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Chapter 4

Etude 4212: The First French Large Liquid Rocket Project*

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Introduction

If the first post-war rockets developed in the United States (the Redstone) and in the Soviet Union (the R1 and R2) were closely based on the German A4 (V2) missile, such was not the case with the first French rockets, such as Véronique or Eole. However, these rockets were preceded by a design study for a long-range ballistic missile, the project 4212, that was a distinct A4 derivative.

The story of this specific project is not very well documented, probably due to the fact that it was never completed: no 4212 was ever built or tested. But this story is of great importance, for this design shaped the future of French rocketry for the next 30 years.

Background

Before studying the 4212, it is necessary to look at the immediate post-war situation. At the end of the war, the Allies began to analyze and take over the German advances in the fields of aerodynamics, propulsion, rocketry, etc. As early as May 9, 1945, a French military mission visited rocket-related sites in

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southwestern Germany and recovered many important pieces of hardware and documents. On August 13, 1945, the DEFA (Direction des Etudes et Fabrications d'Armement) suggested the creation of a Rocket Research Center that would perform the important task of analyzing, reproducing, and improving upon the A4. In order to manage such activities, two organizations were created. The CEPA (Centre d'Etude des Projectiles Autopropulsés) was a strong theoretical "think tank," and the LRBA (Laboratoire d'Etudes Balistiques et Aérodynamiques) that was established in Vernon in western France on May 17, 1946, having the responsibility of designing, manufacturing, and testing future rockets.

It must be kept in mind that France's experience with large rockets was very limited. The French authorities felt that the only way to acquire the know-how necessary to develop new weapons was to hire German specialists. They "could not only bring their know-how to the design of French missiles, but also transmit it to young French engineers." In May 1946, the first contracts with former Peenemünde employees were signed, followed by some more. These engineers and technicians were subsequently gathered in the region around Riegel and Emmeningen in southwest Germany. Here, in a former restaurant, they started to "reconstruct" the A4. It quickly became obvious that if the technology and know-how related to the A4 could be assimilated in less than three years, a rebuilt A4 would still be available no sooner than 1952. That was clearly unacceptable to French authorities. But in the mean time, the German team had been thinking and had created a proposal to their French customers dated September 21, 1946. These "Propositions de Travail" (Work Proposals) suggested the design of two A4 derivatives, retaining the basic shape but with much improved characteristics and performance. These proposed missiles, named R1 and R2, were adopted by the French military in a program started in 1947 and given the military name Etude 4212. This operation was very similar to the Hermes Program of the United States.

Development History

The origins of the 4212 can be traced back to 1942, when a young engineer named Heinz Bringer suggested simplifying the A4 by replacing the complex turbopump feeding system with a much simpler one using tank pressurization by means of a gas generator. The A4 design having been frozen, his plan was utilized only for the later Wasserfall missile. In the early days of the Riegel Design Bureau, this concept was resurrected. The French army requirements were for a "rocket whose efficiency and design could be improved in comparison to the A4." The first rough calculations performed through mid-1947 showed potential ranges being 4 to 6 times higher than those of the A4. The basic requirements were then established as follows:

- Military load: 500 and 100 kg
- Propellants: Liquid oxygen/alcohol; Nitric acid/Alcohol
- Feeding system: Turbopump; Tank Pressurization.

However, before the actual rocket design could be undertaken, some basic know-how had to be acquired. Therefore, the first task undertaken by the German specialists was to "reconstruct" the A4, as requested by DEFA on August 13, 1945. In June 1946, the first proposals for the new rockets were issued. This first study suggested to "update" the design and to use this "updating" to increase the range, to improve the accuracy and to simplify the manufacturing process of the A4. The first objective was to be fulfilled by increasing the propellant capacity and by using structural tanks (the A4 had separate tanks that were heavy). The structural weight was also to be reduced by simplifying the shape of the A4 tail: a cylindrical shape replaced the "boattail" design. The range was also to be increased by increasing the ejection velocity of nozzle gas and by increasing the temperature of the combustion chamber while improving its geometry. The accuracy could be improved by a better "tuning" of the engine. The manufacturing was to be simplified by four main changes:

- Structural tanks with baffles
- Simplified links
- Simplified tail geometry
- No turbopump.

It was allocated the project number 4212, which was apparently reserved to vehicles developed at Vernon (General Barrés's second rocket EA46 was allocated the number 4211, the sounding rocket Véronique whose design started in 1949 was allocated the number 4213). The proposal foresaw a design duration of only one year (which was overly optimistic) and required the construction of no less than five test facilities.

The result of these studies was a missile with a range of 600 to 900 km, two to three times the A4 performance. Further improvements were also considered for future versions:

- A winged rocket gliding further away
- A cruise engine (range : 4000 to 6000 km)
- A winged rocket with a second stage (range 6000 to 9000 km)
- A two-stage rocket.

