AEROPLANE

DATABASE

EARLY GERMAN JET ENGINES

17 IN-DEPTH PAGES

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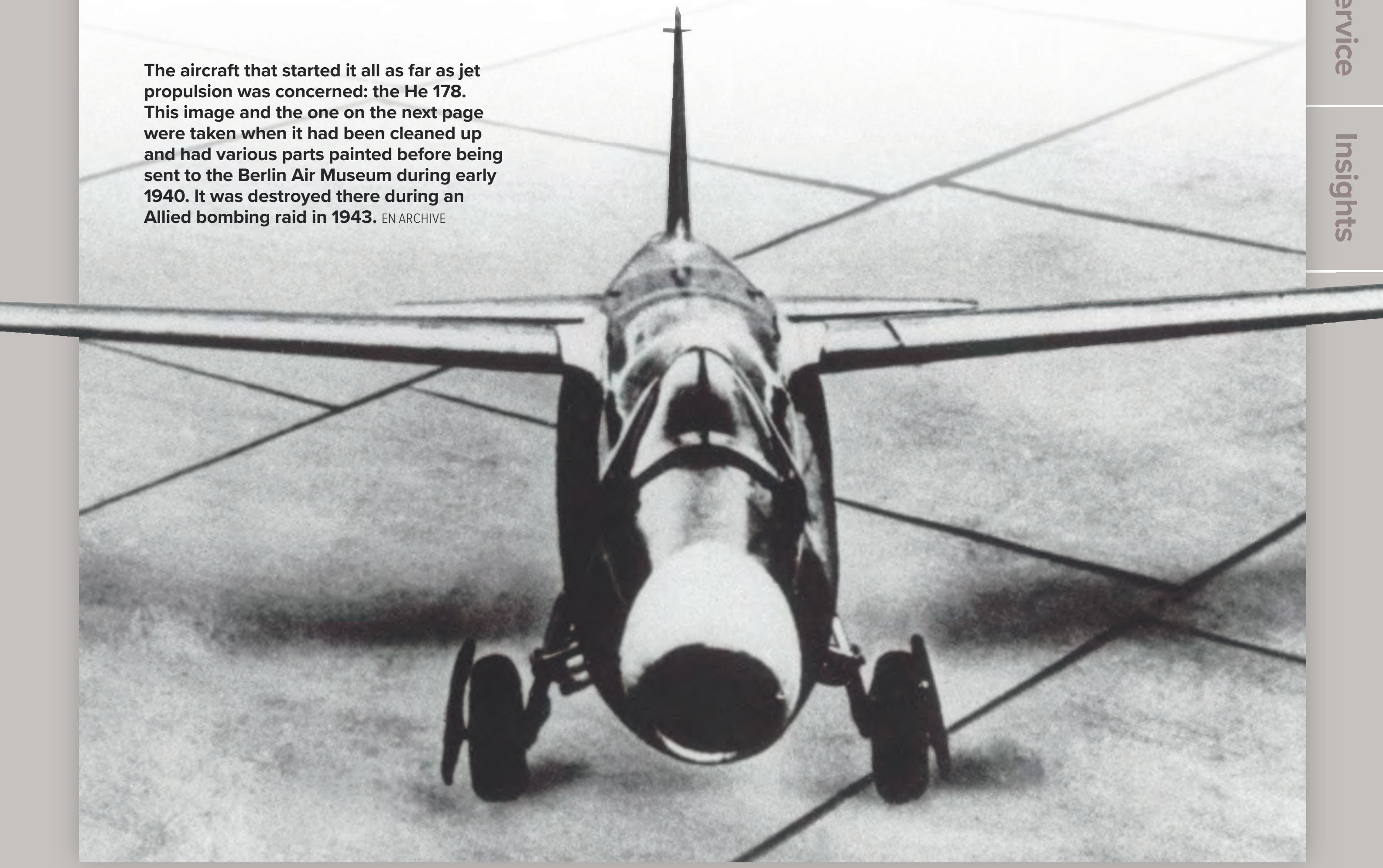
It is no exaggeration to state that the jet engine has changed the world. Whether in military or civil terms, it has helped define an era, and not just in aviation. To mark the 80th anniversary of the maiden flight by a pure jet-powered aircraft, the Heinkel He 178, *Aeroplane* presents a special section dedicated to some of the ways in which jets have pushed the boundaries — from pioneering developments, through new technologies such as vertical and supersonic flight, to preserved classics



The aircraft that started it all as far as jet propulsion was concerned: the He 178. This image and the one on the next page were taken when it had been cleaned up and had various parts painted before being sent to the Berlin Air Museum during early 1940. It was destroyed there during an Allied bombing raid in 1943. EN ARCHIVE

Unlike the situation in Britain, German officialdom gave fulsome support for jet propulsion


The He 178 V1 did not have a canopy fitted at the time of its first flight. USAF

On 27 August 1939, a small, shoulder-wing monoplane rolled along the runway at the Heinkel works airfield at Marienehe in Rostock. Its strange, whining engine note swelled as it picked up speed, and the exhaust roared as it passed the observers on the ground. Correcting for a slight leftward trim of the controls, Flugkapitän Erich Warsitz completed his first circuit of the airfield. Enjoying the diminutive machine's handling, and contrary to his original plan, Warsitz decided to push the throttle forward and to complete a second circuit. Throttling back, he came down for a gentle landing, rolling out to where Ernst Heinkel and his team — including Hans Pabst von Ohain, the engine's designer — were waving jubilantly. Warsitz had just completed the inaugural flight of the Heinkel He 178, the world's first jet aircraft. The He 178, and the engine powering it, had been funded as private ventures, but for the Reichsluftfahrtministerium (Reich Air Ministry, or RLM) the He 178 came not as a bolt from the blue. Rather, it was confirmation that its jet research programme was working along the right lines.

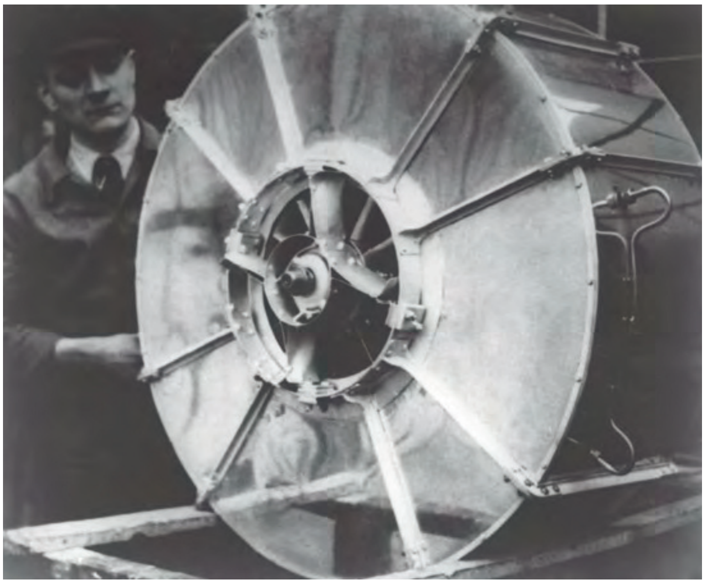
When compared with other countries' air ministries, the RLM committed to the jet engine early and on a large scale. This is perhaps less surprising when set against the wider background of German support for reaction propulsion. The Weimar Republic had many groups of rocket and spaceflight enthusiasts, and the most technically able were soon recruited by the army's ordnance office, which saw in the rocket-powered ballistic missile a way to circumvent the Versailles Treaty's prohibition of long-range artillery. After the Nazi seizure of power, financial support for the army's research increased, and the air ministry began to take an active interest.


Hans Pabst von Ohain, the designer of the He 178's HeS 3B engine, conducted his initial work on gas turbine propulsion at the University of Göttingen. KEY COLLECTION

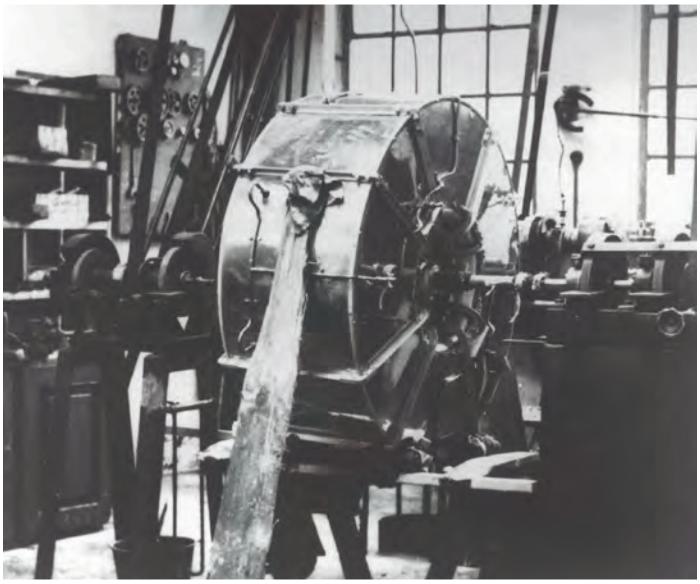
Once the Luftwaffe was officially acknowledged, the new service supported research into those radical technologies that might allow it to leapfrog more established overseas air arms. Under the influence of Maj Wolfram von Richthofen (cousin of Manfred von Richthofen, holder of an engineering doctorate, and head of the RLM technical office's development division), the RLM began to fund rocket research, initially in concert with the army, but then in its own research establishments. This led to a series of small rocket engines tested on a variety of contemporary single-engined fighters, and ultimately to the He 176 rocket-powered testbed. In this environment the RLM's technical division was immediately sympathetic towards the use of gas turbines for reaction propulsion. This Database examines the development of German jet engines before and during the Second World War, concentrating on engines that made it to flight status, and furthermore on those that were put into production.

By the mid-1930s the theoretical and practical prerequisites for the gas turbine were advanced enough that many people were starting to think about how to build one. Hans Joachim Pabst von Ohain had studied for a PhD in physics and aerodynamics at the University of Göttingen. While still a student, he came up with the insight that a gas turbine could be used to provide jet propulsion. After his PhD, he was hired as an assistant to Robert Wohl, professor of the university's physical institute, and patented his engine idea. With some independent means from his family's business, von Ohain commissioned Max Hahn, a local car mechanic, to build him a working model with which to test his ideas. This 'garage engine' had a back-to-back centrifugal compressor and radial in-flow turbine, and was tested at the physical institute. Though compact, the arrangement did not provide enough space for complete combustion, and much of the fuel was burned downstream of the turbine. As a result, the engine had an alarming habit of shooting flames up to 10ft long out of its exhaust, and it needed an auxiliary electric motor drive to sustain running.

