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Propulsion system of A-12/SR-71 aircraft

Introduction

The propulsion system of A-12/SR-71 aircraft consists of The JT11D-20 jet engine and subsystems located in engine nacelle. The JT11D-20 (see Fig. 1), also known by the US military assigned the name Pratt & Whitney J58, is a turbojet/turbo-ramjet jet engine, which was originally developed for supersonic fighters and attack aircrafts for the US Air Force, but after overhaul was used as a power unit for the project A-12 aircraft from Lockheed. To date, it is the only known operationally deployed jet engine capable of long-term flight at Mach 3.0 and higher. This uniqueness has been achieved by the unique design of some parts, thanks to which this engine is sometimes characterized as turbo-ramjet, as the only one in the world. Although this engine was officially decommissioned with the SR-71 in 1999, it has not been officially outdated to date.

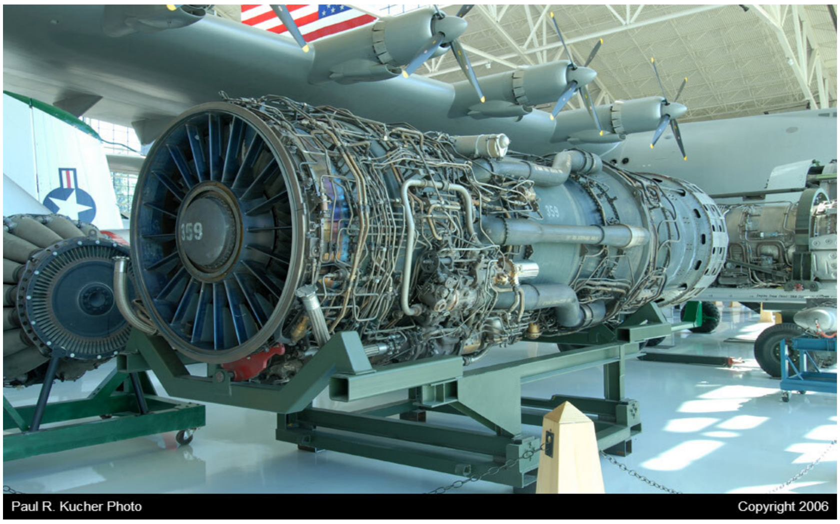

Fig. 1 - JT11D-20 engine at the Evergreen Aviation Museum in McMinnville

Genesis

The engine was originally designed as a 3/4 model JT9 engine with an inlet air mass flow of 300 lbs/s. Originally, the use of the engine for fighters and combat aircrafts of the US Navy was planned. In none of these cases was it used in the end. However, as part of the development of a new spy aircraft by Lockheed‘s special division Skunk works. The concept was used to design a jet engine capable of operating continuously at Mach 3.0 and higher. The development used mainly the experience from the Suntan project and the development of a jet engine for boron-enriched fuels. When adjusting for long-term operation at such high speeds, almost the entire engine had to be redesigned to be part of the propulsion system for A-12/SR-71 aircraft.

Technical description

The propulsion system on the A-12/SR-71 aircraft consists of the air inlet and air flow control system, JT11D-20 engine and the exhaust nozzle assembly (part of the airframe). The JT11D-20 is a single-spool afterburning turbo-jet engine, with 9-stage compressor, 2-stage turbine, and 4th-stage bleed by-pass ducting air into the afterburner. The designed thrust was 30,000 lbf, but at the end of operation the thrust was increased to 34,000 lbf. It was capable of continuous flight at height of 80,000 feets. It has length of 180 inches and diameter of 50 inches.

In the front part of the engine nacelle there is a movable spike, which ensures a reduction of the speed of the incoming air to subsonic speeds (about Mach 0.4) when flying at supersonic speeds, but also ensures the elimination of shockwaves. The movable spike is controlled hydraulically by the on-board computer depending on the altitude and speed of the flight. When flying at altitudes below the FL300[1], the spike is locked in the most extended position. After exceeding this height, the spike is unlocked, and from speed of Mach about 1.6 the spike is inserted approximately 1 and 5/8 inch as the speed increases by Mach 0.1. In this way, the spike can be inserted by a maximum of 26 inches. In the fully retracted position the external shockwave flows directly around the edges of the engine nacelle (see Fig. 2), thus preventing increased drag. On the spike itself ale located orifices, which can take air by by-pass to centerbody bleed exit (see Fig. 3). At low speeds, additional air is supplied by centerbody bleed exit. At higher speeds, the boundary layer which builds up on the centerbody is removed from the spike‘s surface by these orifices, thereby increasing the speed of the air supplied to the compressor as the lowest energy air is removed from the engine.

