The heart of the SR-71 "Blackbird" : The mighty J-58 engine

by Philippe Ricco
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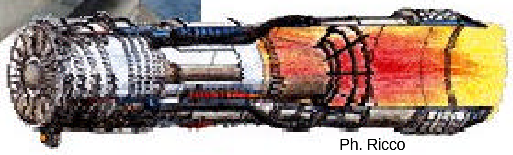
NASA

Part one :

Genesis

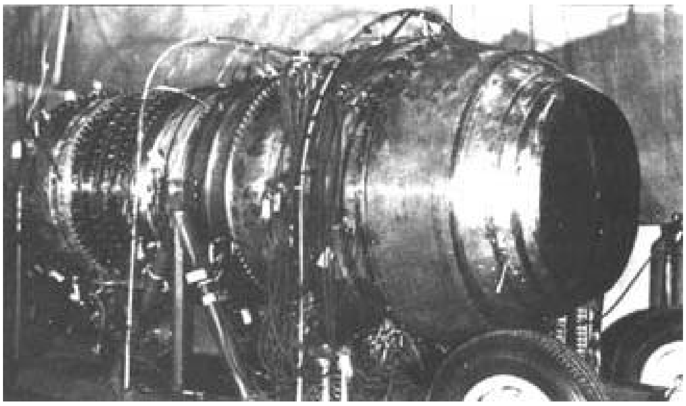


Ph. Ricco

Genesis : 1.1 : Development

The Blackbird was the only aircraft ever to be designed around the J-58 (JT-11). This turbojet engine had been developed for a USN project, by Pratt & Whitney, at their West Palm Beach R & D center in Florida. Eventhough its existence remained a secret until revealed on 28th February 1964 by US President Lyndon B. Johnson, that of the JT-11 engine was already known to specialists.

The very first Mach-3 jet engine, designed by Pratt & Whitney for the North-American XB-70, was the J-91 (aka JT-9). In spite of a hazy future for that six-engined bomber, the design studies for the propulsion units proved fruitful when a somewhat smaller but also Mach-3 engine had to be designed for the US Navy, named JT-11 and known later as J-58. The initial design-studies for this turbojet were launched in 1956.



Pratt & Whitney 304-hydrogen engine prototype planned to equip the project Lockheed "Suntan".
© *Pratt & Whitney*

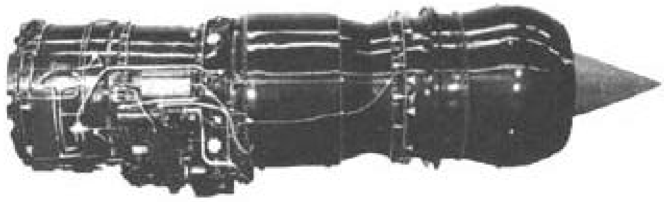
At the outbreak the project was company-funded, but soon the U.S. Navy, which was developing a Mach 3 strike aircraft, started sponsoring its development. The U.S. Navy requirement called for an engine with sufficient thrust for sustained flight in the environs of Mach 2.5, however able to reach short-burst peak speeds exceeding Mach 3.

Initially it was to be fitted on an upgraded version of the North American A3J-1, from which the RA-5C "Vigilante" would later emerge. As part of this program, two projects by Vought designated V-418 and V-419 also came into being, better known under their generic designation of F-8U-3 "Crusader III". The first was fitted with a J-75, the second received a J-58.

The engine would implement the ramjet principle to supplement the low compression rate from the axial compressor. It was designed to supply 26,000 lbs (11,800 kg) of thrust, with afterburning, at sea-level. The first official aid, amounting to $ 11.2 million (55 M Francs) was received in August 1959, with an order for 30 prototypes. In the meantime, the YJ-58 was undergoing ground running trials (in 1957). The 50 hours running acceptance trials were completed in August 1958, thus evidencing the fast pace at which the development of the new engine progressed.

Alas, due to sky-rocketing costs, the US Navy eventually dropped the project. Only the Vought V-418 project succeeded in bringing forth the two XF-8U-3 prototypes, but once again this project was abandoned after the roll-out of the first F-8U-3, the pre-series of the McDonnell Douglas F-4H-1 "Phantom II".

