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TOPAZE

Chapter 15

VE 111 Topaze: The First French Inertial Rocket[*]

Philippe Jung[†]

Introduction

When the story of Agate was written in 1992,[1] it was thought that it had been the last rocket built in Cannes, save for the X 422 cruise missile of 1967. However repeated discovery of Topaze material in the archives of Jean Escursan, the former technical director in Cannes, and even recently of its wind tunnel mock up stored under stairs, confirmed that this significant rocket was initially a mostly "azurean" affair, at a time when SEREB was spreading the deterrent force work across the whole of France.

A recent interview with Roger Béteille, the chief engineer in Cannes from 1957 to 1967, where he invented the cruise missile,[2] has done much to clarify the overall situation in these crucial years for France.

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[*] Presented at the Thirty-Second History Symposium of the International Academy of Astronautics, Melbourne, Australia, 1998. Copyright © 1998 by P. Jung. Published by the American Astronautical Society with permission.

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From Radio to Inertial Guidance

As recounted in Reference 1, France did not wait for a decision on which missile avenues to follow, particularly as the principle of the tactical SSBT (Sol Sol Balistique Tactique) Casseur already had been decided in May 1957. Thus Sud Aviation, competing on this program against Nord Aviation, lost no time, building a mock up of its X 407 proposal in January 1958.

To improve the range and the accuracy of what was to be the successor to the ramjet-propelled Army SE 4200, two main problems had to be solved. The performance of the easy-to-use solid propellant had to be increased, and radio guidance had to be replaced by inertial guidance. In 1958, LRBA built the first French inertial unit, but a lot of work remained before the production of an operational unit. On the propulsion side, the development of an 800 mm diameter solid block of plastolite (a mixture of aluminum perchlorate and polyvinyl chlorine), named Mammouth ("mammoth"), commenced in 1958.

While touring the USA, General Crépin had been so impressed by the American promises that, on August 8th, the infamous decision of canceling anti-aircraft missile work in France was taken: to the benefit of the Hawk, even though it was not yet operational. However, the SSBS (Sol Sol Balistique Stratégique) and SSBT were confirmed, and the idea was aired in September to discuss with the USA a collaboration within the framework of NATO. This was accepted, and a general agreement was reached, concerning solid propellant ballistic missiles. Therefore, French companies approached their American counterparts in the field of gyroscopes, SAGEM teaming with Kearfott Librascope, SFIM with Sperry, Air Equipement with Bendix and SACM (Société Alsacienne de Constructions Mécaniques de Mulhouse) with Honeywell.

By June 1959, Sud had, not surprisingly, won the SSBT contract. Using the Mammouth block, the missile was to be guided by a Kearfott platform, two of which had been ordered. Béteille had arranged for SAGEM engineers to go to Kearfott, in preparation for the licensed production of the equipment back in France. However, relations between the two countries started to degrade in July, and joint meetings were cancelled. But worse was to come in August, when the whole SSBT program was cancelled, because of lack of money and the attendant priority given to the strategic missiles.

The following month saw the creation of SEREB (Société pour l'Etude et la Réalisation d'Engins Balistiques), on September 19th. Given full power to have, within the timeframe set by de Gaulle, an operational nuclear missile, SEREB decided fairly quickly on the future arrangement between its members: Sud Aviation, Nord Aviation, Dassault, SNECMA, SEPR, MATRA, ONERA and CEA (Commissariat à l'Energie Atomique). Charles Cristofmi was the president, Roger Chevalier the technical director, and Pierre Usunier the director for military programs. Within Sud Aviation, the GTC (Groupe Technique de Cannes) was at the time by far the biggest and most advanced group in rocketry in Europe, with 1,200 launches in all categories. However, it could not grow indefinitely, if only because additional engineers could be hired fairly easily, but not professional workers, as they tend to be less mobile, and not many were available in Côte d'Azur. Furthermore, a rather incredible situation occurred, the consequences of which can be felt today.

There was an obvious need to increase factory space, and the Director, the energetic Louis Marnay, quickly reached an agreement with the French railways, SNCF, owner of the adjacent land, on a good price for both parties, with a better than average value. But the deal was refused by the French Domaines (within the Interior Ministry), on the grounds that the price was not...high enough! One would have expected from a state body that it would ask for an agreement between two other state companies at a low price! With GTC expansion blocked (it would take ten years for the transaction to be approved), the large liquid rocket stages went to Nord Aviation in Les Mureaux. As a result, although the Cannes site has now expanded even to the other side of the Marseille-Nice rail line, Ariane is built in Les Mureaux.

Two other factors also influenced such a transfer, however: the Les Mureaux plant, which had been building aircraft for the design bureau of Châtillon, a suburb of Paris, was now desperately short of work; there was also the nearby presence of LRBA in Vernon, which had developed a powerful liquid motor and also owned test stands. In the end, SEREB itself, located in Courbevoie, another Paris suburb, also transferred to Les Mureaux when the Sud Aviation Courbevoie plant closed.

The GTC was, however, able to retain the best part, with all the missile equipment bays remaining there, due to the existence of the large computers performing guidance and control studies. Furthermore, Sud Aviation was given the prime role for the industrialization of the complete submarine-launched MSBS (Mer Sol Balistique Stratégique) system, everything from the missile to the user's manuals for the Navy. Similarly, Nord Aviation became the prime contractor for the easier silo-based SSBS system.

The EBB Technology Program

As early as the end of 1959, SEREB launched a remarkable technology program, EBB (Etudes Balistiques de Base). In the same vein as the Gemini program, which cleared the hurdles for the Apollo program, EBB allowed SEREB—in a daredevil four years—to fly, via an orchestrated and progressive experimentation with modular elements, the basic test vehicle for the 'Force de Frappe,' the VE 231 Céphée (VE = Véhicule d'Essais, or test vehicle), as a preparation for future strategic missiles. Thus the main goals of EBB, with R. Laurentjoye the chief engineer, were to:

- select propellant—solid or liquid;
- test subsystems and equipment in real flight conditions, i.e. inertial guidance and control at hypersonic speeds.

All the initial VEs were developed in Cannes, in an incredible eight months, to qualify the telemetry and recovery equipment of the nosecone and equipment bay for the future VE 231: from the free-falling VE 8 recoverable nosecone (first flight on October 19th , 1960), to the VE 9 (November 12th, 1960) and VE 10 Aigle, alias X 408, (December 17th, 1960) using a SE 4400 booster to test the combination of nosecone and equipment bay, then the VE 110 Aigle II (June 3rd, 1961) using the Mammouth booster for higher speed and altitude.[1]

As Céphée had to be quickly available, it was decided in October 1960 to put to good use a liquid high thrust motor of 16 t developed by LRBA for Vesta. This motor was increased to a thrust of 28 t for use as the Céphée liquid first stage, called the VE 121 Cassiopée. It became the first rocket to be built in Les Mureaux, thus cementing a future unanticipated at that time ... the biggest commercial launcher manufacturing line with Ariane. With a liquid first stage, Céphée then had to have a solid second stage, called the VE 111 Andromède, but again making as much use as possible of available hardware. At the time, the biggest solid motor was the Mammouth, of 1.8 t mass and 200 seconds specific impulse. The block had to be cast separately and then introduced into a steel casing, the allowable stress of which was less than 100 kg/mm.[2,3] This was a long way from the anticipated 16 t and 1.5 m diameter foreseen for the SSBS! The specification for the VE 231 called for a range of 2,450 km with a 400 kg payload.

The VE 111 Andromède

The agreement under NATO had led to the development of a big propellant block, made from the new isolane combination (ammonium perchlorate and aluminum powder, with polyurethane binder), as derived from the Hawk. Although staying with the 800 mm diameter of the Mammouth, it now could be cast directly into the rocket stage, the steel of which had an improved allowed stress of more than 140 kg/mm. Furthermore, isolane had the advantage of being less fragile than plastolite.

By the end of I960, the VE 111 was defined, with four main and significant goals, all of which were firsts for France:

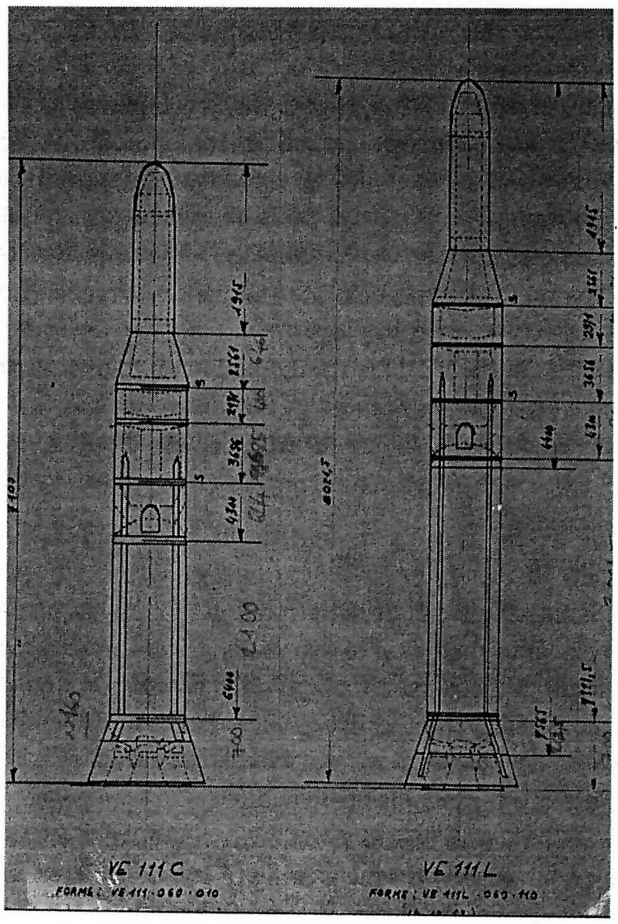
- test the operational isolane solid propellant
- test 3 axis-control by rotating nozzles
- test inertial guidance
- test precise nosecone re-entry.