By February 1936 von Ohain's funds had run out, but Wohl was impressed enough by his assistant's experiments to write a letter of recommendation to the aircraft builder Ernst Heinkel. Heinkel's interest in high-speed flight was well known, and he had already been experimenting with rocket propulsion for aircraft. In his discussions with



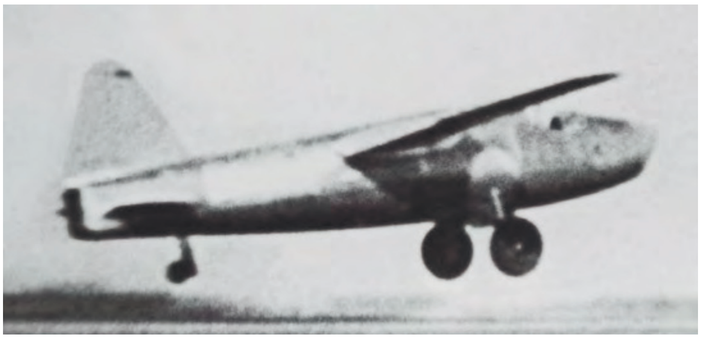
The so-called 'garage engine' designed by von Ohain and built by Göttingen motor mechanic Max Hahn, incorporating a back-to-back centrifugal compressor and radial in-flow turbine. KEY COLLECTION



The 'garage engine' in the experimental lab at Göttingen University's Physikalisches Institut, with a shaft on the right-hand side connected to the auxiliary electric motor that kept it running. KEY COLLECTION

Heinkel, von Ohain's blunt appraisal of the garage engine was that it would never run under its own power, but that the principle was sound. Heinkel's engineers agreed that it was flawed but showed promise. As a result, in April 1936 Hahn and von Ohain were hired by the firm to develop a testbed engine. This was the HeS 2 (HeS for Heinkel-Strahltriebwerk, or Heinkel jet engine). Similar in layout to the garage engine, the compressor and turbine had been moved apart on their shaft to provide enough space for combustion, and an axial inducer fan had been fitted to the impeller inlet, which raised the inlet pressure slightly and helped maintain flow stability. To simplify combustion, the engine was initially fuelled by hydrogen, first running on the bench in March 1937, and then later converted to petrol, on which it ran in September 1937. Initially petrol clogged the combustors, but Hahn came up with a fuel vaporiser that worked along the principles of a soldering torch. Once sustained running was achieved, the HeS 2's lightweight rotor meant its throttle response was almost as fast as a piston engine's. Heinkel decided to proceed with the development of a flight engine and a suitable test aircraft.

> "Heinkel's interest in high-speed flight was well known, and he had been experimenting with rocket aircraft"



The first take-off by a pure jet aircraft, as Erich Warsitz gets airborne from Rostock-Marienehe in the He 178 V1 on 27 August 1939. The undercarriage remained fixed down during all its flights. EN ARCHIVE

Meanwhile, other companies and institutions were taking an interest in the jet engine. In 1935, Junkers aircraft managing director Heinrich Koppenberg hired the Technical University Berlin professor and engineer Herbert Wagner to head up its airframe development programme, including work on high-speed flight. As part of his investigations, Wagner studied various gas turbine proposals, including jet propulsion, with a team led by engineer Max Müller. At this point, the engine and aircraft sides of the Junkers business were still separate companies, but even after their 1936 merger Wagner's powerplant research was funded by the aircraft side. Prof Otto Mader, head of Junkers-Motoren, considered piston engines to be the main technology for the near- and medium-term, and was unenthusiastic about spending resources on more speculative projects.

At the RLM, the Technisches Amt (Technical Branch, or T-Amt) formed a section for 'special propulsion' — including rocket and pulse-jet propulsion — in 1937. It soon became part of department LC8 (engines). In April 1938 the section's new head, Hans Mauch, found out about Heinkel's jet projects, and a few months later Wagner informed him about Junkers' engines. That August Mauch met Helmut Schelp, who was part of the T-Amt's R&D directorate. Schelp had studied for a masters' degree in aeronautics in the US, and had done further study at the German Aviation Research Institute. He was convinced an axial jet engine was the best solution for future high-speed flight. Mauch persuaded Schelp to join his department and help him administer a jet engine development programme. The two men now became the driving force behind the RLM's advocacy for jet engines. In the autumn of 1938 they visited the major German engine manufacturers to try and interest them in jet development. Schelp and Mauch assumed engine firms would be better at developing production units than the relatively small teams working at aircraft manufacturers.

However, they did not meet with unalloyed enthusiasm. Daimler-Benz's staff declined, pointing out that the company was already overstretched trying to meet the Luftwaffe's demand for piston engines. Mausch had tried to convince Heinkel to licence the development of the HeS engines to Daimler-Benz, as Heinkel had neither engine experience nor sufficient development staff. Mausch even tried promising that every licence-built engine would carry a plate stating it was a Heinkel design, but this cut no ice. At

Erich Warsitz, Ernst Heinkel and Hans von Ohain at a dinner held to celebrate the He 178's maiden flight. KEY COLLECTION

German jet engine development budgets, as at early 1939

Engine type	1940	1941
Liquid-cooled engines	30 million RM	30 million RM
Air-cooled engines	25 million RM	25 million RM
Special propulsion	10 million RM	15 million RM

Junkers, Mader was still sceptical about jet propulsion, but accepted an RLM contract. Faced with Mader's control over their projects, Wagner and Müller both left Junkers. Wagner moved to Henschel, and Müller to Heinkel.

Back at Junkers, Anselm Franz reviewed the aircraft division's previous engine work and decided to start with a clean-sheet design. This axial jet engine was now given the RLM designation 109-004 — '109' being the RLM designation for reaction propulsion projects — and the company designation Jumo 004. Even so, Mader made it clear he thought piston engines had priority. He was not alone in this. BMW had begun its own design for an axial jet engine, and after the 1939 takeover of Bramo had incorporated the latter's gas turbine team, but as late as December 1940 BMW's chairman Franz Josef Popp was suggesting that the jet engine was a medium-term project that wasn't that important to the company, and that it might be better developed by one of the state research institutes.

The T-Amt's aircraft sections had also been showing an interest in jet propulsion. In October 1938 Hans Antz produced a report on the contemporary prospects for high-speed flight, concluding that speeds of 800-850km/h (500-530mph) would only be achievable with jet propulsion. He suggested that suitable engines would probably be available before airframes, as further basic research into suitable high-speed aerofoils and planforms was needed. Even so, he argued that high-speed jet flight was now a realistic possibility, if still an embryonic one. Antz recommended the construction of high-speed wind tunnels at aerodynamic research institutes. Aware of the research being carried out at Heinkel, he suggested giving contracts for a jet aircraft to Messerschmitt to avoid one company having a monopoly.

He further recommended that Alexander Lippisch's group at the German Institute for Gliding (DFS) move to an aircraft manufacturer. The group was working on a rocket-powered interceptor, but the DFS did not have the resources to develop the project any further. Antz's advice was heeded. In the late autumn of 1938 Messerschmitt was given a contract to develop a jet aircraft, later to become the Me 262. The following January the DFS group also moved to the company — its project ended up as the Me 163.

Against some resistance, Mauch and Schelp had managed to create a broad programme of jet projects in the aero engine industry. When Mauch left the RLM to form a consultancy company in 1939, Schelp continued to oversee the programme. He drew up a staged 16-year plan to develop four broad classes of engine (below).

Initially the head of the engine development section, Wolfram Eisenlohr, considered the RLM's support for jet engines somewhat premature, but he was overruled by Ernst Udet, head of the T-Amt. Udet was a political appointment — a brilliant pilot who had flown fighters in the First World War, he was a poor administrator with limited technical knowledge, but his enthusiasm for technology led him to support Schelp's programme. Indeed, the RLM's support for 'special propulsion' (including pulse-jet and rocket research) was substantial, as shown in the table above.

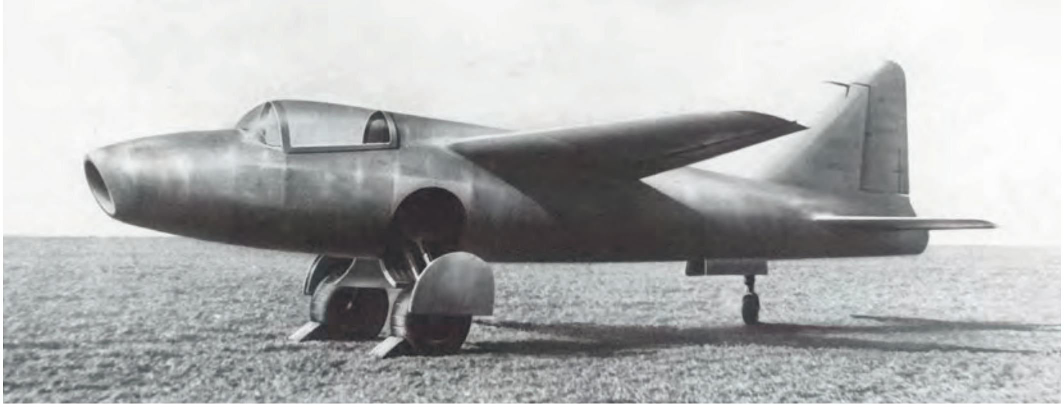
Even after the outbreak of war and the consequent rationalisation of development projects, the RLM was supporting engine projects at Junkers, BMW and Heinkel. Contrary to some later accounts, the T-Amt was far from indifferent to the jet's potential. If anything, Schelp's programme was grossly over-optimistic, calling for bench-test delivery deadlines starting from April 1940.

Junkers' Anselm Franz was forced to pour cold water on these, explaining that in many cases no theory or experiment existed that would even allow for the setting of design goals, never mind the production of actual hardware. Starting a development effort effectively from scratch inevitably meant expending much effort on false starts and blind alleys. Many in the industry felt that the development resources being spent on the jet were desperately needed for their contemporary piston engine programmes. They wanted research institutes

Helmut Schelp's classes of jet engine

Class	Approx thrust (kp)*	Engine pressure ratio
I	Up to 1,000	3.5/1
II	1,300-1,700	5/1
III	2,500-3,000	6/1
IV	3,500-4,000	7/1

** German convention at the time was to quote thrust in kp, meaning kilopond or kilogram-force; 1kp ≈ 9.81N ≈ 2.2lbf*

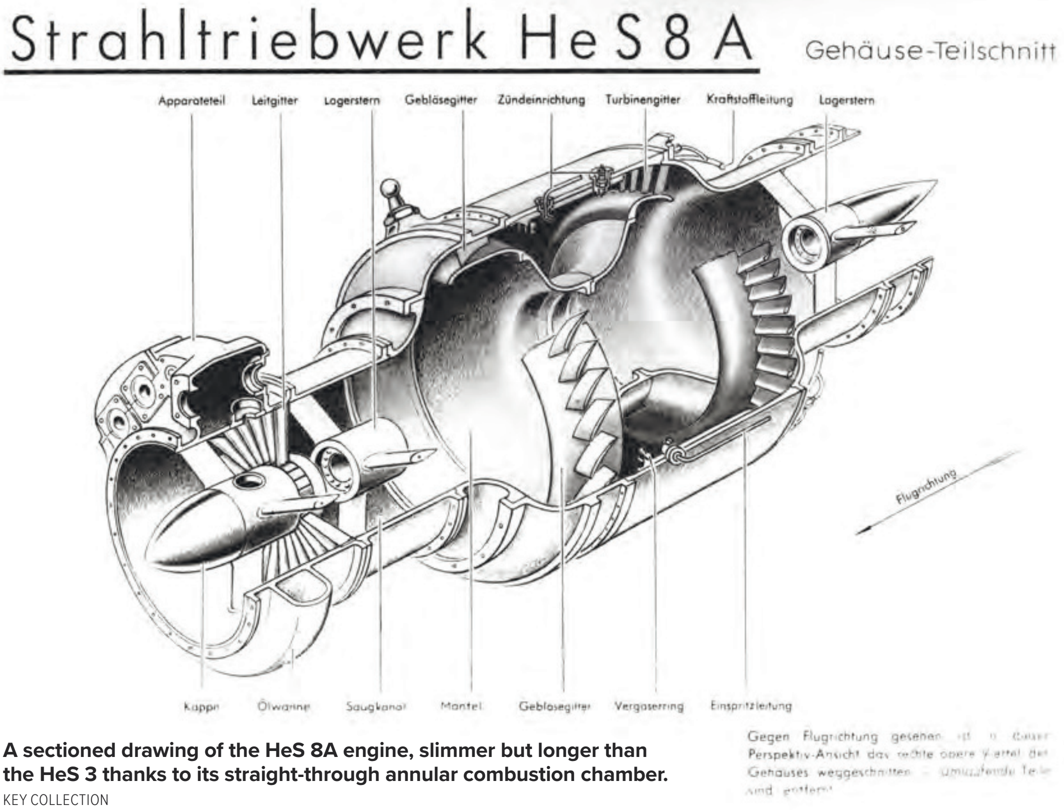


The He 178 V2 incorporated numerous design alterations compared with the V1, but never flew under its own power — only as a towed glider. EN ARCHIVE to carry out more fundamental investigations to bring the jet to a point of greater maturity before industry got involved. Nonetheless, the RLM's pushing of jet projects in industry against initial indifference or even hostility ensured that a broad base of expertise was built up in the companies that would eventually put the jet engine into production.

