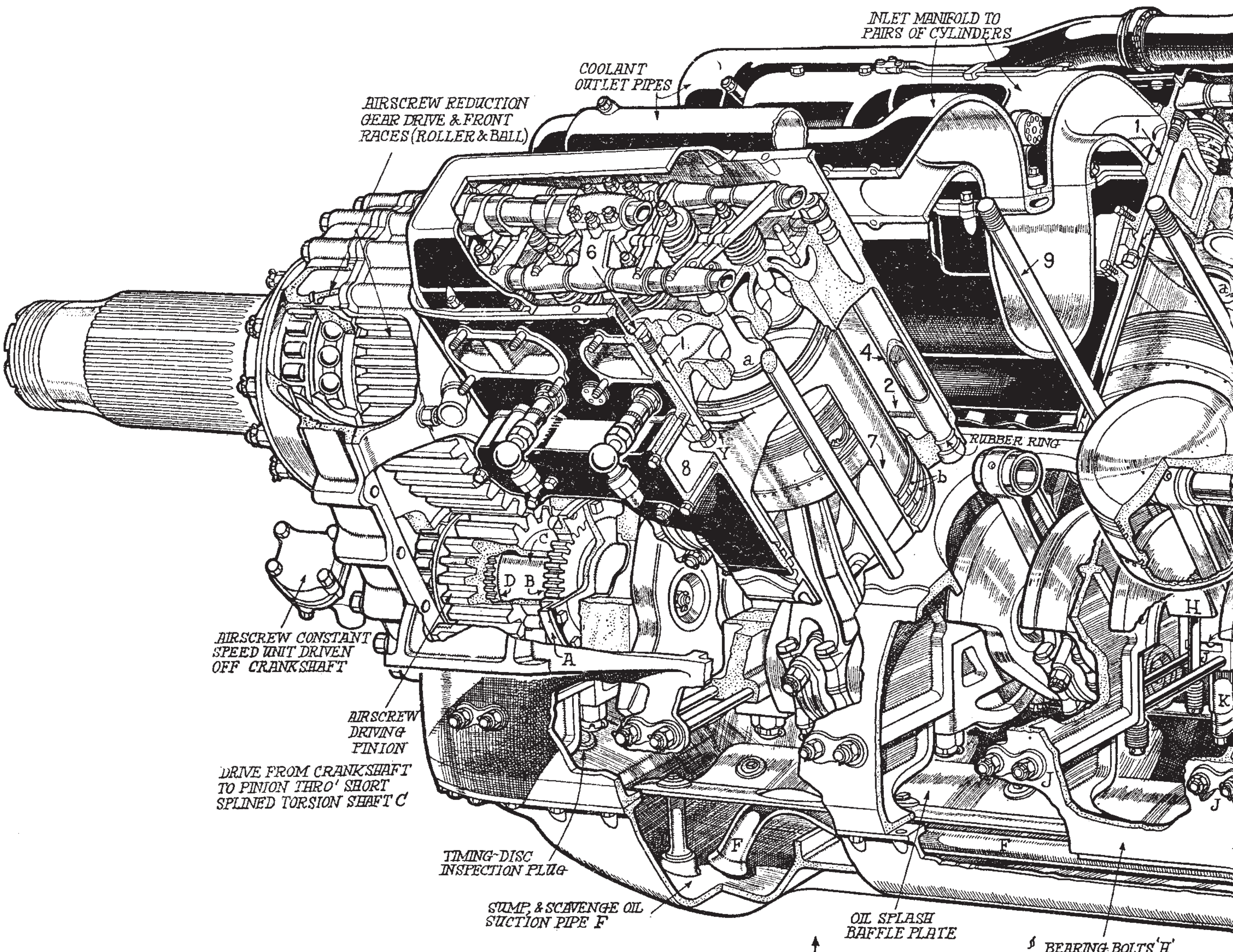
The initial order was for 9,000 engines, of which 3,000 were for the US government, the remainder going to the UK. Engines for the UK were given a Merlin mark number, and US engines were designated V-1650, with a dash number denoting the mark. Units for the US and UK differed mainly in their propeller splines, with the UK engines using SBAC-standard splines, and the US engines SAE-standard. The Packard Merlins used US carburettors, magnetos and other accessories, and an epicyclic supercharger drive rather than the Farman drive used on Rolls-Royce versions.

Contracts were signed in September 1940, and production began roughly a year later. It had been a mammoth undertaking; drawings had to be redrafted to American projection standards and to Packard's tolerances. Because Packard decided to keep the British threads used on the Merlin, rather than re-engineer the engine with SAE standard threads, it had to manufacture its own thread-cutting and rolling machine tools. The company re-engineered the engine to have a two-piece block, where the heads, cylinder skirts and upper crankcase were all separate castings bolted together. Rolls-Royce had plans to do this for its future engines, but under the pressures of war had not yet been able to put a two-piece block into production. The resultant engine was the Merlin 28/V-1650-1, and was based on the Merlin XX. By April 1942 this was coming off Packard's line at the rate of 510 per month, and in 1944 the average monthly production was just shy of a frankly incredible 2,000 engines per month.