Three-axis control was achieved by rotating nozzles around an axis which was offset with respect to their axis of symmetry. There were 4 nozzles, so that, by using two of them in the same direction, pitch (nozzles A and C) and yaw (B and D) could be controlled, while differential use of two of them (B and D) produced roll. Developing mechanisms that could withstand gas temperatures of 3,000°C looked just as a formidable challenge.

A serious problem with regard to the inertial guidance arose at the time of delivery of the Kearfott platforms: the souring of relations between the two allies led to the U.S. providing the hardware, but only on the condition that the SAGEM engineers go back to France. Fortunately, however, they had progressed enough to be able to develop, albeit with some delay, a home-made product!

Both finned and un-finned configurations were considered, the latter corresponding to a 'worst case' submarine-launched missile, where the small space available would preclude the use of stabilizing fins. It was therefore decided, in December 1960, to perform wind tunnel tests with a 1/25 scale mock up of the VE 111 in four configurations:

I- with a lower skirt of a height reduced by 100 mm
II- with a nominal skirt
III- with fin stumps
IV- with four VE 10 type fins.



Wind Tunnel Testing

Wind tunnel testing commenced in January 1961, from the 6th to the 10th, in the S4 wind tunnel of LRBA in Vernon, in the presence of M. Attali from SEREB. The maximum Mach number planned was 3.2 (although only Mach 1.87 seems to have been actually performed). The roll moment was measured as a function of angle of attack. Complementary trans-sonic testing took place in March, from the 6th to the 16th, in the S2 Sud Aviation tunnel at Suresnes. Aerodynamic coefficients were measured on a 1/35 scale mock up at Mach numbers lower than 1.85.

To analyze the lift-off stability under strong winds, further testing was performed in the Marignane wind tunnel of Sud Aviation on April 12th. A ¼ scale mock up was tested there at 40 m/s, with angles of attack ranging from –10° to +40°. Configurations I and IV were analyzed.

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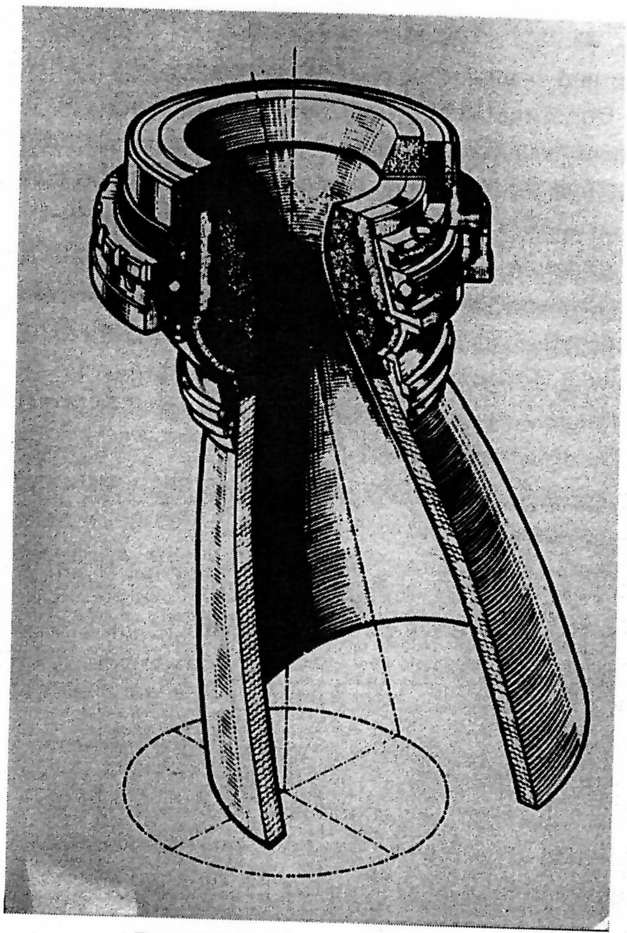


Rotating nozzle with offset axis.

A First Variation: the Finned VE M111

On February 17th, two basic configurations would be selected, probably I and IV as tested in Marignane: the basic VE 111, and the so-called 'transition vehicle' VE M111 with the four VE 10 fins, each of 0.83 m span and 525 mm mean chord. The latter allowed roll to be aerodynamically controlled. In March, a comprehensive testing plan was established for both 111 and M111, including acoustic tests to check the impact of motor noise. Long lead items for manufacturing three VE 111 and two VE M111 (later called VE 111M) were ordered.

Detailed design proceeded fairly quickly in 1961, thanks to a maximum re-use of previous VE equipment, such as the nosecone and the equipment bay of the VE 10 and VE 110. Minor modifications only were necessary to cover the higher loads corresponding to the later use of the VE 111 as the second stage of the VE 231.

The guidance and control loop was to be provided by SFENA: Centrale d'Attitude (with an Iron Fireman NF 4111C as a possible back up), Bloc de Pilotage and Programmeur (an LCT computer had also been considered). It was also planned to use SAGEM GSM 24 gyroscopes: they were to be tested in Courbevoie. To power the nozzles, two companies were selected for the GAP (Groupe Auxiliaire de Puissance), Air Equipement and GAMD (Générale Aéronautique Marcel Dassault). G-standard telemetry, after the type F used with the VE 110, had been planned in three subsets G1, G2 and G3. An additional G4 variation was then added:

- G1 for static pressures and flux measurement
- G2 for internal environment
- G3 for aerodynamics and boat-tail heat fluxes
- G4 for stresses.

However, discussions with SEREB showed that the number of available channels required a reduction to only two configurations. Therefore, by January 1962, G2 and G3 had been merged into G2. It is noteworthy that some experiments were planned to counter the re-entry blackout, even if on-board recorders had to be used.

Analysis work was supported by the large computers introduced by Paul Gross for the necessarily heavy computations. Béteille, when he had arrived at end of 1956, had started investing in a variety of test equipment, extremely useful for the multi-faceted activities of GTC. Thus by 1962, an IBM 650, then one of the biggest computers in France, was available.

Manufacturing and testing of the motor also commenced in 1961. Casings No. 1 (in mild steel), 2, 3, 4, 9 and 10 were hydraulically tested by Nord Aviation and EAT (Etablissement Aéronautique de Toulouse), with good results, except for No. 2 which failed prematurely. Then came the acid test for the first isolane 800 mm blocks, named Soleil. A short 1.4 m long "bomb" was cast at CEB (Centre d'Essais de Bordeaux) at the beginning of November, and a second one was successfully fired later in the month. A PG 445 igniter was used. Complete motors No. 5 and 6 were to be fired in December in St. Médard, near Bordeaux, but with fixed nozzles for the initial trial.

This was also the period when, mid 1961, the selection of solid propulsion was confirmed for the SSBS, thus validating the concept of the MSBS. As an added bonus, in the aftermath of positive feasibility studies dating back to December 1960, a decision also was taken on December 18th, 1961, to derive from the two-stage VE 231 a three-stage space launcher (later to be called Diamant).