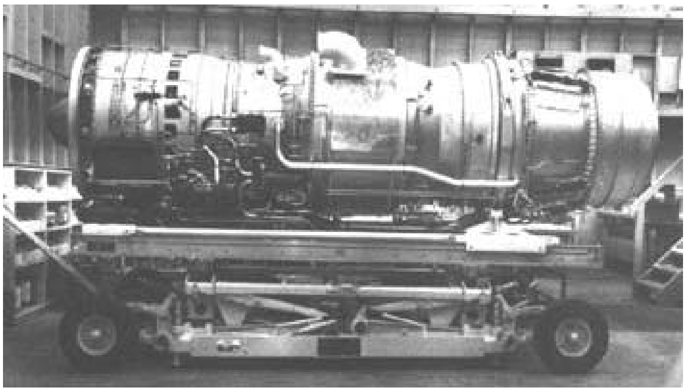
Over that period, trials were successfully performed in the specialized facilities at Wilgoos. On their test benches, flight conditions of Mach 3.2 up to 30,000 meters (100,000 ft) could be simulated. The wind tunnel was capable of supplying air at high-pressure (2 at.) with a flow-rate of 750 lbs/sec. (340 kg/sec.). Pratt & Whitney contemplated two possible developments of their "super jet"; a military version capable of powering an aircraft at stratospheric altitudes at Mach 3 speeds and a civil version, capable of great thrust (to the order of 20 tons) over an extended flight duration – presented in typical 50's jargon as "all supersonic".



One of the first version of the J-58 without after burner as it appeared in the sixties in Pratt & Whitney advertisements. It is probably a YJ-58.
© Pratt & Whitney

Parallel to all this, Pratt & Whitney successfully accomplished trials of their model 304 liquid-hydrogen turbojet-engine which, although it had been officially rejected, was successfully tested in October 1958. The final duration run on the test bench at West Palm Beach lasted 25 hours 30 minute. As regretful as it may be, the 304 turbojet remained only a prototype and the 'Suntan' project, for which it was intended, was closed at the end of 1958 with a bill reaching 250 million dollars. Furthermore, since the General Electric J-93 had officially been selected on 6th November 1957 for the B-70, the development budget for the J-91 was cancelled.

By then Lockheed had commenced working in the greatest possible secrecy on a series of high-performance aircraft projects aimed at replacing the U2, numbered from A-1 through A-12. Numerous engine installations were envisaged, among which some featuring the high-thrust Pratt & Whitney J-58, which had only recently completed 700 running hours. Thanks to the influence of Kelly Johnson and Pratt & Whitney's chief-engineer William H. Brown, Lockheed obtained an advance order on 29th August 1959 for their project designated A-12, fitted with two J-58s, and allocated a development budget of $ 600 million. The program, maliciously entitled 'Oxcart', was officially approved on 30th January, 1960, and included the manufacturing of twelve aircraft for the CIA.

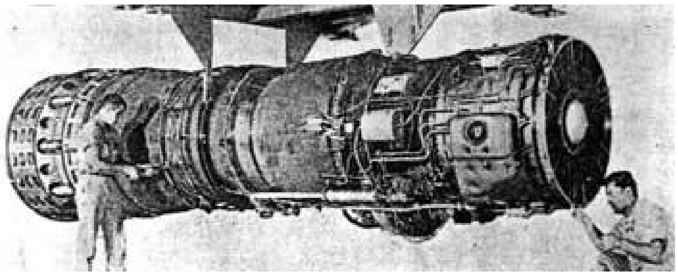


This full-scale model of a J-58-P2 was made by Pratt & Whitney in Hartford in July 1961 to study the global size of the engine.
© Pratt & Whitney

The project propulsion team had a staff of 27 engineers for the initial stages of design-studies and development, including Don Pascal, Norm Cotter, Dick Coar and Ed Esmeier, who would be joined by William Gordon (who had been in charge of Pratt & Whitney's Florida facilities) under the leadership of Brown. Gordon enjoyed a flattering reputation which helped promoting the project as well as fostering at the time a good relationship with Lockheed and the 'silent' partners.

Furthermore the team was reduced and carefully selected. They worked (like everything at the "Skunk Works") using a minimum of documentation and written contracts; instructions mostly took the form of personal memos from engineer to engineer. The privileged relations proved to be most enduring between Lockheed and Pratt & Whitney.

At that time, Pratt & Whitney had one of the most powerful industrial computers at their disposal, an IBM-710. Its calculation capacities were at best equal to that of some pocket calculators of the 1980's. So with all things considered, the J-58 globally still was another offspring of the good old slide-rule. Despite all the performance graphs and bench runs most of power-unit integration problems would only be resolved by flight trials. The Lockheed – Pratt & Whitney duet enjoyed much from the understanding of government officials in charge of that specific file. They let the companies deal with problems in their own way, and refrained too much from interfering in the course of the development phase of modifications which might have operational or major budgetary aftermaths. It is a consequence of this fast reaction to encountered technical difficulties, that project progress was accelerated and this was recouped in substantial financial savings.



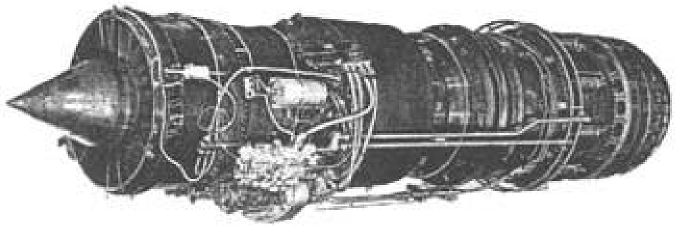
The J-58 was later equipped with an after burner. This model was usually presented as a J58-P2 destined to equip the F8U-3 and A3J of the US Navy.
© *Pratt & Whitney*

When project Oxcart was born, various codenames were employed for each sub-assembly of the propulsion units. So, the forward bypass was baptized 'onion slicer', whereas the aft one was named 'cabbage slicer' whilst the trailing edge flaps were given the most classic term 'tail feathers'. But soon the codenames were dropped, an instruction soon being passed around informing that standard terms should be used.