> "In 1944 the average monthly production of V-1650-1 engines was just shy of a frankly incredible 2,000 units per month"

Some 897 V-1650 engines, mostly late-mark V-1650-7s, were also built by the Continental Aircraft Engine Company, which used Packard's sub-contractors. Packard-built engines were highly popular with RAF mechanics, because they were packaged with an extensive toolkit of excellent quality, which tended to be liberated as quickly as possible by groundcrew.

THE 1,280 h.p. ROLLS-ROYCE



CYLINDER BOLTS 9 HOLD DOWN ONE-PIECE CYL. HEAD & JACKET 2 WHICH HOLDS DOWN LINERS BY TOP GASKET. BOLTS 1 HOLD LINERS TO HEAD. BOLTS 1 ARE TIGHTENED FROM PORTALS 8 & LOCKED BY SCREW PLUGS 6 BOLTS 9 ARE SEALED FROM COOLANT IN TUBES 9. NOTE LARGE COOLANT SPACE AT 2

BEARING BOLTS 'H'
OIL PORT 'h'
TWO TRANSVERSE CLAMPING BOLTS PER BEARING 'J'
OIL SUPPLY 'K'

W—Splined drive from crankshaft for all auxiliaries off T.
t, t, t,—Drives for two-speed single-stage supercharger.
X—Selector forks.
L—Fork operating rod from oil operating-piston.
S—High-speed clutches.
SS—Low-speed clutch.
R—Two driven pinions solid on impeller shaft.
P—Impeller.
Q—Volute vanes.
b—Rubber sealing rings
Y—Flange on liner engages bolt and lug

Drawing by J. H. Clark,
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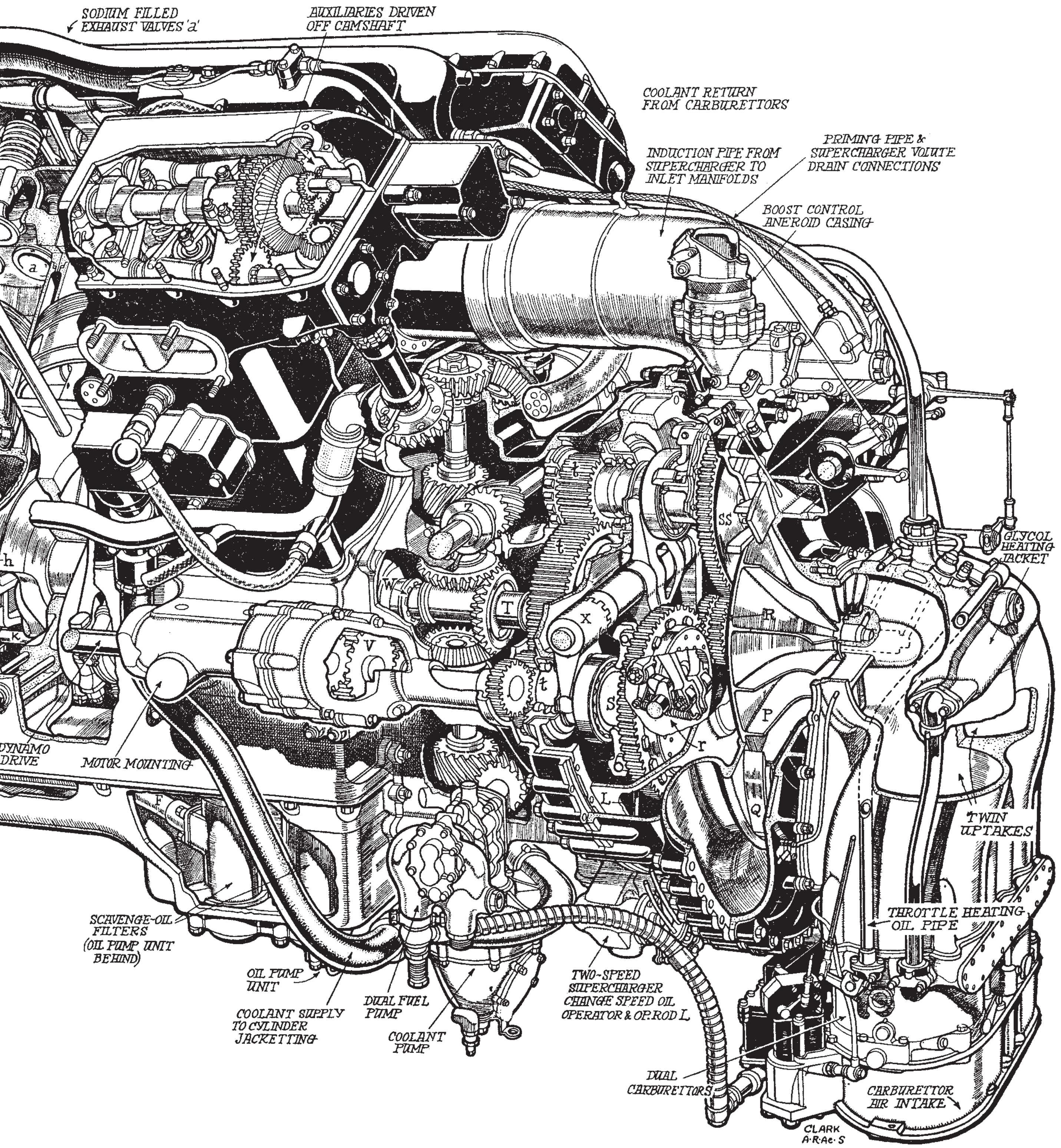
MERLIN 20 AERO-MOTOR



