Acta Astronautica Vol. 22, pp. 213–218, 1990
Printed in Great Britain

0094-5765/90 $3.00 + 0.0
Pergamon Press plc

THE EVOLUTION OF LIQUID PROPULSION IN FRANCE IN THE LAST 50 YEARS

J. VILLAIN

Head of the Information, Industrial Property Department
Société Européenne de Propulsion
Suresnes, France

Abstract

The account hereunder describes the history of liquid rocket propulsion in France through the last 50 years. It shows in particular that the work which truly started on the morrow of World War II in a strictly national scope and for military applications, gradually became European and todate relate only to civil space purposes.

Background

In France, like in the United States and the Soviet Union, the work on liquid propulsion by rocket engines, really starts on the morrow of World War II. It is indeed starting from 1944-45 that became known German work in the field of rockets, which undoubtedly opened the way to the development of space launchers and ballistic missiles. It was based on this background and with the arrival in France, in 1946-47 of about 40 German engineers that propulsion and rocket research actually got started.

Some work however had been conducted previously, worth to be reminded.

Pre-World War II period

A forerunner : Robert Esnault-Pelterie

First known for the invention of the "joystick" and the radial engine of aircraft in the beginning of the 20th Century, Robert Esnault-Pelterie took interest as from 1912 in the theoretical aspects of rockets and Astronautics. From the late 1920s his ideas attracted the interest of the French Military Officials and he was then awarded a contract for the design and development of liquid propellant rocket engines. Esnault-Pelterie at that time used naphta, liquid oxygen, nitrogen peroxide, benzene, and tetranitromethane. In the test facility set up at Boulogne, in the outskirts of Paris, he achieved performance levels remarkable for the time : 100 kg thrust for one minute and a specific impulse of 230 seconds. From 1937, he directed his efforts to the resolution of thermal problems, and then used two techniques, one applying cooling by liquid oxygen, the other making use of refractory material. That was when the war interrupted his work.

The work of Jean-Jacques Barré

Jean-Jacques Barré took over the work of Robert Esnault-Pelterie with regard to rocket engine propulsion and liquid oxygen propulsion in particular.

As incredible as it may seem, the German occupation from 1940 to 1945 did not stop French research in terms of rockets. A team of the Artillery Technical Section worked as a matter of fact, in Lyons, to the development of an engine and a rocket. In order to preserve the secrecy of their tasks, this team, headed by Colonel Dubouloz and of which J.J. Barré was a member, took the name of Central Service of Contracts and Procurement Supervision. This research led as from 1941 to the development of a rocket called EA-1941 or EA-41 burning naphta and liquid oxygen. The engine was fed with propellant through nitrogen pressurization of the tanks.

Static test firings of this rocket, about 4 m in length, were first conducted on 15 November 1941 at the Larzac Field, and carried on at Vancia, near Lyons, clandestinely. Two successful flight tests were conducted on that same year.

It was however only from March 1945, after the liberation of the Provence that the test flights of that rocket could be resumed.

Jean-Jacques Barré accordingly was the first in France, to design and fly a liquid propellant rocket.

1944-46 Establishment of research and development structures

As from the end of the War, France, that becomes aware of the significance of being present in terms of rocket research, establishes its own research and development structures. Two organizations are then born :

- In 1944, Société d'Etude de la Propulsion par Réaction (S.E.P.R.) at the fort of Villejuif. It is a private owned Company at that time.
- And in 1946 the Laboratoire de Recherches Ballistiques et Aérodynamiques (Ballistic and Aerodynamic Research Laboratory) (L.R.B.A.) of Vernon belonging to the Defense Department.

Until 1971, these two organizations will design and develop liquid propellant rocket engines used as well for the aircraft and missiles as for sounding rockets, launch vehicles and satellites.

S.E.P.R. Contribution

The earlier research studies of S.E.P.R. are directed to pressure fed and pump fed systems to assist aircraft take off and power tactical missiles.

Aircraft take off boost

In January 1947, the first experimental rocket motor intented for aircraft take off was producted. Called SEPR 1, this engine worked on the principle of catalytic decomposition of hydrogen peroxide and delivered a thrust of about 500 daN.