Genesis : 1.2 : Evolutions

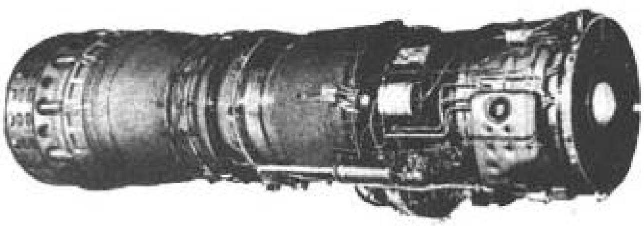
Resolution of the difficult flight conditions which the A-12 was to encounter, being at that period relatively unexplored, proved to be a complex matter. Sustained flight above Mach 3 at high altitudes – demanded extended trials in the supersonic envelope (initially conducted with the J-75) as well as the study of new fuels and lubricants. Moreover, due to the influence temperatures would have upon the function of the engine, every component would have to be manufactured from specialized alloys (stainless steel, Hasteloy X, titanium) which to up that time had only been used for such smaller components as turbine-blades. The trials being carried out at the period with the experimental "X" planes were of little help, as these were mainly rocket propelled and their flights of short duration.

At the outset variable geometry jet-pipes were to be an integral part of the engine. It was decided, jointly with Lockheed, that these would be incorporated in the compression chamber, so as to keep dimensions within acceptable limits. Pratt & Whitney was accountable for the nozzle and post-combustion chamber. On top of this Pratt & Whitney was busy designing the control mechanisms because the engineers at Lockheed had absolutely no experience of material requirements for gears, bearings and welding able to withstand such temperatures. Pratt & Whitney had hardly any more experience, but were compelled to acquire it so as to see the program through.



This Pratt & Whitney J-58-P2 engine was introduced to the French public at the 1963 Le Bourget air show.
© Pratt & Whitney via Jane's

The J-58 went through numerous modifications which, by 1960, included changes to the bypass ducts, increasing the compressor stages from 8 to 9, so augmenting the rather low compression rate, and adopting an afterburner – intended for continuous operation throughout a mission. The J-58-P4 thus conceived for the A-12, had few common parts with the initial J-58-P2 studied for the US Navy. Only the overall dimensions, the aerodynamics of the compressor blades and the turbine unit were retained for the time-being. Some time later even these would also be modified.



The result of the tests carried out in conjunction with Lockheed evidenced, from the start, that at the intended higher Mach numbers the new engine would be unable to cope with the volume of air coming through the air-intakes. This would result in compressor stalling with accompanying loss of efficiency and thrust at high speeds. Pratt & Whitney therefore modified their JT-11 by installing a series of fixed flow-vanes downstream of the 4th compressor stage, which directed the surplus airflow along six longitudinal jet pipes running along the engine casing.

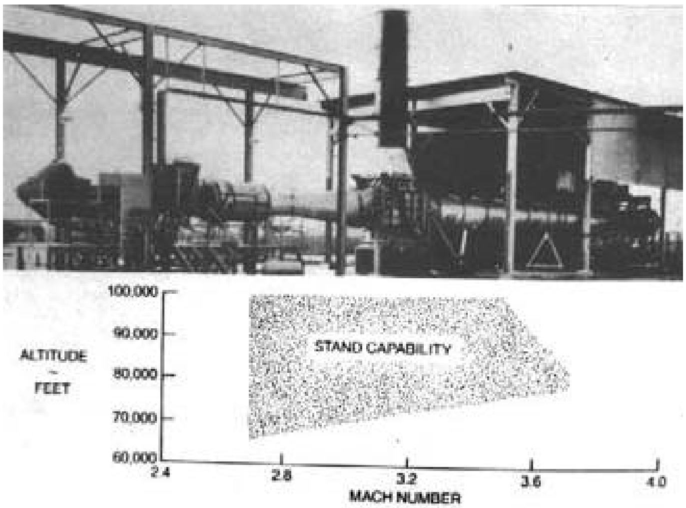
Another variant with after burner of the JT11. This model was not yet equipped with the six discharge veinswitch are the characteristics of the J-58-P4 on the SR-71.
© Pratt & Whitney

The surplus was then carried straight to the afterburner chamber serving to cool the burners, whilst enriching the mixture; so enabling higher combustion temperatures or increased thrust.

