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ABSTRACT

The SEPR 844 rocket engine for Mirage III combat aircraft is the last version of a bipropellant rocket engine family developed by SEP for aircraft propulsion.

The SEPR 844 is a 15 kN thrust, single-chamber rocket engine. It operates with nitric acid and aircraft supplied kerosene. The ignition is made with a hypergolic nitric acid - TX2 combustion. The chamber is fed by two centrifugal pumps driven by an auxiliary shaft coming from the aircraft turbojet engine. The combustion chamber is regeneratively cooled and operates at *2.35* MPa pressure.

Since December 1961, 275 engines of the SEPR 84 class (SEPR 841 and SEPR 844) have been used operationnaly in six countries and have completed more than 10000 flights with a 99 % success rate and a high availability : These engine demonstrated more than 50 ignitions without removal and can be serviced in less than 15 minutes.

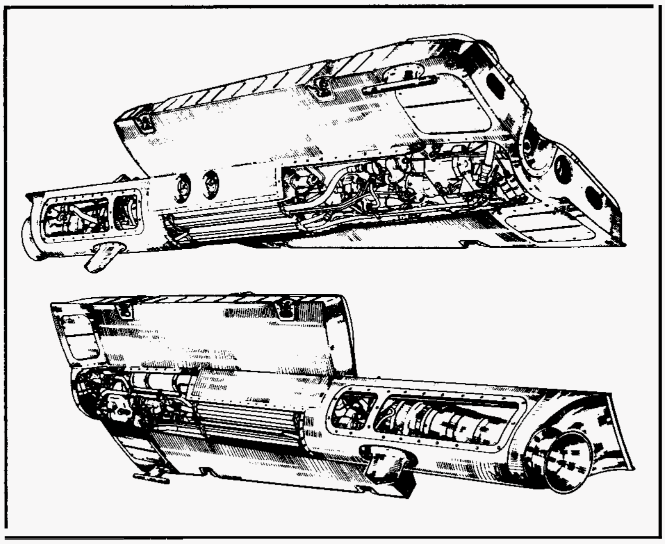


Figure 1** :SEPR 844 **Rocket engine.

GENESIS

Set up in late 1944 and specialized in the field of liquid rocket engines, France's SEPR (Société d'Etudes de la Propulsion par Réaction) - now SEP (Société Européenne de Propulsion) - was studying, as early as 1948, the SEPR25. It was a 15 kN thrustrockct engine that made its first bench test in 1950 and its first flight test in 1952 on a SNCASO Espadon. Eighty nine rocket flights allowed the evaluation of aircraft propulsion by rocket engine.

On the other hand, Dassault answered the 1953 french fighter program with twodelta-wing projects : the MD560 single jet engine and the MD550 twin jet engine. Two prototypes of the latter were ordered. Renamed Mirage I, the MD550-01 made its first flight in June 1955 without rocket engine and eighteen month later with the SEPR 660 : five rocket flights were accomplished. The Mirage II (MD550-02) was never completed due to a modification of the program