In order to save time and due to the (temporary) lack of wind-tunnels, the basic shape of the A4 was retained. Only the tail was modified in order to simplify its manufacture. Guidance systems were those of the A4. The "innards" of the vehicle were very different from those of the A4: structural tanks were selected in order to save weight. In order to avoid "sloshing," these tanks were fitted with baffles. The "boattail" was replaced by a cylindrical shape and the tail planes were slightly wider at their roots. The nose cone that contained the military load was to be separated from the main body by means of explosive bolts. This was to avoid the disintegration observed on many A4s when the rocket reached the latter part of its trajectory.

These proposals were refined and formalized by a much more detailed proposal dated 21 September 1946. In this new document, the basic requirements (increased range, improved accuracy and simplified manufacturability) were addressed in more detail:

Range:
- Increased from 340 km to 700/800 km.
- The culmination (in the case of a vertical launch) is to be increased from 150 km to 320/400 km.
- The maximal speed is to be increased from 1640 m/s to 2500/2800 m/s. This was to be reached by increasing the launch weight/final weight from 3 to 4.5 or 5.5 and by increasing the ejection velocity and by increasing the initial acceleration from 2g to 2.5g.

Manufacturing simplification:
- Structural tanks
- Stressed skin
- Simplified tail geometry
- Simplified propulsion system.

This later point is of interest as it establishes some of the foundations of later projects developed in Vernon:
- Replacement of the former 18-element injector from the A4 engine by a new design using a lateral injection system with a double-wall chamber
- No valves required
- Use of turbine drive-gas to pressurize the propellant tanks
- Alternatively, use of pressure-fed engines.

This later system (see Figure 1) used a water-cooled gas generator to generate gas used for pressurizing propellant tanks and feeding the engine. In case of a turbopump, its turbine was to be started with compressed air on the ground. After ignition, hot gas taken from the combustion chamber was used to drive the turbine. The proposal ended by suggesting that the pressure-fed version be selected if large quantities were to be built. At that time, many propellant were considered for use: alcohol, benzol, gasoline, liquid oxygen, nitric acid, tetranitroethane, etc. But it was too early to decide on that matter.

A meeting in Paris in August 1946 decided to initiate the first design activities. At that time, only limited changes were foreseen, and only where the A4 had been modified. This was the case mostly for the engine (new chamber design, new injector, new propellants, various combustion temperatures, different chamber sizes, different combustion pressures), for the pressure-feeding of the engine, for the turbopump system and its regulation, and also for the valves.

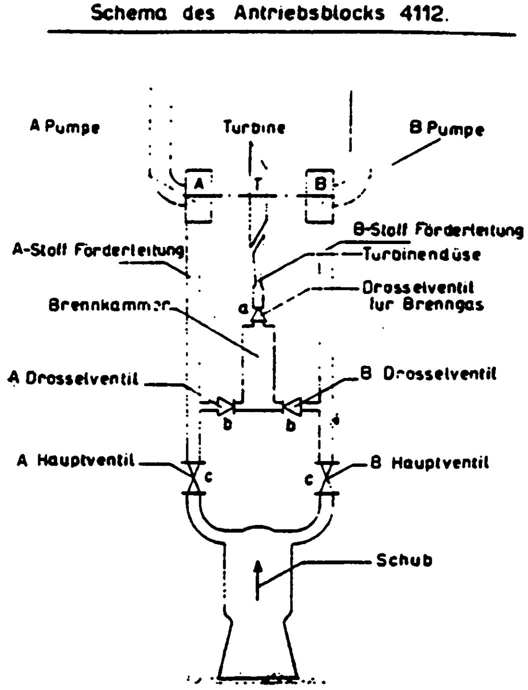


Figure 1 Proposed propulsion system with gas generator and pressure-fed engine.

No less than four possible derivatives were also considered. These formed "further steps in the rocket development" (doc Riegel 2.10.46). It was strongly suggested to "keep an eye" on them. These variants were the following:

- A winged rocket, range increased by 50%
- A vehicle fitted with a cruise engine, range: 4000 to 5000 km
- A two-stage rocket with cruise engine, range: 6000 to 10000 km
- A two-stage rocket without cruise engine, attitude increased.

Detailed design followed, beginning in late September 1946. Apart from the propulsion studies, the vehicle mechanical structure was refined. This applies particularly to the tail whose geometry was modified (see Figure 2). Difficulties soon appeared in this area: in a meeting dated 11 September 1946, it already appeared that the engine was too long to be accommodated in the original A4 tail.

In October 1946, the main versions appeared to have been named R1 and R2. It is not known precisely why this acronym was chosen: R could have stood for Rakete (Rocket) or for Riegel. On 18 October, the thrust of both versions was frozen, but varied according to the propellants still under consideration. In the case of the propellants Salbei and HAP871, the thrust was to be 45 metric tons. In case the liquid oxygen/alcohol mixture was to be selected, the thrust was to be only 40 tons. The R1 was the pressure-fed version, the R2 being fitted with a turbopump. Both rockets were to carry either 500 kg or 1000 kg loads.

