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# SOLID PROPELLANT: CONSOLIDATING THE FUTURE

## SNPE: EXPERTISE THAT IS UNRIVALLED IN EUROPE, ACQUIRED THROUGH 50 YEARS OF CONTINUOUS POLITICAL STEADFASTNESS.

***The Foundation for Strategic Research (FRS) has published a study on solid propellants (authored by Bruno Gruselle). This special issue of TTU is based on the FRS's study.***

No ballistic or cruise missile can truly be a part of deterrence without state-of-the-art propulsion, a key-aspect of any rocket. What is true for missiles is also true for the motorisation of launchers devoted to space applications. France is the second country in the world to master solid propellants. SNPE is gearing its efforts toward maintaining this technological lead, especially over other ballistic players such as China and Russia.

For SNPE, solid propellants are considered a science as well as an "art." Notably working at the Bouchet research centre, chemists (synthesis, formulation, analysis) are developing their knowledge of all aspects of propulsion with plastics specialists (product manufacturing), physicists (modelling, digital simulation). The fact that this highly specialised knowledge is rare makes it valuable and fragile.

Today, the stakes lie in the continuation and preservation of these unique competencies for all kinds of solid energy materials (gun powder, explosives, propellants), which makes it all the more fragile given the commonly held belief that a technology is necessarily dual. However, this is not true for solid propulsion, whose market is not dual and depends exclusively on public financing. The goal is thus to guarantee the "research-development-production" cycle. The survival of this know-how is even more precarious due to the fact its basic teaching does not even exist. Knowledge is passed on through work and research. Expertise thus essentially relies on the experience acquired by SNPE in the formulation, design and production of composite propellant charges, i.e. a specialised branch of chemistry. It is the company's strength in chemistry that sets it apart, enabling it to develop innovative processes that are a part of nuclear deterrence and thus allowing it to participate alongside France on the international scene.

Continuing to invest on the French segment of solid propulsion is a strategic choice that facilitates the operational deployment of missiles. Even though liquid technology still offers advantages, solid propellant is considered by experts to be the most reliable type (no injection devices or mixing controls, no problems with corrosion…), easier to store and use.

In order to ensure France's lead on the solid propulsion segment, for which demonstrators are necessary, significant investments are required.

The political will to invest in the preservation and development on this state-of-the-art sector (SNPE and its Bouchet research centre…) is also the basis of France's national technical and industrial independence.

### The SNPE group – an overview

*Relatively unknown among the general public, SNPE is involved in five major defence and aerospace segments: solid propulsion (M45, M51, Aster, ASMP-A, Exocet, Mica, Milan, Eryx, Ariane 5…); explosives and combustible casing (155-mm ammunition for the Caesar, charges for the 120-mm mortar, 120-mm armour-piercing and exercise ammunition…); pyrotechnic and pyro-mechanic devices (M45, M51, Aster, ASMP-A, Exocet, Mica, MDCN, Scalp EG, Vega…); composite explosive charges (military warheads for the Exocet, Mica, GMLRS, add-on armours…) and grain explosives (ammunition…); aeronautic (pre-impregnated, based on carbon fibre for the Rafale's aerofoil and Rolls Royce engine pods…). In three years the SNPE group has succeeded in re-establishing its financial situation in a spectacular way, by drastically reducing its debt (from 460 million to 164 million euros) and massively increasing its capital (from 28 million to 265 million euros). In 2007, this translated into a net income of 107 million euros and a turnover of 693 million euros. Not to mention a self-financing capacity of 20 million euros. Regarding the branch's activities, energy materials dominate, with 51 per cent of turnover as well as chemistry (39 per cent of turnover). This return to a healthy situation for the SNPE group can notably be explained by a "strategic reorientation" on defence and space activities, according to Jacques Zyss, SNPE's CEO. Indeed, the group's know-how is space and strategic chemistry.*

## SOLID OR LIQUID PROPULSION?

**When the first ballistic rockets powered by solid propulsion were developed during the 1950s, the performance of propellants was inadequate** (combusted too rapidly…). Because of this, the decision was made to use liquid propellant, which was easier to operate, since it makes it possible to stop and re-start the engine. This is an advantage, according to experts, for the higher stages of launchers or missiles. Solid propulsion is more advantageous in the lower stages, which require a stronger thrust.