Heinkel engines

In the meantime, Heinkel was developing von Ohain's HeS 2 into a flight engine. The HeS 3 was similar in layout to the HeS 2, with an axial inducer feeding a centrifugal compressor and a radial in-flow turbine. Most of the compressor air was fed through reverse-flow ducts to the fuel injectors and the annular combustion chamber. The remainder was fed into the combustion chamber downstream of the fuel injectors to mix with the combustion gases, which were then passed through inlet nozzles into the turbine and out through the exhaust. The reverse-flow arrangement and the annular combustion chamber made for a compact but portly engine.

The early units, now designated HeS 3A, suffered from poor combustion and thrust. In an attempt to keep the frontal area down the compressor had been somewhat undersized, and was a poor match to the turbine. Nonetheless, after bench tests, the HeS 3A began flight trials in May 1939 slung beneath He 118 D-OVIE (the He 118 had been Heinkel's entry to the dive-bomber competition won by the Ju 87 Stuka). Because of secrecy concerns, test flights were made at first light before the factory opened. Eventually the HeS 3A's turbine burned out, but in the meantime a redesign had led to the HeS 3B, which was the engine fitted to the He 178 for its flight tests. Following the successful flights in August, Heinkel attempted to seek backing from the RLM, and demonstrated the aircraft to officials in November 1939. Though he didn't appear to get an immediate response, it confirmed to the T-Amt's staff that they were backing a feasible technology.



A sectioned drawing of the HeS 8A engine, slimmer but longer than the HeS 3 thanks to its straight-through annular combustion chamber. KEY COLLECTION

> “A demonstration confirmed to the T-Amt's staff that they were backing a feasible technology”

The HeS 8 was Heinkel's first engine to receive official financing and was given the RLM designation 109-001. Intended for the proposed He 280 fighter, the HeS 8 was designed for higher thrust and lower weight and cross-section than the HeS 3B. It maintained the previous engine's axial inducer/centrifugal compressor/radial turbine layout, but adopted a straight-through annular combustion chamber, making for a slimmer but longer unit. von Ohain had wished to explore axial compressors, but the RLM wanted him to continue working on advanced centrifugal designs while other axial projects were under way. The HeS 8's design thrust of 700kp proved difficult to achieve. By September 1940, the He 280 V1 airframe had been completed, but the engines were not developed enough for

A very rare image of an HeS 8A unit mounted below a Heinkel He 111 for testing in 1941. EN ARCHIVE

A mock-up of Heinkel's HeS 011 engine fitted to the first, unflown, Messerschmitt P1101 fighter prototype. NASM

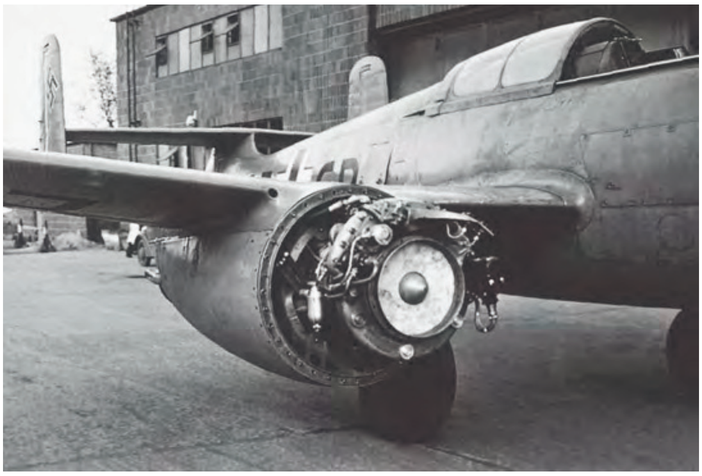
The He 280 V2, the second prototype, showing how early test flights of the twin-jet fighter design were carried out with the HeS 8A engines uncowled as a fire reduction measure. KEY COLLECTION

installation. It took until March 1941 before they were ready to be fitted, but they were still only producing about 500kp thrust.

The He 280 made its first powered flight on 30 March 1941, and the following week the aircraft was demonstrated to Udet, Schelp and Eisenlohr, cementing the RLM's support for a jet fighter. One notable feature from these early flights was that the engines were left uncowled. At this point they had a tendency to leak fuel, and the possibility of it pooling inside the cowlings was considered to be too much of a fire hazard.

The He 280 prototype demonstration did raise Heinkel's stock with the RLM. One consequence was that the company was given permission to obtain control of Hirth Motoren, a producer of small aero engines and engine auxiliaries such as pumps and turbochargers. Crucially, this gave Heinkel access to engine manufacturing capacity and skilled technical staff, both of which were becoming ever harder to find because of wartime material and labour controls. However, progress on the HeS 8 was slow, and engine performance remained disappointing. By early 1942 some 14 V-series engines had been built, but thrust remained stubbornly low, at about 550kp. It was not until early 1943 that the He 280 V2 and V3 were able to fly with HeS 8 engines, which by now were producing about 600kp. Even so, the HeS 8 was clearly being overtaken by the engines under development at other companies and by Heinkel's proposed follow-on engines, and development was abandoned.

> “The HeS 8 engines had a tendency to leak fuel, and pooling inside the cowlings was too great a fire hazard”



The HeS 8A, as fitted here to the He 280 V3 (coded GJ+CB), never achieved its desired power output. KEY COLLECTION

Heinkel only developed two other engines during the war that came close to production: the HeS 30 and the Heinkel-Hirth HeS 011. The HeS 30 was a development of an engine designed at Junkers by Max Müller; as previously noted, Müller left Junkers for Heinkel in October 1939 after Junkers' jet projects were put under the control of the engine division. Müller had built an axial engine with a five-stage compressor of advanced design, testing it in late 1938. However, the engine would not run under its own power. It required an external compressed air supply to the compressor to work and had very high fuel consumption. Junkers abandoned development, but at Heinkel Müller persevered with the design. He had promised to have it running on test within a year of his arrival, and received an RLM contract for three experimental engines (designated 109-006), but it did not run until April 1942. This may have been down to the engine's advanced features, including compressor blading designed for 50 per cent reaction, variable turbine inlet vanes, and a variable-area exhaust.

Shortly after the successful run Müller had a dispute with Heinkel and left the company, but development on the engine continued, and by late 1942 the engine was producing 860kp for a weight of 360kg, a thrust-to-weight ratio better than any other engine project that was then under development. Unfortunately for Heinkel, at the RLM Helmut Schelp was not a supporter of the project. He objected to the compressor design, possibly because the experts at the AVA (Aerodynamische Versuchsanstalt — the Aerodynamic Research Institute, responsible for developing most German axial compressor theory) preferred pure reaction blading. Schelp considered the engine broadly comparable with the Junkers and BMW units that were further along in their development, and did not think it worth the expenditure of resources to get it to production. Instead he wanted Heinkel to concentrate on the development of a larger engine: the HeS 011.

When Heinkel was granted permission to take control of Hirth, one condition was that the facilities at the Hirth factory in Stuttgart be used for the development of a Class II engine with a thrust of 1,300kp, given the RLM designation 109-011. This was to use a 'diagonal' compressor, a favoured idea of Schelp's. In an axial compressor, as the name suggests, the airflow is in the axial direction, and each compressor stage raises the pressure by a small amount. In a radial or centrifugal compressor, the exit airflow is turned through 90° to the compressor axis, and the pressure rise in the stage is larger. A diagonal compressor is a combination of the two; the exit airflow is at an angle to the axis, and the pressure rise per stage is larger than in a pure axial compressor but less than in a pure radial compressor. The claimed advantage of the diagonal compressor was that it would have some of the centrifugal compressor's resistance to foreign object damage and icing, while having a lower cross-section.

Neither Müller not von Ohain were particularly enthusiastic, but they began design work on the engine. By late 1942, the Hirth factory in Zuffenhausen near Stuttgart had been refitted for gas turbine work. All Heinkel's jet work was concentrated there, with about 150 staff working on the HeS 011. The engine's compressor comprised an axial inducer, a diagonal stage, and three axial stages, and was driven by a two-stage axial turbine fed from an annular combustion chamber.

Work began on the initial V-series engines (V1-V5), which were intended as static test engines to ascertain mechanical and aerodynamic details. Completed by early 1944, they made no concession to weight reduction, nor to aircraft packaging. This was to be carried out with the second V-series of engines (V6-V25), which were to be flight test engines leading to the pre-production A-0 series. Progress on the second V-series was slowed by the June 1944 dispersal of development from the Zuffenhausen factory to a salt mine some 40 miles away. Work had resumed by August-September 1944, but the first V-series engines were still having compressor and combustion troubles. Only four engines of the second V-series appear to have completed any running. By January 1945 they had accumulated some 184 hours of running time, including a few flights in a Ju 88 testbed.

The HeS 011 A-0 pre-production engine followed the basic layout of the prototypes, but with detail changes made to enable mass production. Though mock-ups were built, no production engines were ever completed. Production had been dispersed to a facility in Bavaria, which only began operation in April 1945. When the facility was captured by the US Army, enough parts were found to make up 10 engines, and the US Navy sponsored their assembly back at Zuffenhausen. Some were tested to destruction there, others being shipped to the US and UK for further evaluation. Despite having built the earliest experimental flight units, Heinkel never really had the development resources or industrial capacity to put a jet engine design into production.

> **"Having reviewed previous projects, Otto Mader started the Jumo 004 as a clean-sheet design"**

Junkers engines

As noted earlier, in late 1938 Otto Mader, head of the Junkers engine division, accepted an RLM development contract and took over control of the company's gas turbine projects. As he was known to be unenthusiastic about gas turbines, the teams who had been employed by the aircraft division mostly left to take their work elsewhere. This left the engine division's Anselm Franz in charge of the company's jet work. Before heading up the turbojet team, he had worked on supercharger development and on the shaping of piston engine exhausts to provide greater thrust, a topic for which he was to be awarded a doctorate in 1940.

