SyLEx: Space for your test, ArianeGroup's new sounding rocket

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Abstract

ArianeGroup know how in solid propulsion, guidance systems and launcher design has been condensed in the new sounding rocket family, SyLEx designed for hypersonic flights and microgravity researches.

This single or two stages vehicle offers high performances and large payload accommodation capabilities, along with various services such as jettisonable fairing, attitude control, telemetry and two customer zones for experiments (Fairing zone with clamshell release + Experimental case zone).

SyLEx Maiden flight is scheduled in 2025 from Biscarrosse (South West of France) test range, paving the way for future European cooperation and research for both civilian and defence applications.

The SyLEx rocket family is based on ArianeGroup's new 2-ton class motor named "SPARK". This advanced motor provides Europe with enhanced flight domain capabilities:

- Reaching up to 7 or 5 minutes of microgravity condition for a maximum payload of 600 kg in respectively a single-stage or two stages configuration
- Achieving over 1200 or 2400 m/s re-entry velocity @120km in respectively a single-stage or two stages configuration

Sounding rocket flight dynamics is a complex discipline, requiring a deep understanding of numerous phenomena to achieve predictable rocket behavior and minimize fallout scattering areas. ArianeGroup's modelling expertise has been extensively employed to address challenges such as roll locking and aero elasticity, while also investigating the impact of physical parameters on trajectory. These comprehensive models – involving aerodynamic, mechanical, and 6-DOF flight computation – enable accurate prediction of sounding rocket flight paths, thereby enhancing mission safety.

Throughout the development process, ArianeGroup successfully tackled these challenges within an ambitious three-year timeframe.

The resulting system is robust, high-performing, and designed to meet European civilian and defence stakeholders' needs for early-stage flight validations or in situ measurements supporting fundamental research and technological advancement.

Keywords: *Sounding rocket, Suborbital, ArianeGroup, Hypersonic flights, Microgravity*

1. SyLEx Sounding Rocket Family

1.1. Introduction

ArianeGroup has kicked off in 2021, the development of a family of suborbital launch vehicles. Under our French-led management and free from International Traffic in Arms Regulations (ITAR) restrictions, the new SyLEx sounding rocket family will offer diverse scientific and technological services. These vehicles are based proven technologies and share common design elements, allowing for flexible customization based on mission requirements.

With performance levels within the upper range of existing sounding rockets, our family offers capabilities for various civil or military applications:

- Re-entry system development and hypersonic testing: ArianeGroup supports re-entry systems road map by providing platforms for hypersonic flight experiments.
- Microgravity payloads for scientific research: Our launch vehicles enable scientific inquiries through microgravity experiments, accommodating a wide range of payload sizes and masses.
- "Flight proven" equipment testing and validation: ArianeGroup offers realistic flight conditions for hardware qualification and validation, ensuring high reliability before deployment on critical missions.

ArianeGroup is committed to deliver innovative solutions that empower our customers to push the boundaries of space exploration and scientific discovery. By combining expertise with flexible, high-performance hardware, we strive to meet the unique needs of each mission.

1.2. SyLEx Characteristics

The SyLEx rocket family is based on the new solid rocket motor "SPARK" (Space Propulseur for Aeospace RocKet), a 2-ton class engine used in both single (Block 1) and two-stage (Block 2) vehicle configurations.

The main characteristics of these vehicles are presented in the table below and visualized in the accompanying view.

Table 1. SyLEx family characteristics table

	BLOCK1	**BLOCK2**
Length	# 10 m	# 15 m
Diameter	0,7 m	0,7 m
Total Mass	3,3 T	6,5 T
Microgravity time	4 - 5 min	> 6 min
Apogee	140 – 200 km	200 – 400 Km
Max Range	350 km	1 300 km
Max Injection Speed	1 200 m/s	2 500m/s
Max Payload	600 kg	600 kg
Experiment volume	Fairing : 400 l / XP Case: 100 l	Fairing : 400 l

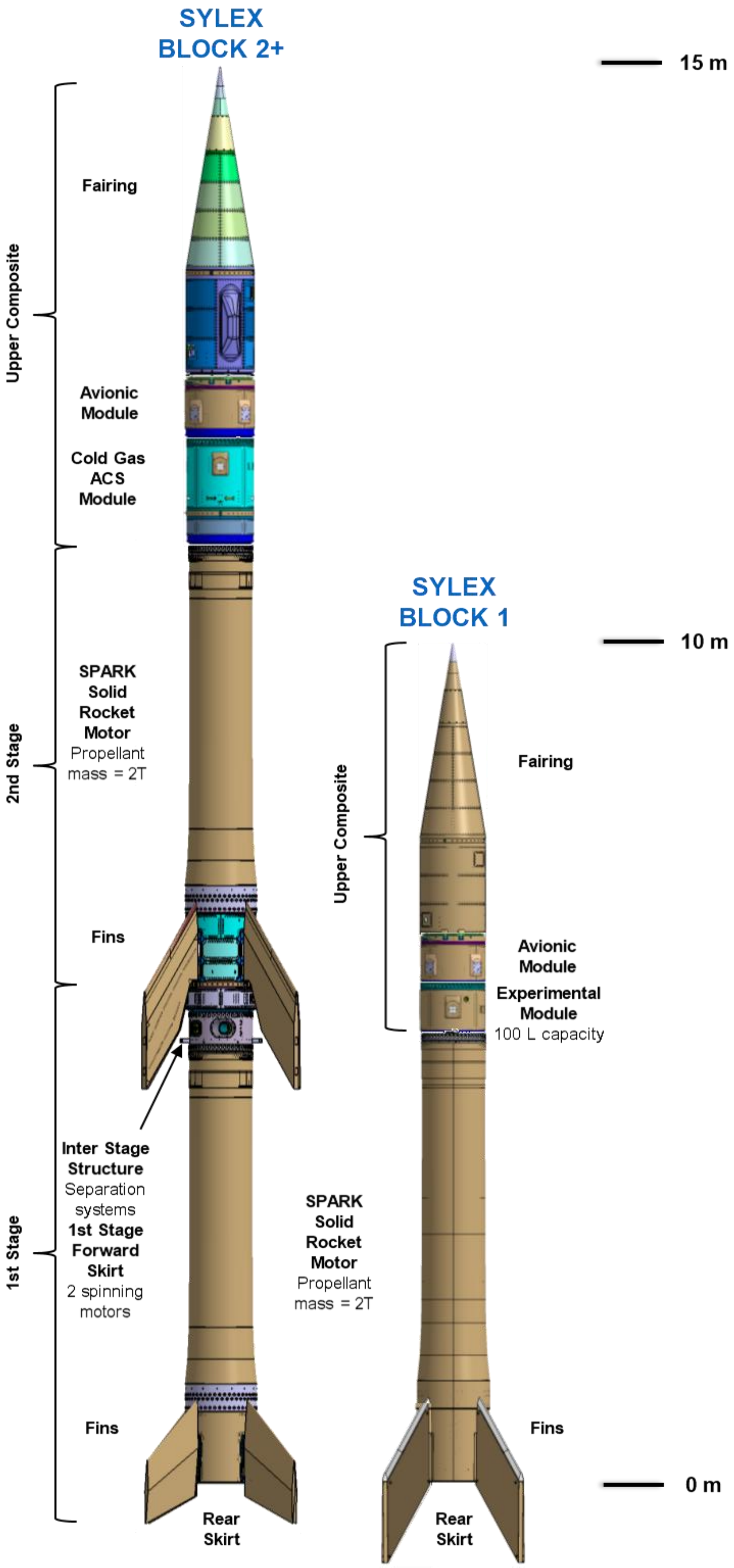


Fig 1 SyLEx family Base configurations

SyLEx sounding rockets feature modular construction, allowing flexible configuration changes:

- 2-ton class motor named "SPARK"
- Fins for Block 1 or Block 2+ versions
- Upper composite (Avionic module, Experimental module, ACS module, Fairing)
- In addition, Block 2+ version includes a first stage forward skirt in order to allow spin-motors and a separation structure between the two stages.

Large payload accommodation capabilities and services are included in the upper composite:

- Avionic module with the following functions:
    - "Yoyo despin" system
    - Flight management system
    - Telemetry
    - Trajectography
- Experimental case module:

Customer zone for experiments installed on two plates, with a total capacity of 100 L and max 35 Kg. Services available for experiments are power, video and telemetry

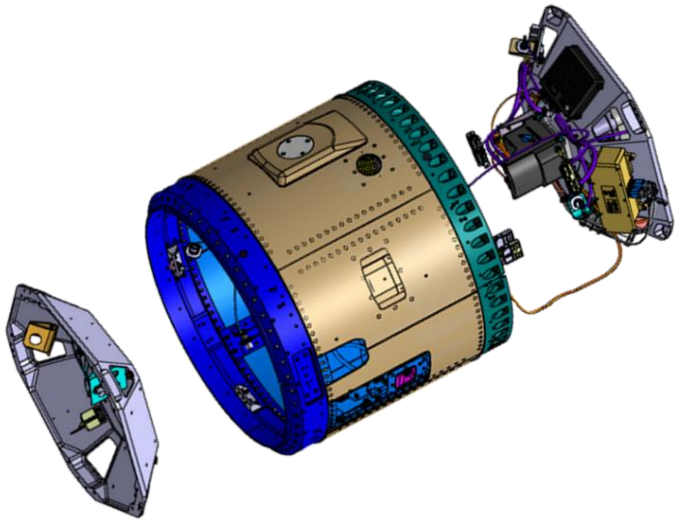


Fig 2 : Experimental case module with experiment example

- ACS (Attitude Control System) module:

This one operates in the exo-atmospheric phase following upper composite separation.

It enables:

- Cancelling residual spin and
- Controlling attitude conditions at injection (angles and angular velocities)
- Optimize microgravity conditions
- Transmitting navigation context to the flight object (position, velocity, attitude)
- Ejecting a possible spinning object (depending on the object and requested mission)

This one is constituted with two sub-assemblies:

- GNC Kit: Navigation and Control System implementing hybrid navigation
- Propulsion Kit: Blocks of 3.5N thrusters with associated tank(s)

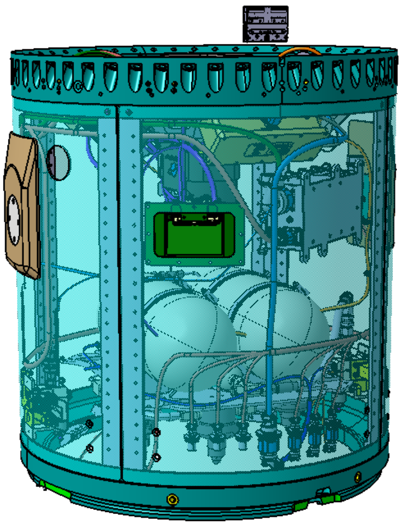


Fig 3 : Cold gas ACS (Attitude Control System) module

- Jettisonable fairings : Fairing zone with clamshell release

These deployable fairings are capable of accommodating an ASX (Experimental Assembly: Payload + Launch System or Adaptive Payload ACU) with a wingspan greater than the current diameter of the sounding rocket.