Motor Tests at Istres

In the beginning of 1961, contract 2055/61 had stipulated that static testing of the Soleil would be performed at the Istres air base, located near Marseille. Its proximity to the Cannes factory of the VE 111 prime contractor, the presence there of a CEV (Centre d'Essais en Vol) annex and of recording installations, all contributed to this choice. This base, which has the longest runway in Europe, was used before the Second World War for the French long distance aviation record flights. SEPR also had installations there, beginning with the SE 1910 rocket sled that had broken speed records on its special track alongside the runway.[4]

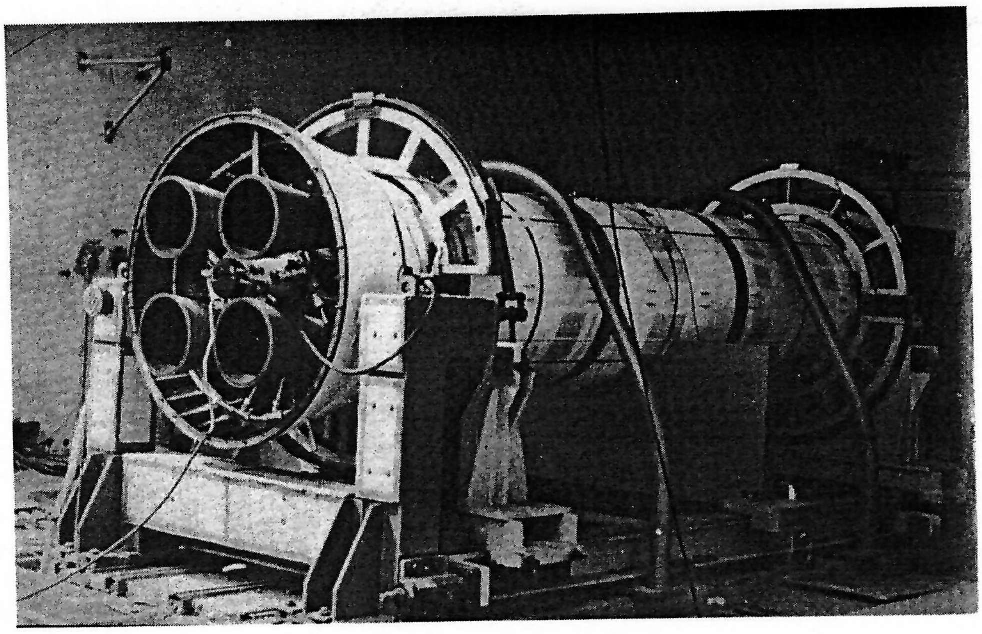
Thus, on February 18th, 1962, block No. 17, equipped with 2 rotating nozzles, was test fired in the SEPR area. Another test on April 18th was successful, although the paint on the thermal shield was burnt away.

While this was going on, structural tests also began at EAT, with a combination of mechanical and thermal stresses, on the forward section (forward skirt equipment bay and recovery bay). Coming after room temperature tests in Cannes, they were performed on April 19th and 20th. Similar tests on the rear section were planned for May. Dynamic testing took place in Les Gâtines, an annex of the Châtillon plant, in March/April, notably to measure the first bending mode: first with the full rocket model (using motor No. 15 with an envelope in Vascojet steel), then with fins added, and finally without propellant. An ONERA suspension was used. The Air Equipement GAP was mounted. The model (could it be No. 6, unaccounted for?) was then transported to Istres, where it was mounted on a sophisticated ED concrete test stand on April 25th and 26th. ED, or EDY, meant Entraves Dynamiques (dynamic tether), as it allowed small movements of the rocket, to check extensively the reactions to active guidance and control loops.

Another way of testing Andromède under vibrations during live motor firings was envisaged: small 100 kg thrust rockets would be fired for four seconds, at the level of the nose. Poudrerie Nationale de Sevran-Livry and SEPR were contacted, but the latter was retained, as they already had the P193 available. ONERA impulsers were to be used, fired at the level of the nozzles: two rockets of 1,200 kg on nozzles A and B before ignition, two of 600 kg on A and B plus two of 1,200 kg on C and D during the burn, and finally two of 1,200 kg on A and B after burn out.

On the guidance side, not everything was rosy, because SFENA, a traditional customer of GTC, was not putting a sufficient amount of effort into solving problems with the Bloc de Commande, which Cannes described as of "bad technology." This suited DEn (Direction des Engins), which wished to bring in GAMD or MATRA. However, GTC proposed a collaborative effort with the Suresnes plant, to assist SFENA. At last, however, confidence in the control loop was such that, some time in 1962, it was decided not to proceed with the finned VE 111M.

An important decision had, in the meantime, been taken when, on February 23rd, studies were initiated on both SSBS and MSBS. Only a few days before, on the 10th, CNES had been created. The French rocketry scene for two decades was now all set.



VE 111 motor ready for static test.

Static Firings

Now came the crucial tests of real hardware, after a string of successful propulsion tests. From a total of 15 under order, three complete Andromède were built for full scale static firings in Istres on the unique ED stand. The aim was not only to test the Soleil itself, but also its impact at system level, including any mechanical perturbations it might introduce. It truly was a full flight simulation. To this end, the complete VE 111 was mounted upside down on the stand.

Three ED tests took place in the second half of 1962, beginning on July 25th with No. 1, which had just been vibrated in Cannes before leaving for Istres.

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Perturbations were to be introduced for the first time during the second test, which was performed with No. 5. A simulated flight, with the Dassault GAP (which was eventually was not retained) and SFENA 130 platform, and with the guidance and control loop active, was performed on September 25th. At the insistence of Colonel Michaud of SEREB, the test took place, despite heavy rain the previous day. The perturbation P193 did not ignite, and at T0+25 seconds, the tethers stuck. It took two orders before they would unlock, and the rocket return to the vertical. Some unwanted yaw perturbation was recorded at the beginning of the test, and yaw reached its limit value at burn out. Such tests were, of course, of interest to many in the vicinity, leading to a complaint from GTC about the interference caused to activities by the high number of people coming to watch ("no less than 17 SEREB people to be educated: far too much!")

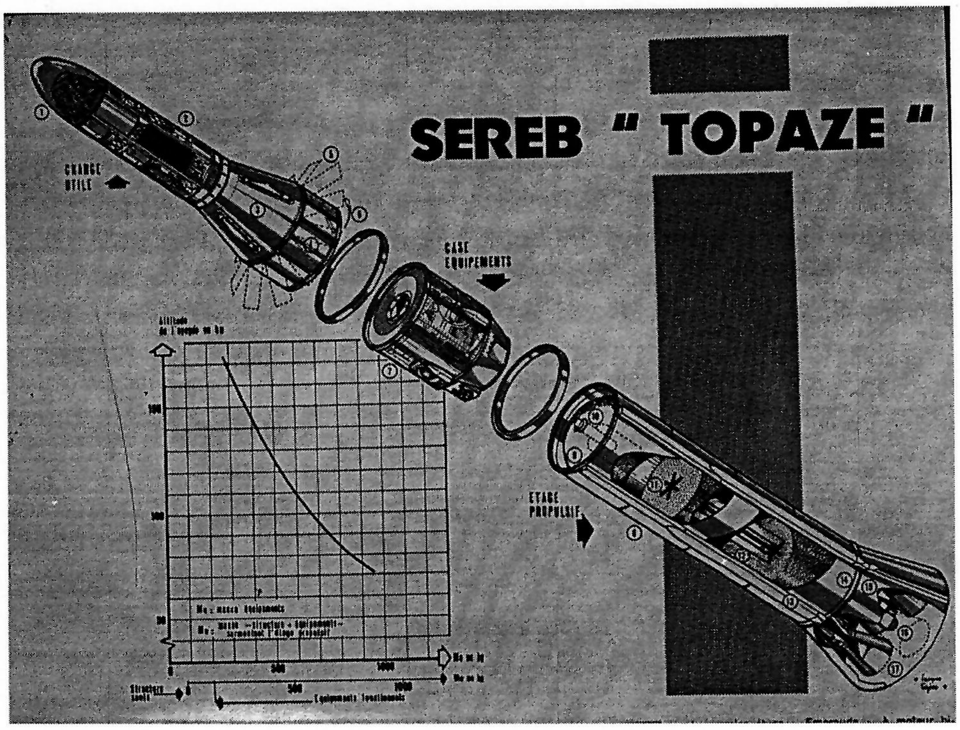
The last ED test, on November 30th, commenced at 10 h 30 m, with the ignition of two ONERA impulsers of 1,200 kg, followed by a simulated flight. Then at 20 h 30 m, the motor was ignited. The firing of two ONERA impulsers of 600 kg at 21 h concluded the test. Everything was fine, with a good correlation between predictions and test results. The explosion of one of the 600 kg impulsers only caused some slight damage to its own bracket.

The way was now open for test flight.

Topaze Description

Besides the technological innovations it brought to SEREB, the VE 111 was also notable in being the first element of the full-blown VE 231 test bed to fly. Things started to become serious, if there was to be any chance of succeeding both timely and technically! In 1963, SEREB switched from naming rockets after the constellations, to the well-known "Precious Stones" nomenclature. Thus the VE 110 became Agate, the VE 111 Topaze, the VE 121 Emeraude and the VE 231 Saphir.

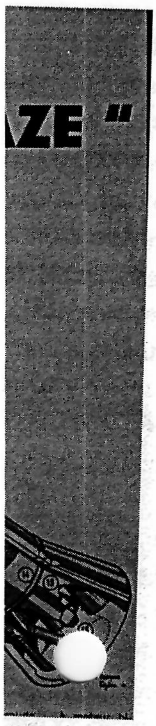
7.07 m long, with a main diameter of 800 mm, Topaze weighed 2,840 kg at launch (the dry mass was 650 kg). A lower skirt was shaped so as to provide neutral aerodynamic stability. Being guided from launch, no ramp was needed on the pad. The rocket's maximum altitude was 80 km, and maximum dynamic pressure was reached at Mach 1.6.