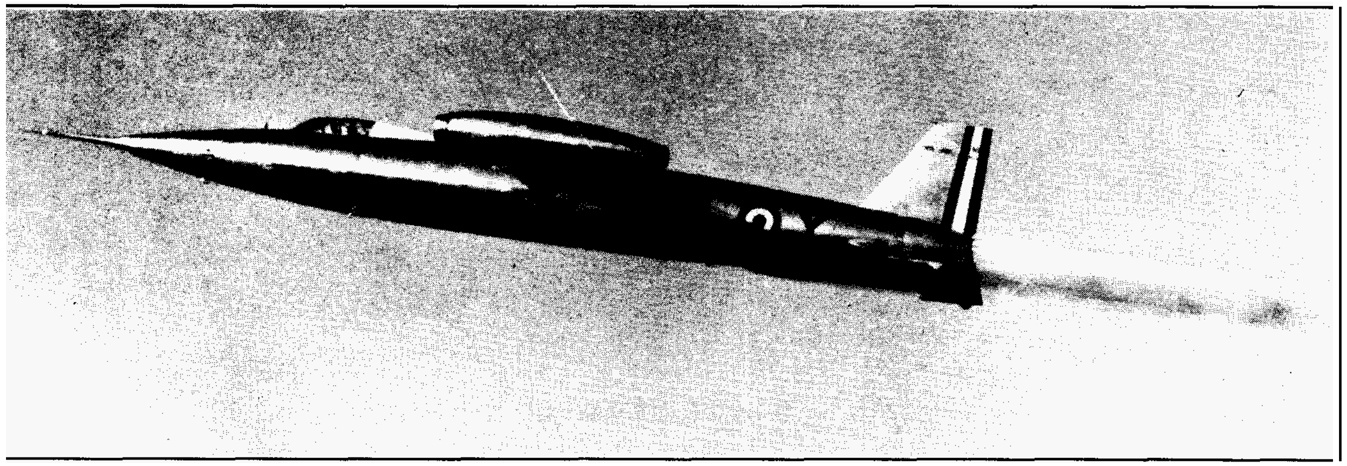


Figure 2 ***Trident** I with one SEPR 481 chamber ignited*

Following the French Air Force encouragement to realise very high performances fighters, numerous aircraft manufacturers proposed their rockct propelled aircraft. SEPK developed a propellent family for them with various combinations of single or multichambers, auxiliary driving or turbopump rocket engines. Those engines utilized nitric acid as the oxidizer and furaline or TX as the fuel.

The two SE212 Durandal prototypes made 45 rockct flights with the SEPK 65 auxiliary engine.

The SNCASO Trident was expected to fly with a rockct propellent as the main engine.
In 1954 began therocket flights on S0 9000 Trident I (see figure 2) with the separated ignition trichambers SEPK 481 (each chamber providing 15 kN of thrust).

Afterwards. in 1955, began therocket flightson S0 9050 Trident II with the hichambers SEPR 63 serie (15 kN per chamber)

These engines operated on nitric acid and furaline, with the propellants fed by turbopump.
A total of 220 rocket flights were performed.

In 1958, a Trident II set three international records of ascensionnal speed (from zero speed) and one world record of altitude (24.217 meters).

In 1954, Dassault proposed the Mystère IV B05 fitted with the SEPR 660 turbopump/single-chamber rocket engine : forty five rocket flights were completed on and after 1956. An ignition delay at the tenth rocket flight dragged an explosion of the SEPR engine

The Mystkre IV B04 was held as test bench for the SEPR 663 and SEPK 631 engines but it made no rocket flight.

DEVELOPMENT OF THE MIRAGE III/SEPR 84 SERIE COUPLE

In late 1955. Dassault launched the Mirage III, using the Mirage II wings and the SNECMA ATAR 101 G turbojet engine. The Mirage III 001 mades its maiden flight in November 1956. In July 1957 began the rocket flights with the new SEPK 84 engine.

This auxiliary drived rocket engine, utilizing nitric acid and TX2, offered two thrust levels (7.5 and 15 kN) with a single-chamber : thirty rocket flights were completed.

The Air Force selected the Mirage III and 10 preproduction Mirage III **A,** improved version powered with the ATAR 9R turbojet engine, were ordered.

From May 1959, the Mirage III A02 (see figure 3) tested the SEPR 840 (15 rockct flights) and SEPK 841 (444 rocket nights), two

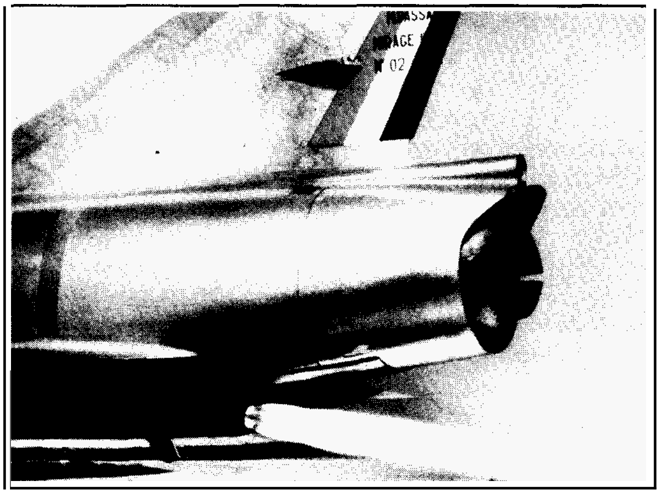


Figure 3 *SEPR 841 and **Mirage** III A02 **ground test***

nearby variants of the SEPR 84 model, both bench tcstcd thc previous year.

The Mirage III C, production fighter equipped with the SEPR 841, made its first flight in 1960 and entered operationnal service in December 1961.

In Febuary 1962, the SEPR 844, intended for the multipurpose Mirage III E, made its first rocket flight.

The SEPK 844 differs from the SEPR 841 by utilizing kerosene instead of TX2, consequently suppressing the necessity of a specific tank, but complicating the general architecture of the propellant feed system due to the non hypergolicity of the kerosene with nitric acid.

SEPR 844 TECHNICAL DESCRIPTION

The SEPK 844 is a 15kN thrust rocket engine utilizing HN03 nitric acid with corrosive inhibitor contained in a 300 liters partitioned tank, and TR0 or TR4 kerosene stored in a tank of the Miragc III E combat aircraft.

The acid tank is made with stainless steel.
In thc lower part of the acid tank is the TX2 (triethylamine and xylidine binary mixturc) tank. The TX2, hypergolic with the nitric acid initiates the combustion.