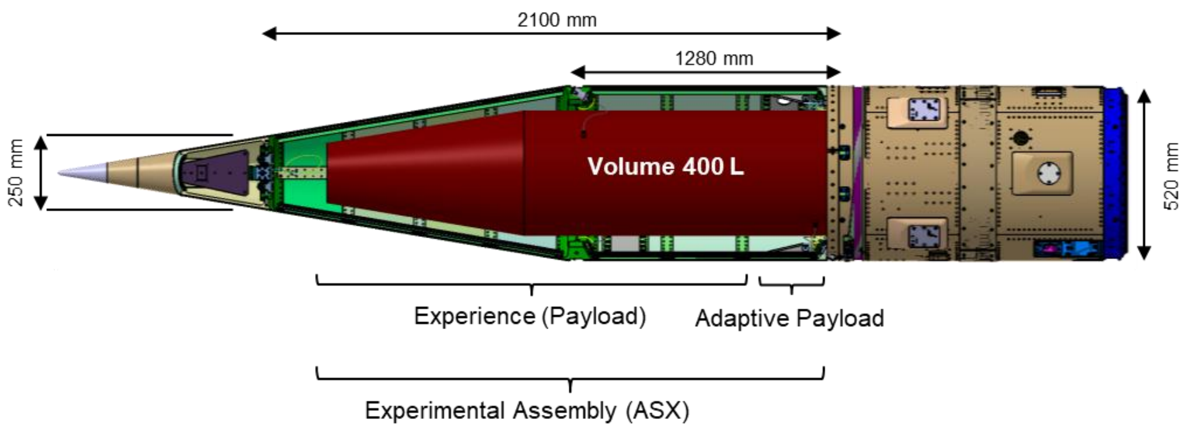


Fig 4 : Fairing characteristics

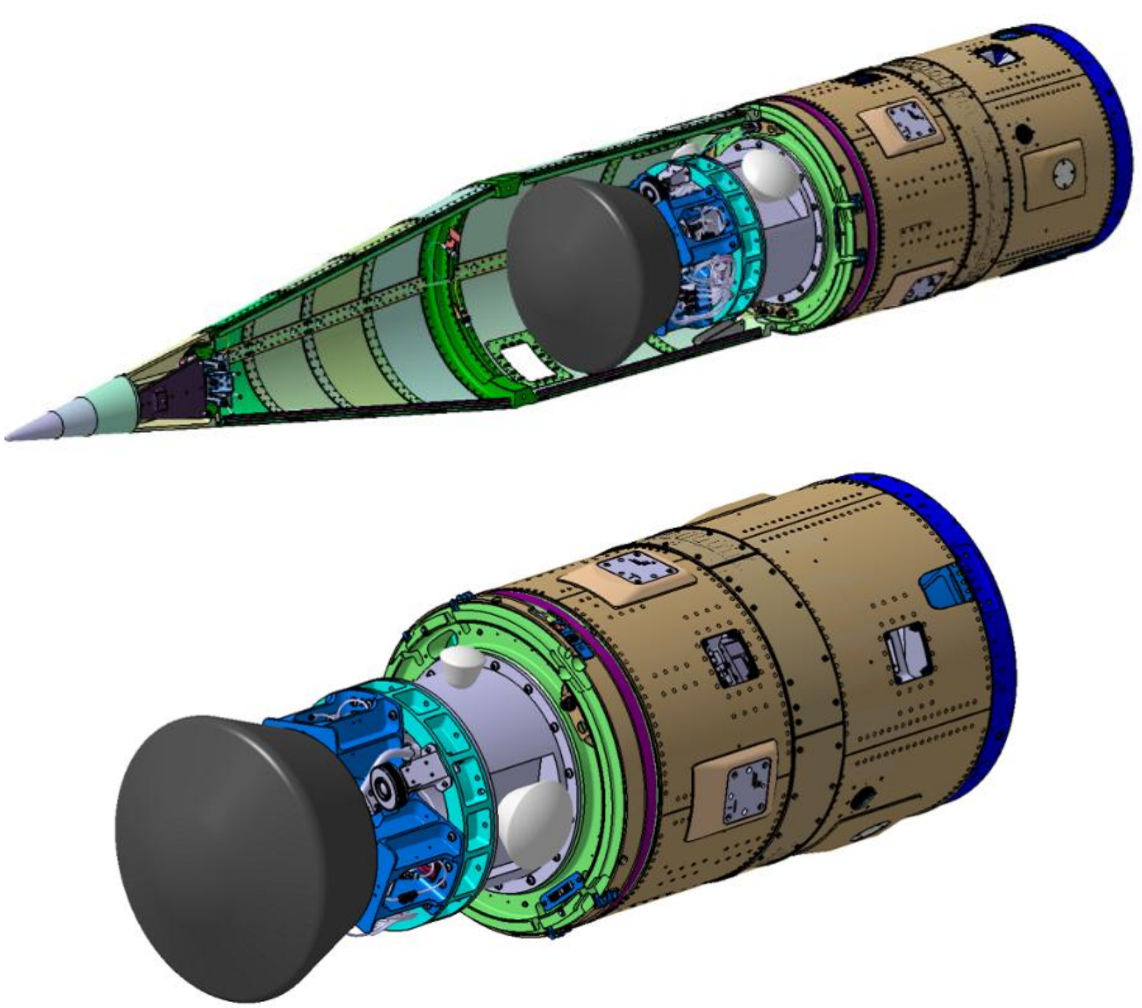


Fig 5 : Example of experimental assembly

1.3. SyLEx Performances

SyLEx sounding rockets ensure purely ballistic flight stabilized by aerodynamic fins complemented by a spin system that eliminates eccentricities and misalignments.

After the propulsion phase, the spin is reduced through a "yoyo despin" system (system of cables + weights). Once the level of the residual rotation is reached, the experimental phase could start.

Both SyLEx configurations, offers performances and large payload capabilities as shown in the performance chart illustrating the apogee and associated possible microgravity (µg) time for different payload masses. This type of trajectory maximize the exo-atmospheric time.

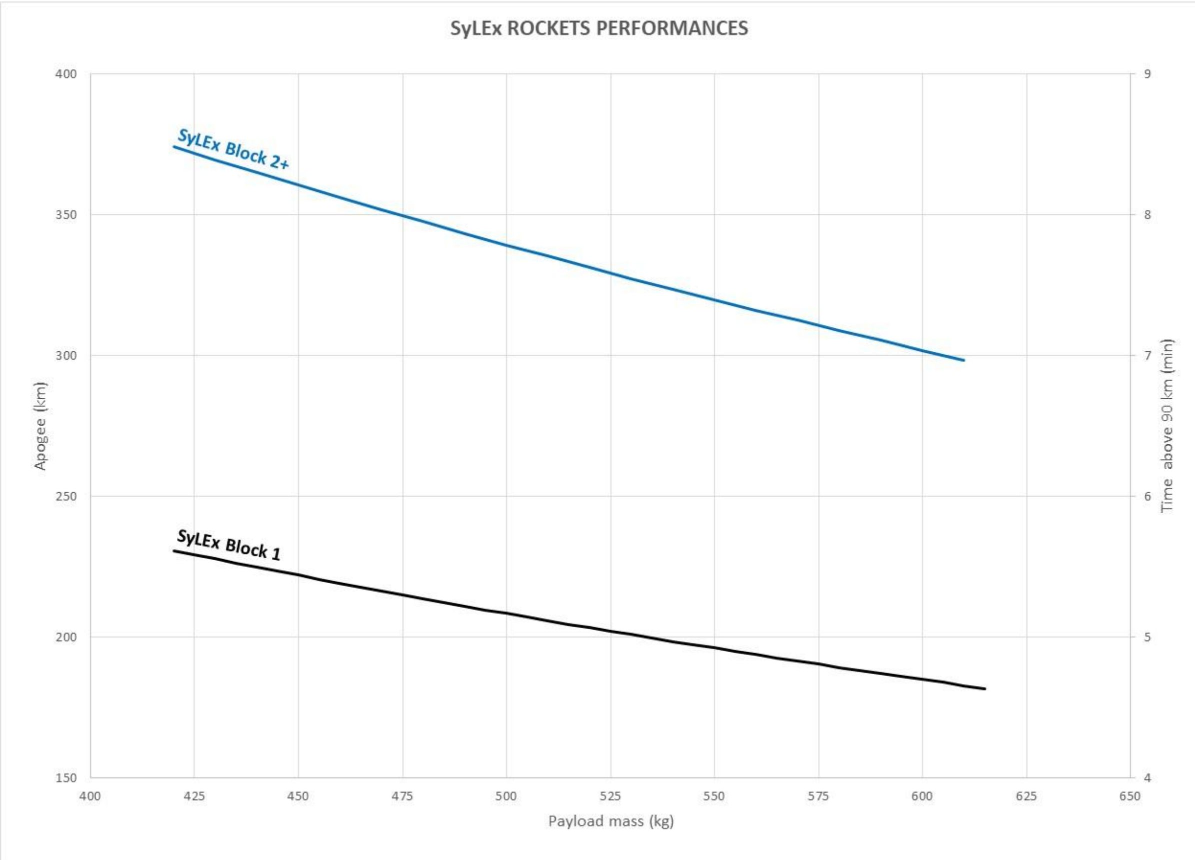


Fig 6 : SyLEx Sounding Rocket Vehicle Performances

For Hypersonic flights, each SyLEx sounding rockets offer great performances for high volume experience. Its advanced motor provides enhanced flight domain capabilities, achieving over 1200 or 2500 m/s reentry velocity @120km in respectively a single-stage or two stages configuration.