Propulsion

The isolane 20/7 solid block, called Soleil (meaning “sun”), was cast by PNSM (Poudrerie Nationale de St. Médard en Jalles, now SNPE). A 6-point star-shaped central channel in the middle kept the thrust of 12 t at sea level constant. The burn time jumped from Agate’s 18 seconds to 39 seconds. The mass was 1,530 kg, and specific impulse 245 seconds. The Soleil’s overall length was 2.85 m. Before casting, a polyurethane liner (incorporating iron oxide and asbestos) was poured by centrifugation into the casing, followed by hot polymerization. The isolane was then was directly poured into the casing and hot polymerized.

Four nozzles, with their rotation axis offset by 15° to the axis of symmetry, were located at the base of the block. After some trials with conical and egg shapes, an intermediate solution was retained. The throat, of 92 mm diameter, was constructed from ablative graphite/phenolic resin with glass fibers by SEPR (one reference mentions durestos, a mixture of asbestos and phenolic resin). The titanium nozzles, of 264 mm maximum diameter, were also built by SEPR. Ball bearings were used for rotation: joints able to withstand 3,000°C ensured tightness.



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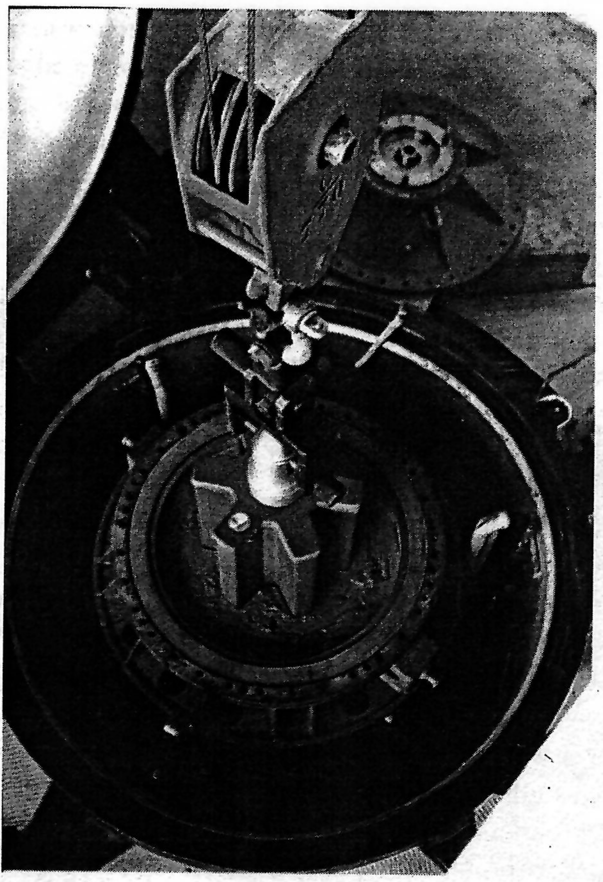


After casting the block, the star-shaped core is removed in PNSM.

A 480 g igniter, made of MI9 powder, was located at the top of the channel, inside a fiberglass envelope. It was initiated by a smaller intermediate MI9 block, itself ignited by two electrically activated Gevelot flames. Numerous tests were performed at Istres to qualify the system, at accelerations of 15 g longitudinally, and 5 g laterally. The complete assembly, with the outer structure, was called NA 802 by Nord Aviation (probably as the second stage built by them with an 800 mm diameter, coming after the NA 801 of Agate). Control tests were performed at Istres.

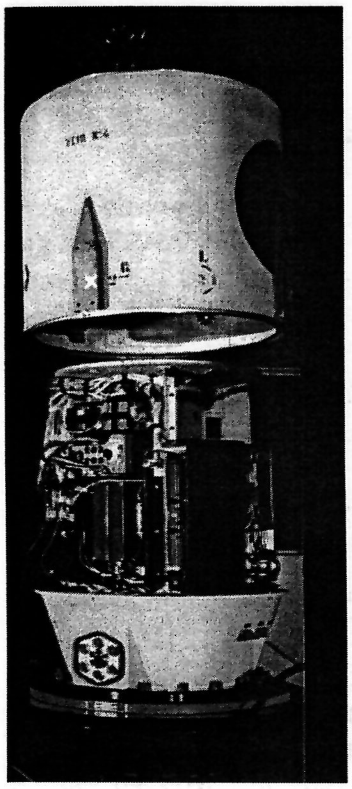
Structure

The conical rear skirt was, as usual, built in Cannes. Of 700 mm height, it was built from Z12CN 18/8 steel of 0.2 mm thickness, stiffened by an intermediate frame and 12 omega-shaped longitudinal stringers. Forward and rearward frames in 15CDV6 Vascojet 90 steel completed the assembly. It was internally coated with Nord Aviation durestos. An upper thermal shield in foam, of 0.25 density with fiberglass/phenolic fabric facesheets covered by aluminum, also incorporated composite sleeves to isolate the nozzles; it was built in Marignane. The rear skirt housed the control loop actuators and an umbilical for the GAP.

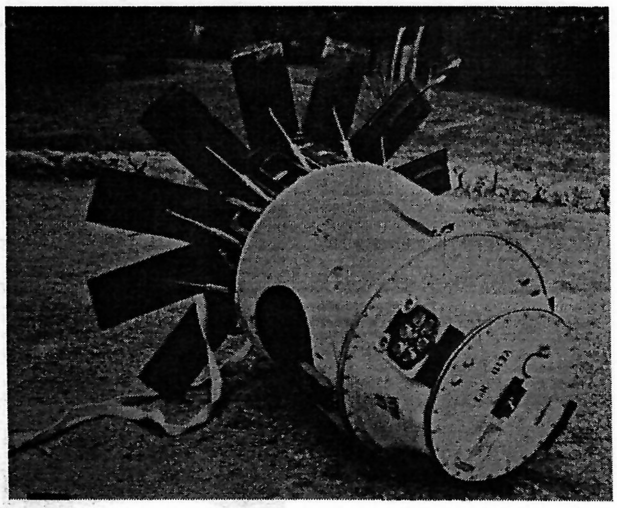
The cylindrical-shaped motor structure, housing the Soleil block, was built by Nord Aviation in Les Mureaux, from 40CDV20 Vascojet 1000 steel, of 1.5 mm thickness. A forward body incorporated 3 welded cylindrical skirts, capped by a welded dome made of a central part and four lateral petals. The central piece supported the igniter, and each petal included an ejectable disc to terminate thrust. The body was closed at its base by an assembly in 15CDV6, comprising an upper spherical dome and a lower elliptical dome, secured by flexible keys. Tightness was secured by a durestos ring. The elliptical dome had a central part for the GAP and four petals, on which the nozzles were attached. The thermal protection for this lower assembly was made by SEPR using carbon/phenolic resin and silicone joints. The body, 2,100 mm in height, was bolted to the lower skirt. Both the motor and rear skirt structures were pistol-coated by PR from Le Joint Français. A thin aluminum sheet was glued on, for protection during transportation.

The forward part of the motor included the forward skin, the equipment bay and the separation bay. The 644 mm high forward stiffened skirt, built by GTC, ensured the interface with the equipment bay, from which it was separated by an ejectable clamp band. Made in aluminum, it incorporated the four ducts of the DAP (Dispositif d'Arrêt de Poussée) system, connecting the ejectable discs of the Soleil to external hatches, which were blown away by gas pressure. The DAP was used to allow precise control of the reentry trajectory. The sequence started when deceleration reached 6.6 gs: after 3.6 s, the air/electric umbilical to the bay was pyrotechnically retracted and the clamp ejected. The discs were blown away 2 seconds later. The first six launches, with Soleil No. 30 to 35 did not use DAPs: their use commenced with No. 36. The skirt supported batteries and the box controlling nosecone separation.

The airtight GTC equipment bay was identical to the one already tested by the previous VEs.[1] It was made from AU4G1 aluminum of 2.5 mm thickness. A lower inverted cone supported a central column from which 4 radial panels delineated four compartments. Forward and rear circular plates capped the assembly. The compartments were closed by a cylindrical outside structure 685 mm high, 50 mm more than for the VE 10/110. The cone housed the batteries, while the compartments contained guidance, Super Cotal and ONERA telemetry equipment. A lateral window allowed inertial platform aiming. Separation from the forward skirt was implemented by 6 jacks. The loaded weight was 274 kg. The GTC separation/recovery bay, 410 mm in height and 142 kg in weight, included Aerazur recovery parachutes and petal airbrakes. Only the rear frame was changed from the VE 10 type.[1]

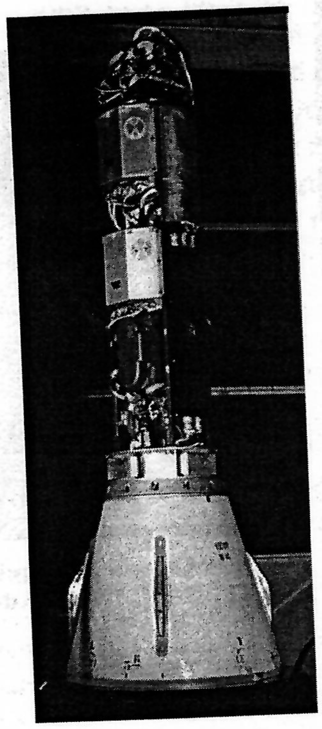


The equipment bay of VE 111 No. 4.