The beautiful Speed Spitfire runs up its Merlin II (Special), a variant that illustrated the engine's development potential. *AEROPLANE*

Keeping the Merlin in power

In the late 1930s, as the ramp head Merlin and its development woes were abandoned, it was clear that the engine had huge potential. In late 1937 Supermarine had begun the modification of a 'Speed Spitfire' for an attempt on the world air speed record. As with the 'R', Rolls-Royce provided support, testing the engine on another of Rod Banks' special fuels. By January 1939 this Merlin II (Special) was flying at more than 2,160hp, with +27 boost. Even though, with its special spark plugs and coolant systems, it could only maintain this power for a few minutes at a time, at heart it was still basically a strengthened production Merlin II. As Spitfire test pilot Jeffrey Quill noted, this did more to reassure Supermarine's chief designer Joe Smith of the power growth that could be expected from the Merlin over the next few years than "any number of Rolls-Royce brochures and technical forecasts."

Hives was worried that Rolls-Royce could be too insular in appreciating expertise from outside the company. Among the changes he made after being appointed general works manager was taking on more technical staff from outside, and one of them was a young mathematician and fluid dynamicist called Stanley Hooker. The decision turned out to be incredibly fortuitous.

When Hooker arrived in early 1938, he was left to his own devices for a while to settle in. On casting around for something to work on, he came across the supercharger test section, and was shown the experimental plots of supercharger pressure. Feeling that this was a matter of aerodynamics, and therefore familiar ground, Hooker asked to borrow a set of test curves and went off to familiarise himself with supercharger theory. On examining the Merlin's design, he came to the conclusion that the rotor and diffuser of the supercharger were mismatched. If this mismatch were corrected, the efficiency of the supercharger could be improved from 65 per cent to 75 per cent or so.

Hooker wrote up his deductions in a report and gave a copy to A. G. Elliott. The chief designer's response was, "This looks very interesting; I must send a copy to Mister Ellor". A few days later Ellor burst into Hooker's office holding a copy of his report. "Did you write this?" he demanded. Nervously, Hooker admitted he had, and was told: "Well done, jolly good stuff. From now on you are in charge of supercharger development."

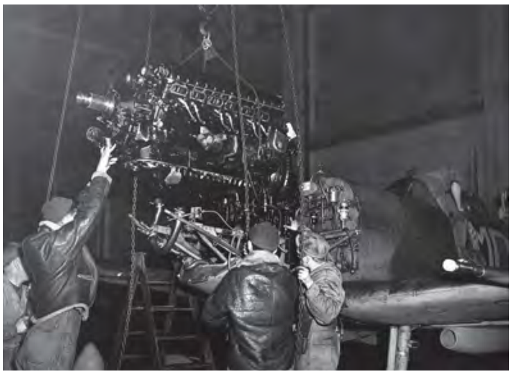
Up until this point the Merlin supercharger had been essentially unchanged from its original 1934 design. Though the Merlin X, introduced in 1938, had a two-speed supercharger, it used the same impeller. The two-speed drive allowed the supercharger to run at the gear best suited to the inlet air pressure: 'moderate supercharge' ('MS' or 'M' gear) for lower altitudes, and 'full supercharge' ('FS' or 'S' gear) at higher altitudes. After trying and failing to overcome the development problems of its own two-speed drive, Rolls-Royce licensed the French Farman design. The disadvantage was that this was less compact than the Derby version, and so the overall engine length increased.

> "The Speed Spitfire reassured Supermarine's chief designer of the power growth that could be expected from the Merlin"

Supercharger drive was mechanically a difficult proposition. The supercharger rotor was geared up to roughly 10 times the crankshaft speed; not only did this mean the drive had to spin at tens of thousands of rpm, but any accelerations in the engine were multiplied ten-fold. Coupled with the need to tolerate the loads from supercharger gear changes, this meant the drive had to be flexible, as well as durable, compact, and ideally light. The Merlin used a torsionally flexible quill shaft, driven off the crankshaft. Its supercharger gears were of such high quality that when German engineers needed a gear unit to drive test compressors for Daimler-Benz and Junkers engines, they used Merlin supercharger drive assemblies removed from shot-down RAF aircraft.

Because of the supercharger's location at the back of the engine, the intake ducting had a number of bends, and the flow into the supercharger rotor was less than ideal in efficiency terms. After some experiments to quantify the pressure losses, Hooker redesigned the intake and supercharger casing. Together with the redesigned rotor and a new pressurised water/glycol cooling system, this was incorporated into the two-speed Merlin XX. The new supercharger raised the engine's full-throttle height by 3,000ft.

Because of the two-speed supercharger drive the engine



TOP LEFT: Stanley Hooker took on Merlin supercharger development.