The propellant fed system is made by two centrifugal **pumps** (the TX2 is in a piston pressurized tank) which are driven **by an** intermediate shaft coming from the aircraft turbojet engine. The pump impellers and bodies are made with light alloy. **A** gearing **set** permits the desired pumps rpm (including the oil pump) and a shear shaft protects thc rocket cngine from overtorques.

A chemically neutral oil is utilized for the ball bearings and the gears.

A pneumatic controlcd cluth provides for the **connections-deconnection** of the driving shaft.

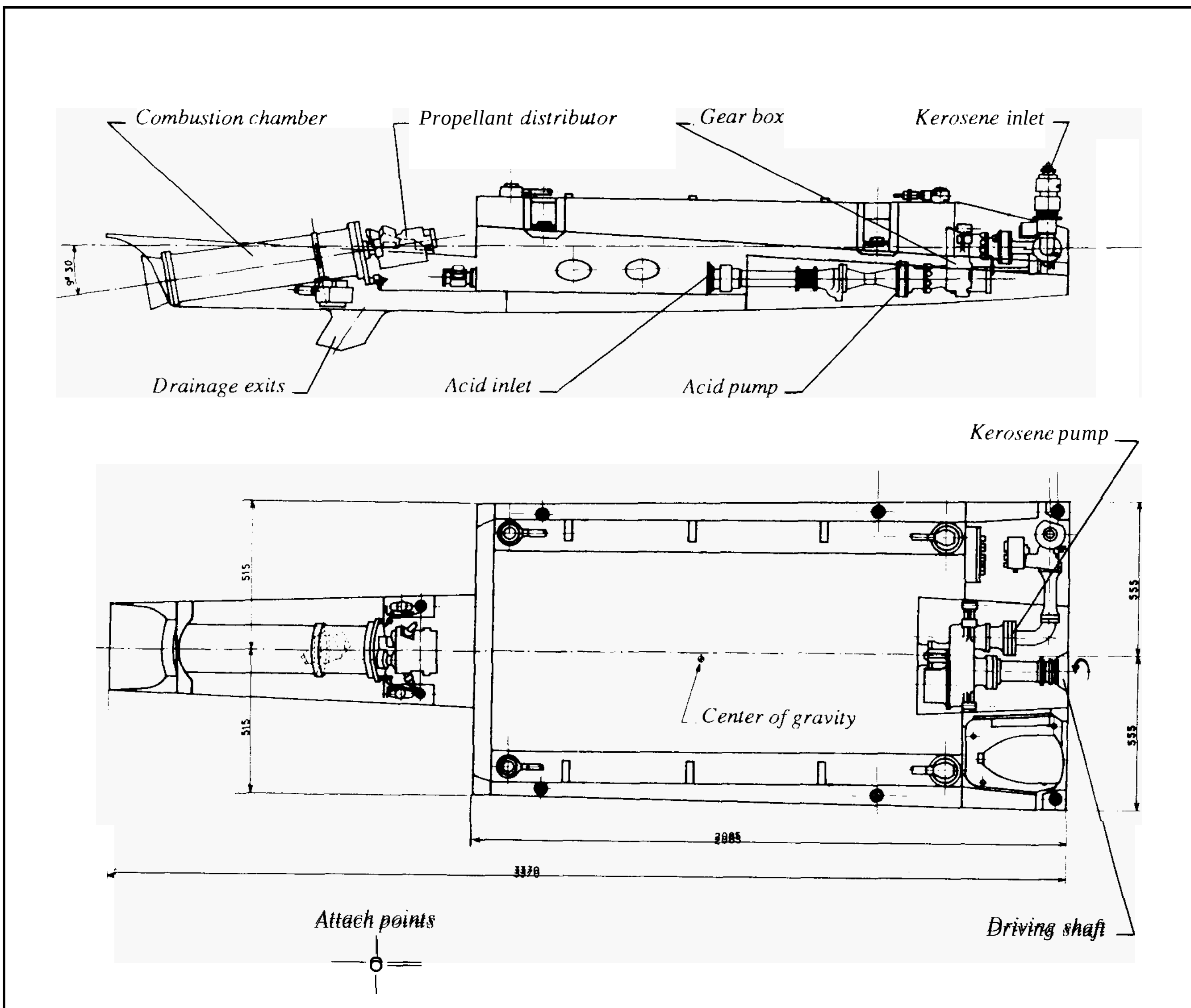


Figure 4 SEPR 844 Engine layout

A self alimented JET PUMP system, which utilizes a part **of** the pressure given by the pump to increase the average static pressure of the liquid before the pump inlet, is employed for both kerosene and acid pumps to avoid cavitation (see figure 5).