This principle, innovative at that time, figured largely in the future development of other engines called ”bypass jets". The J-58 cannot be properly referred to as being bypass jet, an unknown principle at that time, as that did not derive from flow-vanes with an irregular cooling affect, so serving to relieve the compressor at certain stages of flight, which was obtained by a bypass flow constantly shifting air from within the compressor towards the turbine outlet. Nevertheless the chosen formula allowed an effective limitation of the phenomenon of unstarts and compressor fall-off due to variations in inlet temperature, on top reducing specific consumption from 10 to 15%. This is the system which Ben R Rich (Kelly Johnson’s successor as head of the ”Skunk Works”) qualified as being a ”bypass jet engine by air withdrawal”.

Genesis : 1.3 : Ground and flight tests

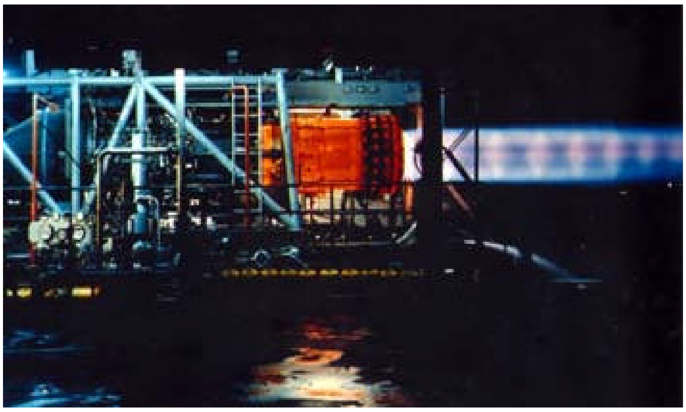
Despite the major difficulties inherent to such an ambitious program, the first prototype of the A-12 was ready to fly in less than two years. Concurrently improving the JT-11 was a much slower process, and the initial flights of the A-12, in 1962, were carried out with the Pratt & Whitney J-75, only half as powerful but already proven. The maiden flight of the A-12 took place on April 26th, 1962, three months ahead of preliminary flight trials of the new engines, 3 years, 4 months after the governmental go ahead was given.



To adequately conduct the "high temperatures" tests of the J-58, a special test bench was installed at Wilgoos to send the hot exhaust air of a J-75 engine directly into a J-58.
© Lockheed

Numerous tests were carried out on the prototypes and pre-production engines before flight testing in an A-12 was undertaken. One of the problems which had to be overcome was that so far no engine had explored these performance ranges, so no regulatory documentation existed. Pratt & Whitney would not only have to prove their new motor, but also simultaneously establish validation procedures. Featuring amongst large number of tests were prolonged endurance tests of engine-functioning over a duration of 150 hours.

As no test bench would possibly simulate the overheating likely to be encountered in service, it proved necessary to build one for that specific purpose. The adopted solution included the exhaust flow from a J-75 engine to supply hot air to the intake and casing of a J-58 during a course of experimentation. Furthermore, available instrumentation did not make it possible to obtain the required results in real time.



As soon as Pratt & Whitney developed more robust measuring instruments and adapted calibration techniques to suit, much more precise results were registered. Lockheed was kept informed on how things were progressing and on the analysis of acquired data.

In the course of July 1963 the final pre-flight engine tests were successfully carried out. It was not until January 1963, nine months after the maiden flight of the A-12 that 60-6924 received the first J-58 installed in the starboard nacelle, so that at last the first flight tests could be undertaken.

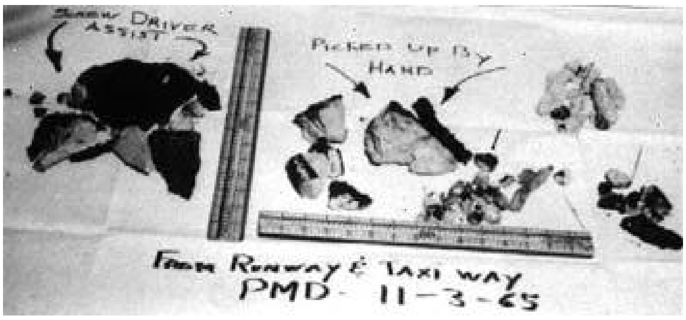
The J-58 was an engine conceived to operate continuously at Mach 3 with the after burner on for the duration of the flight, providing spectacular results: seen here is a J-58-P2 at the test bench, at night, with red hot after burner exhaust "Diamond" shock waves can be seen in the burning discharge.
©Pratt & Whitney

From the outset the J-58 proved to be tricky. Due to the unique nacelle geometry and the considerable gluttony of the JT-11, the compressor suffered from air deficiency. The wind-tunnel models had not established well enough the mass of airflow which was demanded by the engines. At first, this problem forced Lockheed to start up the engine with certain access flaps open, and, in any case, to alter the aerodynamics of the fairings and to install two extra air-ducts downstream of the compressor to eliminate the trouble when it occurred. The first A-12 flew for some months with one J.75 and one J-58, almost up to the final stage of testing.