Having reviewed and discussed the previous projects, he started the Jumo 004 as a clean-sheet design. The RLM's specification was for an engine to provide 600kp of thrust at 900km/h, equivalent to a static thrust of about 680kp. Franz's basic design was deliberately conservative, in order to try and ensure as low-risk a development process as possible. He chose an axial design for the engine, mainly because of the lower frontal area this gave. Junkers had previously developed an axial supercharger with the assistance of the AVA's aerodynamicists, so Franz turned to the AVA's Walter Encke for help in designing an axial compressor. The compressor had eight stages and a total pressure ratio of just over 3:1, which was a relatively low pressure rise per stage. The combustion system used six can-type combustion chambers; though these gave greater pressure losses than an annular combustion chamber, development could be carried out on individual cans at savings in time and cost. For the turbine, Franz turned to the Allgemeine Elektricitäts-Gesellschaft (AEG), one of Germany's largest heavy turbo-machinery producers, and they helped design the single-stage turbine. Following Franz's previous exhaust research, the Jumo 004 had a complex variable-geometry nozzle with a moveable bullet, or 'onion', to change the effective exhaust area.

Initially Franz wanted to construct a scaled-down model to provide design data, as a smaller compressor could be tested on Junkers' existing rigs, but it suffered from combustion problems and in late 1939 the compressor model burst on test. Because of these maladies, in December 1939 the Junkers team decided to move to building a full-size prototype engine, the Jumo 004 A. The engine first ran on the bench in October 1940, albeit without an exhaust nozzle, and by January 1941 it was producing 480kp bench thrust. This appeared to validate Franz's conservative design. However, the engine soon encountered compressor vibration problems, and was nearly destroyed through compressor stator blade failures. Junkers brought in the vibration specialist Dr Max Bentele, and with some detail changes the problems were partially solved.

By early August 1941 the 004 A ran at its design thrust of 600kp for the first time, but it was still another eight months before it was suitable for flying. Initial flight tests were carried out in March 1942 using a Bf 110 testbed, and soon afterwards a pair of 004 A-0s were sent to Messerschmitt for installation in the Me 262 V3 prototype, which made its maiden flight on 18 July 1942. These engines were rated at 840kp static thrust; Junkers produced a small series of about 30 A-0 engines, of which Messerschmitt received a further two for the Me 262 V2 prototype, which flew on 2 October.

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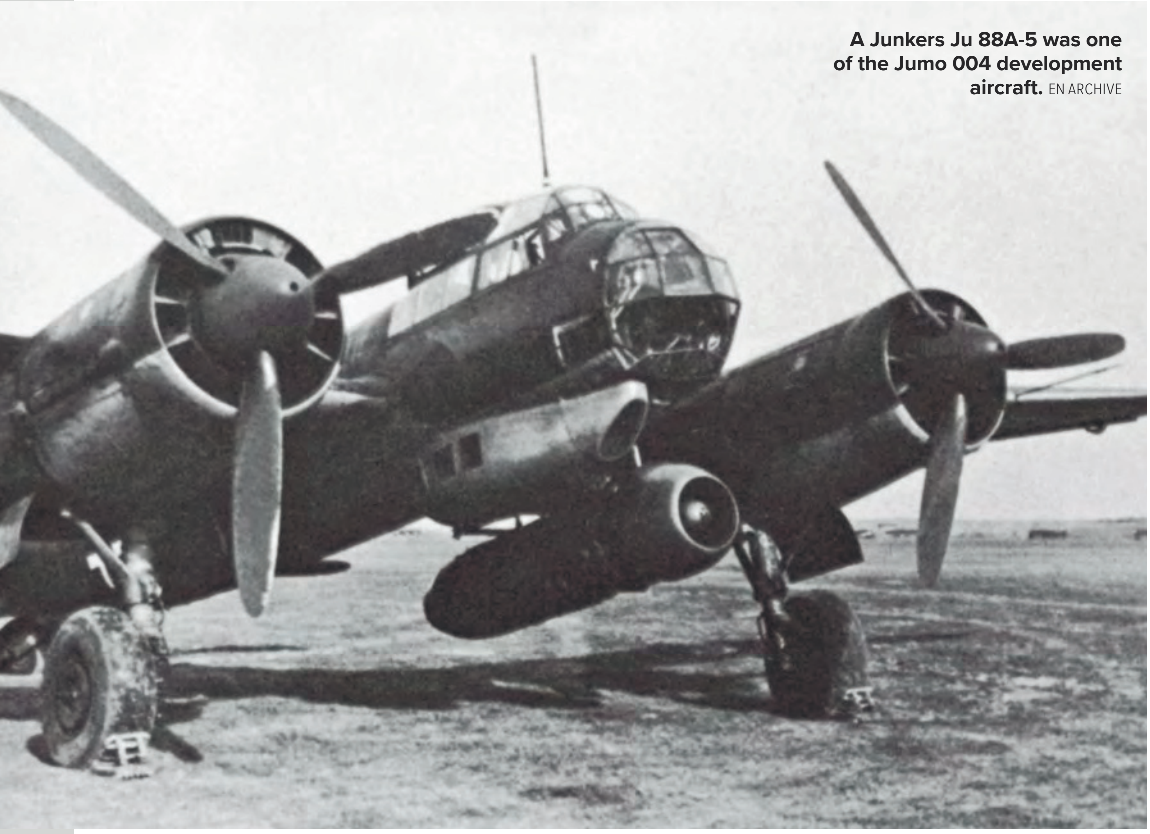
Fritz Wendel begins the first flight of the tailwheel-equipped Me 262 V3 under jet power, with two Jumo 004 A-0s, at Leipheim on 18 July 1942.
KEY COLLECTION



A Junkers Ju 88A-5 was one of the Jumo 004 development aircraft. EN ARCHIVE

All the while, Junkers had been working on turning the Jumo 004 into a production engine. The A-series engines had been built to test the engine concept, without much regard to weight and production considerations, but the RLM was particularly keen to reduce the use of strategic metals such as nickel, cobalt and molybdenum. The layout of the B-0 production engine was fixed in December 1941, and detail design was complete by October 1942. The major differences were a modified inlet and compressor construction, replacement of castings with sheet material where practical, and substitution of strategic materials in the alloys as much as possible. The changes meant the Jumo 004 B-0 weighed 100kg less than the A-0, whilst maintaining the rated thrust of 840kp (the weight of individual engines could vary by up to 20kg, as the rough castings were machined only where necessary).

From mid-1942 Schelp and the RLM had been pushing Junkers to prepare for mass production of the Jumo 004. The major production variant was the Jumo 004 B-1, with changes to the compressor blading in order to try and reduce vibration. The first few B-1 engines were delivered in May or June 1943, and the Me 262 V6 — the first prototype with a nosewheel undercarriage — made its initial flight with these in October 1943. The same prototype was demonstrated to Adolf Hitler on 26 November, after which he made his infamous 'Blitz-Bomber' edict insisting that the aircraft be modified to carry a bomb load, which supposedly delayed the Me 262's introduction by six months. In fact, it made little difference. The Me 262 prototypes were far from ready for service acceptance, and the Jumo 004 was still having vibration troubles, with turbine blades failing at full engine speed.

Another use of the Jumo 004, in B-1 guise, was in the Junkers Ju 287 experimental jet bomber, here in four-jet Ju 287 V1 form. The V2 and V3 versions upped the powerplant count to six. KEY COLLECTION

To try and discover the natural frequency of the turbine blades, Franz asked a professional violinist to stroke the blades with his bow and use his musician's ear to determine what pitch — and therefore what frequency — the blades were ringing at. The problem was finally solved by consulting Max Bentele again, who worked out that the airflow through the combustion cans was interacting with the exhaust nozzle struts downstream of the turbine to excite a higher harmonic of the turbine blades. In the A-series engines this had been above the turbine's rev limit, but the higher turbine temperatures and speeds of the B-series engine had caused it to appear within the running range. By early 1944, modifying the turbine blade taper and reducing maximum running speed had cured the problem.

The only major development of the 004 to see service was the B-4 variant, which was basically similar to the B-1 but used hollow instead of solid turbine blades, mainly in an attempt to further reduce the use of strategic metals. Initially Junkers tried folding and welding the blades, but the Tinidur heat-resistant steel used proved unsuitable for welding. Junkers had already worked with the manufacturing firm William Prym to develop hollow blades for a piston-engine turbocharger, and in February 1943 asked Prym to develop a process for deep-drawing them. By late 1944 the company was producing hollow blades that were half the weight of their solid predecessors. Junkers also joined forces with the metalworking firm Wellner to develop a welded blade process using another heat-resistant steel called Cromadur, which was also successful. As neither Prym nor Cromadur could achieve high enough production rates, both types of blade were used for B-4 production, which began in late 1944.

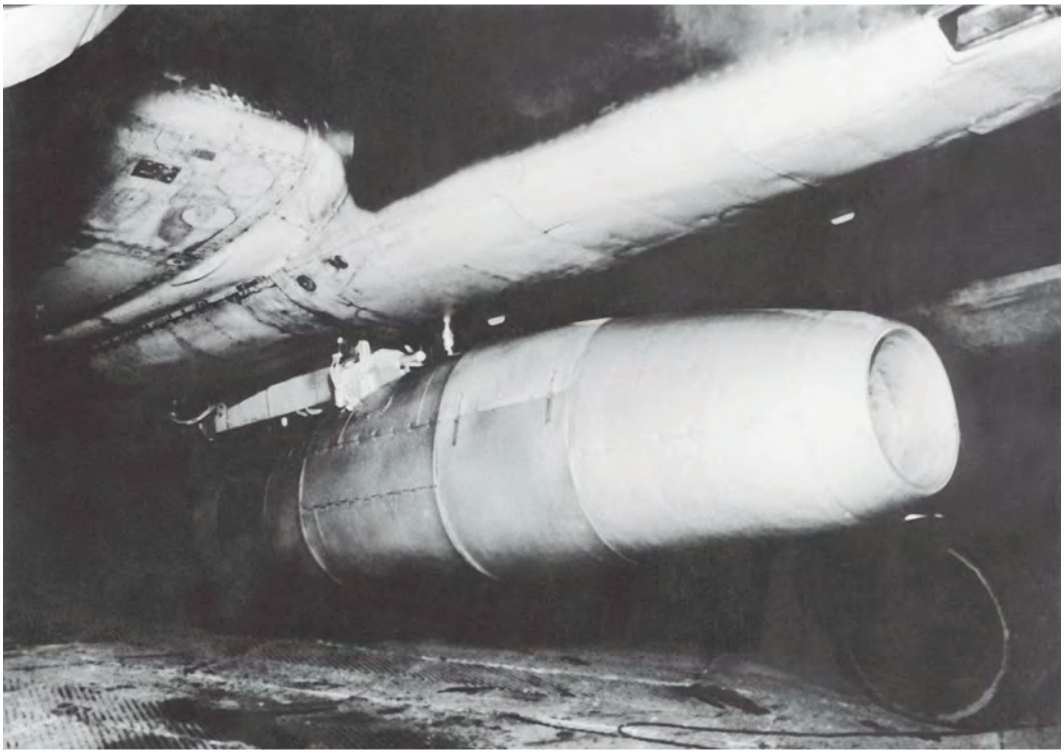
BMW engines

BMW's jet project was the result of work from two companies. Like Junkers' Otto Mader, BMW's director Franz Josef Popp preferred to concentrate on the immediate development needs of the company's piston engines rather than on the speculative jet. Though BMW accepted a development contract from Mauch and Schelp in late 1938, the project was assigned to the company's head of research Kurt Löhner, who was responsible for both piston and gas turbine studies.