At that time, were also developed engines intented for unexpected application. That was the case for one of them intended to accelerate and decelerate a land vehicle, the SE 1900-1910.
A few years later, by the end of the 1960s, SEPR even tested a propulsion system for individual lift platform. It was the Ludion.

A major step was passed on 30 October 1950 with the first stand tests of a new take off boost engine. This engine, called SEPR 25, working on nitric acid and TX (*) delivered a thrust of 1,500 daN. The special feature of this system was in the fact that the pumps were driven directly and mechanically by the aircraft jet engine. On June 10, 1952, the SO 6025 ESPADON aircraft took off for the first time with the SEPR 25 that worked perfectly.

The feasibility of this concept was thereby demonstrated.

From 1953, the new engines made use of independent turbopumps to feed the chamber with propellant. A rocket engine of that type, the SEPR 48 using nitric acid and furaline, was flight tested from Septembre 1954, on the TRIDENT I, SO 9000 aircraft.

Until the end of the 1950s, several other types of engines were made for varioux test aircraft, the ESPADON, TRIDENT I and II, the GERFAUT, MYSTERE, DURANDAL and the MIRAGE I, II (See Table 1).

Finally in 1961-1962, for the first time in the world, an aircraft, the MIRAGE III, became operational with a take off boost liquid rocket engine, which further gave the aircraft incrased maneuvering capability in fighting conditions.

Since then, these engines cumulated several thousand flight hours and demonstrated outstanding qualities of endurance, readiness of use and reliability.

Propulsion of tactical missiles

From 1947 to 1958, many tactical missiles programs were born in France. Many of them involved the use of liquid propulsion, which in the 1960s will give the way to solid propulsion enabling easier storage (See Table 2).

(*) TX : Triethylamine and Xylidine

Table 1 Characteristics of the Major Rocket Engines for Aircraft take off Boost Made by S.E.P.R.

AIRCRAFT NAME	ENGINE NAME	FIRST FLIGHT YEAR	PROPELLANT	THRUST (daN)	NUMBER OF CHAMBERS
ESPADON SO 6025 and SO 6026	SEPR 25	1952	Nitric Acid + TX (*)	1,500	1
TRIDENT I SO 9000	SEPR 481	1954	Nitric Acid + Furaline	1,500, 3,000	3
TRIDENT II SO 9050	SEPR 631	1957	Nitric Acid + Furaline	1,500 and 3,000	2
MYSTERE IV B 05	SEPR 662	1956	Nitric Acid + Furaline	1,500	1
MIRAGE I MD 550	SEPR 661	1956	Nitric Acid + Furaline	750 and 1,500	2
DURANDAL SE 212	SEPR 65	1956	Nitric Acid + Furaline	750	1
MIRAGE III C MD 550	SEPR 841	1957	Nitric Acid + TX (*)	750 and 1,500	1
MIRAGE III E	SEPR 844	1963	Nitric Acid + JP1 or JP4	1,500	1
SUPER-VAUTOUR SO 4060	SEPR 81A	--	Nitric Acid + TX (*)	Variable 500 to 3,200	2

Table 2 Characteristics of the Major Rocket-Engines for Tactical Missiles Made by S.E.P.R.

MISSILE NAME	ENGINE NAME	DESIGN START YEAR	PROPELLANT	THRUST (daN)
AA 10 (Air-Air)	SEPR 16	1946	Nitric Acid + TX	200
SE 4100 (Surface-Air)	SEPR 4 + SEPR 2020	1950	Nitric Acid + TX	1,250 1,350
R 04 (Surface-Air)	SEPR 44	1950	Nitric Acid + TX	1,500
R 04 (Surface-Air)	SEPR 43	1950	Nitric Acid + TX	1,250
M 04 (Surface-Air)	SEPR 12	1950	Nitric Acid + TX	1,250

L.R.B.A. Activities

Although dedicated to the military, the L.R.B.A. had an essential part in the development of the rocket engines of the French and then European civil launch vehicles.

At the end of the 1940s, two types of main activities are being conducted there : continuation of Jean-Jacques Barré work and research on sounding rockets.