The propellant fed valves open pneumatically and are closed under a spring effort.

The figure 6 shows the entire feed system

The pneumatic system requires 0.8 MPa air contained in a IS MPa pressurized tank.

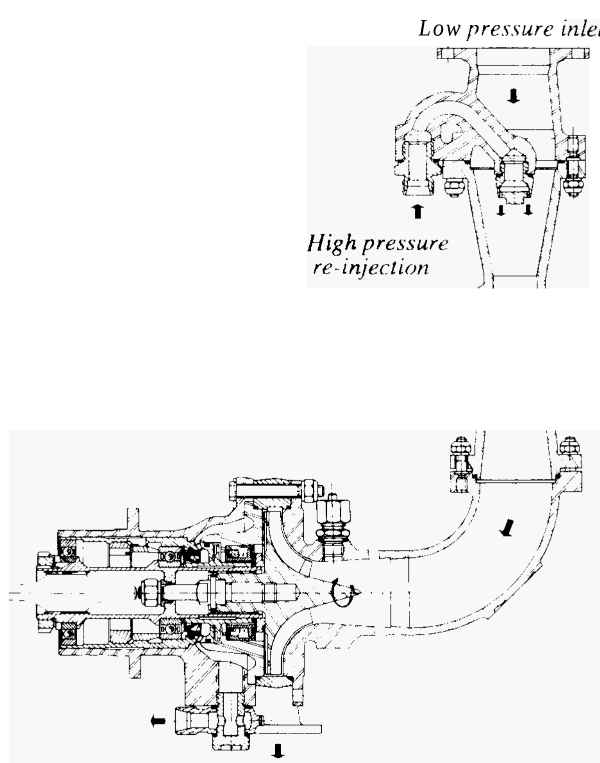
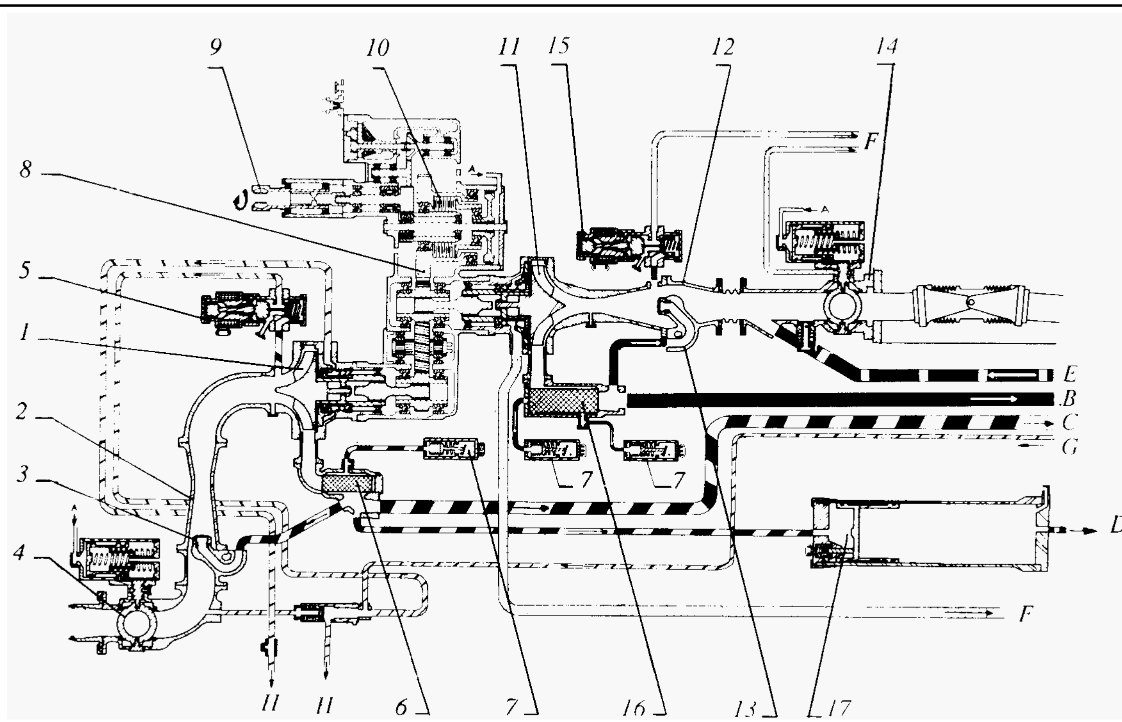