For BMW's P3303 study Löhner decided to use components the company was already familiar with. The compressor used two centrifugal impellers in series, and the turbine was based on the designs of the company's turbine consultant Alfred Müller. However, in the summer of 1939, BMW took over the aero engine manufacturer Bramo, which had been carrying out its own jet studies. Bramo was a second-rank piston-engine manufacturer, and had been at risk of losing RLM development funds for its piston engine projects, so the company eagerly accepted the chance to develop a jet project.

Once Bramo was absorbed by BMW, Popp decided to have BMW's main Munich works concentrate on the development of its BMW 801 engine, and moved BMW's gas turbine work to the former Bramo factory at Spandau near Berlin. Bramo's Dr Hermann Oestrich took over the combined companies' gas turbine projects. One engine was an axial turbojet that incorporated elements from Bramo's work — a six-stage axial compressor based on AVA research, and an annular combustor — and from BMW's research, in the form of an air-cooled hollow-bladed turbine. This engine was soon given the BMW project number P3302 and assigned the RLM number 109-003.

When the engine was first tested in August 1940, performance was disappointing, producing only 150kp on the stand against a design thrust of 700kp. Investigating the causes, Oestrich's team concluded that the engine needed a redesign. With an updated turbine and combustion system, by the following summer the BMW 003 was developing around 450kp, and flight-testing began with the engine slung underneath a Bf 110. In the autumn two engines were delivered to Messerschmitt for installation in the Me 262 V1, which had a Jumo 210G piston engine and propeller fitted in the nose as auxiliary propulsion. At the first flight attempt on 25 November, both turbines failed as the BMW engines were brought to take-off power. It was early 1942 before replacements were available, which by now had a bench thrust of 550kp. On 25 March 1942 Messerschmitt's test pilot Fritz Wendel carefully lifted the Me 262 prototype off the ground, but at a height of some 50m the port engine failed, immediately followed by the starboard. With great skill Wendel managed to bring the aircraft safely down to the ground using piston power alone, but it was a near-fatal blow to the BMW engine.



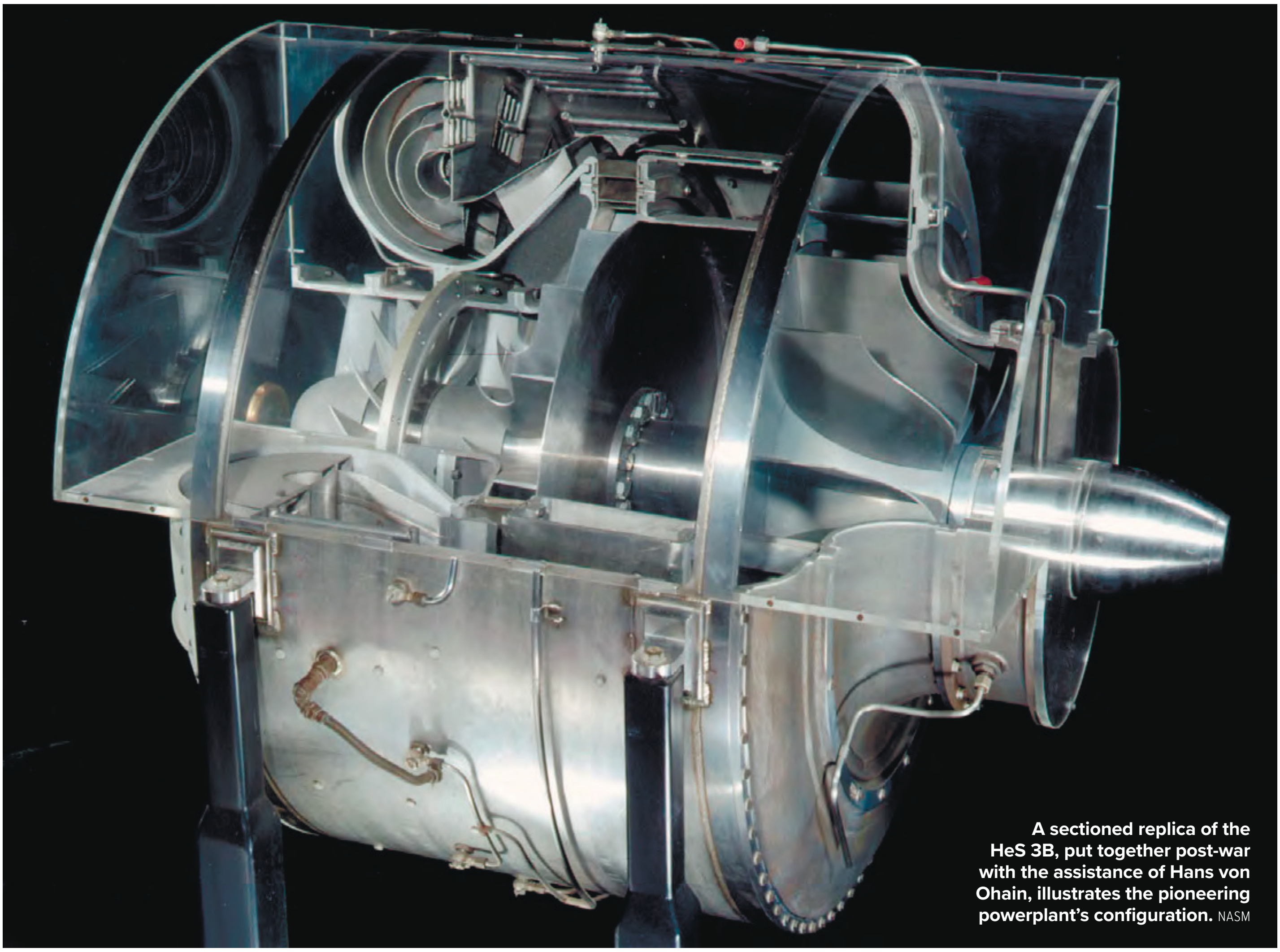
A Ju 88A fitted with a BMW 003 engine, in an experiment to try and increase the Junkers twin's speed. It was planned to fit two of the powerplants to a Ju 88T-1 variant, attaining a speed of 652km/h. EN ARCHIVE

> “Wendel brought the Me 262 prototype down, but it was a near-fatal blow to the BMW engine”

Over the next few months, the engine team redesigned the compressor and turbine for greater mass flow and efficiency. The compressor now had seven stages instead of six and thicker blading, and the turbine blades were pinned rather than welded to the rotor. Other improvements were made to the shape of the inlet and exhaust nozzles, the latter having variable geometry. The new design provided more thrust than the previous engines, but there were still problems with combustion and with turbine blade failures. The new compressor's starting characteristics were poor, and the first-stage blades were cracking after a short period of running. Nonetheless, by the end of 1942 the engines were developing 600kp thrust, and proposed solutions were available for most of the difficulties. Changes were made to the compressor front bearing supports and first-stage blades, the burner design in the combustion chamber was changed, and a new method of attaching and cooling the turbine blades was developed.

With these changes incorporated, the engine reached its A-0 pre-production series. In August 1943 the He 280 V4 and V9 prototypes flew with BMW 003 A-0 engines, and in October 1943 the V5 and V6 did the same. Despite good performance, the He 280 was cancelled in favour of the Me 262, in part because of the latter's superior range. Alongside these flight trials, development testing was carried out in a Ju 88 testbed aircraft.

By the end of the year the BMW 003 was developing 800kp and had been approved for production. It took until October 1944 for the A-1 and A-2 production variants to start coming off the line, mainly because the RLM had demanded changes to make the engine as easy to mass-produce as possible. It also said the engine should be able to run on heavier fuel oils, which required changes to the combustion system. The A-1 and A-2 models were also produced as the E-1 and E-2 variants, which had the auxiliaries moved around so that the engine was suitable for installation above a wing or a fuselage rather than being slung underneath. The main use for these engines was as powerplants for the He 162, and with the priority given to this programme, most production BMW 003 engines were one of these variants.



A sectioned replica of the HeS 3B, put together post-war with the assistance of Hans von Ohain, illustrates the pioneering powerplant's configuration. NASM

Three different companies demonstrated three different design philosophies

Heinkel engines

The HeS 3B, which powered the He 178, was a centrifugal engine. The air inlet was fitted with an eight-bladed axial inducer, but the main compressor was a 16-bladed centrifugal unit. Air left the compressor through tangential diffuser slots; most was guided through a reverse-flow bend that led to the entrance to the annular combustion chamber, where the fuel injectors were. The injectors were supported by a grid of fuel pipes, which acted as pre-heaters for the fuel. The combustion chamber ran back to the radial turbine entrance; at the edge of the compressor disk there was a slot that allowed the remainder of the compressor air to mix with the combustion gases before entering the turbine. The gases entered the 16-bladed turbine radially and passed out along the turbine axis through the jet nozzle. The HeS 3B ran on petrol, which was pumped through the turbine bearing housing in order to cool the bearing and pre-heat the fuel.

HeS 3B data

Thrust: 450kp (992lbf) at 800km/h and 13,000rpm
Weight: 360kg (794lb)
Pressure ratio: 2.8:1
Diameter: 0.93m (3.05ft)
Length: 1.48m (4.85ft)

The HeS 8 was of a similar layout to the HeS 3B, but with a straight-through combustion chamber. It had a 14-blade axial inducer feeding a 19-blade centrifugal compressor; the radial in-flow turbine had 16 blades. In the annular combustion chamber, fuel was sprayed onto two annular rings, from which it evaporated and burned. The HeS 8 was lighter and had lower frontal area than the HeS 3, but performance was disappointing — the design thrust was 700kp at 800km/h, but it never reached this. This may have been because of the relatively low compressor ratio; the V15 prototype added a single axial compressor stage, raising the pressure ratio to 3.2, but this does not seem to have been pursued further.

HeS 8 data

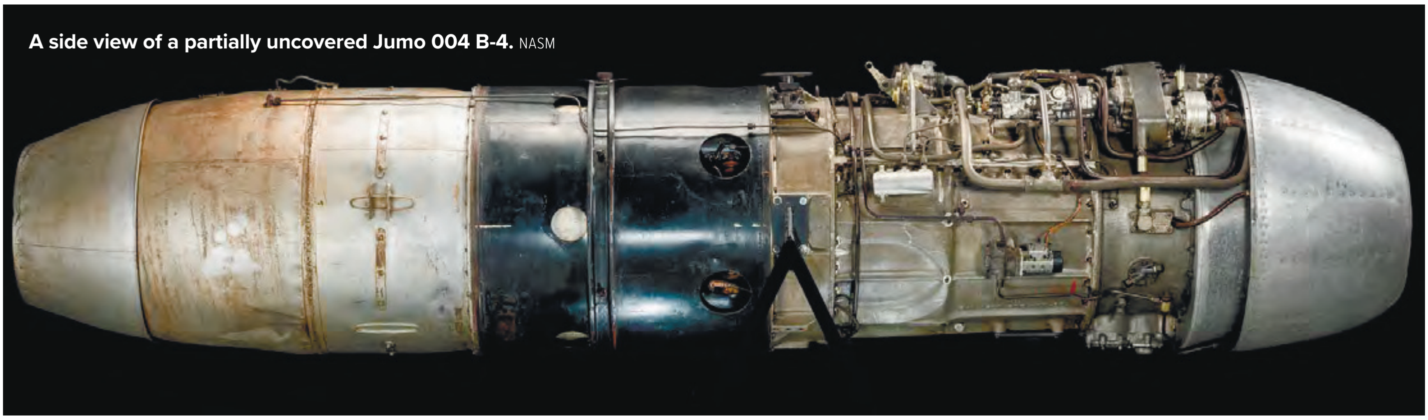
Thrust: 600kp (1,328lbf) static at 13,500rpm
Weight: 380kg (838lb)
Pressure ratio: 2.7:1
Diameter: 0.775m (2.54ft)
Length: 1.60m (5.25ft)

The HeS 30 was a development of the engine which Max Müller had started work on before he left Jumo. It had a five-stage axial compressor and a single-stage axial turbine. The compressor blading was designed for 50 per cent reaction, and the turbine had moveable guide vanes. The combustion system consisted of 10 cans, and the engine had a variable-area nozzle.