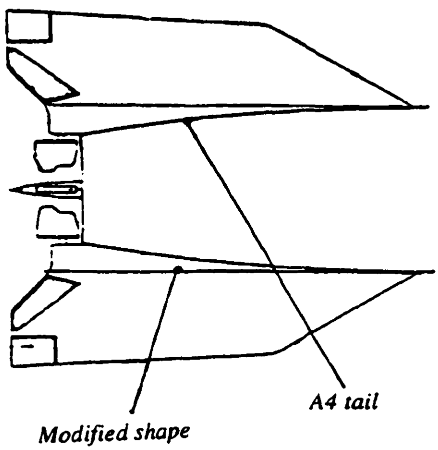


Figure 2 Simplified tail geometry.

At the same time appeared an interesting modification of the tail. Some sort of stiffeners that reinforced the tail fins and tried to increase the somewhat restricted stability of the rocket were added (see Figure 3).

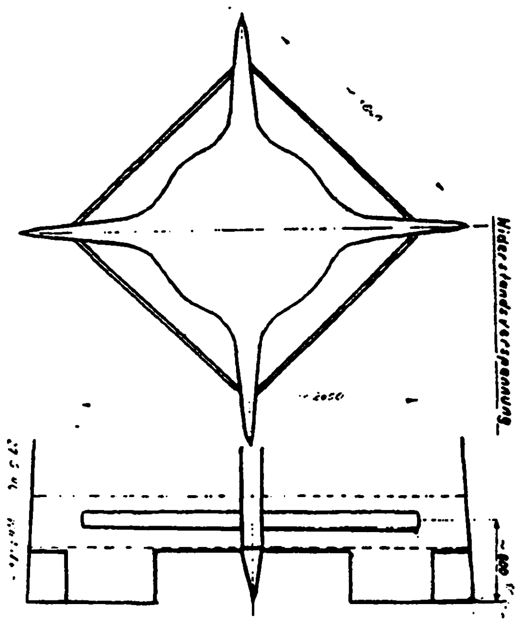


Figure 3 Modified tail with reinforcements.

Another of the early difficulties was the rather average stability of the 1000 kg load version and the poor stability of the 500 kg version. These worries led to the undertaking of comprehensive activities including detailed trajectory calculations. In December 1946, two basic versions were retained:

- Rl and R2 using Salbei as propellant (thrust 45 t)
- R2 using LOX (thrust: 40 t).

The stability-related activities proved to be very difficult, and in January 1947, the non-stability of the R1 and R2 was still not satisfactorily solved.

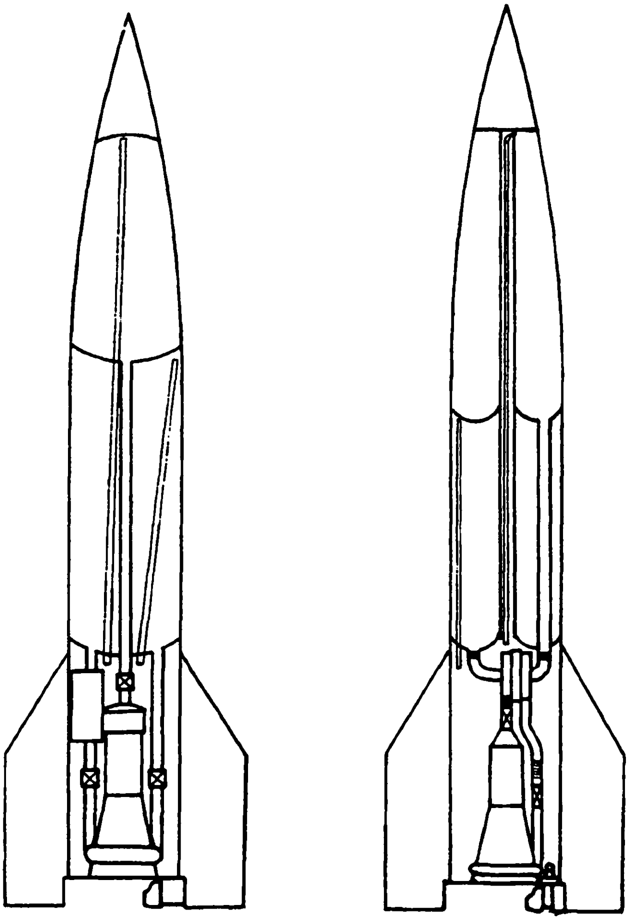
In the meantime, the rocket engine team had performed preliminary work on the projected turbopump. Of course, each of both propellant combinations (Salbei/HAP871 and LOX/Alcohol) had to be taken into consideration, leading to different designs. Preliminary design of the thrust chambers had been undertaken. The thrusts were ranging between 30 and 90 tons. The R1 gas generator had also been designed in detail, on the basis of a similar equipment built at Trauen in 1945 under the auspices of the British Ministry of Supply. In February 1947, valves and other "small equipment" had been designed. A possible operational flaw had been detected: the rocket was highly sensitive to winds at take-off and could not be launched in windy conditions.