J-58 metal insignia almost intact after being ingested by its compressor. After that, the factory marking was engraved directly on the engine case.
© *Lockheed*

But the greatest difficulties were to appear during in-flight trials. The J-58 proved to be extremely vulnerable to ingested debris. The great thrust, its immoderate thirst for air and the tortuous intake system over the complex nacelle structure, meant that the smallest nut, bolt or fragment of metal forgotten at the factory was subsequently ingested – with disastrous consequences. The smallest piece of gravel or asphalt on the taxiways or runway would cause catastrophic damage.

Many unfortunate events marred the first trials, caused by ingestion of gravel or other foreign bodies such as the manufacturer's logo which had to be moved to another location to prevent it to be ingested in the future. One day an inspector, assigned to the removal of foreign objects from the intakes, forgot his flashlight in one of these. This was duly ingested whilst running-up the compressor.



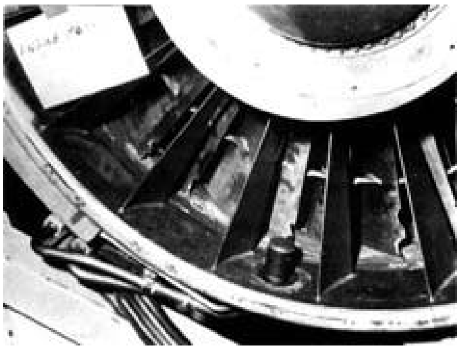
Some examples of foreign objects absorbed by a J-58 during taxi tests: parts of a screwdriver, gravel, chunks of asphalt…
© *Lockheed*

The resultant bill for damages came to $ 250,000. An intensive campaign against foreign objects of all kind was introduced at all stages of manufacture and operational trials. The tests and checks were practical in nature and accompanied the nacelles throughout manufacture. Blanking covers were fitted everywhere, warning signs were positioned visible to all workshop personnel, the runway and its environs were systematically swept twice with the greatest care along the route taken by the engines. By these means the problem was reduced to a more reasonable proportion.

The rather complex system of the air-intake made an even supply of air to the compressor difficult to achieve. It was subject to sudden drops in airflow, provoked by numerous flight maneuvers of the aircraft which caused compressor unstarts. This chronic Blackbird problem was not really solved until computers had been perfected which allowed compensating the slightest fluctuations in supply to prevent untimely unstarts.

This forced Lockheed to replace the pneumatic air-intake control system with a more efficient electronic system, despite related complications caused by heat and vibration. Nonetheless this critical aspect of flight at low altitude would remain, making the handling of the SR71 always a difficult task.

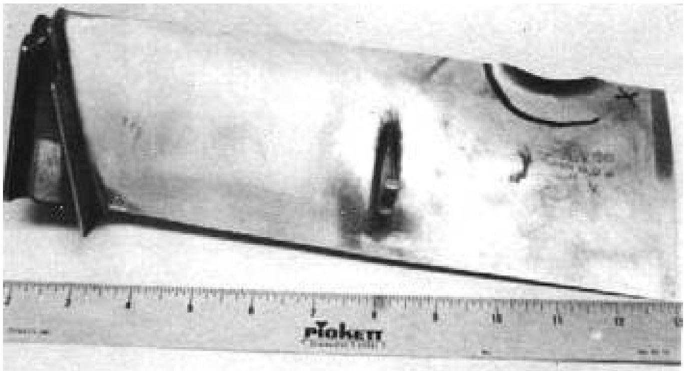
Many other problems to be solved cropped up during the in-flight testing. Kelly Johnson told that during one of the first flights, as a result of a sudden unstart, an A-12 had to make an emergency landing, but the engine casing had cooled down faster than the inner body; the compressor blades made contact with the 'shrinking' casing inner wall. This provoked "one of the most impressive firework displays on earth" to use the description given by the Skunk Works chief-engineer. To avoid re-occurrence of such an incident, pilots had to maintain power during the descent, so as to hinder too quick cooling during deceleration. In emergencies the pilots had to cut the fuel supply completely so as to recover safely.



J-58 air inlet after the ingestion of an inspector's flashlight in charge of checking for foreign objects…Total damages: $ 250,000.
© *Lockheed*

The very high temperatures encountered during flight-testing compelled the engineers to develop adequate new measuring instruments, or alternatively to adapt instruments available to the difficult ambient conditions encountered by the J-58 in operation, and for which they had not originally been designed. Therefore the trial units were cooled using a water system, specially fitted only for that purpose, so as to acquire the data necessary at that stage of testing. Many thousands of measuring points were plotted during this stage of testing, particularly to study airflow at the air-intake and jet-nozzle.

Later a second J-58 was installed in the port nacelle, replacing the J-75 which had been fitted. If the initial difficult testing tended to confirm fears that performance would be below that expected, these were subsequently, little by little, relieved thanks to the joint efforts of Pratt & Whitney and Lockheed.