HeS 30 data

Thrust: 860kp (1,896lbf) static at 10,500rpm
Weight: 390kg (860lb)
Pressure ratio: 3:1
Diameter: 0.62m (2.03ft)
Length: 2.72m (8.92ft)

The HeS 011 was a class II engine, influenced by Helmut Schelp's ideas about diagonal compressors. The compressor system comprised an 11-blade axial inducer, a 12-blade diagonal compressor, and three axial compressor stages. The combustion chamber was of the annular type, and the turbine blades and guide vanes were hollow and air-cooled using


A side view of a partially uncovered Jumo 004 B-4. NASM

compressor bleed air. The A-0 engine had a moveable tail cone to provide a variable-area nozzle.

HeS 011 data
Thrust: 1,300kp (2,866lbf) static at 11,000rpm
Weight: 950kg (2,094lb)
Diameter: 0.864m (2.83ft)
Length: 3.455m (11.34ft

Junkers Jumo 004

The Jumo 004 used an AVA-designed reaction-type compressor. All the pressure rise took place in the rotor blades, which meant the stators could have simple construction and did not require fine tolerances. However, this meant that the compressor needed eight stages to achieve the desired pressure ratio and so was relatively heavy. The first two rotor stages had broader chords, with the later stages being relatively thicker. About 3 per cent of the compressor air was tapped off for cooling of the turbine guide nozzles and blades. The six combustion can-type chambers were from mild steel with an aluminium coating to prevent oxidation; fuel was J-2 diesel oil. The turbine guide vanes were hollow and air-cooled; air passed through their roots and out through slots in the trailing edge. In the B-1 engines with solid turbine blades, coolant air passed over the turbine blade roots. The turbine disk of the B-4 engines had passages for the air to pass through into the hollow blades and out through the trailing edge. The turbine blading was designed for 20 per cent reaction, and the engine was fitted with a moveable body in the exhaust to provide variable geometry. Engine starting was via a Riedel two-stroke engine contained in the nose bullet. The main engine was started with petrol from an auxiliary tank, then switched to J-2 diesel oil once it was running.

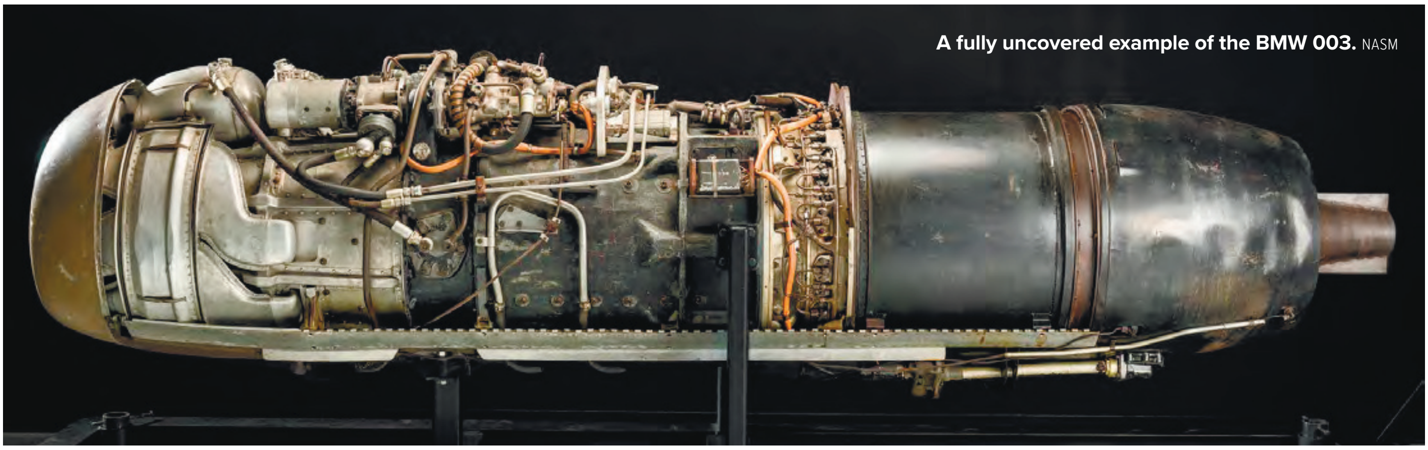
Jumo 004 B-1 data
Thrust: 900kp (1,984lbf) static at 8,700rpm
Weight: 720kg (1,587lb)
Pressure ratio: 3:1
Diameter: 0.960m (3.15ft)
Length: 3.80m (12.47ft)

BMW 003

The engine had a seven-stage axial compressor, using blading with 30 per cent reaction. The compressor blades were of constant chord, and their thickness tapered from 12 per cent at the root to 5 per cent at the tips. In the pre-production A-0 engines, coolant air was tapped off from the fourth compressor stage, but in later production engines it was taken from the secondary airflow just inside the combustion chamber. The annular combustion chamber had sheet metal liners with nozzles for secondary air, which entered roughly half-way down the combustion chamber's length. Initially the engine was designed for petrol running, but in late 1944 this was changed to J-2 diesel oil. To convert to this as quickly as possible, BMW adapted the Jumo 004's fuel system. Like the Jumo, the engine was run up with a Riedel two-stroke starter in the nose bullet and started on petrol before switching over to J-2. The turbine inlet nozzles were hollow and air-cooled, the air leaving through slots in the trailing edges. The turbine blades were also hollow and were pinned to the turbine wheel; in the A-1 engines there were 77 blades, but in the A-2 this was decreased to 66. They were fitted with inserts that helped secure the blades; they meant the coolant air space inside the blade was only about 1mm wide, which helped keep the coolant air consumption low. The exhaust nozzle had a moveable bullet for variable geometry.

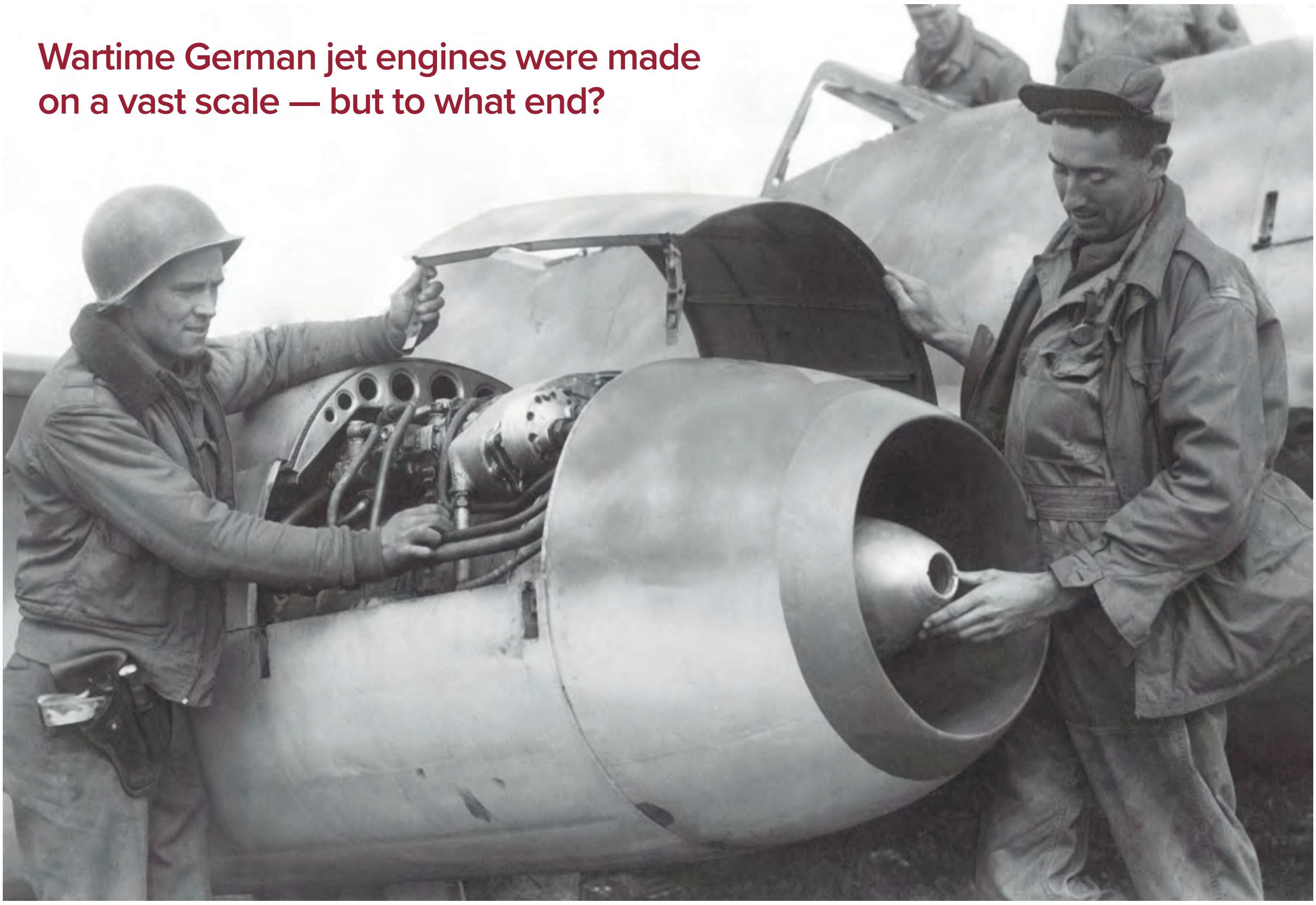
> “Like the Jumo, the BMW 003 was run up with a Riedel two-stroke starter in the nose bullet”

BMW 003 A-1 data
Thrust: 800kp (1,764lbf) static at 9,500rpm
Weight: 570kg (1,256lb); A-2: 600-610kg (1,323-1,345lb)
Pressure ratio: 3.1:1
Diameter: 0.690m (2.26ft)
Length: 3.565m (11.70ft) with exhaust bullet extended


A fully uncovered example of the BMW 003. NASM

PRODUCTION

Wartime German jet engines were made on a vast scale — but to what end?



A Me 262's starboard Jumo 004 is inspected by American troops in April 1945. KEY COLLECTION

Compared to the other combatant nations, during the Second World War Germany produced jet engines on a gargantuan scale. Its jet producers built more than 6,500 engines, nine times as many as the UK's, and in excess of 22 times as many as the US's. Yet this is not in itself proof of technical superiority. Indeed, as described above, German jet engines were designed as much for minimal use of strategic materials and the demands of mass production as they were for pure performance. They were pushed into production by the RLM in part because of the failings of its conventional armaments programme, trying to square the competing demands of quantity and quality. The development delays or failures of some of the Luftwaffe's most important follow-on types during 1941 and 1942 — such as the Me 210, He 177 and Me 309 — put pressure on the production and development capacity of an aviation industry that was already having trouble meeting the military's production needs.