Progressively, solid propulsion was developed and improved, with slower combustion and more effective protection of the engine's internal walls. The situation shifted toward better control of solid propellant combustion, using combustion-inhibiting coating, preventing it from propagating on certain charge surfaces. Similarly, the development of new production techniques associated with adapted charge profiles made it possible to develop important dimension blocks, capable of burning for a long time as well as optimising the thrust.

Technically speaking, the difference between solid and liquid propulsion depends on the physical state of its components (or propellants) but also on the mixing and combustion method. Hence, in a liquid propelled engine, the two propellants are stored separately and injected in the combustion chamber. For a solid propellant, the components are, on the contrary, directly stored in the combustion chamber, already mixed, called the charge.

Overall, the advantage of one propellant over the other is not clear-cut. However, the advantage of solid propellant lies in its security, thus it is much better adapted for missiles operated aboard submarines. The efficiency of propellants depends on a series of factors (specific impulse, density/weight). So, which one to choose? Despite difficulties and risks inherent in their design, the U.S., like France, prefers solid propellant, due to several advantages. First, today they offer greater acceleration. On the other hand, they are stable and can be stored in the engine for many years, without the need for maintenance (important when it comes to deterrence). Hence, even if solid propellants require state-of-the-art know-how, and thus some investment on the long run, their ease-of-use when it comes to storage and operation makes them particularly advantageous for fitting on missiles fired from submarines. Moreover, the progress made in the development of new chemical components (work on energy performance…) today allows them to compete with liquid-propelled engines, at a lower cost.

From an economical point of view, due to the complexity of their design and production, liquid systems are generally considered expensive, especially when it comes to having a long-range, for which some components are difficult to produce (turbo-pump, injector, combustion chamber…). For some, the economic difference between the two systems is not that different, as solid propellant requires a long-term investment, with a knowledge that is carefully preserved and handed down.

The SNPE group draws on this experience, especially in the areas of testing and manufacturing, as even minor flaws (fissure, separation…) can lead to the destruction of the engine. For all these reasons, France, like the U.S., has decided to invest in solid propellant. Russia is still using liquid propellants for silo-based missiles as well as the SLBM (from submarines).

## THREE TECHNICAL POINTS

### ➤ Air-independent propulsion

Since it requires no atmospheric oxygen to work, this type of propulsion is the preferred method for platforms whose trajectory extends beyond the earth's atmosphere (space launchers, ballistic missiles).

### ➤ Solid propellant

In an air-independent engine, the thrust is obtained thanks to a propellant stored inside the engine. This propellant is composed of two basic elements (combustible, often ammonium perchlorate), which, when put together, burn and provide the thrust.

### ➤ Know-how

Aside from chemistry, at the heart of the design and production of solid propellants is a combination of know-how, from mechanics to multiphase "aerothermochemistry," which makes their realisation possible. The development and production of a propellant charge are crucial steps as they require many tests.

## SOLID PROPULSION OUTSIDE FRANCE

**The United States has the most advanced research and manufacturing in the field of solid propulsion. From the creation of the first composites to the use of Nitralane™ for Trident-II D5 systems, American laboratories have pursued the development of new components.** This is especially true in the field of binding agents, with the use of energetic polymers (glycidyle polyazoture or PAG), and in the field of oxidising charges, with the use of high energy materials (hexa-nitro-hexa-aza-isowurtzitane or CL20). The United States is seeking to improve its strategic vehicles while positioning itself on the space launcher market. Hence, the three stages of the Trident II-D5 use solid propellant mainly based on octogen (HMX).

In Russia, the first missile powered by solid propellant, the SS-13, entered operational service at the end of the 1960s. The SS-13 is the result of work by the Moscow Thermal Engineering Institute on a composite propellant based on ammonium perchlorate. But it is only later that this technology began to offer advantages, notably for submarines such as the N-17, in 1980. Its range reached 3,900 km with a charge of 450 kg. In 1984, with the SS-N-20, composite propellant was used on ballistic missiles. Russian researchers are pursuing their efforts, with in the ground sector the development of two missiles (RS-24 and Topol-M) and in the naval segment the SS-NX-30 Bulava, announced with a 8,000 km range.