Eole

It was indeed at that time that J.J. Barré designed a rocket called Eole of 800 mm diameter, and carrying one ton of naphta and liquid oxygen. Static tests were conducted at the L.R.B.A., one of which in 1951 resulted in the explosion of the rocket and destruction of the test stand. In 1952-53 a number of flight tests were carried out from Colomb-Bechar in Algeria, but were not very satisfactory, which led to the end of Eole development and also to the end of L.R.B.A. work on liquid oxygen engines.

Propulsion of Sounding rockets

On 15 March 1949, the decision was made to develop sounding rockets for research in the upper atmosphere. The related responsibility was awarded to the L.R.B.A. which from then started the development of the Veronique family vehicles.

The first liquid propellant engine developed under that scope was flight tested with a Veronique R, starting from 1950. It was a 4 metric ton thrust nitric acid and kerosene rocket engine.

From May 1952 to April 1953, the tests of a new model, the Veronique N, pointed out a previously unknown phenomenon : Combustion instability at low frequency. With an engine delivering a thrust of 65 kg for 31 seconds, Veronique N carried a load of 65 kg to a 65 km altitude. Next, in 1954 burning time went up to 45 seconds with Veronique NA. For the International Geophysical Year, in 1958, was built the Veronique AGI sounding rocket. Kerosene was replaced by turpentine, less sensitive to combustion instability. The last version of the Veronique, called Veronique 61, was set into service in 1964. It had a 6 ton thrust engine derived from the 4 ton unit.

Thrust was further increased, up to 16 tons with the engine of the Vesta sounding rocket that succeeded Veronique in 1965.

All the engines used in the various versions of the Veronique and Vesta were fed with propellant through tank pressurization. Thus the pressurizing gases generated in the version N resulted from the combustion of nitric acid and a solution of ammonium nitrate and furfuryl alcohol. The engines of the versions N and NA were double walled, cooling being provided by circulation of nitric acid between these walls, and also through flowing of an acid film on the inner wall of the convergent and divergent chamber. In the engines of the AGI and 61 version, there was only a single wall and cooling was made only through the flowing of an internal film. Nozzle throat in that case was in graphite. Finally, from the version N to version 61, combustion chamber pressure was set and kept to 20 bar (See Table 3).

Table 3 Main Characteristics of the Liquid Rocket-Engines for Sounding Rockets Made by the L.R.B.A.

NAME OF SOUNDING ROCKETS	SETTING INTO SERVICE DATE	KIND OF PROPELLANT	ENGINE THRUST (daN)	BURNING TIME	ISP (sec)
VERONIQUE R	1950	Nitric Acid + Kerosene	4,000 (Sea level)	5 Sec.	189 (Sea level)
VERONIQUE N	1952	Nitric Acid + Kerosene	4,000 (Sea level)	31,5 Sec.	189 (Sea level)
VERONIQUE NA	1954	Nitric Acid + Kerosene	4,000 (Sea level)	45 Sec.	181 (Sea level)
VERONIQUE AGI	1959	Nitric Acid +Turpentine	4,000 (Sea level)	45 Sec.	203 (Sea level)
VERONIQUE 61	1964	Nitric Acid +Turpentine	6,000 (Sea level)	55 Sec.	201.5 (Sea level)
VESTA	1965	Nitric Acid +Turpentine	16,000 (Vacuum)	56 Sec.	

Propulsion of Diamant A and B launchers

In the course of the years 1957 and 1958, the Soviet Union and The United States took a considerable edge over the other countries in the space fields and a particular in the development of launchers and ballistic missiles. From 1958, France also engaged in both of these areas, by developing in parallel solid and liquid propulsion

In the latter area, the L.R.B.A. built up a 28 metric ton thrust engine called Vexin and derived from the 16 ton thrust engine of the Vesta. It was first used in 1964 on the first stage of an experimental ballistic missile called Emeraude, and carried 12 tons of nitric acid and turpentine.

In October 1960, it was demonstrated that such an engine could equip the first stage of the Diamant Space launcher that will place into orbit on 26 November 1965 the first French satellite. The Vexin was the first steerable engine, techniqui applied to directional control of the launcher. Feeding with propellant was through tank pressurization from gases resulting from the burning of a solid grain, and cooled by water injection.