As the Allied bombing campaign stepped up throughout 1943, it became clear that immediate defensive capacity could only be increased by stepping up production of existing — and in some cases semi-obsolescent — types. With the German aero-engine industry's failure to produce a viable piston engine of more than 2,000hp in a timely fashion, the hope was that the jet engine would provide a solution by leapfrogging advanced piston designs. The RLM also hoped to push the new kind of engine into service quickly. As the development and teething troubles showed, like contemporary piston engines, jets took about five years to become truly mature and production-ready.

Where jets did have an advantage over piston engines was that it was possible to build them with little use of strategic materials and run them on diesel oil. Piston engines couldn't be made from sheet materials, requiring more casting and machining than the jets. They also needed much more labour input. Most late-war German piston engines took approximately 3,000 man-hours to build; by the end of the war, the Jumo 004 took about 700 man-hours, and the RLM demanded 500 man-hours for production versions of the BMW 003, though in practice it was probably higher. The engines were also suited to dispersed manufacturing. With their modular design — compressor, combustor, turbine, jet nozzle — they could be built and partially assembled at separate sites, then brought together for final assembly and testing.

> “It was possible to build jet engines with minimal use of strategic materials”

The RLM placed production orders for the Jumo 004 in August 1943. By January 1944 the ministry was suggesting that Jumo production should be 1,000 engines a month at the end of 1944, and as of late 1945 it was planned to have 3,000 engines a month rolling off the assembly lines. As a comparison, in 1943 German piston engine production from all the major manufacturers combined reached 4,000 per month for the first time.

Even if jets were much easier to produce, the scale of their production plans was unprecedented and, as Germany's war situation deteriorated, entered the realms of fantasy. By late 1944 one plan aimed for production of 5,000 Jumos a month, along with 6,000 BMW 003s. A production order for the BMW 003 was given in the late summer of 1943, though it was briefly suspended in December of that year. The RLM's dilemma was that concentrating production on a single type was more efficient, but — and this was a particular risk when pushing novel projects into production — development difficulties would then affect the entire production programme.

The main Junkers plant at Dessau was heavily bombed in late 1943, affecting Jumo 004 production. The problems caused by this appear to have been exacerbated by management difficulties, the RLM's Erhard Milch describing the situation as "Schweinerei erster Klasse", or a first-class mess. In the event, Jumo production began not at Dessau but at the Muldenstein plant some miles south. This was intended to have a peak monthly output of 1,200 engines, but never built more than 467 in a month. In part because it started production early, the factory ultimately built some 45 per cent of all Jumo 004s produced. BMW-Bramo's Spandau factory was also bombed during 1943, and its Zühlsdorf plant was the only factory to turn out complete BMW 003 production engines. Because of labour and material shortages, Zühlsdorf's planned monthly output of 1,500 engines was never achieved, peak output being a mere 150 engines in March 1945.

As the aviation industry's skilled labour shortages became more severe from the mid-point of the war onwards, the RLM tried to find solutions. The initial response was to try and standardise production on existing types. Learning curve effects were particularly strong for complex products such as aircraft and aero engines, so building existing models could bring large productivity gains, though obviously at the cost of performance. Another response was to encourage the use of specialised machine tooling to increase productivity and allow the use of semi-skilled labour, and, as for the production jet engines, to insist on mass production-friendly design features. While all of the Second World War's combatants had to make these kinds of trade-offs, at least to some degree, the Third Reich employed another method to increase production: the use of forced and slave labour.

German wartime jet engine production numbers (production models)

Engine	1944*	1945	Total
Jumo 004	2,660	3,350	6,010
BMW 003	189	370	559
HeS 011	-	(10)	(10)
Total	**2,849**	**3,730**	**6,579**

**includes production engines for 1943*

That the SS concentration camp system became an increasingly important source of workers for German industry is well-known, but the extent of its involvement with jet engine production is perhaps less so. As early as September 1943, Schelp had approached the SS main leadership office to ask for assistance with production matters. With reference to the needs of air defence, the head of the office agreed that the SS should try and assist production, and ordered trials to be carried out at the SS-Kraftfahrtechnische Versuchsanstalt (SS vehicle mechanical research institute), which was part of the Sachsenhausen concentration camp, and was near the BMW factory at Zühlsdorf. By the end of the war some 1,000 prisoners were involved in producing BMW 003 parts, compared to 2,000 factory workers at Zühlsdorf.

> "By the end of the war some 1,000 prisoners were involved in producing BMW 003 parts"

As Allied bombing continued to take its toll, in March 1944 fighter production was removed from the RLM's control and made the responsibility of the Jägerstab (fighter staff). The following month responsibility for air armaments production was transferred to Albert Speer's armaments ministry. The Jägerstab argued for the relocation of Junkers jet engine production to the underground Mittelwerk factory, a former mine and underground storage facility where the SS was already using concentration camp labour to produce the V2 rocket. The Junkers factory, in the complex's northernmost tunnels, became known as the Nordwerk. Though the Junkers workers were mostly forced foreign labourers rather than concentration camp inmates, working conditions remained harsh, the presence of the Mittelwerk's murderously bad working conditions being used as a constant threat.

Jumo manufacturing began at the Nordwerk in October 1944, with some parts being made in the factory and others being brought in from sub-contractors elsewhere. Production ramped up very quickly, especially as bombing affected production elsewhere. By February 1945 half of all jet engines produced in Germany were coming out of the Nordwerk, which ultimately produced one in three jet engines built in Germany during the war. BMW had also begun to set up facilities at the Nordwerk, but the war ended before these became operational.

What this system meant was that even as the Reich fell apart, jet production continued to rise. Fully half of all jet engines made during the war were built in the first quarter of 1945. At the war's end, enough parts and components had been built to allow for the assembly of thousands of further engines. That the Luftwaffe had neither fuel nor pilots available was no longer really a consideration. The remorseless logic of production at any cost had taken over.

American forces stand at an entrance to the notorious Mittelwerk, within which a Jumo engine plant was established, largely using forced foreign labour. USAF

An Ar 234B-2 bomber climbs out, its two Jumo 004s augmented by a pair of jettisonable rocket-assisted take-off units used to improve the Arado's performance on departure when heavily laden. KEY COLLECTION

The performance advantages of the Luftwaffe jets were huge, but came too late

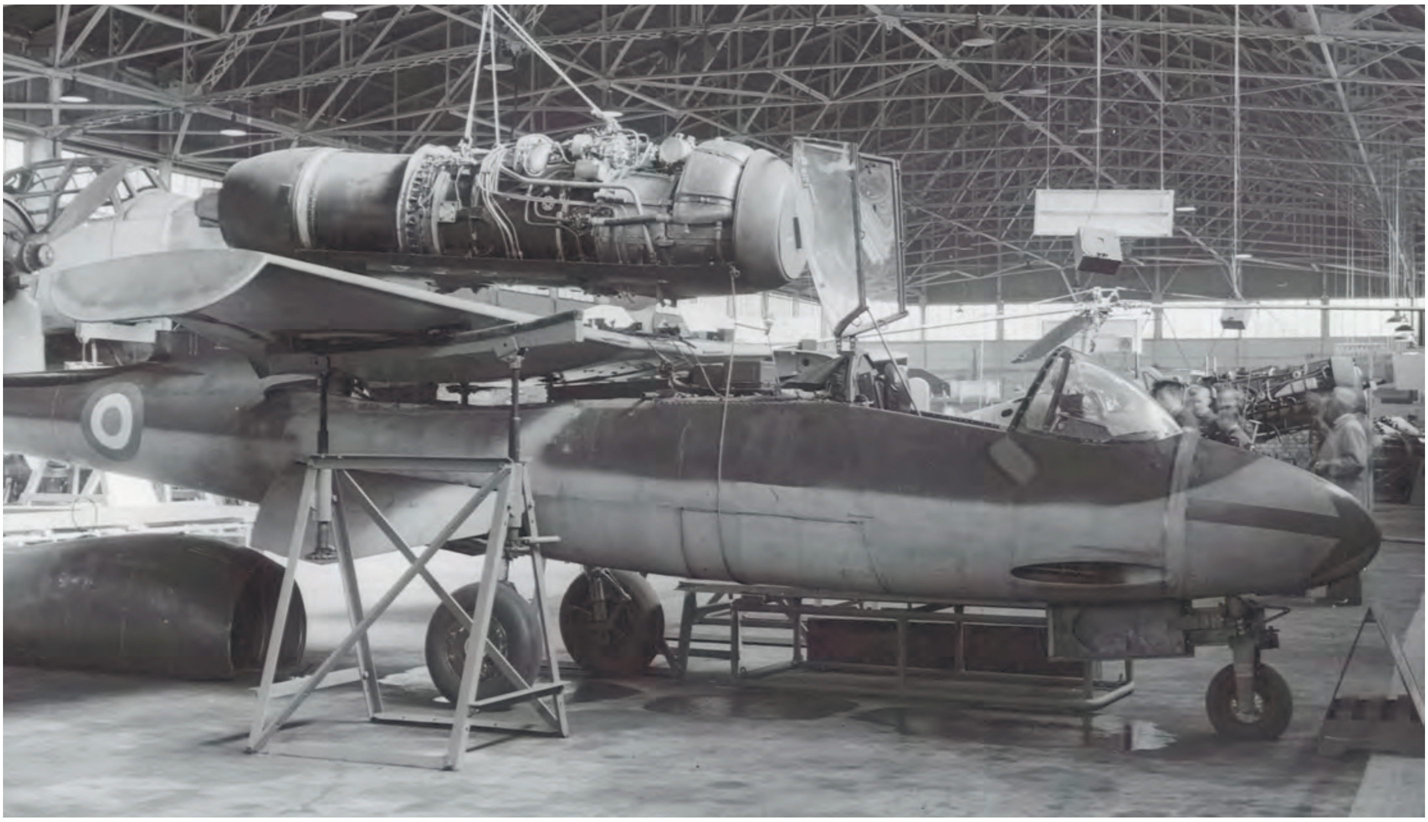
The only jet engines to see active German service during the Second World War were the Jumo 004, mostly the B-4 version, and the BMW 003, the majority in E-1 and E-2 variants. Of the two, the BMW was the more advanced. Despite developing similar power to the Jumo engine, it was a lighter, more compact unit, used a smaller amount of strategic metals, and had better turbine and combustion chamber life. On the other hand, as it entered series production some nine months later than the Jumo 004, it was produced in much smaller numbers.

The Jumo 004's main service types were the Me 262 and the Arado Ar 234. Both had been ordered in 1940, and were ordered into production in 1943. The BMW 003 had been mooted for the Me 262, but its 1942 flight test failures caused that to be shelved. More than 1,400 Me 262 airframes were built, but because of transport shortages and problems with production quality only about 358 became operational. The service life of the Jumo 004 turbine was nominally 35 hours before total overhaul, but the combustion chambers had a life of only 25 hours, and their replacement required an engine strip-down. In practice, engine life could be less than 10 hours, especially in aircraft that had to make frequent changes in throttle settings, such as wingmen trying to keep station on a formation leader.

A Me 262 from III./Erprobungsjagdgeschwader (EJG) 2, the Luftwaffe's operational training unit for the type, rolls for take-off. VIA CHRIS GOSS

On the other hand, by the time the Me 262 was operational, pilot and fuel shortages were probably as much a limiting factor as engine life. One particularly unpleasant Me 262/Jumo 004 failure mode was related to the variable-geometry exhaust system: if the 'onion' came loose from its mountings, it could block the exhaust and cause an engine flame-out. This was sudden enough that the aircraft would yaw violently, putting the rudder far enough into the fuselage wake to make recovery impossible. Nonetheless, if the engines were running smoothly, in the right hands the Me 262 was the most formidable fighter of the Second World War, and was almost untouchable apart from on its take-off run and landing approach.