TOP RIGHT: The first test run-up of a 20mm cannon-equipped Hurricane IIc, straight off the assembly line at Hawker's Langley factory. AEROPLANE

ABOVE LEFT: A Spitfire V from the USAAF's 4th Fighter Group having its Merlin 45 changed. USAF

ABOVE RIGHT: A new Lancaster I in August 1942 shows the Merlin XX 'power egg'. AEROPLANE

was longer than the Merlin II/III, and was initially intended for heavy bombers. It could be fitted into the Hurricane with the addition of a fuselage plug in front of the cockpit, but the Spitfire's more complex structure would take longer to modify. As the Hurricane I was in greater need of a performance boost than the Spitfire I, the Merlin XX-engined design was put into production as the Hurricane II, entering service in September 1940. The Spitfire would have to soldier on until the planned service entry of the Merlin XX-powered MkII in 1941.

In the event, Rolls-Royce realised that by retaining the FS gear of the Merlin XX and moving the carburettor, it could produce the Merlin 45, an engine of the same effective dimensions as the Merlin III, which maintained the Merlin XX's medium- and high-altitude performance. Fitted to the Spitfire I airframe it created the Spitfire V. This 'interim' mark was so successful that more were built than any other variant, and the Spitfire III never entered production. To boost performance at low altitudes the supercharger blades were shortened, creating the Merlin 45M. On MkV airframes with the wingtips removed for increased roll rate, this created the 'clapped, clipped and cropped' Spitfire LFV low-level fighters of legend.

Another problem tackled was carburettor design. The float carburettors on early Merlins were susceptible to negative g-loads, when fuel would flood the carburettor chamber. Once positive g was re-established the engine suffered loss of power or a rich mixture cut-out. The Luftwaffe's Daimler-Benz engines used direct fuel injection, which was immune to g-effects, so bunting over into a dive at full throttle could give German fighters a momentary advantage or means of escape. Merlin-engined Spitfires and Hurricanes had to half-roll and pull to follow them without risking an engine cut-out.

Rolls-Royce had considered fuel injection, but chose the carburettor because the fuel vaporising in the inlet system cooled the charge, increasing power. Beatrice Shilling, an engineer working at the Royal Aircraft Establishment, worked out a solution: a restrictor ring was fitted to the carburettor, which limited fuel flow to that required at maximum throttle, preventing the flooding of the float chamber and the rich mixture cut-out. Fitted to front-line aircraft from early 1941, this elegantly simple solution was officially called the 'RAE restrictor', but with predictable service schoolboy humour became known as 'Miss Shilling's Orifice'. It only allowed short periods of negative-g flight, so a longer-term solution was the adoption of the Bendix pressure carburettor, and ultimately fuel injection into the supercharger.

Rolls-Royce also did work on packaging the Merlin into 'power egg' units, with standard mountings and fuel and other connections to be mounted into different aircraft types. Starting with the Merlin XX, these were fitted to the Bristol Beaufighter and the Avro Lancaster.

With the success of the Merlin XX and 45, Hooker and the engineers began to consider how to improve performance further. He calculated that refining the existing supercharger would only give marginal improvements in power, as the maximum efficient compression ratio achievable from a single blower was about 4:1. What was needed was a new approach. By placing two superchargers in series on the same shaft, the Merlin would be able to develop 1,000hp at 30,000ft. Rolls-Royce did consider a turbocharger system, but decided that, especially for fighter applications, the advantages were offset by the weight and complexity of the ducting. The Merlin's exhaust energy was not wasted — the engine's ejector stacks produced a useful measure of thrust, equivalent to an extra 200hp at typical combat speeds and altitudes.

At the same time, the Kestrel-type cylinder blocks introduced with the Merlin II were reaching their limits. To develop more power, the engine would have to be redesigned to have separate blocks and heads. The Merlin's engineers had known this for a while; when Packard Merlin production was being planned, the Rolls-Royce engineers told Packard to develop its own two-piece block (once Rolls-Royce had developed its own two-piece design, Packard switched production over to this), but the immediate demands of production had taken priority. Introduced on Derby-built engines in the two-stage Merlin 61, the two-piece

TOP LEFT: The Merlin 61 breathed new life into the Spitfire, and the resulting MkIX was an outstanding fighter. Pictured is MH869 of No 302 (Polish) Squadron escorting USAAF bombers. USAF

TOP RIGHT: The initial Merlin installation on the P-51, with chin-mounted radiator, is shown by prototype Mustang X AM121. IWM

ABOVE RIGHT: P-51B 42-106950 from the 355th Fighter Group's 354th Fighter Squadron at Boxted. USAF

ABOVE LEFT: Sea Hornet F20 TT202 being powered along by its twin Merlin 130s. *AEROPLANE*

blocks allowed the use of boosts up to +15 on 100-octane fuel. From 1944, 150-grade fuel permitted emergency boosts of +25, giving over 2,000hp. Equally importantly, power was maintained at altitude, giving more than 1,500hp at 15,000ft, and in excess of 1,300hp at 23,000ft.