In China, interest in solid propellant appeared in the 1970s. But it was only at the end of the 1980s that the first mobile tactical missiles (300- to 600-km range) were deployed within strategic forces. The first test of the strategic missile, the DF-21, which also adapted for naval applications (JL-1), took place in 1985. Around the same time, efforts to develop an 8,000-km range system (DF-31 / JL-2) led to first tests in 1992. But a series of failures delayed the development and entry in service. The DF-31 was reportedly put into operation in 2006; the JL-2 has so far not been deployed aboard a submarine. In Italy, the Vega launcher has allowed Avio to position itself in partnership, notably with France, in the launcher market. Japan and Israel are also present in this segment. Especially Israel, which has acquired considerable autonomy regarding the solid composite charges, with the Shavit and Jericho systems. Recent tests of the Jericho 3 suggest ongoing Israeli research, with enhancements to the system's range, thanks to an additional propulsion floor. Moreover, work carried out on the development of the Arrow-2 interceptor may favour technology transfers between the U.S. and Israel.

India has also been at the forefront of research in this field over the past 30 years. Its expertise is reported to equal that of the Chinese with the AGNI-III. In Pakistan, solid technology also exists in the Shaheen range of products, but under a strong dependence on the Chinese.

Finally, Iran appears to have sufficient knowledge to produce short-range missiles that use solid propellants.

## FOUR STEPS IN THE PRODUCTION OF PROPELLANT

### ➤ 1. Structure coating

The first step is to apply a coat of resin on the thermal protection inside the propellant chamber. Resin is the binder that ensures contact between the structure and the solid propellant charge.

### ➤ 2. Propellant kneading

The various elements (oxidising, reducing agent, binder and additive) are mixed to form a paste. The preparation differs according to the size of the charge. The goal is to allow homogenisation and polymerisation of the element.

### ➤ 3. Flow and reticulation

Propellant, once at the paste state, is poured into the propellant body. Once the polymerisation is obtained, the core, which will provide the shape of the propellant's internal canal, is withdrawn. This is a particularly delicate process.

### ➤ 4. Assembly and engine formation

The thrust nozzle that ensures the flow, expansion and ejection of the gas produced by combustion is assembled including the igniting device, with the charge produced for the shape of the propellant engine.

SNPE

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## A PROMISING FUTURE FOR SOLID PROPELLANTS

**The dynamic research in the United States as well as the development of the new triad of nuclear deterrence, offensive conventional means and missile defence, are generating the development and production of new composite solid propellant engines.** For rapid global strike capability, the Pentagon is planning to transform part of its strategic missiles. In the field of missile defence, in addition to systems in the production phase, which are based on composite propellant (Patriot, SM-3), the propulsion of new interceptors should rely on a solid solution. This will allow the two engine manufacturers ATK and Aerojet to develop their competencies in the field of solid propellants

It is however doubtful that cooperation on these projects will have any influence on French technical and industrial capabilities. Among the questions that remain is the political orientation of the next U.S. administration.

For France, the strategic solid propellant sector must continue to progress. President Sarkozy's speech in Cherbourg must be interpreted in this light, considering the fact that in his remarks the international context was presented as uncertain, with the ongoing risk of a strategic surprise. Beyond 2030, Russia will probably strengthen its nuclear capabilities with a modernised arsenal, while China will see its nuclear potential beefed-up, like India, and pressures from new nuclear powers (Pakistan, Iran…).

This context underscores the need to develop more sophisticated missiles with an increased range. Maintaining and improving French competencies in this field, notably regarding solid propulsion, is the key to France's strategic future, the country's "life-insurance," as President Sarkozy put it. The strategic future lies in these efforts. It is essential that France's work remain independent, so as not to have to rely on any other power (and not follow the example of the U.K., which shields itself behind the United States.)

## WHAT NEXT?

**Better performance in terms of range and precision, maintaining national competencies… Continuing these efforts calls for specific measures.** In the meantime, they should permit carrying out research and development activities and production work, a minimum on the large scale demonstrators to guarantee synergies between development and manufacturing. Two paths are possible. First, by launching a project for a demonstrator of an exo-atmospheric or high endo-atmospheric interceptor, within a European-Atlantic cooperation. Second, by engaging the development of a new-generation propellant demonstrator. Both solutions call for a budgetary effort until 2020, in order to be able to, if necessary, replace the propulsion floors of missiles currently entering service.

European cooperation will have the advantage of theoretically maintaining know-how, without loss of national competencies. With the condition that France maintain control over the development and production of its own propellant charge. This could become a problem, considering Italy's ambitions in the space field. The solid propellant sector in France has reached a crucial stage. With a risk of a breakdown of development-production cycle, which until now, made it possible to improve the capabilities of strategic systems according to the requirements stated by political authorities. The end of the development of the M51 engine could lead to the attrition and disappearance of unique competencies that could only be re-developed with massive investments. To avoid this scenario, new prospects in terms of programmes are needed.

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