The following graphs illustrate for each vehicle and depending on the payload mass, but also on the ramp elevation between 75° and 81°, the range and the reentry velocity @120km.

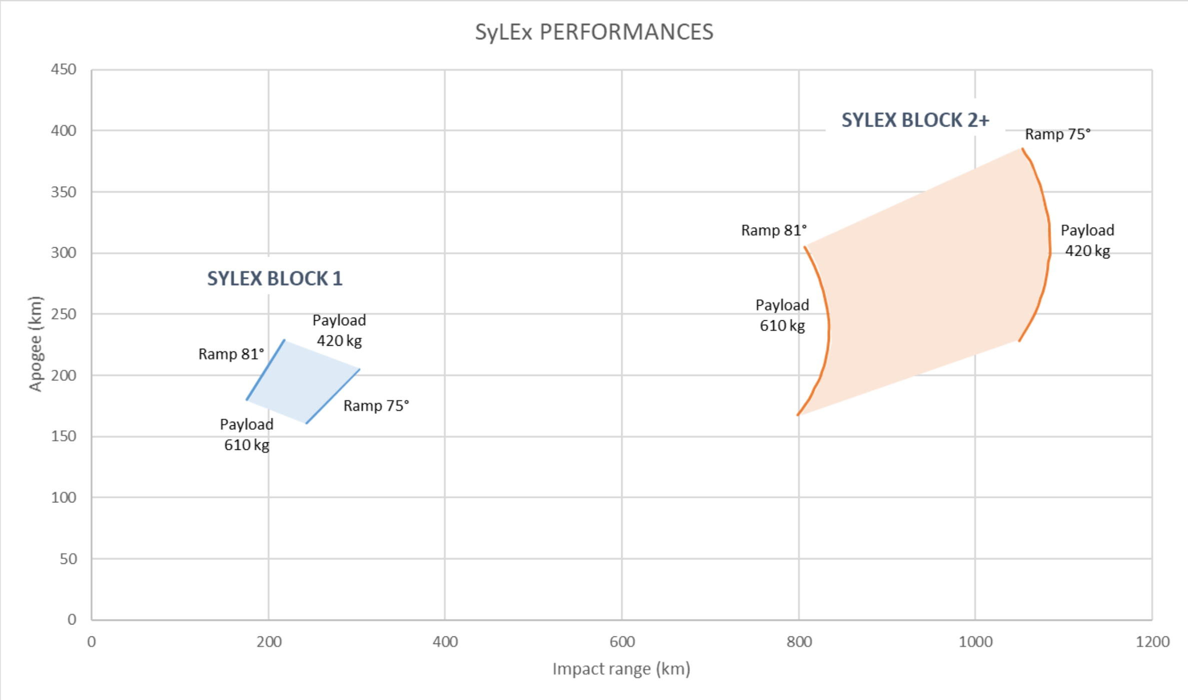


Fig 7 : SyLEx performances impact range & apogee depending on payload mass and elevation ramp

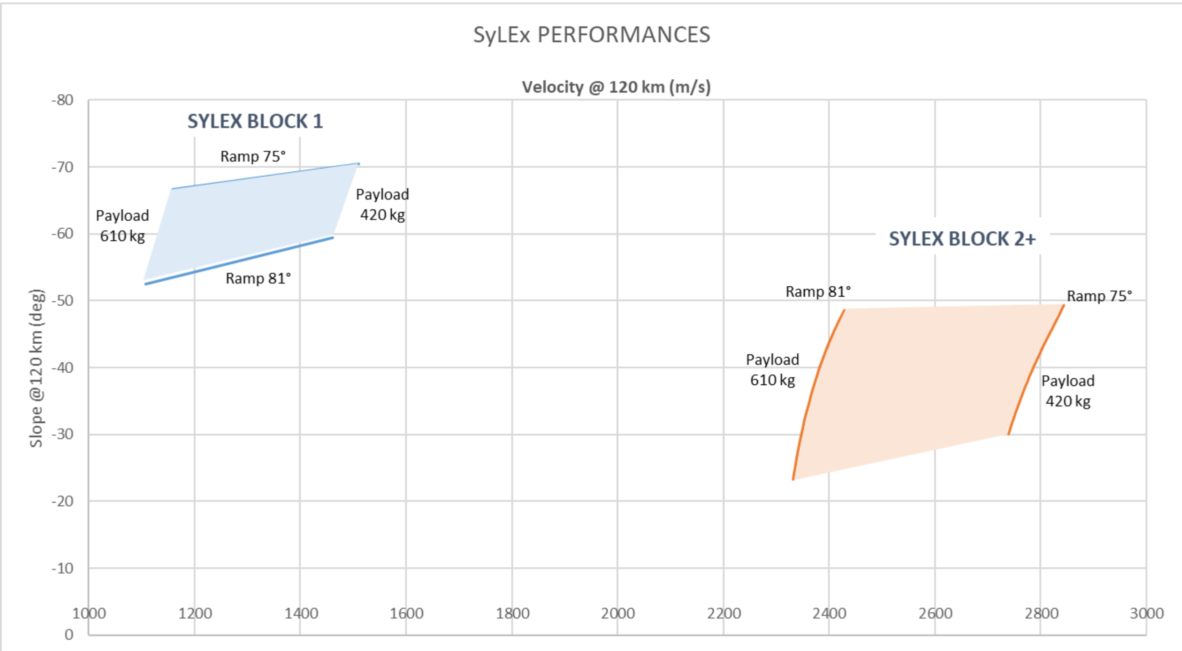


Fig 8 : SyLEx performances velocity achieved at 120 km (m/s) depending on payload mass and elevation ramp

2. SyLEx First Mission Challenges

Scheduled this year 2025, first SyLEx mission called "DEMO1" aim at demonstrating the single stage configuration (Block 1) capabilities and validate the whole launch system and operations to be performed at Biscarosse facilities (South West of FRANCE).