First stage turbine blade of the same J-58 after impact by a flashlight.
© *Lockheed*

Test pilot Bill Parks, who conducted the first Mach 3 flights for Lockheed, stated that he had at his disposal a propulsive thrust more than twice that provided by the combined engines of the "Queen Mary".

Serious wear and cracks which appeared the long drive shaft between the engine and its gearbox, also posed several key problems related to the torque and fatigue on the shaft support bearings. The propulsion engineers had to provide data, although they were incapable of knowing exactly the relative positions of the control box to the motor during operating tests, at the time calculations were not sufficient.

Measurements had therefore to be taken during flight. These evidenced, amazingly, a displacement of about 4 inches (12 cm) of the gearbox from the engine during high speed flight. The gearbox was then unable to support the shaft, which not surprisingly was often found to be twisted. The problem was solved by providing a new shaft containing a double universal joint.

The fuel system, upstream of the engines also showed signs of fatigue and distortion. Measurements taken using a fast recorder indicated that the fuel supply pressure to the engine was going off scale.

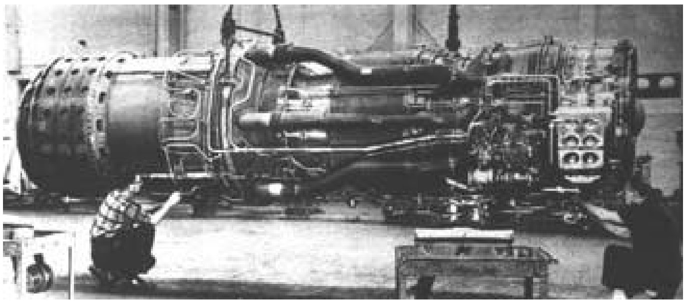
This over-pressure was fouling the engine hydraulics system. The phenomenon did not show up either during rig testing nor during engine ground testing, because of the minimal quantities of fuel involved. To solve the problem Lockheed designed a ”high-temperature sponge”, (promptly nicknamed ”football”) which was installed in an accumulator ahead of the engine. By this means pressure spikes were reduced to acceptable levels.

The major difficulties encountered during flight trials appeared in the phases of transonic flight. Under certain conditions, the outer half of the nacelle would rotate into the engine and crush the engine plumping and anything else in the way.

Pratt & Whitney had to totally redesign the attachment points at the rear of the engine. The initial stiff rails located above the engine, reinforced by a bracing strut between the motor and the casing were replaced by tangential links between the lower engine casing and the external nacelle. This maintained a finite distance between the nacelle and engine under all conditions.

Above: This superb view of the SR-71s assembly plant depicts some of the precautionary measures taken following the problems encountered by the powerful J-58s during the first tests.
© Lockheed

Below: Specifically, Lockheed instituted an awareness campaign for the personnel working on the SR-71s, especially displaying large warning signs alerting them to be on the lookout for "FOD": foreign objects damage.
© Lockheed

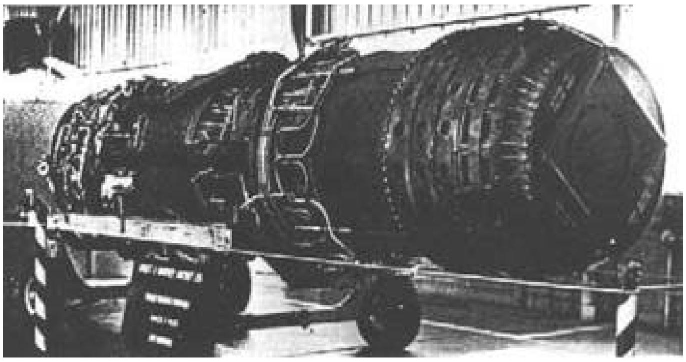


The J-58 final version: the J-58-P4, alias JT-11-D20B, with its typical six-vein bypass.
© Pratt & Whitney

It is strange to think that, although Pratt & Whitney had reached a paranoid level with the high-temperatures and the almost impossible cooling requirements, their engineers had neglected to consider that, during certain stages of flight, the fuel would be cold whilst the ambient environment was hot – and vice-versa. When these conditions occurred the fuel supply and ignition systems would malfunction. To remedy this it proved necessary to install heating for the main controller and to tweak servo responses.

Genesis : 1.4 : Improvements

Testing and proving the complex propulsion system of the Blackbird would continue for several years after the SR-71 was accepted into operational service, especially to overcome the violent eddies blocking airflow at the air-intake, accompanied by loud bangs (rumbling) which was traced to popping of the inlet shock. Trials were conducted until the start of the 1970s by NASA on the YF-12A and YF-12C. Specifically the introduction of SAS (stability augmentation system) and digital aircraft flight and inlets control systems (DAFICS) for the propulsion units allowed for improvement in engine functioning and thus aircraft handling…



A J-58-P4 engine was presented to the news media at Ewards in 1964, at the same time as the YF-12. Up until then, only two photos had been revealed by President Johnson.
© *Aviation Week*

According to NASA the analyses confirmed that an integrated flight and engine control system would, from then on, have a major influence on the flight characteristics of advanced-technology aircraft flying at high supersonic speeds. Tests carried out in 1978 showed that in-flight regulation of air-inlet and nozzle exhaust flow brought with it a reduction in the intake air withdrawal effect, and also permitted extension of operating range and shortening the time needed for crew training.