As had happened with the Merlin XX, the engine was designed for bomber applications, but when fitted to the Spitfire it provided a major performance boost, especially at altitude. At 30,000ft the Merlin 61-engined Spitfire IX was 70mph faster than the MkV. Initially the RAF displayed a certain diffidence towards the MkIX, as the MkV was considered adequate, and the Griffon-engined MkIV was under development. The arrival of the Focke-Wulf Fw 190 changed this attitude completely, and the RAF wanted all the Spitfire IXs it could get.

Having transformed the Spitfire's high-altitude performance, the Merlin was to do the same with the North American Mustang. In late April 1942, the boss of the Air Fighting Development Unit at Duxford invited Rolls-Royce chief test pilot Ronnie Harker to flight-test a Mustang. Harker was very impressed by the aircraft's handling, and especially by its performance even with its Allison V-1710 engine, which was noticeably inferior to the Merlin at height. This suggested that the Mustang was aerodynamically cleaner than the Spitfire. Harker went away and asked Rolls-Royce's performance experts to estimate what the performance would be like fitted with a two-stage Merlin. Their analysis suggested a Merlin Mustang would gain 40mph at heights above 25,000ft.

Harker wrote a memo recommending that Rolls-Royce attempt a Merlin Mustang conversion, and management took up his case with the Air Ministry. Though there was some concern about the prospects — Spitfires were taking all the two-stage Merlins that could be produced — in the medium term the situation looked better, as Packard was starting to make two-stage V-1650-3s. The conversion was approved, and a number of Mustang airframes were sent to Hucknall. First test flights took place in October and November 1942, and even with the provisional Rolls-Royce installation — the Merlin's increased length and cooling requirements meant a slightly ungainly chin radiator — performance was significantly improved, the Merlin Mustang easily breaking the 400mph barrier.

North American's version of the Merlin installation was put into production as the P-51B/C, entering service with the US Army Air Force over the summer of 1943, and with the RAF at the end of the year. All production Merlin Mustangs were fitted with Packard engines.

As the Merlin's power increased, Rolls-Royce's army of development testers continued to improve the engine, whether by drawing up field modifications, or incorporating improvements into the next major mark. The main problem was maintaining reliability while power was increased. To this end, most major components of the engine were redesigned and beefed-up, including pistons, crankcases, crankshafts, cylinder blocks, cylinder heads and reduction gears.

One quirk of the engine was that both magnetos were powered off the camshaft drive, which ran up the back of the unit from the crankshaft to the top of the cylinder heads. Unfortunately, torsional vibration coming back from the camshaft sometimes caused the skew gearing to fail, which would result in, as the production Spitfire test pilot Alex Henshaw put it, "deafening silence" and total engine power loss. The skew gear design was not changed, but careful attention to the backlash adjustment of the drive gearing kept problems under control.

The earlier Beaufighter and Lancaster-type 'power eggs' were also developed into the Universal Power Plant (UPP), for later-mark Merlins. Fitted with an annular radiator and mounting to the standard SBAC 56in circular bulkhead, the UPP was easier to manufacture; the panels only required simple curvatures rather than the more complex shapes of the earlier versions. Installed on Lancaster VIs, Lincolns and other post-war types, the UPPs were totally interchangeable and could be fitted to any wing position, rather than being location-specific like the earlier installations. One could mix and match UPPs of different engine marks and even engine types — there was a Griffon UPP, too — though in practice this was only done on testbeds.

The ultimate production Merlins were the 100-series. First built in 1944, these incorporated a revised lubrication system for the main engine bearings, larger superchargers, and metered direct fuel injection into the supercharger from an engine-driven pump. They were mostly used on late-mark Mosquitos and on DH Hornets, with the equivalent Packard Merlins employed on late-mark Mustangs.

An experimental 100-series engine, the RM17 SM, passed a type test at 2,200hp, was cleared for flight at +30 boost and 2,340hp, and, with water injection, ran on a 15-minute test at +36 boost and an incredible 2,640hp. However, by the time these trials were being performed in late 1944/early 1945, it was clear that the future for high-powered military engines lay with gas turbines. Instead the Merlin's development team turned its attention to increasing reliability with an eye on commercial markets.

ABOVE: Trans-Canada Air Lines' second DC-4M2 North Star, CF-TCB *Cornwallis.* AEROPLANE

THE CIVIL MERLIN

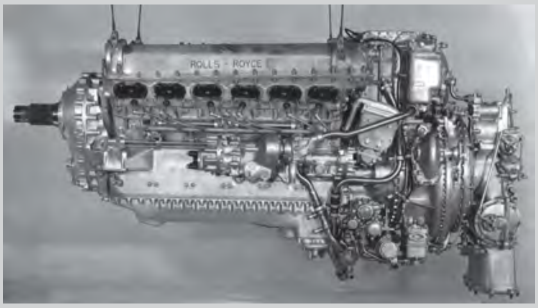
The earliest Merlins to operate in a civil mode were the Merlin T24 series, developed in 1944. These were single-stage twin-speed units similar to the Merlin 24s fitted to the RAF's Lancasters, but were modified to improve service life, and were fitted to Transport Command's Avro Yorks. Long-range transport operation entailed running at relatively low cruise power for long periods — under these conditions the lower cylinder head temperatures caused deposits of lead oxide from the fuel, resulting in excessive spark plug fouling. To counter this, the Merlin T24/4 incorporated a charge heater to increase the inlet temperature. Post-war, the Merlin 500 series essentially comprised civil and export versions of the T24, incorporating its modifications, though only the Merlin 501 included a charge heater.