Figure 5 :Kerosene pump

Figure 6 :Feed system



1	*Kerosene pump impeller*	9	*Driving shaft*	A	*Pneumatic circuit air inlet*
2	*Kerosene jet pump*	10	*Cluth*	B	*High pressure acid feed*
3	*Kerosene jet pump injection*	11	***Arid** pump impeller*	C	*High pressure kerosene feed*
4	*Kerosene feed valve*	12	*Acid jet pump*	D	*High pressure TX2 feed*
5	*Kerosene bleed valve*	13	*Acid jet pump injection*	E	*Low pressure acid reinjection*
6	*Kerosene filter*	14	*Arid feed vulve*	F	*Acid drainage*
7	*Pressure switch*	15	*Acid bleed valve*	G	*Distributor control valve drainage*
		16	***Acid** filter*	H	*Kerosene drainage*
		17	*TX2 tank*		

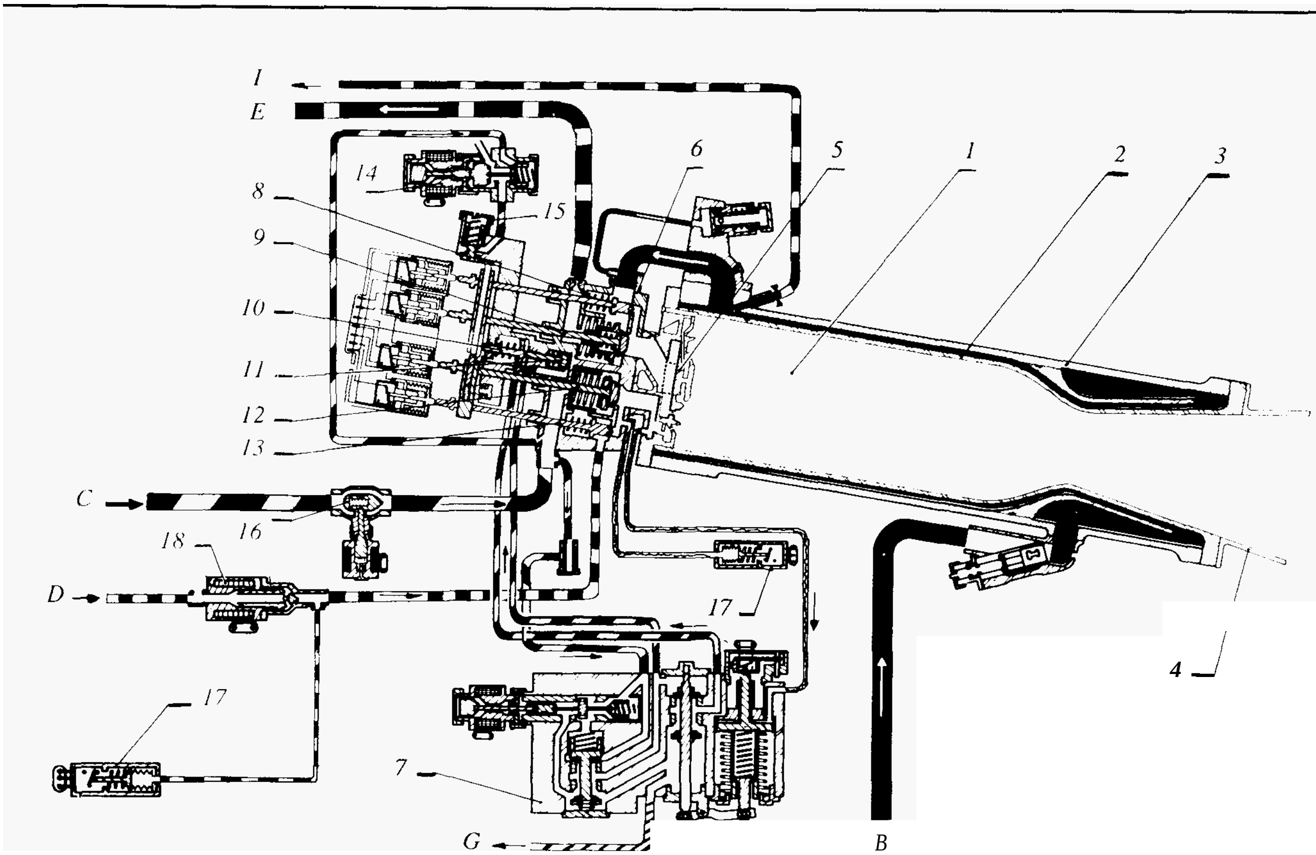
The propellants distribution in the combustion chamber is made with a complex but reliable and safe system (see figure 7). It is composed of a distributor (location 6 in the figure 7) directly coupled to the injection casing, and of a distributor control valve (location 7in the figure 7). The latter controls the hydraulic feed of the «double stages» distributor actuator (locations 10and 11 in the figure 7). **This** actuator controls TX2 and nitric acid valves (locations 13 and 8 in the figure 7) for the ignition (actuator's first stage moving) and then, the kerosene valve (location 12in the figure 7) and the second acid valve (location 9 in the figure 7) for the steady state rate (actuator's second stage moving). The closure of the TX2 feed forthesteady staterateismade with anupstream electricvalve (location 18 in the figure 7).