Shortly after development commenced, a wager was opened between Kelly Johnson and Bill Brown, over which of the two companies would succeed in producing the best fuel-injection system for the aircraft. It was settled that the loser would have to carry the costs for use of the wind-tunnel, which Brown estimated would be about 12,000 $. Pratt & Whitney won and true to his promise, Kelly Johnson sent a check of sufficient value. The event was used to play a prank. Bill Brown acquired a complete naval sailor's uniform, with cap and blue jacket, and thus attired had himself photographed in front of the 12.5 meters long private yacht of Bill Gordon. He sent the photograph to Johnson with the comment "thanks for the check". The photograph hung for many years afterwards on the wall of Lockheed's staff reunion room.

Genesis : 1.5 : Projects and variants

An initial batch of 50 motors was delivered to Lockheed in 1963 for fitting in the A-12 and the YF-12s. A second batch of one hundred examples was dispatched in 1964 to equip the SR-71s.

The Convair B-58C bomber project was to be equipped with 4 J-58 engines without after burner. © Convair

Pratt & Whitney had great plans for their JT-11 super engine. They saw the prototype and the those as JT-58s destined for the Blackbirds unfolding into a production series. Adaptations of this motor were proposed for all the design studies of the period for hypersonic programs, much treasured in the 1950s – 1960s, such as the SST or the Convair BJ-58. This latter four-engine design, also known as the B-58C, was contemplated as a supersonic transport flying at Mach 2.5 and cruising at more than 70,000 ft (21,300 m), powered by four J-58s (without after-burning) of 23, 000 lbs thrust (10.400 kgp) mounted in two wing-tip nacelles.

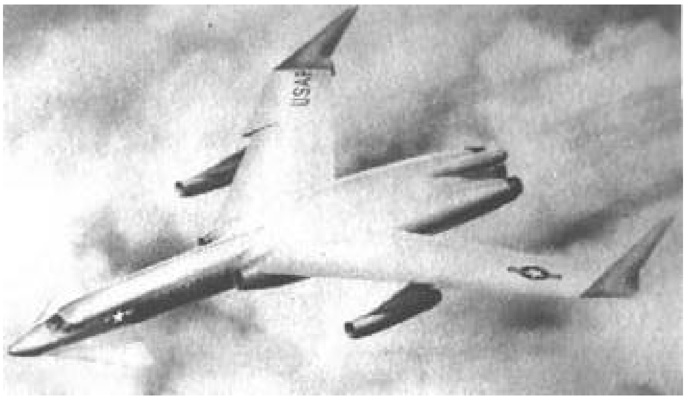
In its civilian version, the Convair 62 was to be equipped with the same engines. © Convair

A military version of this Convair model 58-9 was also announced under the name of model 62. It would have had the capability to transport 52 troops. Twin-engine interceptor variants called B-58D (for Air Defense Command) and B-58S (for the Tactical Air Force) were also proposed fitted with J-58s capable of propelling a load of more than 30,000 lbs (13.600 kg). It is likely that the Pentagon encouraged this profusion of projects using these engines so as not to draw attention to the A-12.Much later development of a double-flux version of the J-58 using compressors of greater size was contemplated.

At the same time Pratt & Whitney proposed a nuclear version of the J-58 using an indirect propulsion cycle, fuelled by a solid-fuel reactor cooled by a twin line system? The USAF intended being equipped with a guided missile capable of low-altitude penetration. The program, named CAMAL was cancelled in 1960, but it had demanded of Convair, involved with the project – in competition with Pratt & Whitney and General Electric, construction of two subsonic NX-2 aircraft to experiment with the mode of propulsion.

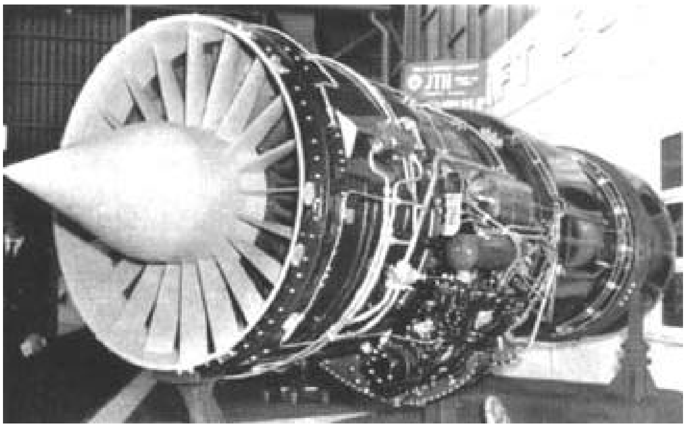
These studies mainly permitted a comparison of the two classes of nuclear flux engines, those envisaged by General-Electric (the simplest but dirtier system as the radioactive material was sent directly into the combustion chambers) or those using the indirect cycle proposed by Pratt & Whitney which utilized liquid sodium as a high-temperature conductor between the nuclear reactor and the combustion chambers of the J-58 propulsion unit.