The 600 and 700-series engines were two-speed two-stage affairs, based on the military 100-series. They were fitted with the so-called 'transport heads and banks', strengthened for greater reliability. Most marks had some form of variable intercooling to allow for charge heating to reduce plug fouling under cruise conditions. Initially the system was plagued by coolant leaks, but as experience showed that zero intercooling at cruise allowed enough charge heating to reduce leading, a simple stop valve was fitted to the system. This allowed full intercooling for take-off and climb, which could then be turned off for cruise.

Civil Merlins were fitted to Avro Lancastrians, Yorks and Tudors, but their flagship role was on the Canadair DC-4M North Star, a Douglas DC-4-derived design intended for Trans-Canada Air Lines (TCA). The North Stars used a modified Universal Power Plant installation, as the DC-4's nacelle bulkheads were slightly larger than the SBAC standard. In practice it turned out the Merlins were not ideally suited for use in civil operations: though the North Stars flew higher and faster than DC-4s, their time between engine overhauls was around 850 hours, roughly a third of that of commercial US radial engines. The engines also produced a lot of cabin noise, though this was alleviated somewhat by revised 'cross-over' exhausts that ducted the cabin-side stacks outboard, developed first by TCA and then by Rolls-Royce themselves.

The extra running costs were mostly borne by Rolls-Royce. When TCA's managing director expressed dissatisfaction with the Merlin's commercial performance, Hives asked what a reasonable level of maintenance cost would be. Being told $4 per engine hour, he agreed to service the fleet's engines for this amount. This early form of 'power by the hour' was initially expensive for Rolls-Royce, but by the end of the Merlin's life the company had learned enough to supposedly make a small profit at this level.

What was undoubtedly true was that Rolls-Royce learned a great deal about the harsh realities of commercial operation in a short time. Hives is supposed to have said to TCA, "We didn't know the Merlin until you started operating it!" In the longer term, this paid off, TCA — later Air Canada — selecting Rolls-Royce engines for its future fleet: Darts in Viscounts, Tynes in Vanguards, Conways in DC-8s, and RB211s in TriStars.



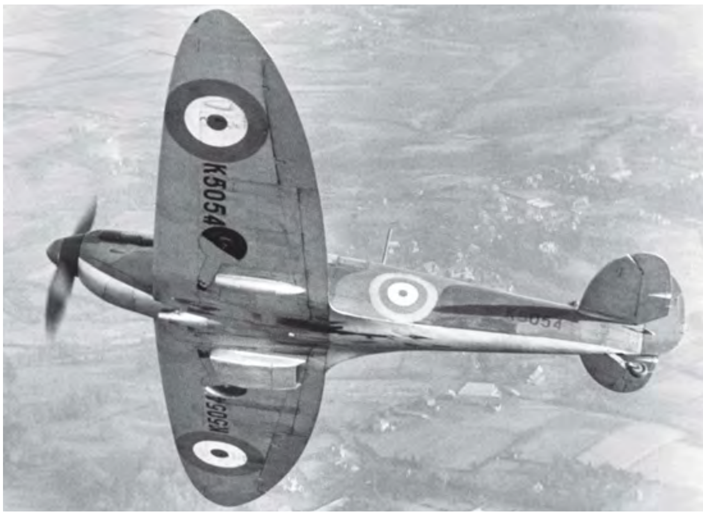
ABOVE: The Merlin 620, as fitted to the North Star among other types. AEROPLANE

Operating the Merlin

The Merlin was, by wartime standards, a reliable engine. To quote the Spitfire's chief test pilot Jeffrey Quill, "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."

The advantage of liquid-cooled engines such as the Merlin over the big radials was that the coolant provided a certain 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, such as through battle damage, would lead to a white stream of coolant evaporating off, a rise in cylinder temperatures, and piston or head failures in short order.

Controlling a Merlin required manipulation of three closely-linked engine settings: boost, propeller pitch and RPM. Boost was controlled with the throttle lever — as long as the supercharger could maintain it, automatic boost control kept this at the level selected by the pilot. There was generally a throttle 'gate', which the throttle could be pushed through by the pilot to select emergency boost. This was only supposed to be used for five minutes, but in combat, where the extra power might make the difference between shooting the opponent down and being shot down, this restriction was usually ignored. In some aircraft the gates were sealed; if emergency power was selected, the groundcrew could see this from the broken seals and knew to check the engine more closely.



Spitfire prototype K5054 being handled by Jeffrey Quill, who gave the Merlin high praise. *AEROPLANE*

Propeller pitch was analogous to the gearing in a car. Fine pitch was equivalent to a low gear, giving high thrust at low speed, and coarse pitch to a high gear, suitable for high speeds. The rpm was determined by the throttle setting and the pitch setting. By 1940 most combat types were fitted with constant-speed propellers, which were usually automatically controlled to govern rpm based on throttle settings. Pitch and boost could be manually controlled for take-off or for efficient cruise — as frictional losses in the engine scaled as the square of rpm, it was most efficient to cruise at a high boost and low rpm. In car terms this is akin to cruising along the motorway in an overdrive gear. As the RAF slogan put it, "Reduce the revs and boost the boost, you'll have enough petrol to get home to roost."