Back in Cannes, the equipment recovery bay of VE 111 No. 7. Note the deployed braking petals.

Finally, the type P nosecone, the prototype of which had been the VE 8, was built by GTC. Weighing 403 kg (although another SEREB source quotes 325 kg), it was composed of a rear skirt, 646 mm high, capped by a 1,361 mm high cylinder in XC18 steel, with a top steel blunt shroud 554 mm in height. Separation from the bay was implemented by an ejectable clamp band, and six pyrotechnical impulsers. Thanks to two outside layers of ablative composite material, internal structure temperature was kept at about 200°C. The skin housed the recovery parachute, two batteries, two flash lights and two dummy flash lights for balance. The central container incorporated an H-section support beam in XC18, on which were mounted the Leach and A22 recorders, the telemetry boxes, the F2 and C3203 commuters and the radar transponder. On top of the beam, a plate housed the forward container, with batteries (4 VB 1200 and 24 VO 15K) and a number of sensors; this container was enclosed by a cover made from XC18. The cylinder supported the four TM/TC and two SECOR antennae. Four longitudinal gutters ran from the equipment bay to the propulsion bay to protect electrical lines. They were attached with stainless steel clamps.



VE 111 No. 4 nosecone inside view: From the top, TM1, TM2 and Leach recorder.

Guidance and Control

The development of the first French inertial loop was GTC's responsibility. The sensors were Référence d'Attitude SFENA 130 or SAGEM E.23 (the gyroscopes), and a Bloc Gyrometrique SAGEM 10.721 G (giving angular speeds). A SFENA 7.524 Programmeur (computer) set the required com-

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mand attitudes. The attitude signals were provided to the Bloc de Commande, the SFENA computer. This equipment, and its battery supply (silver-zinc SAFT V023), was located in the equipment bay. SAGEM commenced the production of its platform in 1960.

In the propulsion bay, orders from the Bloc de Commande were received by the GAP, an AE 90 050 Air Equipment Power Block. Turbine powered oil pumps (pressurized with nitrogen) actuated the nozzles via jacks. Silver-zinc batteries were used.

Telecommand and Telemetry

Telecommand, under the responsibility of GTC, was implemented using a SFENA 250T receiver (whose development was under Suresnes' responsibility) and two Cannes antennae. Its main purpose was to initiate destruction in the event of problems.

The telemetry, also under the responsibility of GTC, was finally delivered in G1 and G2 standards. G1 was itself broken down into three subsets:

- G1A for aerodynamics, flight mechanics, kinematic heating and stresses
- G1B with some variations on vibration and stress measurements
- G1C for the incoming static tests.

For G1C, two SAT transmitters, Suresnes' responsibility, were used for telemetry, on 245 MHz (TM2) and 252 MHz (TM1). They had a main carrier modulated in amplitude, while the sub carriers were frequency modulated. Two antennae were built by Cannes. Two ONERA telemetry chains at 87 and 94 MHz were used to record the acoustic noise with microphones. These were checked out by having someone yell as much as he could!

The SECOR system was used for positioning, as well as the Super Cotal radar. SECOR had three receiving stations for triangulation: Hammaguir, Colomb-Béchar and Béni-Abbès in Algeria. The equipment was powered by 28Volt VB 100 batteries. For the Super Cotal radar, two CFTH Thomson Houston RS2 transponders were used (one each for the nosecone and the equipment bay). Finally, the flash lamp previously utilized on earlier VE's, was also used.[1] This equipment was located in the nosecone.

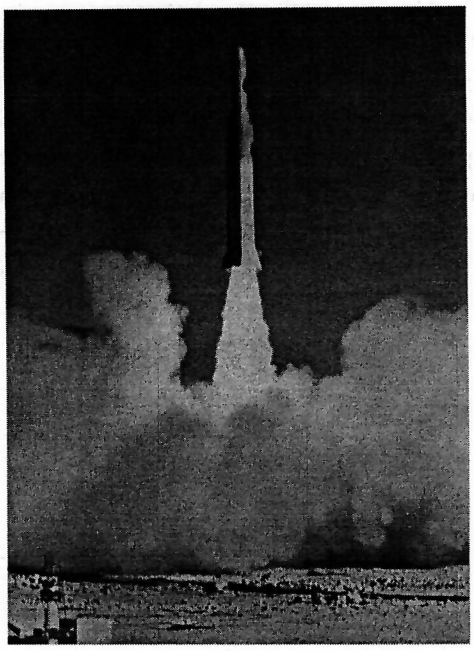


Photo of one of the first three launches of VE 111.

The First Flight from Hammaguir

VE 111 No. 3 and No. 4 were first tested in Istres, before being sent to Hammaguir via the Colomb-Béchar airport in the Sahara desert. They were equipped with a new C3212 version of the SFIM Commuter, a GTC Sacom commuter instead of the F3, and a SFIM 47.094 Converter. The SECOR, Ledex, SFENA telecommand and flash unit were not mounted, and a new G1D measurement loop had small changes in the number and location of its sensors.

On December 12th, VE 111 No. 3 rose from its Brigitte pad, beginning a successful flight, with a good control, which ended with recovery of the nosecone and the equipment bay. Detailed analysis showed some oscillations in pitch and yaw 3 seconds before burn out, followed 2.5 seconds later by roll initiation. Between burn out at 46.7 seconds, and nosecone separation at 55.5 seconds, this oscillation increased, due to the lower dynamic pressure. However, the trajectory kept within lateral limits, though this was not the case in-plane. The rocket reached an altitude of 20 km, with a range of 15 km. This was the first French flight of an inertially-guided rocket, although there was no integrated inertial platform as such. (In fact, SFENA never was able to gets its own platform to work properly, unlike the SAGEM one.)

A second launch campaign took place early in 1963. VE 111 No. 4 was launched on March 22nd, 1967, again with good results. Only one incident is recorded, the loss of a parachute at opening, however this did not prevent a successful recovery. The next launch, No. 7, inaugurated a new preparation procedure, with the CAPE (Centre d'Achèvement des Propulseurs et des Engins) in St. Médard, near Bordeaux, in the loop. The work was still performed by GTC personnel, but assembly and disassembly were done by SEREB, with GTC assistance. SFIM C 3203s were again used. A new G2 measurement loop also was installed, with slight variations of sensors. With problems during acceptance of the SECOR and flash on the test table in Cannes, this equipment was still not mounted. On March 16th, an initial simulated flight was performed in horizontal position. Some vibrations were recorded on nozzles B and D in yaw, due to a yaw gyro in the Bloc Gyrometrique. Then, on the 19th, a similar test was performed in the vertical position. The launch, on the 28th, was successful, although the nosecone suffered damage due to hardness of the landing site.

At this point, the program was publicly acknowledged by SEREB, under the name of Topaze, and the first details revealed. The achieved results allowed such disclosure, since the very concept of deterrence is based upon the adversaries knowing their respective capabilities.

The third launch campaign took place in June, with flight No. 8 utilizing a SFENA guidance platform, and No. 9 a SAGEM one. Both now had SECOR and flash lamp on board. No. 8 flew with zero yaw, and perturbations in pitch and yaw. No. 9, with zero roll and yaw, had perturbations introduced in pitch and yaw and on the nozzles. Both flights went well, although the equipment bay of No. 9 was not recovered.

Progress was such that No. 10 was entirely prepared at CAPE, going directly to the launch pad in CIEES. Once again the flight was successful, although the initial launch command produced no response, despite pushing the button for more than 20 seconds! The second attempt still required pushing for 4 seconds before the rocket finally decided to launch. The problem resulted from some interference on a relay.

A total of 10 flights had been planned, but with the excellent rate of success achieved, it was decided to halt after these 6 tests, and modify the last four vehicles into a new unstable version, the VE 111Ci (Court instable, meaning "short unstable"). Such necessity appeared in the course of the program, when on-going parallel studies led to a MSBS of cylindrical shape as space was at a premium in the submarines. Without fins or even skirt, the stability of the MSBS thus had to be quickly proven.

Another significant change had already appeared by May 1962, when a lengthened version, VE 111L (L for Long), is mentioned. The cause was an increase of the performance of the VE 231, which could be better achieved at the level of the second stage: this stage was the most advanced in development, since the first stage was still under study, and furthermore it placed SEREB closer to the operational missile. The original VE 111 then became, retrospectively, the VE 111C.