Main mission objectives are:

- Validate the launch operation sequence and vehicle flight behavior in single stage configuration
- Assess the actual vehicle performances
- Assess the environmental conditions in both powered and ballistic flight

The mission profile is described on below figure:

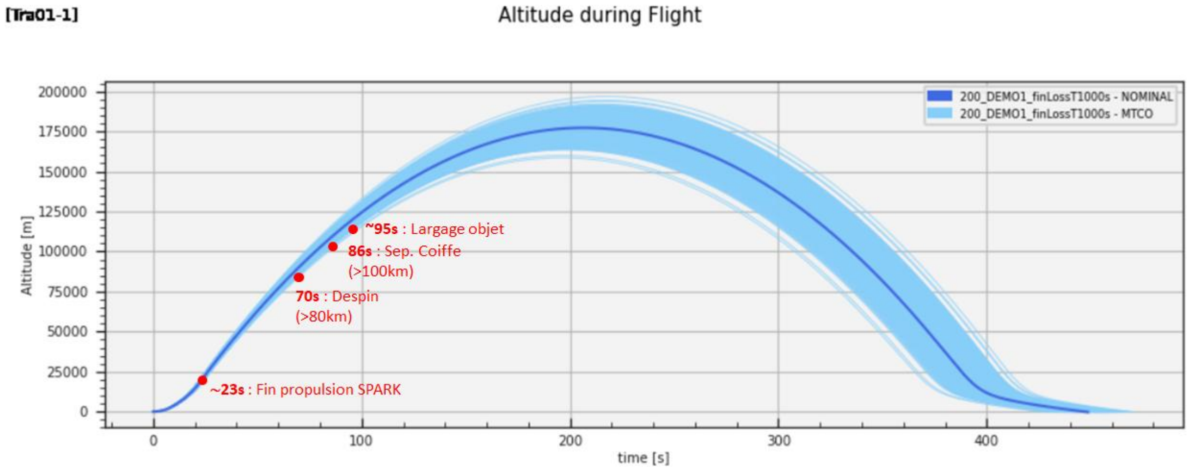


Fig 9 : DEMO1 Flight profile with its sequence (SPARK propulsion end, Despin, Fairing jettison, Experiment release)

Sounding rocket flight dynamics is a complex discipline, requiring a deep understanding of numerous phenomena to achieve predictable rocket behavior and minimize fallout scattering areas. The following paragraphs explains the main challenges tackled for this first mission.

2.1. Q.alpha max event

The so-called Q.ɑ max event generates the maximum mechanical load on the rocket. It is defined by the product of the dynamic pressure and the vehicle angle of attack in the airflow. The maximum value of this product allows spotting the instant of the flight which is the most demanding for the vehicle. The next paragraphs will underline the main contributors of this event.

2.1.1. Static Margin

Unlike other ArianeGroup's launcher, SyLEx rocket is not guided or controlled during ascent, hence the launcher behavior is driven by aerodynamic stability and spinning.

Aerodynamic stability or static margin defines the vehicle ability to steer itself and cancel its angle of attack. This torque applied to the rocket depends on:

- Static Margin : SM = Xcog – Xaero
- Transverse aerodynamic force

$$Torque = SM\, C_{N\alpha} \alpha\, Q\, S_{ref}\, L_{ref} \quad (1)$$

Four categories can be found:

- Unstable vehicles: the generated torque increases the angle of attack and lead to mission loss
- Over stable vehicle: the generated torque is strong and generate strong oscillations
- Indifferent: the static margin is too weak and the vehicle leaves its nominal trajectory
- Stable: vehicle attitude and trajectory under control.

Minimum Static Margin of one caliber of the vehicle is usually defined at the beginning of a project and can be challenged throughout the development.

A single stage rocket shall ensure sufficient static margin over a wide range of Mach number. As the aerodynamic center moves backward when the speed increases, SyLEx single stage fins are sized in order to ensure stability over Mach 6.

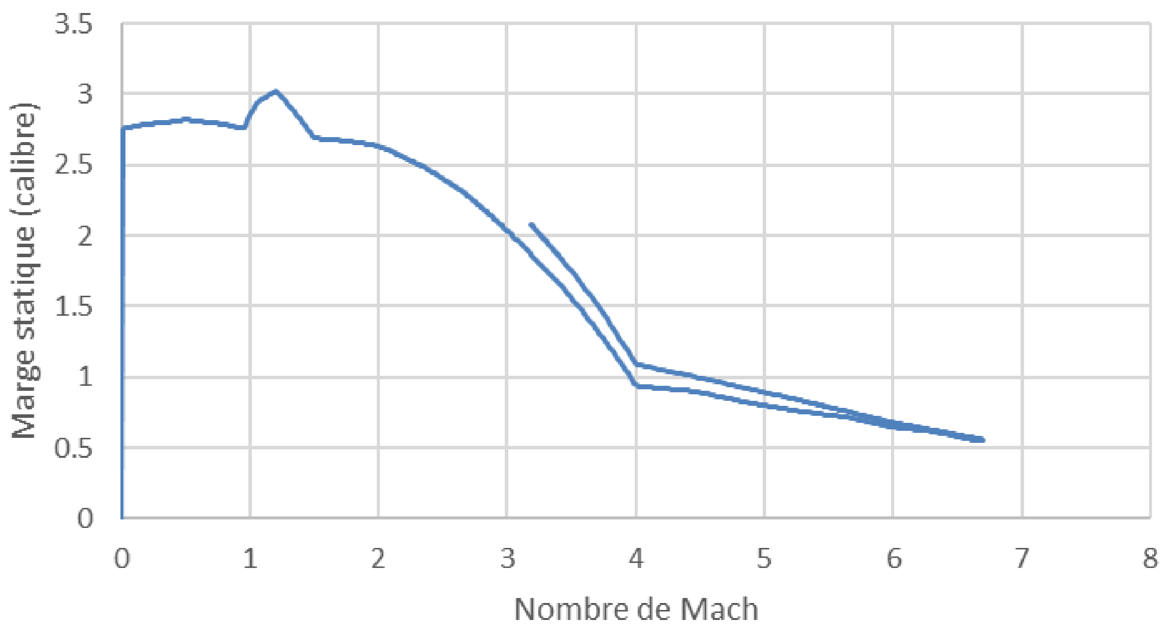


Fig 10 : SyLEx Block 1 Static Margin

2.1.2. Dynamic stability

As explained in the previous paragraph, SyLEx flight stability is ensured by aerodynamic equilibrium as well as gyroscopic spinning. The latter generates a conical motion around its inertia axis, which can be interpreted as an extra bit of angle of attack.