In late February 1947, the turbopump was beginning to take shape. Its assembly in the rocket tail was also studied in detail. At that time, the final propellants had not yet been selected. As for the trajectory, no less than 6 of them were computed for establishing the optimal thrust chamber pressure for the R1 vehicle. This value was located between 17 and 23 atmospheres or 11 to 15 atmospheres, depending on the material used for manufacturing the vehicle.

Detailed manufacturing drawings for an experimental chamber with a thrust of 4 tons were compiled. The propellants were to be injected through a spiral-shaped line in order to minimize flow resistance. The R2 stability was still bad at that time and extensive computations were performed in order to overcome this very critical problem.

In a document dated 28 February 1947, the first cutaway drawings of both versions were published (see Figure 4). In the meantime, test stand equipment was recovered in Raderrach (near Friedrichshafen, at Lake Constance in Germany) where A4 engines were being tested in late World War II. This equipment was necessary to build the first engine test stand in Vernon.

In March 1947, the engine assembly in the rocket's tail was finalized for the R2 version. The stability computations were slowly progressing, and the overall design progress enabled the various teams to be more optimistic about their results. Propellant specialists at that time considered using nitrogen peroxide N_2O_4 mixed with Salbei. They however had to realize that such a mixture would decrease the overall rocket's performance! The gas generator used for driving the turbopump's turbine was also designed at that time. A procedure enabling simplified stability computations was also established and parametric studies on the problematic stability computations were thus greatly eased. The influence of many parameters such as empty weight, propellant mass, ejection speed and combustion chamber cross section could be studied in detail and established.



R1 *R2*

Figure 4 First concepts for the R1 and R2 dated 28 March 1947.

But again, a new problem appeared: the components of HAP871 (Visol and Optol) proved to be very difficult to obtain. So, the design team switched to gasoil/salbei, but without any loss of performance for the R1 and R2. This meant however that Fantol (Furfurylic alcohol) was to be used for the hypergolic ignition with the Salbei. Therefore, the turbopump had to be redesigned in order to operate properly with the new propellants. However, the possibility to retain a common turbopump body for both versions was studied, apparently with positive results.

In mid-April 1947, the R1 vehicle was taking shape more and more. Its propellant masses were now fully defined (see Figure 5), and its range was frozen at 1150 km with a tank whose wall thickness now amounted to 3 or 4 mm. Its engine thrust was fixed at 45 tons. At the same time, new considerations appeared on the subject of propellants. Gasoil and regular gas were studied, as well as the possibility to perform a pyrotechnic ignition of the liquid oxygen/alcohol version. If the R1 gas generator was now fully designed, the design of the thrust chamber for the R2 version was still underway.

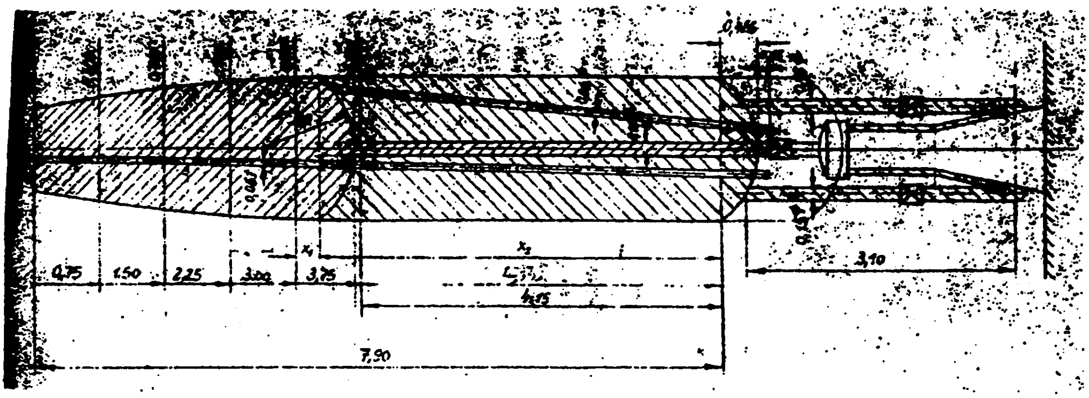


Figure 5 R1 vehicle propellant masses.

In June 1947, a meeting concluded that all previously attained results were satisfactory: "these show how promising possibilities do exist, but they still leave open numerous questions and do not always assure that these can be turned into practice. Those questions can and have to be cleared only by tests." As at that time the transfer from Riegel to Vernon had to be undertaken, the design team was confident to be able to perform (at long last) the mandatory tests. The Riegel offices were only offices, no tests whatsoever could have been undertaken there. In August 1947, the transfer to Vernon was fully completed and all reports now bore the mention "Vernon...". The difficult and pioneering days of Riegel were now over. It must be noted here that the Vernon establishment had to be literally opened by a team of tank engine designers under the leadership of Prof. Karl Maybach who all arrived in Vernon in December 1946. A few days before Christmas 1947, the first R1 gas generator was tested, marking the beginning of decades of tests in Vernon. A few other tests of this generator followed.