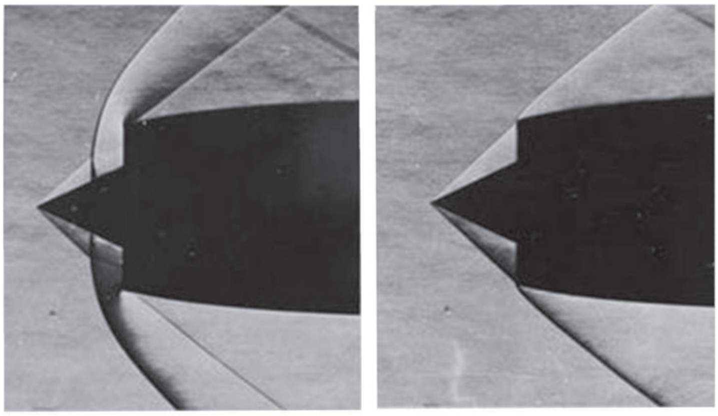

Fig. 2 - External shockwave

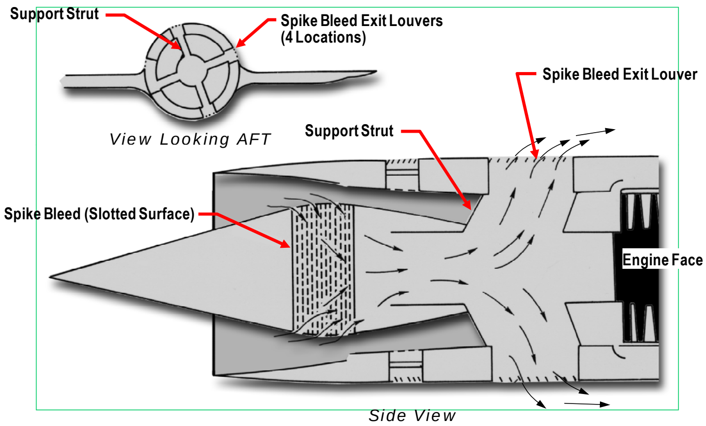

Fig. 3 - Centerbody bleed arrangement

At low speeds the additional by-pass/suck in doors are opened, so additional air could be sucked into the engine (see Fig. 4). This includes forward by-pass doors, aft by-pass doors, tertiary doors and suck-in doors. At higher speeds all these doors are being gradually closed (see Fig. 4), but can be opened to i.e. compensate lack of air. Forward by-pass doors, located close to the throat match the inlet to the engine, by-passing air overboard. Aft by-pass flow joins the cowl bleed flow and passes through the engine ejector. During acceleration, aft by-pass is used to reduce the forward overboard by-pass with its attendant drag.

Beyond the movable spike starts the engine with 9-stage compressor. The unique design in this engine are 6 by-pass tubes, which leads from behind the 4th stage of the compressor directly into the afterburner. This is called by-pass bleed cycle. Because of this, the engine can act as partial ramjet, even though it does not fulfill the characteristics. The reason for these by-pass tubes was because at high supersonic speeds the front stages