Hence aerodynamic stabilization oscillation and spinning rate both act on the rocket behavior and a dramatic increase of the angle of attach occurs when the two motion frequencies are too close. The following figure shows this effect on the SyLEx launcher:

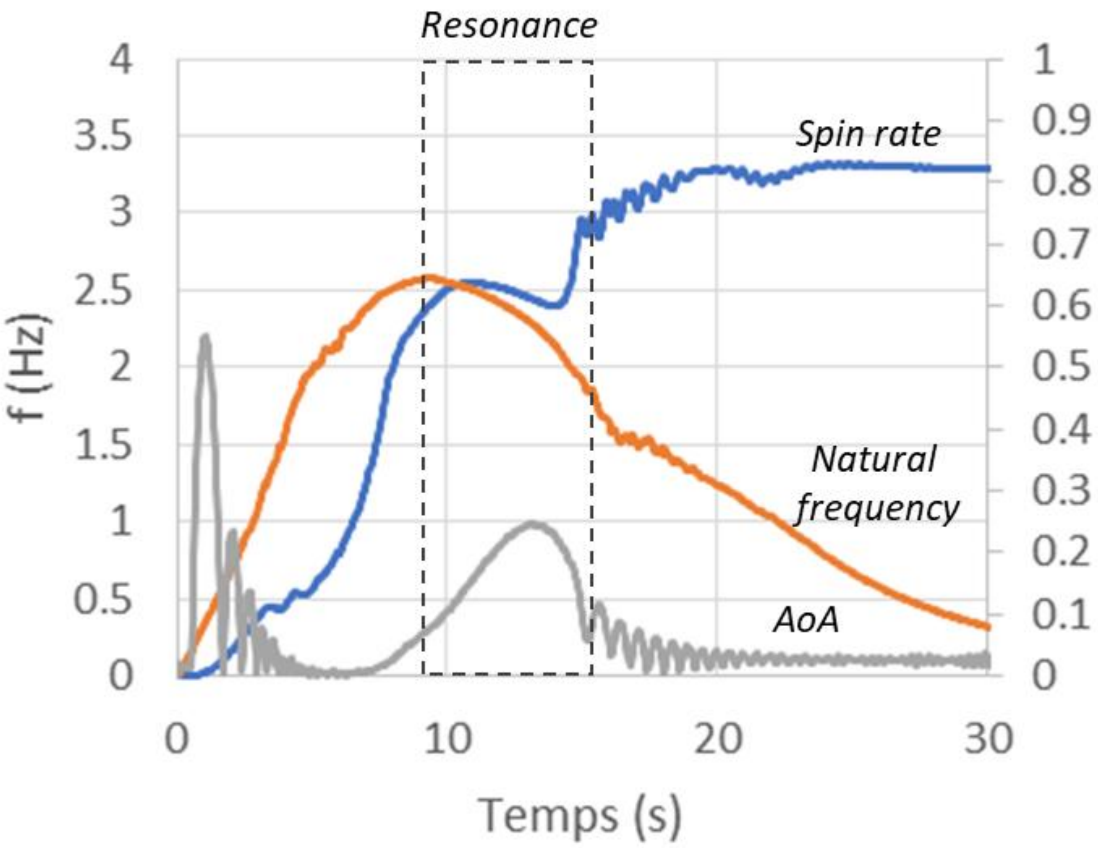


Fig 11 : Example of pitch / yaw and roll resonance

Under the right circumstances, the interaction is so strong that the spinning rate follows the oscillation frequency and angle of attack diverges, resulting in the loss of mission.

This phenomenon is well known in the sounding rocket industry and is mainly related to the natural behavior of the vehicle. However, it also depends on the rocket actual geometry and centering for instance:

- Rocket alignment : a mismatch in the rocket longitudinal axis and aerodynamic axis can induce a non-null angle of attack equilibrium
- Thrust vector misalignment which can generated a transverse force on the rocket
- Center of gravity and balancing biais
- Dissymmetry between pitch and yaw aerodynamic coefficient

These items were carefully monitored during the development to ensure proper behavior the vehicle in flight.

2.2. Maximal heat flux

2.2.1. SyLEx Block 1 flight domain

SyLEx single stage configuration has a unique flight domain when compared to ArianeGroup's other launchers. The following figure shows a comparison between Ariane 6 Low Earth Orbit mission and SyLEx Block 1 Mach number with respect to altitude.

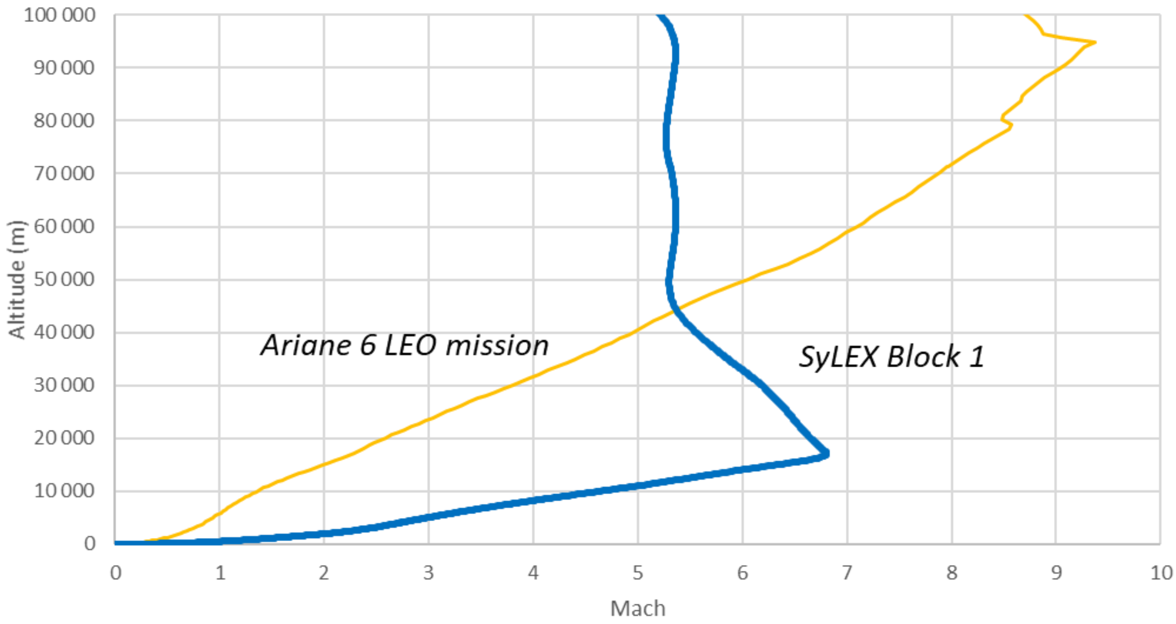


Fig 12 : Ariane 6 – SyLEx Block 1 trajectory comparison

One can notice that SyLEx rocket enters the hypersonic regime at 10 km altitude leading to intensive heat flux on the rocket. Typical cold wall heat flux value on the rocket fuselage varies from 400 to 600 kW/m² and can exceed 5 MW/m² on the leading edge of the fairing and the fins.

At these altitudes, parietal friction and the concentration of oxygen in the atmosphere shall be taken into account in the selection and sizing of thermal protections. Furthermore, thermal protection and thermomechanical loadings are key drivers in the structural sizing of the rocket.

SyLEx fins design is a good example of the challenges faced to define a light yet robust structure with regards to both mechanical and thermal loading.