By increasing the vehicle length, it appeared soon after that the stability could be somewhat improved. The R2 vehicle general arrangement was modified and its tail section was now to be built out of wood and light alloys. Interestingly, this configuration appears on the Véronique sounding rocket prototype of 1949/1950 preserved at SEP Vernon.

In mid-March 1948, new general assembly drawings of the R1 and R2 appeared. Both vehicles now had a very high degree of commonality, as the following components were common to both: load compartment, tail, equipment, electrical lines and tail fins. The only differences were in the tanks and the propulsion systems (see Figure 6).

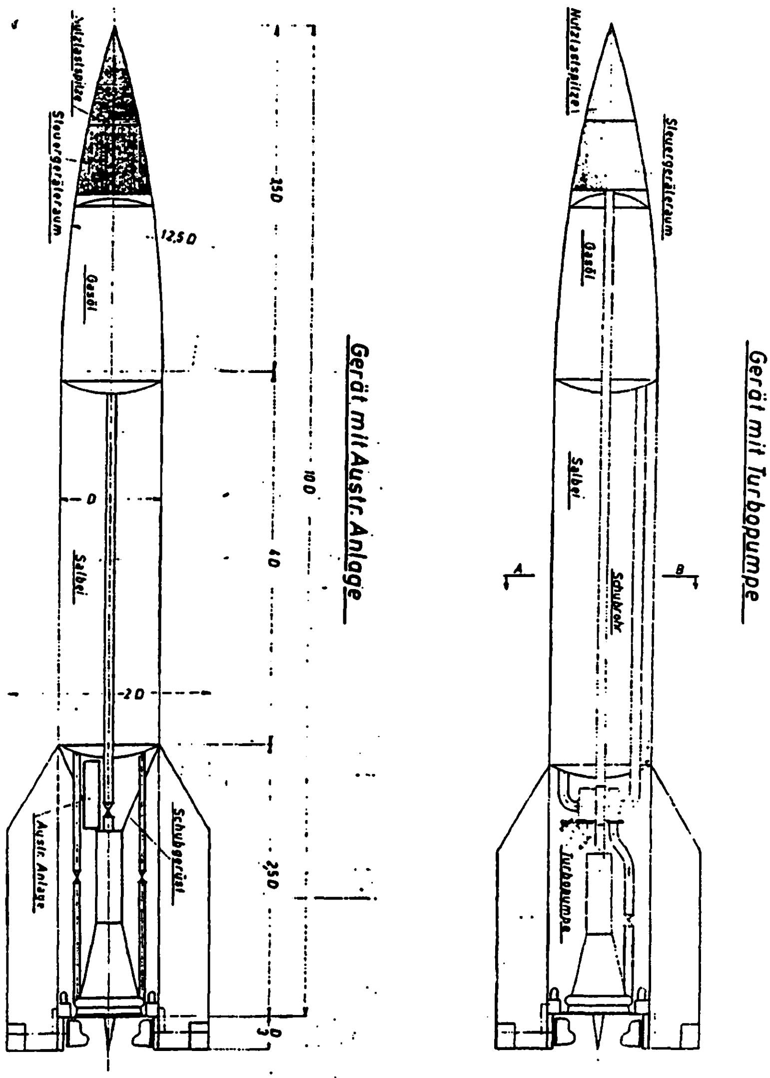


Figure 6 R1 and R2 designs dated March 1948.

In April, the test facilities for the pumps and the combustion chambers were planned and designed. The first tank tests were prepared. Three basic tests were foreseen:

- Behavior of the tanks under pressure and thrust

- Behavior during ground transportation
- Behavior of tank baffles and caps.

At the same time, the first injector had been manufactured and was to be shipped to Vernon.

May 1948: some refinements appeared on the R1 vehicle. It was considered to take the gas generator propellants directly from the main tanks (as is done today on the Viking engines of the Ariane launcher), only a separate water tank was still necessary. Both versions were considered for a long time.

The following month, a report was established describing two of the planned test facilities: the F1 and F3 stands, The F1 was the test facility for all chamber tests. The maximal thrust to be tested was of about 10 tons, with the stand being able to withstand 12 tons (margins were much narrower then than today). The propellant tanks were pressurized in order to feed the thrust chamber. The flame trench was not cooled with water as was the case for all facilities built in Vernon. Next came the F3, a pump test stand. Two possibilities were considered for the propellant feeding: turbine-driven pumps or pressurization of propellant tanks. Finally came a third facility, the F2 which was to accommodate both a turbopump and its gas generator.