1 Flight level 300, height of 30,000 ft above sea

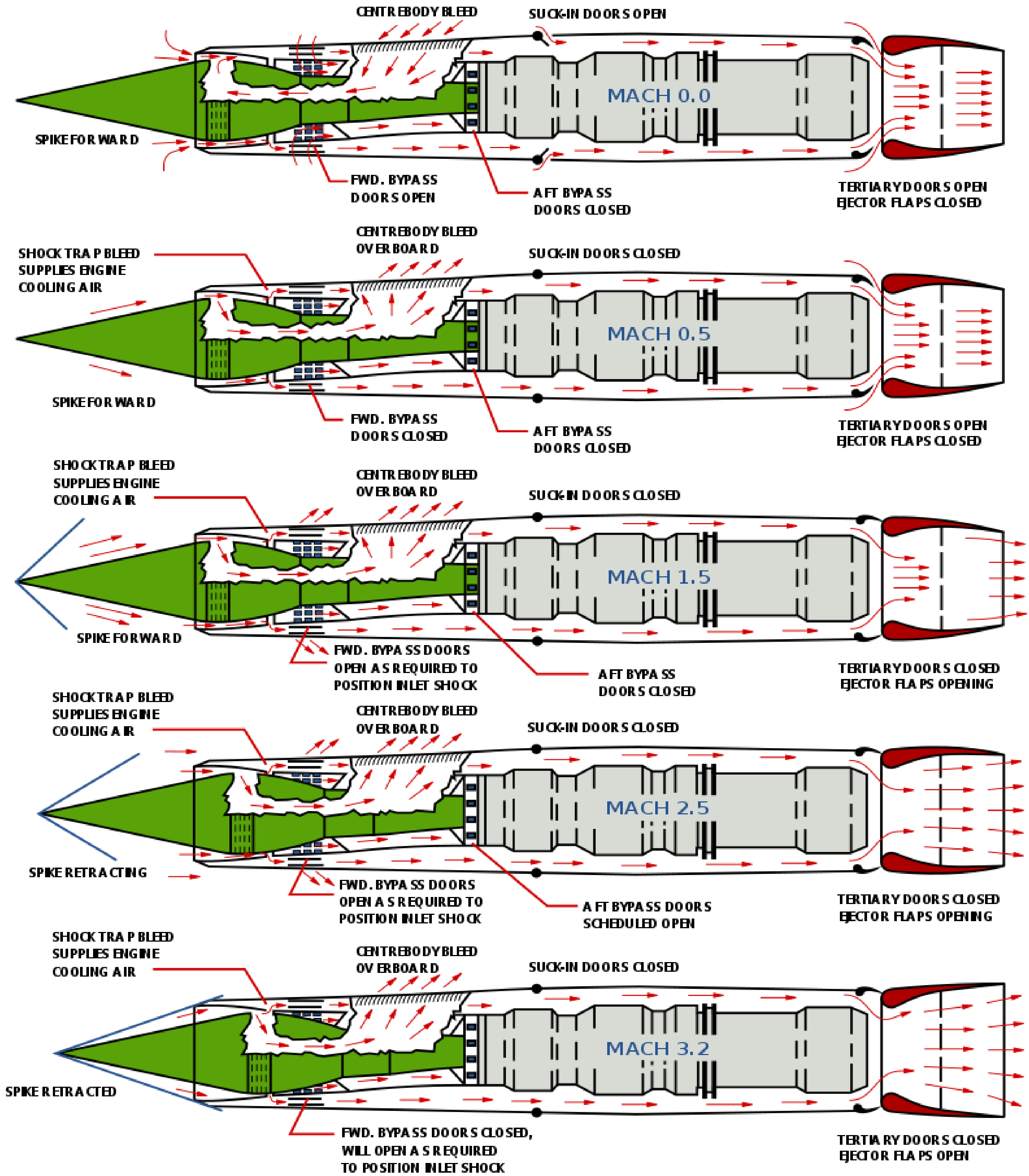

Fig. 4 - Operation of the air inlet and nozzle showing air flow through the nacelle at various speeds

of the compressor would be stalling and the rear stages of the compressor would be overchoaking. This design also improves the efficiency of afterburner by adding unburned air, with which the fuel in afterburner can react. At the maximum speed, by-pass airflow is 20% of total flow into engine. The openings to by-pass tubes are being opened at aircraft speed of Mach 2.8 to Mach 3.0 approximately.

Behind the compressor is located the combustion chamber, which is ensued by 2-stage turbine and afterburner.
The turbine provide energy for the compressor, but also to almost all essential subsystems like fuel pumps.

The afterburner (see Fig. 5) is consisted of four rings with orifices, which fed the fuel. The time to fulfill these orifices can take up to 3 seconds at sea level and up to 7 seconds at high.

As can be seen on Fig. 6, in the forward part of engine nacelle are located shock traps, which removes part of incoming air, which then flows around the engine itself and cools it. This air is combined with the exhaust gases from afterburner just before the exhaust nozzle. Because of the cooling of the engine, the temperature and pressure are increased, so the overall efficiency is thus improved.