The Lengthened VE111L

The main change in this new version was at the level of the Soleil block, the increased length of which brought the overall height to 8.022 m. Heavier by 700 kg, it burnt for 44 seconds. The VE111L nozzles were made from parastrasil, a silica/phenolic resin fabric wrapped around a mandrel and polymerized under pressure (although another source cites graphite being used). The nozzles also had a larger exit diameter of 300.7 mm, impacting on the cutouts of the thermal shield, but increasing the thrust to 15 t. This new NA 803 motor had a length of 3.022 m. Static ground tests began in July 1963, at Istres, and were successful, with the exception of the second one when, after 30 seconds of perfect operation, the rear dome suddenly broke away, as the increased characteristics of the new motor had led to higher thermal fluxes than foreseen.

On the rocket, the skirt was modified internally, with the upper cone increasing in height from about 160 to 240 mm, while the overall height remained at 700 mm. In July 1963, Roger Chevalier decided to use a new lighter version of the GAP, with an electric motor and a 30V battery. In September, it also was decided to use the same destruct command box as for the VE 121. These changes modified the first mode of the stage, decreasing it by 2 Hz. At the same time, the deletion of the DAP thrust termination system was confirmed.

Development of this new version entailed additional wind tunnel testing. The tests were defined in September 1962: the 1/25 mock up, suitably modified, was to be tested at LRBA up to Mach 3.2. At EAT, the equipment bay structure was also to be subjected to combined mechanical/thermal stresses, corresponding to VE 231 flight loads, possibly up to rupture. It was planned to use Nord 2501 Noratlas or Bristol 170 cargo planes for transportation.

The first VE 111L was launched on December 12th, reaching an altitude of 74 km. The second one followed on March 3rd, 1964, with a new SFENA 0129 Command Block and a heavier solid of 2,260 kg. At launch, the umbilical collided with the ignition cable, but only a small control anomaly was recorded at 34 seconds.

VE 111LR, VE 111R, VE 111LI, VE 111LP Projects

In the meantime, the basic VE 231 was being progressively defined in 1962, in the wake of the top level decisions, and the flight results of the GTC VE's. Thus, three versions were selected:

- the VE 231P (Propulsion), to qualify liquid and solid propulsion, control and separation
- the VE 231G (Guidé), to qualify the inertial guidance, thrust and termination systems
- the VE 231R (Rentrée) to qualify the re-entry.

All these versions had the new, fatter nosecone, to be tested by the VE 110RR, as well as a modified wider equipment bay. The R version, however, had a smaller and lighter bay, without cylindrical extension, so as to be able to reach maximum range and re-entry speed.

The idea was to continue preparations for the VE 231 versions by flying its upper stages earlier in the form of corresponding VE 111 marks. Therefore, by October 1962, the VE 111LR already had been defined as the VE 231R second stage. Of M2 (or M', as the 231R had the M) standard, two vehicles were planned for test in June 1964: No. 3 and 4, coming after the two VE 111L tests. However, they were, curiously, to use the full 231G equipment bay, probably because the motor performance allowed such a mass to be flown, and testing guidance equipment was more important than re-entering at a speed lower than that of the VE 231.

A February 1963 reference has been found to a VE 111R, with a recoverable nosecone using an Aerazur parachute. This probably corresponds to the use, on a short VE 111C, of the VE 110RR nosecone, being thus probably replaced by the lengthened VE 111LR version, with higher performance. But a letter March 13th, 1963, refers to the decision taken to replace the VE 111LR by the VE 111LP, the second stage of the VE 231P. This was probably due to the lack of interest in flying a lower speed VE 1111LR for reentry tests. Waiting for the VE 231R must have been considered more profitable. Thus, the equipment bay structure was the same as for the VE 231G, and the measurement loop of N2" standard (where the 231G had N). Eventually this version did not proceed: with the VE 111 propulsion fully qualified, the only interest was to test, as soon as possible, the guidance equipment of the future VE 231G, with VE 111LG No. 5 and 6.

In the same vein as the VE 111Ci, a VE 111LI (Long Instable) was planned to study the stability of the future MSBS. Wind tunnel testing was defined in April 1963, to take place at LRBA at various Mach numbers (1.51–2.14–3.2), still using the 1/25 mock up. With vibration testing at Les Gâtines, an annex of Châtillon, also being planned, Cannes was asked to deliver there the forward and rear skirts already used for VE 111C vibration tests. It was eventually realized that such stability tests could as well be performed with the shorter VE 111C, of which 4 examples were available for modification, so this version was not pursued.

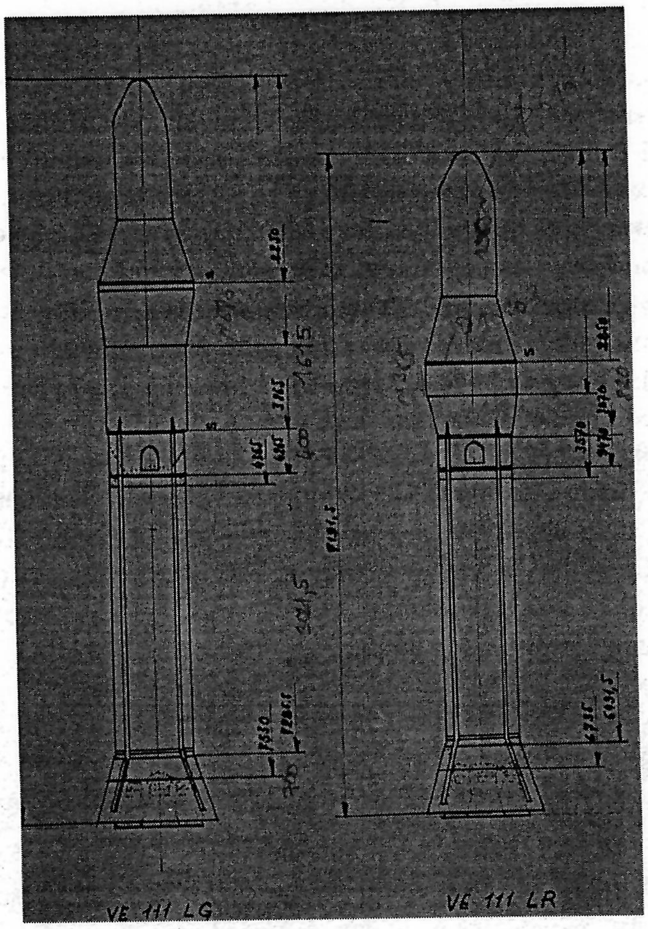
While considering unbuilt projects, it should also be noted that reference has been found on studies of a NA 806 motor, equipped with a single nozzle.

The Unstable VE 111Ci (VE 111I)

As noted above, the last four VE 111C were modified into VE 111Ci (also called initially VE 111I) to examine the feasibility of controlling the highly unstable MSBS. The transformation was similar to the one which had been planned initially from the VE 111L to the VE 111LI, essentially by using a lighter skirt. The maximum diameter was decreased from 1,260 to 1,039 mm. In April 1963, a wind tunnel program was established, using the modified 1/25 mock up in Vernon, with new skirt and gutters. The aim was to measure aerodynamic coefficients, drag and longitudinal stability at Mach 1.5–1.85–2.45. An analysis in May proved that the VE 111Ci could validate the stability of the MSBS statically (wind profiles), but was not as useful for the dynamics (wind gust), due to its lower speed compared to the strategic missile.

Additional testing also was planned for September in the Suresnes tunnel, on the 1/35 mock up, between Mach 0.7 and 1.65, with a program similar to the LRBA tests. The goal, as defined in July, was to perfect the control loop.

As already noted, the four VE 111Ci were obtained by modifying the VE 111 No. 11 to 14, which meant building new skirts. These were of reduced height, and with a smaller angle, to achieve aerodynamic instability. The skirts of No. 11 and 12 were then transferred to the two VE 111LG, and the manufacturing of the latter's skirts was stopped.



The launch of Ci No. 1 took place on June 4th, 1964. The GAP was initiated at minus 13 seconds, followed 3 seconds later by the release of the platform. The umbilical was removed at minus 3 seconds. But disaster quickly struck. The minor change in the skirt shape had, in fact, led to higher thermal fluxes than was foreseen, and the autopilot cabling was burnt out at 15 seconds. Soon the Topaze was arcing back ... to the launch pad, which saw everybody running for cover! Fortunately no one was hurt: it was the only failure in the entire Topaze program.

SEREB, however, was in very bad shape during this period. Newly arrived in the business, Nord was experiencing its share of trouble with the VE 121, already much delayed. To compound this, when the first VE 121 was launched finally on June 17th, two weeks after the VE 111Ci failure, disaster struck after only 10 seconds, when control failed. The second flight, on June 25th, ended in an explosion after 55 seconds: the Pogo Effect was being discovered. Then, on October 20th, the third Emeraude again exploded at 56 seconds!

The situation therefore was quite tense the following day in Hammaguir. Personnel and material had arrived from Paris Orly on the weekly Caravelle, and from Istres on CIEES Noratlas and DC-3 shuttles, to launch Ci No. 2. In the aftermath of the failure of No. 1, the base of the second vehicle was covered with thermally sensitive paint to check thermal fluxes. As a result the launch was successful and everybody was relieved. After peaking at 49 km, the bay was recovered 20 km away and the nose cone at 23 km. An Alouette II helicopter retrieved the parachutes. However, after analysis, it was decided that it would be better to add a 4 mm thick steel plate at the base to protect the equipment of the rear skirt.