An absolute safety has been introduced in the distribution system : safety for the bad openings or bad closures of the valves, safety in case of **propellants** total consumption and safety for the jettisoning of the rocket engine.

The high pressure kerosene is used as hydraulic fluid.

The combustion chamber is regeneratively cooled with internal circulation of nitric acid in the double wall structure (see figure 7). The guidance and good repartition of the coolant fluid is made **by** steel wires along the nozzle and by broached fillers along the cylinder part.
The inner wall is fixed at the jacket at one tip and is free at the other tip to permit the longitudinal dilatations.
The chamber combustion system is in aluminium alloy.

Figure 7 :Distribution and chamber system



1	Combustion chamber	10	Actuator second stage		
2	Chamber inner wall	11	Actuator first stage	B	Highh pressure acid feed
3	Chamber external wall	12	Kerosene valve	C	High pressure kerosene feed
4	**Nozzle** extension	13	TX2 valve	D	High pressure TX2 feed
5	Injection system	14	Jettison control valve	E	**Low pressure** acid reinjection
6	Distributor	15	Jettison actuator	F	Acid drainage
7	Distributor control valve	16	High pressure kerosene valve	G	Distributor control valve drainage
8	Acid ignition valve	17	Pressure switch	I	Low pressure acid **tank** reinjection
9	Acid steady state rate valve	18	TX2 closure valve		

The stainless steel chamber injector is constitued by injection holes located on three concentric rings : the two internal ones are acid and kerosene impinging doublets and the external one is kerosene injection used as film cooling along the inner wall (see figure 8).

The table 1, below, gives the main caracteristics of the SEPR 844 rocket engine.

TABLE 1
SEPR 844 MAIN CARACTERISTICS

Oxidizer	: nitric acid (HN03)
Fuel	: kerosene (TR0 or TR4
Ignition	: HN03 + TX2
Nominal thrust at sea level, daN	: 1255
Nominal thrust at 20 kms, daN	: 1555
Specific impulse at 20 kms, seconds	: 220
Engine mass flow, kg/sec	: 7.15
Mixture ratio	: 4
Chamber pressure, MPa	: 2.35
OXIDIZER PUMP :	
Inlet pressure, MPa	: $\geq$ 0.06
Exit pressure, MPa	: 5.3
FUEL PUMP :	
Inlet pressure, MPa	: $\geq$ 0.1
Exit pressure, MPa	: [illegible].4
TX2 tank pressure, MPa	: **3.4**
Driving shaft speed, rpm	: 4890
Pumps speed, rpm	: 15500
Weight (without tank), kg	: 158
Acid tank weight, kg	: 82
Maximum flight operating time, sec	: 80

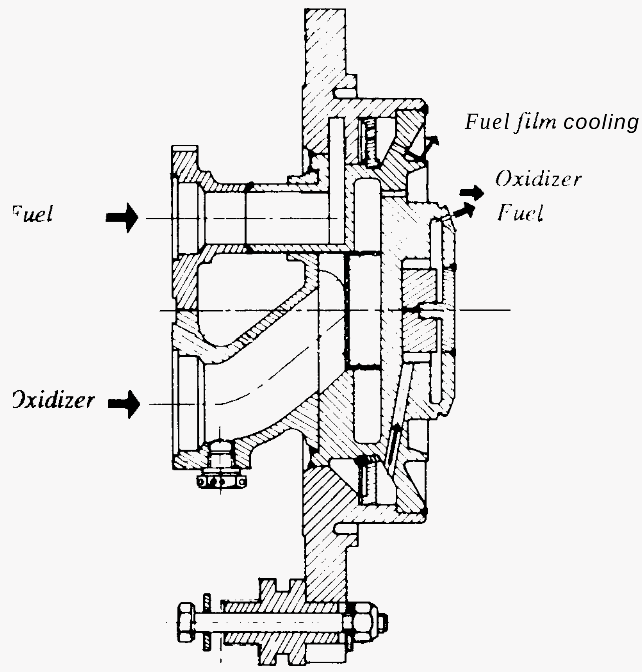


Figure 8 :Chamber injection

The SEPR 844 rocket system is installed in a box beetwecn the frames 27 and 36 of the Mirage III E.

Eight attach points connect the rocket engine to the combat aircraft. Mechanical connectors assure the attachment between the rocket engine shear shaft and the driving shaft coming from the accessories relay of the Mirage ATAR 9C turbojet engine ; hydraulic and electrical connections are also used, the former supplying the kerosene alimentation.

The SEPR 844 thrust axis makes a 9" 30 angle with the aircraft thrust axis (see figure 4).