In 1970 Diamant B succeeded Diamant A. The load capacity of the launcher went up from 45 kg to 75 kg, by increase of the propellant weight of the first stage. Thus, the new stage called Amethyste carried 17 tons of propellant, that is 5 tons more than Emeraude. On the other hand, a more powerful engine was developed : the Valois, of 35 ton thrust.

It should also be mentioned that the N_2O_4/UDMH propellant combination was selected to replace nitric acid and turpentine, with a resulting 10 % performance increase. Propellant feeding to the chamber was achieved through tank pressurization by water cooled gas from a generator using the same propellant as the engine. As in the Vexin engine, cooling of the internal wall was by fuel film flowing.

Propulsion of Coralie, Second stage of the Europa I and II launchers

In 1962, the earliest studies of the Europa I launcher came into being, followed moreover, from 1966 by the Europa II program. For these launchers, France won the responsibility of the second stage Coralie equipment with 4 identical engines fed with UDMH and N_2O_4.

The design of the engine was entrusted to the L.R.B.A. that had started to acquire qualification in storable propellants since the late 1950s. It was a 7 metric ton thrust engine fed by tank pressurization through water cooled gases generated by combustion of the propellants. Its technology was in fact derived directly from the knowledge acquired in the previous programs.

The first flight tests of theses engines were carried out in 1966 from Hammaguir in the Sahara.

Unfortunately, the many flight failures of the complete launcher brought the program to an end.

Liquid hydrogen and liquid oxygen propulsion

As from 1960, whereas the earliest studies of the launcher were started, S.E.P.R., began to investigate liquid hydrogen and liquid oxygen propulsion. Two stages were studied under the scope of the Diamant launchers : the H2 and the H3.

The engine of the H2 was comprised of four chambers, propellant feeding being provided by a turbopump of which the turbine was driven by the gases from a generator. Expected thrust was 6 metric tons, the stage being intended to carry 2.2 tons of propellant. As for the engine of the H3, of a 380 kg thrust, it was to be fed with oxygen by tank pressurization through helium, whereas the hydrogen tank was pressurized by the gases used to chamber cooling. The H3 stage was to carry 500 kg of propellant.

These, initially technological studies were stopped with regard to the H3 by the end of 1964, whereas those related to the H2 were immediately followed by those of a new engine : the HM4, the studies of this engine being funded by the Defense Department.

The HM4

This was a 6 ton thrust four chamber engine with gas generator turbopump fed and intended for the 3rd stage of the Diogene launcher, using 3.5 tons of propellant.

While component testing were proceeding satisfactorily, the engine thrust was brought down to 4 ton in 1965, for launcher optimization purposes. The first tests of the complete engine were carried out from July 1967 to November 1968, and the nominal performance levels, 4 ton thrust for 360 seconds, were achieved. France became, after the United States the second Country in the World having developed a cryogenic engine.

Although the HM4 program was discontinued in 1968, it had allowed establishing the technological background essential to the achievement of the Ariane program.

In 1969, the year of forning of Societe Européenne de Propulsion, (S.E.P.), which in 1971 will combine the resources of SEPR and the LRBA, was started the study of a 7 ton thrust cryogenic engine operating under 30 bar, and intended for use on the Europa III launcher. This single chamber engine made use of the MH4 turbopump, to which however some improvments were brought about.

Then in 1970, the study of a 20 ton thrust cryogenic engine intended for high pressure (120 bar) and staged combustion operation, was started by S.E.P. and Rolls Royce for the EUROPA III B project, under the frame of a joint venture called Cryorocket, formed for the purpose by the two companies. Two years later this project was stopped, giving place to the L III S project, a prefiguration of the future Ariane launcher.

In parallel with the large liquid propulsion studies, investigations were conducted at the time on fluorine propulsion and also on the development of small thrusters operating on the principle of catalytic decomposition of hydrazine. Thus, a 3.5 N thruster was used in 1975 aboard the D5A satellite, and another are of 15N on GEOS.

The final stage : Ariane Propulsion

The use of stages carrying heavy propellant weights required the use of turbopumps instead of the gas pressurization system. It was by 1965-66 that the L.R.B.A. started the study of turbopump fed engines.