After afterburner the exhaust from the engine is combined with the air, which by-passes around engine and cools it and heads toward nozzle. The geometry of the nozzle is controlled by the exhaust pressure, so it can be changed from converging nozzle up to converging-diverging nozzle for high speeds. This ensures proper exhaust gas expansion, thus giving better thrust.

Fig. 5 - Afterburner of JT11D-20 engine

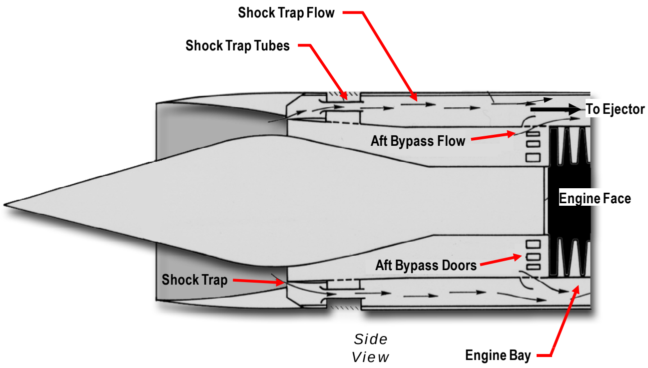

Fig. 6 - Secondary flow system

Engine function at low speed

At the low subsonic speeds the propulsion system works as follows. The movable spike is fully extruded. Some of the by-pass doors are opened, namely at least the tertiary doors near the nozzle opening, which provides that there is no flow separation in the nozzle.

As can be seen on Fig. 7 on next page, at low speeds, about 70% of thrust was provided by the engine, about 15% was provided by afterburner and about 15% was provided by the inlet (differential pressure between external and internal surfaces of the inlet spike)

Engine function at high supersonic speed

At high supersonic cruise at speed of Mach 3.0+ the propulsion system works as follows. The movable spike is fully retracted. The external shockwave flows directly around the edges of the engine nacelle. The by-pass tubes located behind the 4th stage of the turbine have opened inlet doors and the maximum air flow pass through this passage (about 20% of total flow into engine). The ejector nozzle has converging-diverging form.