Finally, it must be pointed out that the rocket system can be jettisoned at low speed.

OPERATIONAL UTILISATION

The SEPK 841 entered operational service in December 1961 at the Dijon Air base. To the end of its operational service in 1970, these engines completed 1505 rocket flights (representing 2064 ignitions).

The SEPK 844 entered operational service in June 1967 at the Colmar Air base.

One hundred and sixty four SEPK 841 and one hundred and eleven SEPK 844 have been produced (see Figure 9) and used operationaly in 6 countries : France, Lybia, Pakistan, South Africa, Spain and Switzerland.
More than 10000 rocket flights have been completed with a 99 % sucess rate.

In its repair planning, the SEPK 844 has to be removed from the Mirage III every 50 ignitions. The most critical parts must be changed : it concerns mainly the acid subsystems like the acid pump, the acid valves, the acid filter. The chamber inner wall must also be changed, but it has been demonstrated operationaly that this clement can complete 70 ignitions without any damage.

There is no routine bench test after such subsystems removal but, a test is needed when the rocket engine is totaly disassembled (every 200 ignitions or after 15 months of acid Laying).
The presence of nitric acid never generated maintenance incident.

The maintenance operations are very easy. By way of proof, the NATO «Air Defense» concourse won by the Colmar Squadron in April 1970, and including turn around operations of four identical aircrafts after each mission. The Colmar's Mirage III E equiped with SEPR 844 made turn around times beetween 12 mn 9 secondes and 14 mn 55 secondes.