Because of its relatively high boost, the Merlin was not quite as smooth as the Allison V-1710, which had greater displacement. Even so, it has secured the affection of almost all pilots who have operated it, maintaining Rolls-Royce's reputation for excellence. In 1963, the American pilot Bill Lear was living in Switzerland and operating a P-51. Having trouble with the Packard Merlin's starter clutch, he contacted Rolls-Royce and was told to send it for inspection. On receiving the repaired unit back he rang to ask for an invoice, and was told: "My dear Mr Lear, Rolls-Royce-designed products do not fail. They may require occasional adjustment, but this is covered by our unlimited warranty. So there is no charge, sir."

MERLIN VARIANTS

Perhaps unsurprisingly for an engine made in greater numbers than any other of the Second World War — more than 112,000 in the UK, and over 168,000 if one includes the American-built Packard Merlins — the engine was produced in a dizzying array of variants. Unfortunately Rolls-Royce's mark numbers were assigned more or less in chronological order, and offer little clue to what the characteristics of any particular engine might be. Late-mark Merlin designations are slightly easier to decode, and by 1944 Rolls-Royce had started to assign Merlin marks to a particular series (see table).

Apart from the prototypes and the very earliest engines, Merlins either had a Kestrel-style single-piece block, with the cylinder skirts and heads as a single casting, or a two-piece block, where the heads were separate and bolted down onto the cylinders and upper crankcase. The single-piece was susceptible to coolant leaks at the head of the cylinder liner, especially as the Merlin's power was increased, but production pressures meant that Rolls-Royce could not introduce it on its engines until late 1942. Packard Merlins had a two-piece block of their own, but reverted to the Rolls-Royce design once it entered production.

The Merlin had three basic supercharger designs during its career. Early engines had a single-speed supercharger, while later marks had a twin-speed supercharger drive. Though initially fitted to fighters, the main use for these was in heavy bombers. The ultimate Merlin variants used a twin-speed twin-stage supercharger, with an intercooler and aftercooler, and were for high-altitude bombers and high-performance fighters. Packard V-1650s were all twin-speed twin-stage engines, apart from the V-1650-1, which was a twin-speed single-stage unit.

100	Late-mark two-speed two-stage engines
200	Packard-built Merlins for the RAF
300	Packard-built 100-series
500	Single-stage civil/commercial (for non-RAF customers) engines
600/700	Two-stage civil/commercial engines

SINGLE-SPEED SUPERCHARGERS

PV12	First prototype; cylinder skirts integral with upper crankcase
Merlin B	Ramp heads
Merlin C	Ramp heads; cylinder skirts and upper crankcase as separate castings
Merlin E	Ramp heads
Merlin F	Ramp heads
Merlin G	Ramp heads
Merlin I	Production model of Merlin G
Merlin II	Reverts to flat heads; Kestrel-type block
Merlin III	Similar to Merlin II; revised propeller shaft
Merlin IV	First of the Merlins to use pressurised coolant; 70/30 water/glycol
Merlin V	Similar to Merlin III
Merlin VIII	RN engine, similar to Merlin V; Coffman starter fitted
Merlin XII	Similar to Merlin III, but with pressurised coolant
Merlin 30	RN engine for low-level use; Coffman starter
Merlin 32	Similar to Merlin 30 but with two-piece blocks
Merlin 45	Similar to Merlin XX but without twin-speed drive
Merlin 45M	Similar to Merlin 45 but with cropped supercharger impeller for low-level performance
Merlin 46	Similar to Merlin 45 but optimised for high-altitude performance
Merlin 47	Similar to Merlin 46
Merlin 50	Modified Merlin 46; service test of anti-g carburettors
Merlin 50A	Similar to Merlin 46
Merlin 50M	Merlin 50 modified for low-level performance
Merlin 55	Merlin 50 modified with two-piece blocks
Merlin 55A	Similar to Merlin 45
Merlin 55M	Similar to Merlin 45M
Merlin 55MA	Similar to Merlin 45M, but with two-piece blocks
Merlin 56	Modified Merlin 55

TWIN-SPEED SINGLE-STAGE SUPERCHARGERS

The Hispano HA-1112-M1L Buchón, as here being used to make *The Battle of Britain*, received the Merlin 500/45. AEROPLANE