One month later, manufacturing orders for many components were issued to the AP (Ateliers de Puteaux). They were to build and deliver two experimental thrust chambers for mid-September 1948, and 10 others later. Furthermore, four gas generators and nozzles were also to be delivered. A modification of an A4 turbopump was planned but could not be realized. Finally, a test tank of the R1 was to be built.

The rest of the year was apparently (due to the lack of records) spent refining the previously undertaken work. In spring of 1949, a new version appeared: the R2M, which was basically a standard R2 fitted with ramjets (see Figure 7) and was following principles similar to the basis of the Hermes Ram-Wing A4 test vehicle of the United States Hermes program. These were to be integrated into the tail fins (as ramjet pods) and not fitted in ramwings as on the Hermes vehicle. Here again, two versions were considered: two and four ramjets were studied. This new arrangement was believed to increase the range to over 3000 km with a top speed of Mach 3 or even Mach 4 being planned. Surviving documents do not clarify the location of fuel tank for the ramjets.

The project 4212 was finally cancelled in 1949, apparently due to the lack of interest of the army. Available sources do not clarify these reasons.

When it was cancelled, the characteristics of Project 4212 were frozen as follows. Five versions were established, the R1, R2, two versions of the R2S (either carrying 500 kg or 1000 kg) and the ramjet-boosted R2M based on the R2S. The R1 and R2 were using nitric acid/gasoil as propellants while the R2 used liquid oxygen/gasoil. The ranges were the following:

R1 - 1493 km

R2 - 1409 km

R2S (1000) - 1863 km
R2S (500) - 2255 km
R2M - 2380 to 3629 km

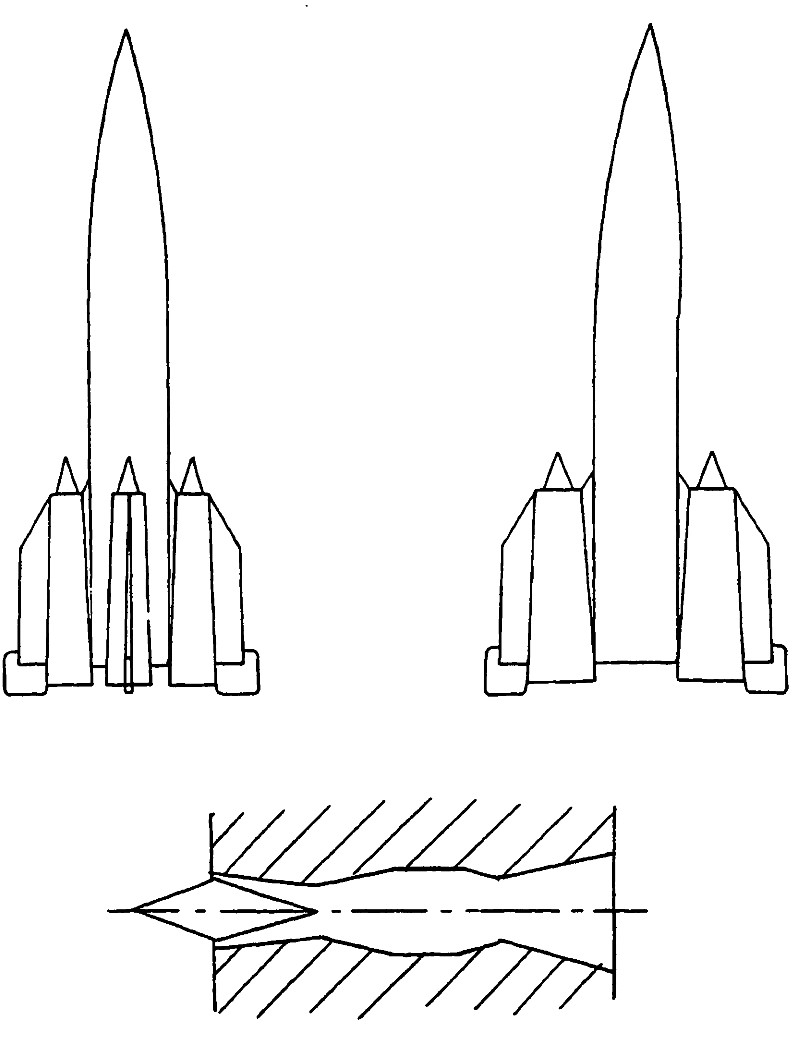


Figure 7 R2M versions with ramjet pods. Cutaway of the ramjet pod.

Cancellation: Reasons and Aftermath

The lack of interest for strategic ballistic missiles displayed by the French military authorities explains the cancellation. Some other reasons can deepen this explanation. It must be kept in mind that in 1949, no western missile program had been really started. Only the USSR had decided to improve the A4 and to produce the R1 (the Soviet copy of the A4) and the R2 (the improved version of the A4). No foreign equivalent or competitor to the 4212 was in existence, which is another cause for the cancellation: being the only country engaged in such a program might have rendered the authorities skeptical about its validity.