Indeed, the leading edge of the fins shall met the following requirements:

- Sustain the heat flux and protect the aluminum structure
- Sustain the parietal friction and oxygen concentration in the air flow
- Sustain thermomechanical loading

2.2.1. SyLEx Block 1 fins leading edge development

ArianeGroup's expertise in developing high performance thermal protection materials led to select a silica-phenolic resin material for the leading edge of SyLEx Block 1 fins:

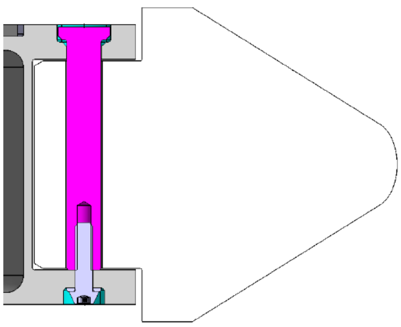


Fig 13 : SyLEx Block 1 Fins leading edge

To assess the material capabilities and compliance with SyLEx flight environment a dedicated plasma jet test campaign has been performed at ArianeGroup Issac premises. The objectives of this campaign was to assess the capability of the material to sustain up to 8 MW/m² heat flux for over 10s.

The test sample is composed of a supporting system that maintains the material near the plasma torch nozzle and an instrumented leading edge:

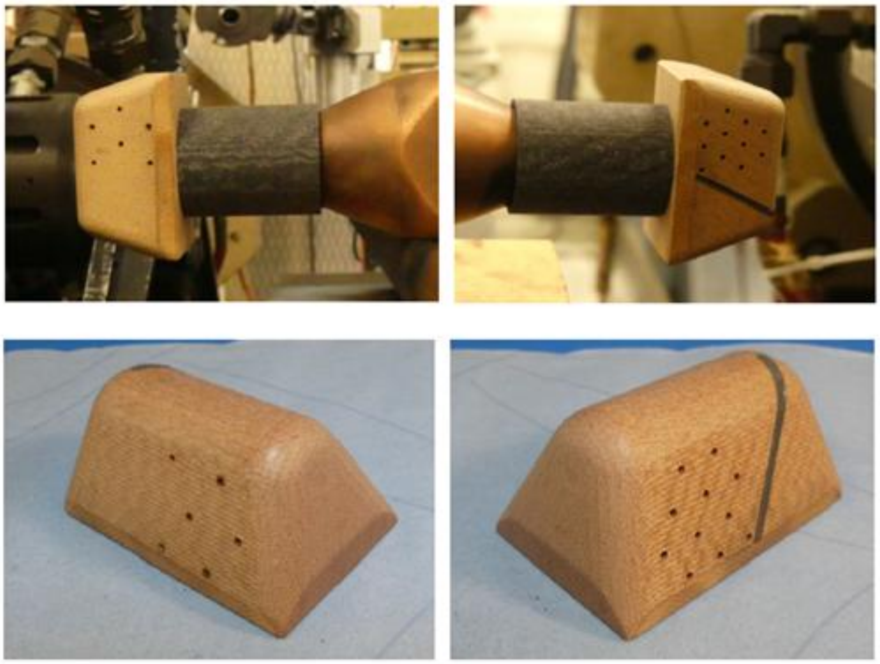


Fig 14 : Leading edge sample

ArianeGroup's JP200 test facility provides a wide range of measurement means such as slow motion camera, thermal cameras or spectrometers which allow to characterize the material degradation during the test.

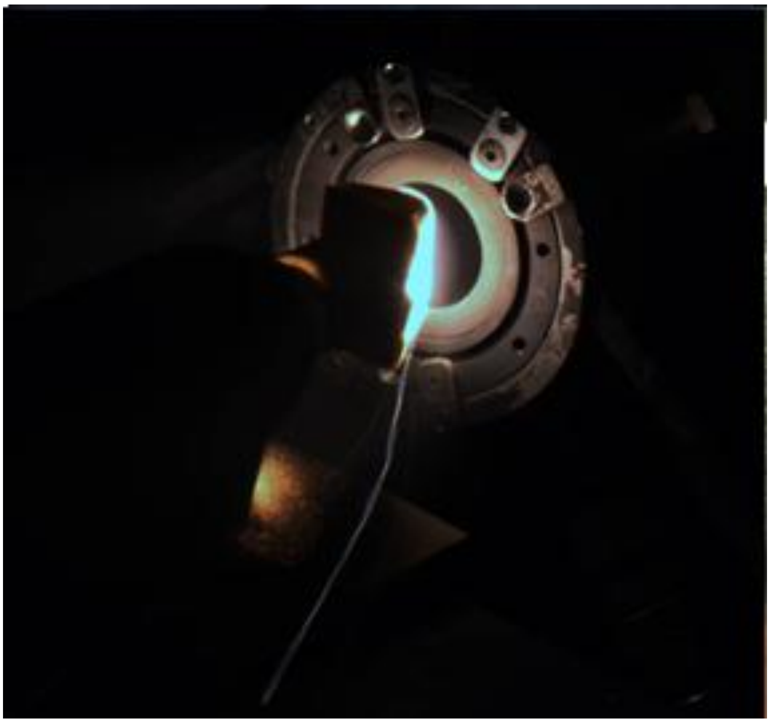


Fig 15 : Test sample during firing

Results exploitation allowed verifying thermal computation and drove the design and justification of the fins.

As an example, pyrolysis thickness were measured at 3 mm on the test sample and compute at 5 mm showing conservatism in the sizing approach and confidence in the rocket robutness.

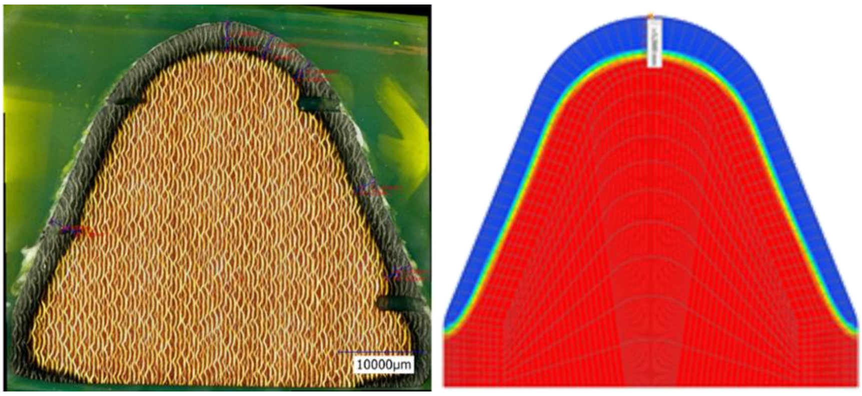


Fig 16 : Test sample pyrolysis comparison with computation

2.3. Fairing Separation

SyLEx is equipped with a clamshell jettisonable fairing for both Block 1 and Block 2 configuration. This fairing can also be adapted to the experience geometry by adding dedicated protrusion.