Flights No. 3 and No. 4, with SFENA platforms, Leach MTR 800 and loop G1A (and four 1,200 kg ONERA pyros?), went very well on December 11th and 15th, after simulated firings on November 28th and December 4th respectively. Only the failure of the parachute prevented recovery of the nosecone of No. 3. Propulsion was slightly under performance, while the yaw loop had small oscillations for No. 4.

The VE 111LG

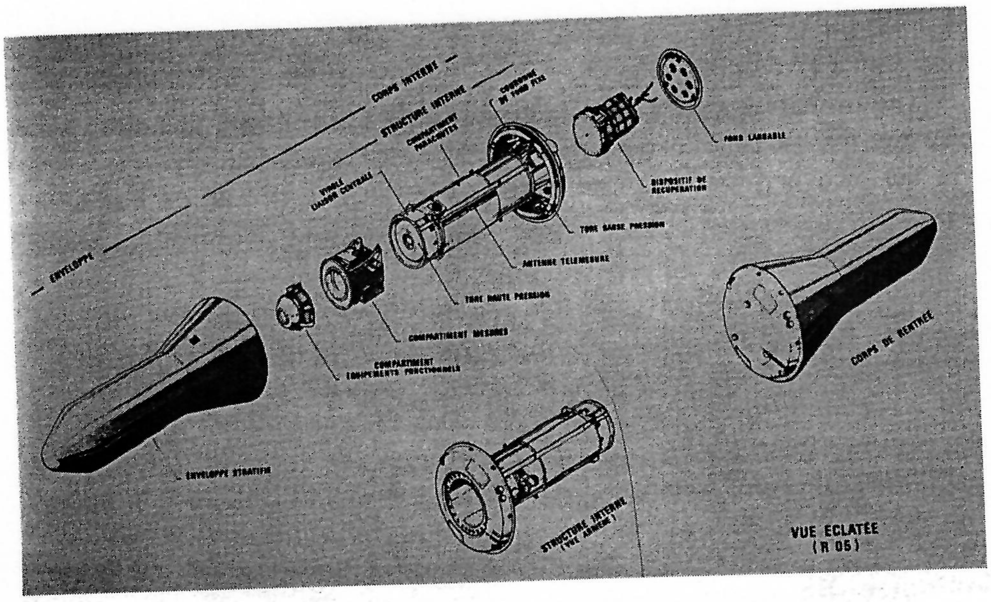
A final VE 111LG (Long Guidé) was initially defined by October 1962, curiously with a VE 231 R equipment bay. Two flights had been planned, No. 5 and 6. Eventually the vehicles were duly equipped with the VE 231G bay. This was to be the important first test of the exact upper stage configuration of the Saphir, including controlling the re-entry of the new nosecone.

Nosecone

The bigger Thesa nosecone was built by Courbevoie on the basis of several constraints: low drag, low mass, low heat fluxes, maximum volume and stability for the whole flight envelope. Having been already tested on the four VE 110RRs, its cylindrical section was wider—600 mm diameter—in order to accommodate various equipment. The stability requirements then defined the skirt dimensions, with a maximum diameter 1.025 mm bigger than the VE 111 diameter. The upper nose was of spherical shape, followed by a conical section interfacing with the lower cylinder.

The outer structure was a honeycomb/fiberglass sandwich, on which orthostrasil was glued. Orthostrasil was a silica/phenolic resin fabric, laid up on a mandrel and pressure polymerized, the fibers of which were perpendicular to the surface. Stiffening aluminum frames were glued to this structure, which also included silica windows for antennae (both on the skirt and the cylinder).

Inside, a rear compartment of cylindrical shape was linked to a curved cap, which closed the nosecone. The cap had a jettisonable central door, for parachute extraction. It housed the control equipment. Above, an H-shaped central compartment contained the measurement equipment. Finally, a hexagonal forward compartment held the batteries and functional equipment. Internal pressure was maintained at 500 mb.



Exploded view of the VE 111LG "Thésa" nosecone.

Stabilization was maintained by a combination of measurements and predefined values. A Barnes infra-red horizon detector and a diagonally opposed Sextant Sun sensor at the base of the nosecone allowed measurement of the attitude before reentry. The Sun sensor was qualified during the winter of 1964/1965 at the Montlouis solar center. Command electronics and a sequential programmer, in the upper bay, activated 6 thrusters with electrovalves (two per axis) at the base of the nosecone. The propellant was nitrogen, stored in an high pressure (250 bars) ring-shaped tank made of Maraging steel, connected to a low pressure (20 bars) ring in aluminum, both located in the lower bay. 1.6 seconds after separation, pitch thrusters implemented a pre-determined pitch over, followed by initiation of roll stabilization with the roll thrusters. Then, pitch and yaw thrusters were used to dampen oscillations.

The middle bay housed telemetry equipment. The new transistorized SAT Ajax system (to the American IRIG standard) was used.[*] It had already been tested in 1963/1964 by the two J standard VE 10A. The radar transponder (Motorola), the SECOR box, a Tolana A4310 magnetic recorder, mechanical and electronic commuters and various sensors (including a five-gyrometer block and seven accelerometers for analysis of the re-entry) completed the fit out. TM1 was used for the entire flight, while TM2 initially only transmitted during the powered phase. A few seconds before re-entry (and its corresponding black out, the speed reaching to Mach 15 in the case of the VE 231), TM2 was re-activated, reading the measurements of the recorder with a 12 seconds delay.

The two silver-zinc SOGEA batteries (27 V - 7 Ah) were of a new type, with a high mass to capacity ratio: they were activated pyrotechnically.

For recovery, the use of an Aerazur 64831 chute of 3.86 m^2 had been planned in January 1961, as a possible replacement for the Radioplane (later Northrop) assembly selected for the VE 110RR. When deceleration reached a given level, three pyrotechnical jacks ejected the bottom door, thus extracting the pilot chute. It, in turn, trailed the drogue chute, which after a given time extracted the main chute, first partially opened, then fully un-reefed. After landing, the chute was separated, and a beacon activated. A floatation bag also could be inflated for maritime recovery.

This nosecone was of quite advanced design, and, indeed, on Saphir high accuracies of only 100s of meters were achieved at ranges of 2,000 km.

Equipment Bay

A new, non recoverable, equipment bay was used, constructed from aluminum. A central column supported four radial panels delineating four compartments. Upper and lower circular panels, as well as an inverted cone, enclosed closed this volume of 725 mm height. It was topped by a cylindrical skirt of 390 mm height, attached with a clamp.

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[*] Beginning in 1966, GTC would commence the development of a new standard, to be used for strategic missiles, called PCM Cannes.