A first such engine was accordingly developed and tested for the first time on 5 June 1969. It was a 40 ton thrust engine called M40, operating under 30 bar, and which in fact was extropolated from the VESTA, but using a turbopump. This engine at the time was used to the definition of the first stage of the EUROPA III launcher. Finally, the selected solution was that using four engines of 60 ton thrust each, to be operated for 150 seconds. Three prototypes of this engine, that took the name of VIKING I, were then developed with a thrust limited to 55 metric tons. The first test of a complete engine tool place on 8 April 1971 and the satisfactory results achieves thereafter enabled turning very soon to the VIKING II version, of 60 ton thrust, of which stand testing began from December 1973.

It is during that same year 1973 that the Ariane program came into being that European launcher will use 4 VIKING V engines on its first stage, and on VIKING IV engine for its second stage, both versions derived from the VIKING II (See Table 4).

The 6 ton thrust HM7A engine shall derives directly from the 7 ton engine studied for the EUROPA III. This engine shall be subject to its first test on horizontal stand on 7 November 1975, then to its first vertical stand test on 22 September 1976, and tested under altitude simulation on 9 June 1976.

With the Ariane program, launch vehicle propulsion took a truly European scope. Along with S.E.P. could be now found companies from Germany, Sweden, Belgium, among others.

After a long course mostly run in the research and development field, marked with hopes as well as ups and downs, European propulsion entered with Ariane, the industrial production stage.

Table 4 Main Characteristics of the Liquid Rocket Engines for the French then European Launch Vehicles

STAGE OR LAUNCHER NAME	ENGINE NAME	SETTING INTO SERVICE DATE	KIND OF PROPELLANT	ENGINE THRUST (KN)	BURNING TIME (sec)	CHAMBER PRESSURE (bar)	I S P (sec)	PROPELLANT FLOW RATE (KG/sec)	ENGINE WEIGHT (KG)
DIAMANT A (1st stage)	VEXIN	1965	Nitric Acid +turpentine	283 (sea level)	95	17.6	203 (sea level)	142	370
DIAMANT B (1st stage)	VALOIS	1970	N2 04 + UDMH	344 (Sea level)	112	19.6	219 (sea level)	160	?
CORALIE (EUROPA 2nd stage) 4 engines	--	1966	N2 04 + UDMH	70 (vacuum)	104	13.2	281 (vacuum)	97	?
ARIANE I (1st stage)	VIKING V	1979	N2 04 + UDMH	617 (sea level)	142	53.5	247.6 (sea level)	255	818
ARIANE II,III,IV (1st stage)	VIKING V	1980	N204+UDMH +Hydrazine hydrate	678 (sea level)	137	58.5	278.4 (vacuum)	275	826
ARIANE I (2nd stage)	VIKING IV	1979	N204 + UDMH	721 (vacuum)	136	52.6	295 (vacuum)	251	905
ARIANE II,III,IV (2nd stage)	VIKING IV	1980	N204+UDMH +Hydrazine hydrate	805 (vacuum)	125	58.5	295.5 (vacuum)	278	886
ARIANE IV (Boosters)	VIKING VI	1988	N204+UDMH +Hydrazine hydrate	678 (Sea level)	143	58	278.4 (vacuum)	275	826
ARIANE I	H M 7 A	1979	LOX / LH2	62 (vacuum)	570	30	442.4 (vacuum)	14	149
ARIANE II,III,IV	H M 7 B	1980	LOX / LH2	63 (vacuum)	730	35	444	14	155

THE KEY DATES OF LIQUID PROPULSION IN FRANCE

Decade

1930 : advent of the earliest liquid rocket engines

1945 : first flights of a liquid propulsion rocket

1947 : first developments of liquid propellant rocket engines for aircraft take off boost

1950 : early tests of 4 ton thrust engines

1953 : early tests of turbopump engines

1964 : early tests of 28 ton engines

1964 : early tests of steerable engines

1966 : early tests of storable propellant (N_2O_4 - UDMH) engines

1968 : early tests of liquid hydrogen and liquid oxygen engines

1969 : early tests of 40 ton thrust engines

1973 : early tests of 60 ton thrust engines