Three other reasons might have played a role in the cancellation. The lack of experience in the field of large rockets and liquid propulsion might have caused concern about the technical feasibility of such a large rocket. The financial burden of 4212 development at a time when France had to rebuild a country devastated by war is also a possible cause for cancellation. Finally, conventional bomber planes could also easily carry more load to farther targets, without having to develop a new technology. As the French Air Force had commissioned the design of two new such planes by the French industry (the SO 4000 and the NC271), and as both planes could do better that the 4212 (the same range as the R2 but with a load 4 to 5 times greater), the need for a rocket was not easy to justify.

It is quite possible that a mix of these reasons motivated the official services' cancellation of project 4212. However, all activities did not stop in 1949, and reports of activities related to the 4212 continued until December 1951.

The Legacy of 4212

Even if the 4212 was never built nor even partially tested, many achievements of this project had a lasting influence on French rocket programs. Among those achievements, one may distinguish the following:

- First hypergolic gas generator, built and tested in late 1947.
- First water-cooled gas generator concept.
- Three propellant tanks for the 4212 were built and pressure-tested in 1948.
- A mock-up of the tail and the fins was built in 1948.
- A Turbopump from the A4 was modified and tested. In particular, the start-up of this turbopump using a solid propellant cartridge was tested, with the cooperation of the Service des Poudres.
- The detailed design of the turbopump for the R2 vehicle was elaborated by the Rateau company. The pump test facility was built but not used.
- All valves were designed, manufactured and tested on dedicated test facilities built in Vernon.
- An experimental thrust chamber (thrust : 4 tons) was designed, built and tested.
- First idea of use of N_2O_4 as fuel in France.
- First concept f a water-cooled gas generator (used later on Véronique, Vesta, Coralie, Diamant B and Viking).

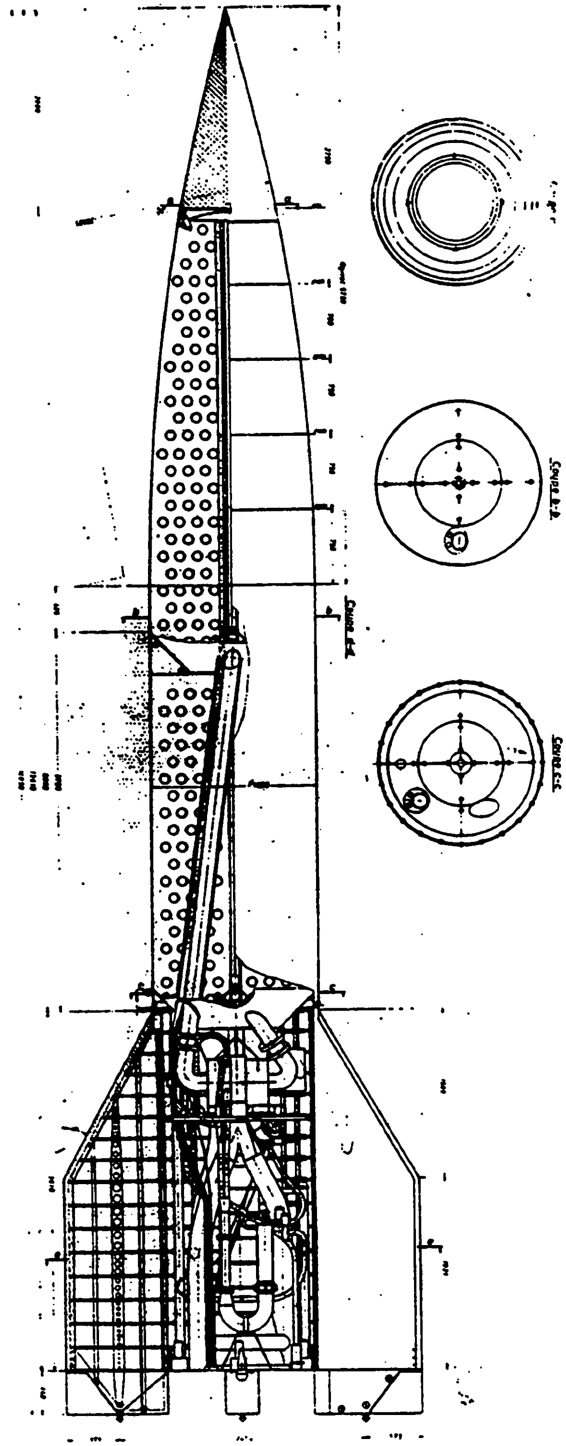


Figure 8 Final design of Project 4212.