The Ar 234 was designed as a twin-engined reconnaissance aircraft, but was soon modified as the Ar 234B 'Schnellbomber', or fast bomber. Ar 234 units tended to get better life from their engines, mainly because bomber and reconnaissance operations spent most of their time at constant throttle settings, which put much less strain on the powerplants. The



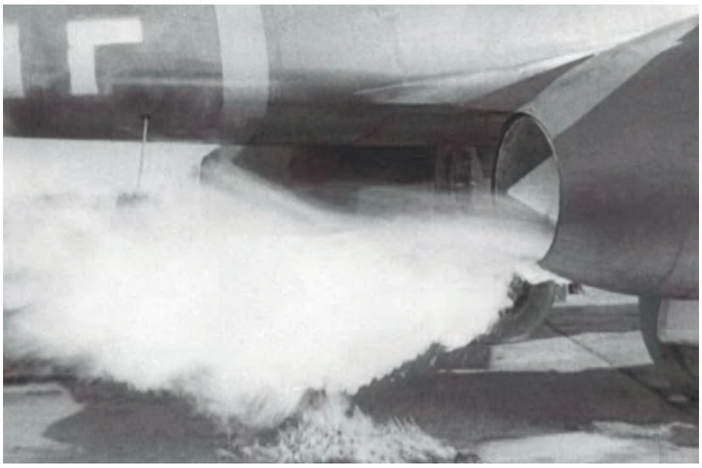
During the enemy aircraft exhibition at Farnborough in 1945, He 162A-2 Werknummer 120091 was exhibited with its BMW 003 extracted. *AEROPLANE*

Ar 234 was also trialled with four BMW 003s — in February 1944 the V8 prototype flew with paired engines in nacelles under the wing. This installation was unsuccessful, generating local shockwaves between the nacelle and fuselage, and the V6 prototype used individual engine nacelles for its first flight in April 1944. A few months later the V13 reverted to the paired nacelle layout as the shock issues had been solved and the layout was considered more efficient. It was retained for the production four-engined Ar 234C. The BMW 003s produced nearly twice as much power as the twin Jumo 004s, giving greater load, speed and range, not least because the aircraft could climb to efficient flight altitudes much more quickly. Though performance was excellent, only about 14 or so Ar 234C production airframes were built, of which fewer than half were fitted with engines.

The BMW 003's main use was as the engine of the He 162 'Volksjäger', which was, of course, a last-ditch attempt at a cheap air defence fighter. With one engine and a structure built largely of wood, it was so much cheaper than the Me 262 it was considered near-disposable. As it had an endurance of only 30 minutes, fuel starvation destroyed more than were lost in combat. Some 320 He 162s were completed, using well in excess of half the production BMW 003s built. Because of its more advanced combustion system and turbine cooling system, its design life before major overhaul was around 50 hours, though production test engines did not necessarily reach these running times.

> “Ar 234s tended to get better engine life, as they spent more time at constant throttle settings”

The Ar 234 V8 was powered by four BMW 003s, but problems were encountered with this prototype configuration. VIA CHRIS GOSS



Caused by unburnt fuel in the exhaust, a fiery start-up for a III./EJG 2 Me 262. VIA CHRIS GOSS

The wartime German jet engines offered a step forward over piston power — but a qualified one

Trailing a long plume of tyre smoke, Me 262A-2a Werknummer 500200 lands at Farnborough during 1945 in the hands of RAE Aerodynamics Flight commanding officer Sqn Ldr Tony Martindale, with many other captured German types in the background. Allied evaluation of the German jets, and their engines, proved very insightful. AEROPLANE

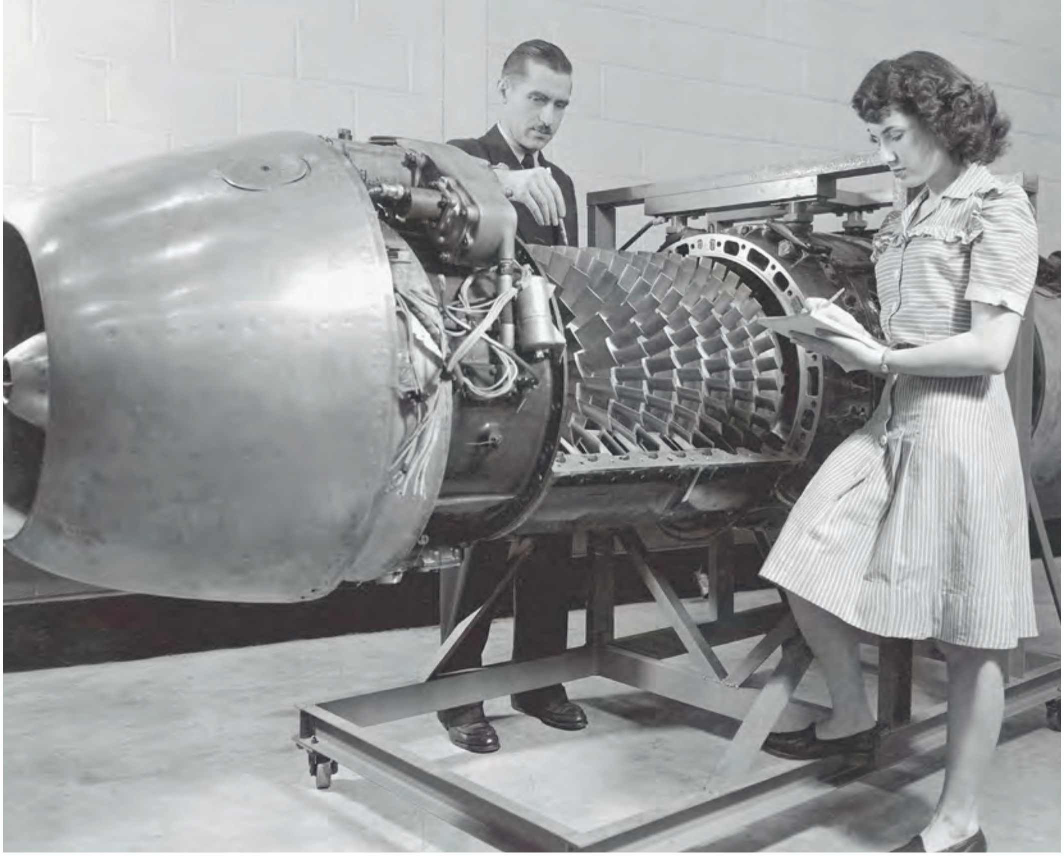
In flight, most pilots were delighted with the handling characteristics of the German jet aircraft, and enjoyed the lack of noise and vibration compared to piston powerplants. The Achilles' heel of early jet engines was their throttle response: not only did they spool up slowly — some 15 seconds from idle to full power — but any large changes in throttle setting could lead to overheating and turbine failure. In the Jumo 004, rough handling could raise the turbine temperature by 200°C. Later engine marks were slightly less sensitive, and incorporated governors in the throttle and fuel system to reduce the engine's response to throttle movements, but this was not effective at lower rpm and at altitude.

Even starting the engines required the skills of a juggler. Pilots had to fire the starter engine, wait for the revs to come up to the point where jet combustion could be started on petrol, then let them climb further until the engine could be switched over to J-2 fuel, and ensure they reached the correct idle setting. This involved manipulating various switches, fuel cocks and ignition buttons, as well as a throttle lever, all while keeping a close eye on the temperature gauges. And that was only to reach engine idling, at which point the Luftwaffe manual for the Me 262 warned, "Gradually move throttle lever forward from 3,000 to 6,000rpm. Temperature may not rise above highest permissible point. The control unit only operates above 6,000rpm. Therefore, if the throttle is moved forward too quickly there is danger of considerable flame and therefore fire."

Pilots were also enjoined not to use engines for taxiing or manoeuvring, but to ensure they were towed to the take-off point and to use brakes rather than engine settings to turn on the ground. In the last months of the war an improved governor could regulate the throttle at lower rpm, but it was still temperamental.

The major tactical disadvantage caused by the throttle response was on take-off and landing. The German jets cruised at such high speeds that they were mostly immune from interception, and could accelerate away if they needed to. All aircraft were vulnerable if caught in the landing pattern, but piston aircraft could go to full throttle much more quickly. In addition, violent manoeuvring and sideslips at low power

An Ar 234 pilot looking rather exposed at the helm of his very impressive new machine. Engine handling, though, had to be most careful. KEY COLLECTION



A captured Jumo 004 is inspected by scientists from NACA, the US National Advisory Council for Aeronautics, at its Aircraft Engine Research Laboratory in Cleveland, Ohio, during March 1946. Just visible in the nose cone of the engine is a pull ring, which enabled starting by means of an attached cord if necessary. NASA

settings could disrupt the flow into the jet intakes enough to cause flame-outs.

At high altitudes, above 6,000m (19,685ft) or so, any change to throttle settings could cause a flame-out, and the engines could not be restarted until below 4,000m (13,125ft). One exercise developed for Me 262 conversion training was for pilots to fly a training sortie in a piston-engined aircraft at a fixed throttle setting after take-off and initial climb, to get used to manoeuvring in a loose formation without being able to make the normal power adjustments.

The Allies had a healthy respect for Luftwaffe jet aircraft, but their assessment of the engines themselves was more equivocal. Though they recognised aspects of the designs and the performance achieved under material constraints, it came at a cost in engine life and handling that most would have considered unacceptable. When the UK's National Gas Turbine Establishment (NGTE) reviewed the Jumo 004 B-1, the report's conclusion was, "For general future design of gas turbine engines, there does not seem much to be learned from this engine. The enemy has always tended to sacrifice everything to production and has made strenuous efforts to overcome his shortages. In consequence, performance has suffered but it still shows that a useful jet engine can be built when heat-resisting steels are in short supply". This was of course a consequence of the fact that the western Allies did not have to push their jet designs into production with the same urgency as German manufacturers, and were able to concentrate on developing next-generation designs.

> "The Achilles' heel of the early jet engines was their throttle response"

Even in areas such as axial compressor design, the NGTE's staff felt they were ahead of contemporary German practice, but German jet engineers did provide the nucleus for many jet projects abroad after the end of the conflict. In the eastern bloc, Jumo 004 copies powered the first generation of Soviet jet aircraft, and ex-Jumo and BMW engineers helped build up the USSR's jet expertise. In France, Hermann Oestrich was recruited to build what eventually became the Atar engines. Among others, Anshelm Franz and Hans von Ohain went to the USA, where they designed many further jet powerplants.

Helmut Schelp can have the last word. After the war he was taken to London for interrogation, and while there he saw a display of the Gloster E28/39. As he put it, "it had a sign on it saying: 'This aeroplane made the first turbojet flight in the world.' The next time I saw [Air Commodore 'Rod'] Banks [responsible for engine research and development at the Air Ministry], I kidded him about it. I said, 'you know that's not true.' I told him that certainly he knew that Ohain and Heinkel flew their turbojet on 27 August 1939, and, well, hell, I knew that was true because I was there. He said, 'I believe we overlooked that fact.'"

Gun camera footage of a Me 262, wheels down for landing, in a US 8th Air Force fighter's sights. This was a phase of flight in which the Luftwaffe jets were most vulnerable. KEY COLLECTION