The planes would fly in 1965 under the designation of WS-125A/L, but had been registered in 1961 as a back-up for the WS-110A "Weapon System" which gave birth to the North American XB-70 Valkyrie. Certain Pratt & Whitney nuclear reactors were adopted a little later by the commission for nuclear energy in its "System for Nuclear Auxiliary Power" (SNAP) However, despite some trial installations of a nuclear reactor aboard a giant B-36 bomber (alias the X-6) no atomic propulsion unit would ever be air-tested. Not even the General Electric system, design of which had progressed further than that of Pratt & Whitney's system.



This strange experimental aircraft, the Convair NX-2 was to be built (two of them) to test the General Electric and Pratt & Whitney nuclear engines. Effectively, an atomic version of the J-58 was seriously considered.
© Convair

The description of another project derived from the J-58, namely the SNECMA M-35 is of equal interest. In 1959 the French SNECMA company signed a partnership agreement with Pratt & Whitney which offered enviable prospects. Not least because, at the start of the nineteen-sixties, France decided to conquer the challenge of supersonic-transport, SNECMA thus had to design a propulsion system for the future aircraft. That led to negotiations concerning the possibility of manufacturing under license the JT-11B3, a civil variant which was being proposed at the then stage of J-58 development. The Franco-British agreement of 1961, brought an end to this project, with the decision to equip the future "Concorde" with a turbojet of British origin. However, one sometimes finds reference to the M-35 engine among the many Mach-3 aircraft projects fashionable in France at that time.



The SNECMA Company considered building the M35, which was the equivalent of the JT11B built under license for the supersonic transport airplane project (future Concorde). It is without doubts the reason that Pratt & Whitney introduced this J-58-P2 at the 1963 Le Bourget air show, whereas the "Blackbird" the only airplane equipped with this engine was still totally unknown. Its existence was indeed not revealed until February 29, 1964.
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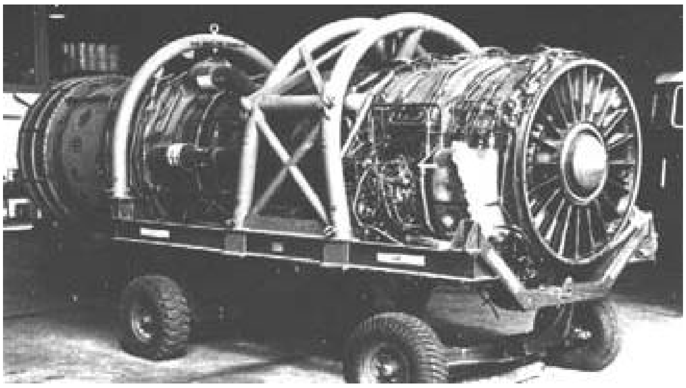
Genesis : 1.6 : Note about designations

The military designation for this engine is J-58, but that given by its constructor is JT-11. The test-bench testing conducted in 1958 was with the YJ-58 prototypes. The turbofan version envisaged in the 1960s for the American SST ("Super Sonic Transport") projects carried the designation of JT-11-F4. A JT-11-B4 variant with increased thrust was envisaged during the same era same era for studying Mach 3 flight. It seems that the designation J-58-P4 corresponds to the JT-11-D20B series as the J-58-P2 is the version developed for the US Navy, without bypass, with only a 4 stage compressor (eight stages in all) against five in the J-58-P4. The letter "B" at the end of a Pratt & Whitney engine designation signifies that it is modified for high-altitude flight (for example with burners adapted for JP-7 fuel).



The maneuvering dolly specially adapted for the J-58-P4 equipping the SR-71 "Blackbird". © Pratt & Whitney

The American system of engine designation is almost identical to that used for aircraft; a letter indicates the type of engine (for example R –"radial") followed by a distinguishing number. With jet motors, their designation commences with "J" (for jet engine), e.g. J-58 or J-75. double-flux engines, which appeared much later, are designated by a letter "F" (for fan), e.g. The Pratt & Whitney F-100, which equipped the F-15 and F-16 fighters. These letter-number combinations continue with one or two letters indicating the factory of manufacture, ("GE" for General Electric, "P" for Pratt & Whitney) and a "batch number" indicating a particular production batch. For example the J-79-GE15 which equipped the McDonnell F-4D Phantom II, or the J-57-P55 which equipped the McDonnell F-101 Voodoo whereas the Lockheed U-2 is fitted with the J-57-P31. The entire designation can also be preceded by a special letter, for example "X" for an experimental unit, or "Y" for a pre-series unit, or even "R" (for a ramjet).