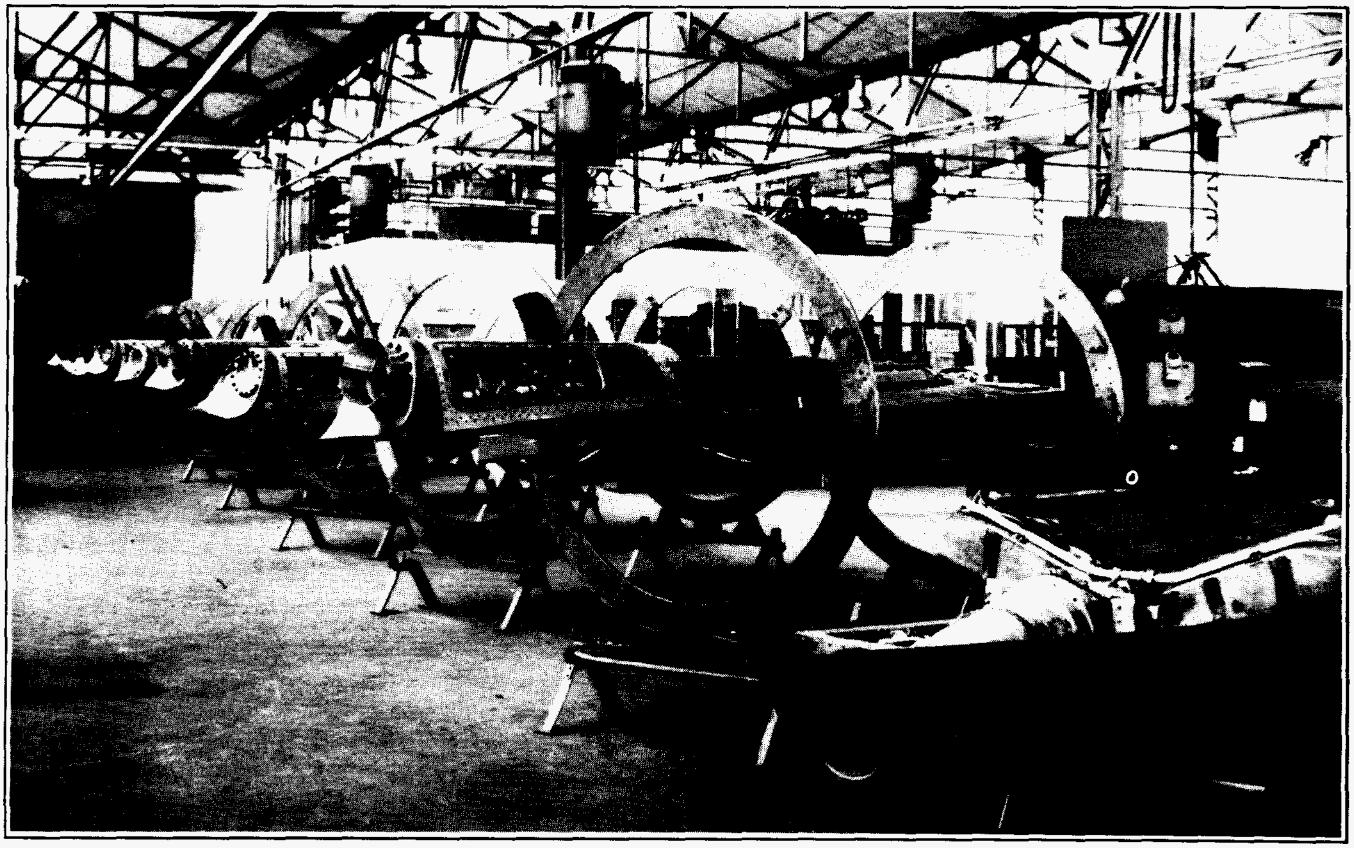


Figure 9 SEPR 841 and YLPR 844 production line

The end of the SEPR 844 operational service in the French Air Force happened in 1984.

The Swiss Air Force still utilizes the SEPK 844 rockct engine with its Mirage III S (see figure 10).
From May 1969 to April 1990, the twenty Swiss SEPK 844 have performed 2170 rocket flights, representing 4575 in flights ignitions (for a total of 5699 in flights and ground ignitions).

Figure 10 : Mirage III S and SEPR 844 rocket engine during a ground test.

CONCLUSION

In the fifhties, the required performances for a fighter were a very fast climbing to bring the aircraft in a very precise firing angle, due to the limitations of the air to air missiles.
Due to the lack of turbojet engines thrust, the rocket engines (used as main or auxiliary propellent) offered, at that time, the answer with a high thrust/weight ratio.

The modification of combat aircraft needs (multipurpose aircrafts with more range) and the improvements of the air to air missiles. on board radars and turbojet engines performances, made the rocket engines less attractive.

Also, the utilization of acid with the consistent constraints it insolves (the navy always refused to have this propellant in its aircrafts-carriers) was a criteria against the concept. The rocket propellent for aircraft, as successfull as it was (and still is), had no following.

The SEPK 841 and 844 showed that the rockct propulsion answered well to their required specifications and that the reusability of rockct cnginc with a high availability can be possible.

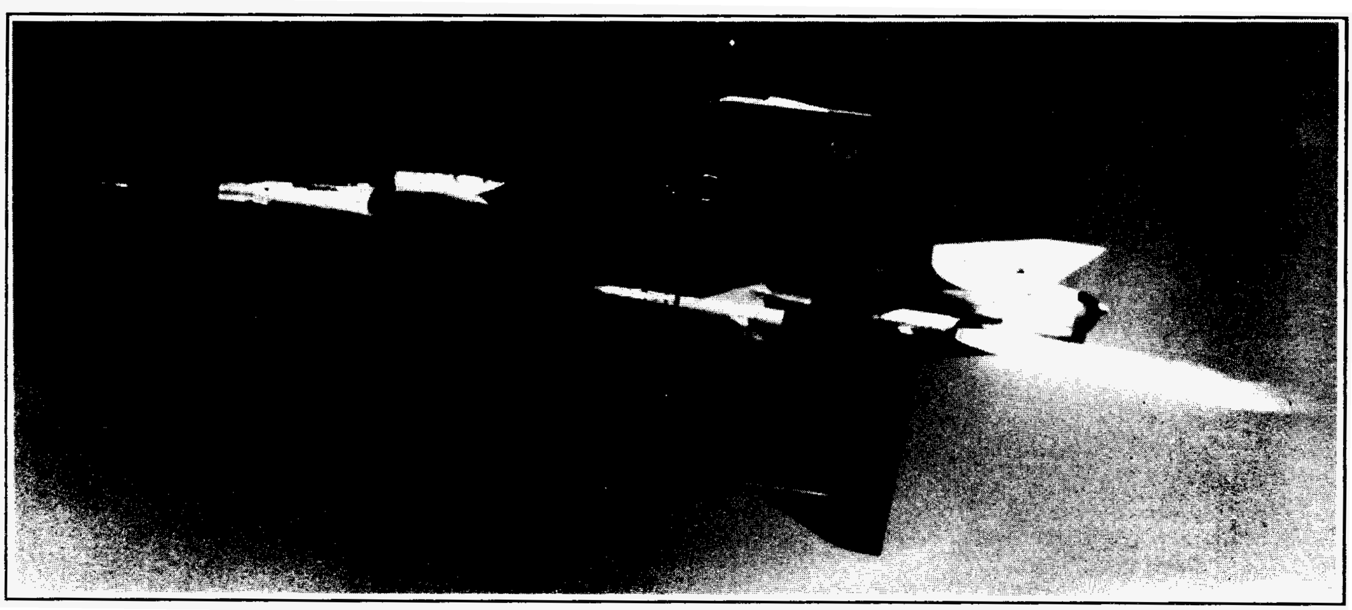


Figure 11: Mirage III C and SEPR 841 rocket engine