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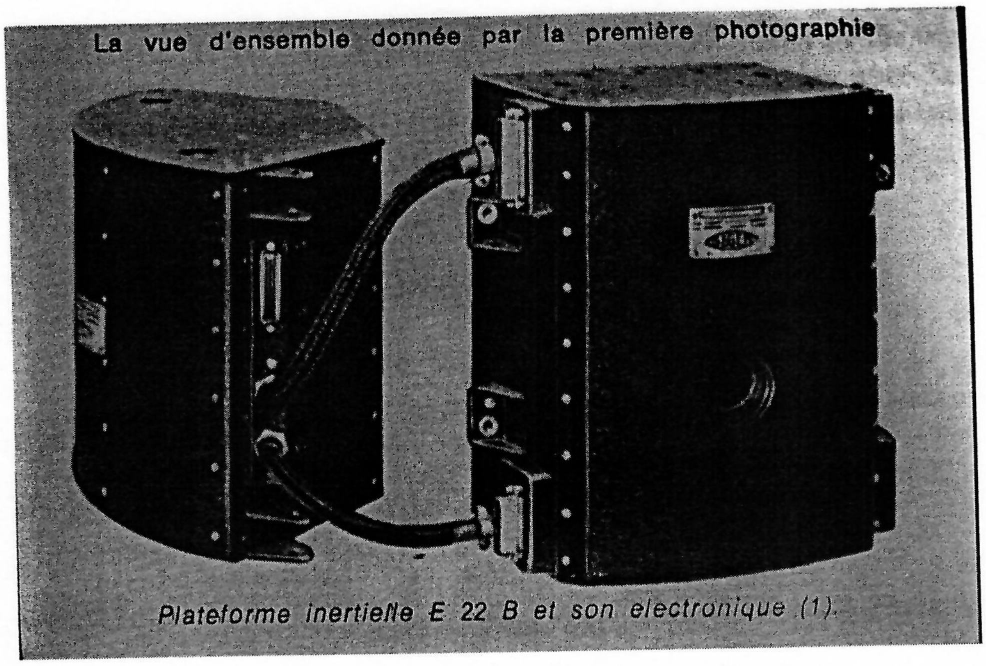
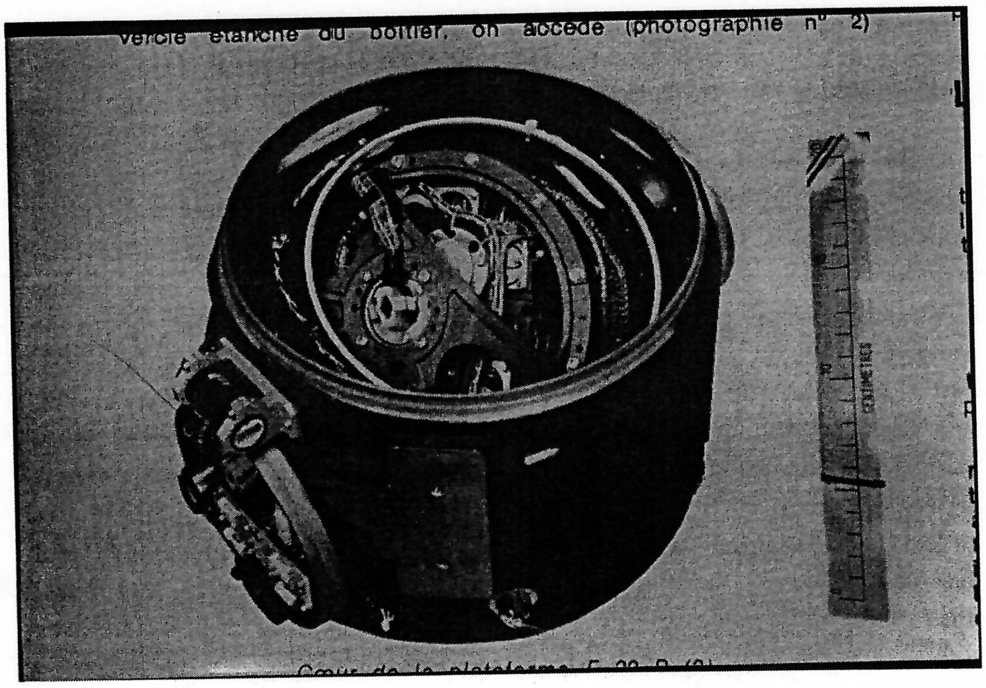
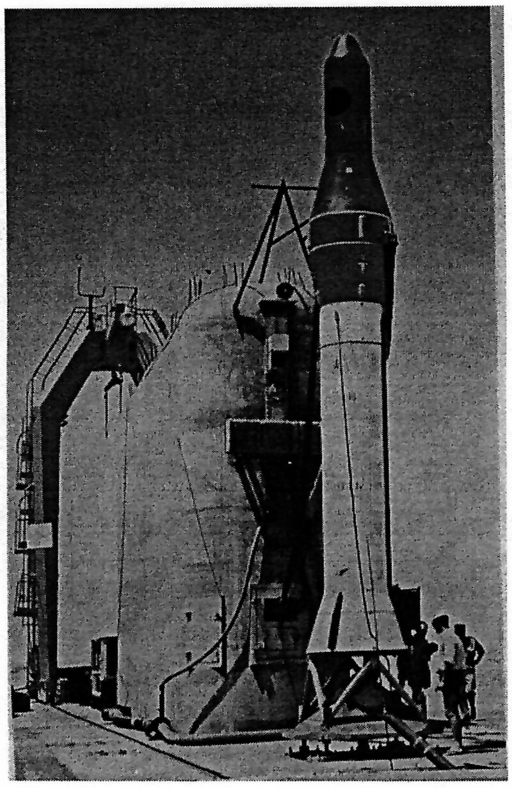


SAGEM E22B platform, with its electronics.



SAGEM E22B core unit.



Both launches went well. On May 18th 1965 No. 1 became the first inertially guided French rocket, followed three days later by No. 2.

The bay housed the guidance and control equipment, including an E22B SAGEM platform (SAGEM A gyro + SAGEM accelerometers) and its electronics, and a SAGEM C640 computer. It represented significant progress, as this was the first French fully integrated inertial platform: it also delivered all parameters in a single digital signal, of digital format, where the previous equipment had worked only in analog mode.

There were also two new TC 601 Sud Aviation telecommand receivers, three Sud electronic commuters and an Ajax transmitter. Batteries were bolted below the bottom of the bay. Two umbilicals, with 6 Deutsch connectors each, were pyrotechnically ejected before launch. Air ventilation was similarly implemented with an ejectable connector (both for the bay and nosecone). The new thermal screen successfully used on the Ci was maintained and a more powerful AE 90 160 GAP, at a pressure of 250 bars, was used.

Initially, the development of the guidance system was marred by failures, delaying, among other items, the MFG (Maquette Fonctionnelle 231G)

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mock up. But, in the end, solutions were found, as shown later by the successful VE 111LG flights. Both launches went well: on May 18th, 1965 No. 1 became the first inertially guided French rocket, followed three days later by No. 2.

Conclusion

The Topaze program, with, only one failure out of 14 launches, was an outstanding success. It was a seminal rocket, as it allowed France to develop:

- its first inertially guided rocket
- a recoverable high accuracy re-entry vehicle, soon to fly at half orbital speeds.

All the basic components for ballistic missiles (and astronautics as well) had now been qualified by GTC, vindicating De Gaulle's Force de Frappe decision. It only remained for the 2-stage Saphir to expand the flight envelope of the nosecone to Mach 15 speeds.

Topaze thus was to continue flying for some time, with 15 Saphir, 4 Diamant A and 5 Diamant B vehicles, for a grand total of 38 flights. However for GTC, it meant losing the VE 111 prime contractorship to Nord Aviation, although it retained all technical responsibilities for control, TM/TC, separation and the equipment bay (all SSBS and MSBS bays were later built in Cannes as well).

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[2] Jung, Philippe, "The X 422: The First Cruise Missile in History," in Donald C. Elder and George S. James, eds., *History of Rocketry and Astronautics*, Proceedings of the Thirty-First History Symposium of the International Academy of Astronautics (Volume 26, *AAS History Series*) (Univelt, Inc.: San Diego, 2005), pp.313-353.

[3] Villain, Jacques "La Force de Dissuasion Française. Genèse et Evolution," *Docavia 26*.

[4] Jung, Philippe, "The French SE 1900 and SE 1910 Rocket Sleds," in Lloyd H. Cornett, Jr., ed., *History of Rocketry and Astronautics*, Proceedings of the Twentieth and Twenty-First History Symposia of the International Academy of Astronautics (Volume 15, *AAS History Series*) (Univelt, Inc.: San Diego, 1993), pp.395-414.

Test date	VE 111 No.	Platform	Measurement standard
25.7.62	1	SFENA?	G1C
26.9.62	5	SFENA	G1C
30.11.62	2	SFENA	G1C

Launch Date	VE 111 No.	Platform	Measurement Standard
19.12.62	3	SFENA?	G1D
22.3.63	4	SFENA?	G1D
28.3.63	7	SFENA?	G2D
21.6.63	9	SAGEM	G2D
27.6.63	8	SFENA	G2D
24.10.63	10	SAGEM?	G2A
21.12.63	LNo. 1		G1D
11.3.64	LNo. 2		G1D
4.6.64*	11(Ci-1)		G2A
21.10.64	12(Ci-2)		G2A
11.12.64	13(Ci-3)	SFENA	G1A
15.12.64	14(Ci-4)	SFENA	G1A
18.5.65	LGNo. 1		L2
21.5.65	LGNo. 2		L2

* Failure

* All launches from Brigitte base in Hammaguir

No. 6: the model, to G1 standard, in Les Mureaux

	VE111 (VE 111C)	VE 111M (VEM111)	VE 111L	VE 111LR	VE 111R	VE111LI	VE 111LP	VE 111Ci (VE 111)	VE 111LG
1st flight	19.12.62	-	21.12.63	-	-	-	-	4.6.64	18.5.65
Length (m)	7.07	7.07	8.022	7.192		8		7.08	
Max diam (mm)	1.26	2.3	1.26	1.26		1.04	1.26	1.04	1.26
Mass (kg)	2,840		3,700						
Motor	NA802	NA802	NA803	NA803		NA803	NA803	NA802	NA803
Motor mass (kg)	1,530	1,530	2,260	2,260		2,260	2,260	1,530	2,260
Motor diam	800	800	800	800		800	800	800	800
Thrust (t, sea lev)	12	12	15	15		15	15	12	15
Burn time (s)	39	39	44	44		44	44	39	44
TM standard	G1,G2		Gl	M2			N2"	G1,G2	L2
Nosecone	P	P	P	Thésa		P	Thésa	P	Thésa
Inertial P/F	SAGEM E23 SFENA 130							SFENA	SAGEM E22B
Equipment bay	VE111		VE111	VE231G		VE111	VE231G	VE111	VE231G
Speed	M3.2?								
Altitude (km)	80		130						
Number built	10	-	2	-	-	-	-	4	2
Num. launched	6	-	2	-	-	-	-	4	2