The most tangible legacy of project 4212 are the test facilities PF1 and PF3 that were used for decades on all subsequent developments. Amusingly, they were initially planned to be built in Grammat, in southern France. The hypergolic and water-cooled gas generator served as a basis for subsequent developments. As project 4212 was replaced by project 4213 (better known as the sounding-rocket "Véronique"), the later project reused this component. Its basic principles (hypergolic liquids and water cooling) are still being used on the Viking engines that power Ariane. The experimental thrust chambers built for 4212 were also used as a basis for the Véronique chambers. Nitrogen peroxide was also used in the early 1960s, after having been considered initially for the 4212.

It is interesting to make a comparison of Project 4212 with the missiles designed in the early 1950s in the United States and the Soviet Union (see figure 9).

Country	Germany			USA			USSR				France	
Type	A4	A9	Redstone	Jupiter	Thor	R1	R2	R3	R1	R2	R2S	R2M
Development start			1950	1954	1955	1947	1949	1949	1945	1945	1945	
Operationnal in...		n.o.	1958	1958	1959	1950	1952	n.o.	n.o.	n.o.	n.o.	n.o.
Weight	12.5		28	47	50	13.5	20.4	71	14	17.6	22.8	
Thrust	25	30	35	68	68	26	36	118	25	40	40	
Range	200-300	800	400	3200	3200	300	600	3000	1500	1400	180-2200	3600

n.o. : never operationnal

Figure 9 Comparison table of all existing missiles in the early 1950s.

Conclusion

Project 4212 was probably too ambitious for its time. It was also too advanced: had it been started a few years later, and after the beginnings of Véronique sounding-rocket, due to the existing competition between the United States and the Soviet Union, 4212 might very well have been completed successfully. But this program is nevertheless an important one, as it set the course for events that finally led to the Viking engines that power Europe's launch vehicle Ariane 4. Many of its achievements were of great value for later programs, and project 4212 can be considered as the ancestor of all subsequent liquid-propellant rockets developed in Vernon. And for this very reason it has to be preserved from oblivion.

Acknowledgements

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T/TB/8/47	28/02/47	Stabilität des Gerätes R2 mit 100 kg und 500 kg Nutzlast bei Schüben von 30t, 35 t und 40 t
	05/03/47	Bericht über die Reise zum Prüffeld Oberraderach am 25.2.47 (Dipl. Ing. Geertz)
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	15/03/47	Essais du générateur
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	02/04/47	Aktennotiz über die Wochenbesprechung Nr 6
T/TB/11/47	11/04/47	Betrachtung über die Erwärmung der Haut beim Eintauchen des Gerätes R1
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T/TB/13/47	17/04/47	Bestimmung des günstigsten Ofendruckes hinsichtlich der maximalen Schussweite des Gerätes R1 bei 45t Schub
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	30/04/47	Aktennotiz über die Wochenbesprechung Nr 8
T/27/47	12/08/47	Considérations fondamentales à propos des calculs de résistance statique des réservoirs de l'engin R2 par le Dr Bornscheuer
T/TB/9/48	05/03/48	Aufzeihnung der Antriebsbahnen für die Projekte R1, R2 und R2S.
T/TB/11/48	10/03/48	Gewichte von Raketen
T/TB/14/48	08/04/48	Notes sur les discussions techniques du 30 mars et du 1er avril à Emmendingen.
T/TB/39/48	23/06/48	Beurteilung des R-Ofens RWV-1

T/Vers/41/48	28/06/48	Wasserversorgung des Ofenprüfstands F1 und des Pumpenprüfstands F3.
	12/07/48	Notes sur les conférences
du 26 et 28 juin 1948		
T/TB/43/48	13/07/48	Transportfall für Gerät R2
T/TB/47/48	21/07/48	Relative à l'exécution d'in jecteurs, d'installations de chasse de liquides, de réser voirs divers et de turbopompes.
T/TB/28/48	24/05/48	Notes sur les discussions techniques du 18 et 19 mai
à		Emmendingen
T/TB/50/48	17/08/48	Überschlägige Untersuchung der Einflüsse der Triebwerksschwankungen auf die Verlegung des Brennschlusspunktes bzw. auf die Schussweite
T/TB/62/48	14/10/48	Querkräfte und Biegemomente im Flug für Gerät R2
T/TB/18/49	14/03/49	Flugbahnen für das Projekt R2M mit verschiedenen Marschgeschwindigkeiten
T/TB/20/49	20/03/49	Aktennotiz über die Besprechung am 25.3.49
T/TB/19/49	04/04/49	Projekt R2M mit 4 bzw. 2 Lorin-Marschtriebwerken am Leitwerk
T/65/49	22/06/49	Compte-rendu de la mis sion effectuée le 15 juin 1949 auprès de M. Iablokoff de l'ONERA par l'I.M. Corbeau accompa gné du Pr. Bornscheuer et de l'Ing. Dipl. Walther
NT E/31/8/51	18/01/51	Demande de mesure dans la soufflerie
	28/12/51	Etat d'avancement des étu des confiées au LRBA, service propulsion
NT E/43/56	09/07/56	Etude 4212