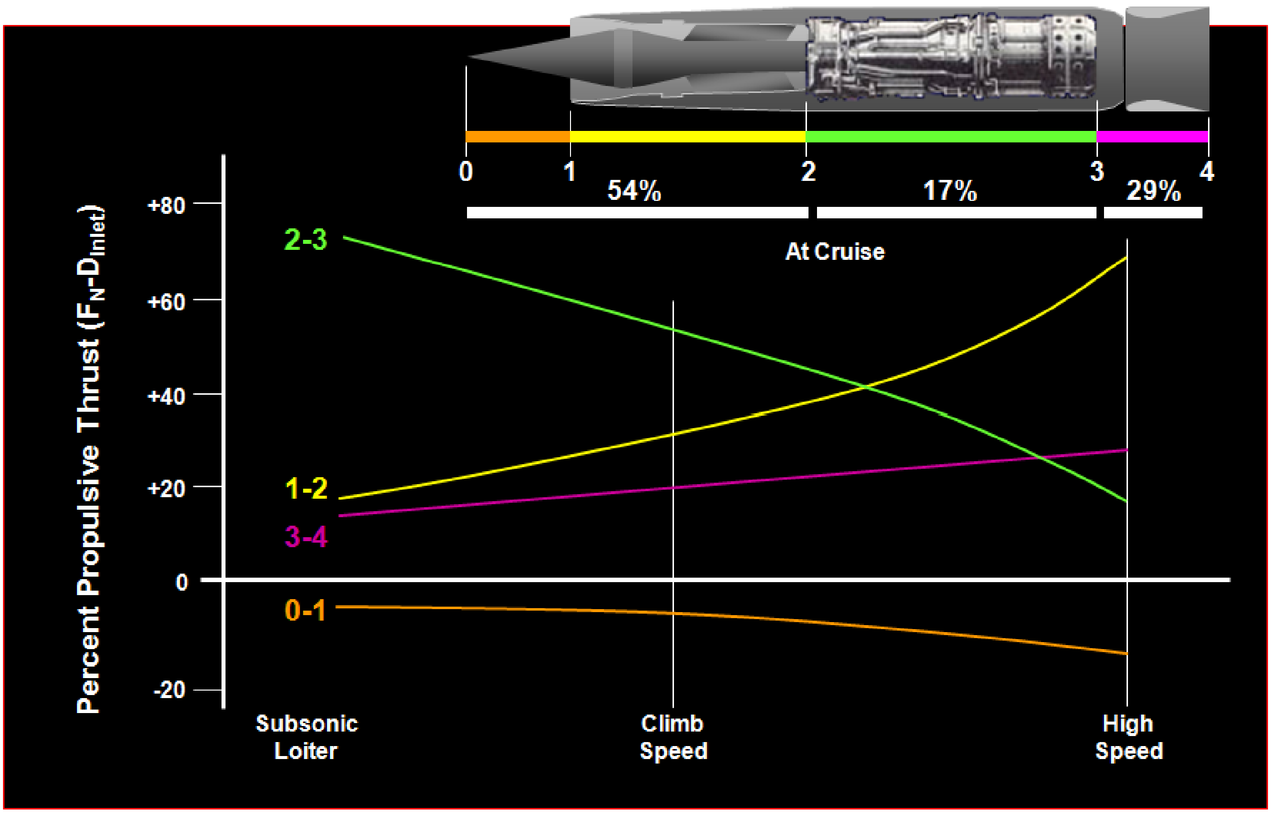

Fig. 7 - Thrust production distribution at various speeds

As can be seen of Fig. 7, at Mach 3.2, 54% of the thrust was provided by the inlet (differential pressure between external and internal surfaces of the inlet spike), 17% by the engine, and 29% by the ejector. Engine acted as a gas generator.

Used materials and production processes

The main material for the construction of this propulsion system, as well as the entire aircraft, was titanium[2]. Titanium was used mainly due to its high strength at higher temperatures, high heat resistance and relatively low density. The original design envisaged the use of Mar-M200 as a material for the compressor blades, but the material was not able to withstand enough stress, so it was replaced by nickel alloy Inconel 718, which also has a 10% lower density, which reduces stress on the entire compressor . Another widely used material was Waspaloy. This alloy was used mainly on very stressed parts. In the Fig. 8 can be seen

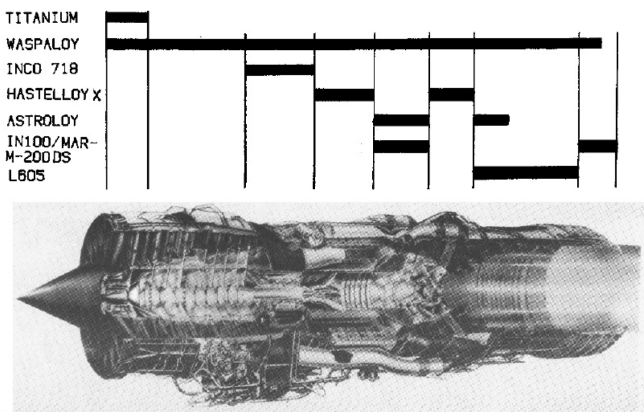

Fig. 7 - Materials usage in engine

Mainly due to the great use of titanium, there was a need to use new methods of joining the material, especially new types of welding. However, during high thermal stress,

2 Not on the engine itself

the joints were degrading, so it was possible to observe a fuel leak at the joints. This was taken into account in the design, so there was also a manual with standardized fuel leaks at specific locations.

The fuel for this engine was JP7, developed by Shell, to which was added lubricant . This fuel also served to cool the entire aircraft by the heat sink. For this reason, and the high temperatures of the entire aircraft at high supersonic speeds, it was necessary for the fuel to have a high decomposition temperature and also a low vapor pressure. Due to the low volatility of the fuel, Triethylborane was used to ignite the mixture. Triethylborane is capable of spontaneous combustion when in contact with air at temperatures higher than -5 ° Celsius. In emergency cases, it was possible to use conventional fuels JP4, JP5 and others, but the maximum speed was limited to Mach 1.5 and subsequent engine inspection was required.

Conclusion

Even though this propulsion system design started in 1950s, it is still officially (not containing any unknown classified projects) unbeaten in any of this parameter for manned air-breathing winged vehicles. It can also remain unbeaten in the field of air-breathing hydrocarbon fuel-fed propulsion systems, because nowadays developed new supersonic propulsion systems are thought to be hydrogen-fed. The uniqueness of this propulsion system still remains and will be probably used in the near future to design new propulsion systems for continuous flight at high supersonic speed.

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