Merlin X	First two-speed variant
Merlin XX	First variant licence-produced by Ford at Trafford Park
Merlin 21	Reversed-flow coolant for use with high wing-type (rather than chin-type) radiators, such as on Mosquito
Merlin 22	Two-piece block as used on Merlin 61; employed on all later engine marks
Merlin 22A	Merlin XX modified with two-piece blocks
Merlin 23	Similar to Merlin 22, with reverse-flow coolant
Merlin 23A	Merlin 21 modified with two-piece blocks
Merlin 24	Similar to Merlin 22, with anti-g carburettor
Merlin T24	Transport variant of Merlin 24, modified for longer service life
Merlin T24/4	Merlin T24 fitted with charge heater to reduce plug leading
Merlin 25	Similar to Merlin 24, with reverse-flow cooling
Merlin 27	Similar to Merlin 25, with conventional cooling
Merlin 28	Packard-built, with two-piece block of Packard design. Similar to Merlin 22A
Merlin 29	Packard-built; similar to Merlin 28 with SAE propeller splines
Merlin 31	Packard-built; similar to Merlin 21
Merlin 33	Packard-built; similar to Merlin 23
Merlin 38	Packard-built Merlin 22
Merlin 224	Packard-built Merlin 24
Merlin 225	Packard-built Merlin 25
Merlin 228	Packard-built Merlin 28
Merlin 266	Packard-built Merlin 66

Civil/commercial engines

Merlin 500	Civil version of Merlin T24
Merlin 500/29	Similar to T24; for Spanish CASA 2.111D
Merlin 500/45	Similar to Merlin 500/29; for Spanish Hispano HA-1112-M1L
Merlin 501	Civil engine with afterheater to reduce cruise plug leading; similar to T24/4
Merlin 502	Similar to Merlin 500 with increased climb boost

TWIN-SPEED TWIN-STAGE SUPERCHARGERS

Merlin 60	One-piece block
Merlin 61	First two-stage two-speed engine for fighters; two-piece block
Merlin 62	Merlin 60 modified with two-piece block
Merlin 63	Similar to Merlin 61, without cabin blower
Merlin 63A	Used Merlin 64 crankcase but without cabin blower
Merlin 64	Similar to Merlin 63 but with cabin blower
Merlin 65	Prototype engine for Merlin Mustang
Merlin 66	Optimised for low-level power
Merlin 67	Reverse-flow coolant system
Merlin 68	Packard-built Merlin 85
Merlin 68A	Packard-built; as Merlin 68 but with charge-temperature control
Merlin 69	Packard-built; similar to Merlin 67
Merlin 70	Similar to Merlin 66, but supercharger optimised for high altitude
Merlin 71	Similar to Merlin 70
Merlin 72	Similar to Merlin 70, but with reverse-flow coolant
Merlin 73	Similar to Merlin 72
Merlin 76	Similar to Merlin 66, but supercharger optimised for high altitude
Merlin 77	Similar to Merlin 66, but supercharger optimised for high altitude
Merlin 85	Similar to Merlin 66; Modified intercooler tank and auxiliary gearbox drive
Merlin 85B	Similar to Merlin 85, with different propeller constant-speed unit
Merlin 86	Similar to Merlin 85
Merlin 100,101	Test engines with larger-diameter supercharger
Merlin 102	First civil two-stage engine
Merlin 102A	Experimental Merlin 102 modified with after-heater
Merlin 104	Similar to Merlin 114 with different supercharger gear ratios
Merlin 110, 112	Similar to Merlin 100
Merlin 113/113A	Reverse-flow coolant system
Merlin 114/114A	Similar to Merlin 113
Merlin 130	For DH Hornet; down-draught intake and neater profile
Merlin 131	As Merlin 130, but with opposite propeller rotation
Merlin 132/133	As Merlin 130/131, but with reverse-pitch drive
Merlin 134/135	As Merlin 130/131, but with modified throttle
Merlin 140	Contra-rotating propeller drive
Merlin 150	Commercial engine, later redesignated Merlin 620
Merlin 300	Packard-built Merlin 100
Merlin 301	Packard-built Merlin 101

Civil/commercial engines

Merlin 600	Civil Merlin 102A
Merlin 600A	Similar to Merlin 600
Merlin 604	Military version of Merlin 621, for use in Argentinean Lincolns
Merlin 620	Civil Merlin 150; used in Canadair DC-4Ms
Merlin 621	Civil Merlin 151
Merlin 622	Civil powerplant with selective intercooling
Merlin 623	Similar to Merlin 622 but with UK propeller splines
Merlin 624	Similar to Merlin 622
Merlin 626-1	Variable intercooling
Merlin 626-12	Similar to Merlin 626-1 but with selective intercooling (off/full on)
Merlin 631	Experimental engine with different compression ratio
Merlin 641	Experimental engine with different compression ratio
Merlin 724-1	Similar to Merlin 626 but with selective intercooling
Merlin 724-1C	As Merlin 724 but with crossover exhaust system to reduce cabin noise

PACKARD V-1650 VARIANTS

V-1650-1	Twin-speed single-stage engine
V-1650-3	Packard equivalent of Merlin 63
V-1650-5	Experimental engine, used on Bell XP-63

XP-82 44-83887 was the second Twin Mustang prototype. Both XP-82s and early production P-82Bs were powered by V-1650s before the Allison V-1710-100 was substituted. USAF

V-1650-7	Similar to Merlin 66
V-1650-9	Similar to Merlin 100 series; fitted with water-methanol injection
V-1650-9A	Similar to -9A, but without water injection
V-1650-11	Similar to -9, with different fuel system
V-1650-21	Similar to -11, but with opposite-handed rotation for use in P-82 Twin Mustang
V-1650-23, -25	Similar to -11 and -21; opposite-handed engines used in XP-82 Twin Mustang prototypes