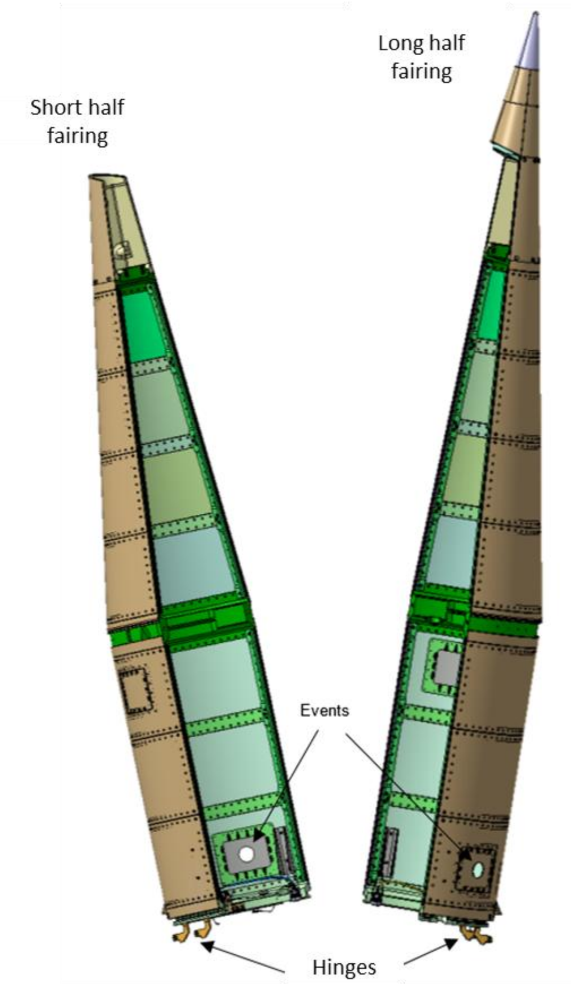


Fig 17 : SyLEx Fairing

The key functions of this fairing is to protect the customer experience during the atmospheric flight and provide direct access to space.

Thus the fairing separation shall be carefully study in order to ensure that the kinematic of both half shell does not endanger the experience. The jettison is performed in 4 steps:

1. The intermediate belt is released
2. The bottom V-Band junction is released
3. The upper joint is released and 2 springs push both half shell around its hinge.
4. After a rotation of 30°, both half shells are released from the vehicle

Assessment of the parts motion is performed through rigid body finite element model computation. The next figure gives an overview of the modelization and an actual half shell in ArianeGroup's premises:

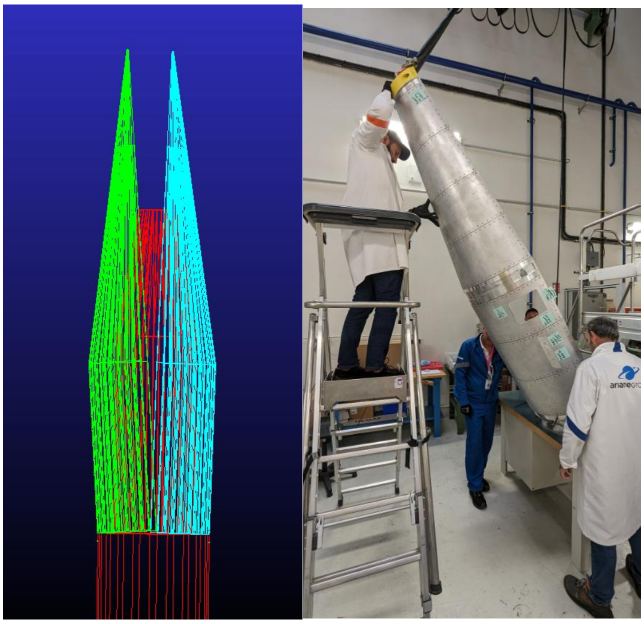


Fig 18 : SyLEx Fairing

A monte carlo analysis allows to predict the fairing separation for a numerous set of parameters such as the vehicle attitude, the spring forces and the inertia of the parts. The distance between the vehicle and the shell is then computed to demonstrate that no damage or disturbance is foreseen with the relevant reliability.

The following figures shows the shell trajectories and the clearance between the experiment and the shells.

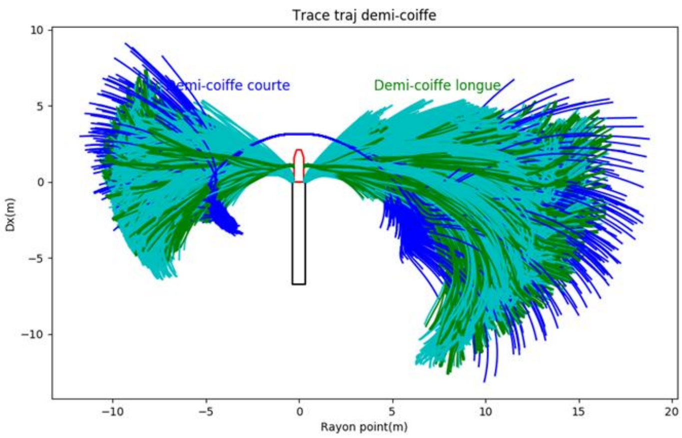


Fig 19 : SyLEx Fairing separation trajectory

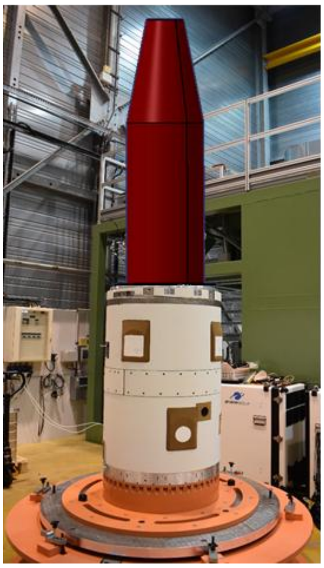
3. SyLEx DEMO1 Ready for Flight

ArianeGroup in the past months has handle the finalization of development and demonstration of the flight performances. In parallel, to shorten the development and manufacturing schedule, components were already manufactured and tested.

The last phase involved the full assembly of the DEMO1 rocket, including the payload assembly.

The aim of the payload assembly operations was to ensure the proper installation of the experiment and to guarantee the correct balancing of the upper composite. This was achieved by adding mass slugs to nullify both static and dynamic unbalances in the structure when fitted with payloads and experiments.

Experiment assembly with avionic module and experimental case module Functional tests



Fairing assembly Vband installation Pyrotechnical initiators assembly

Nose cone assembly Lifting operations

Fig 20 : Payload Assembly process 1

Fig 21 : Upper composite balancing test before final assembly

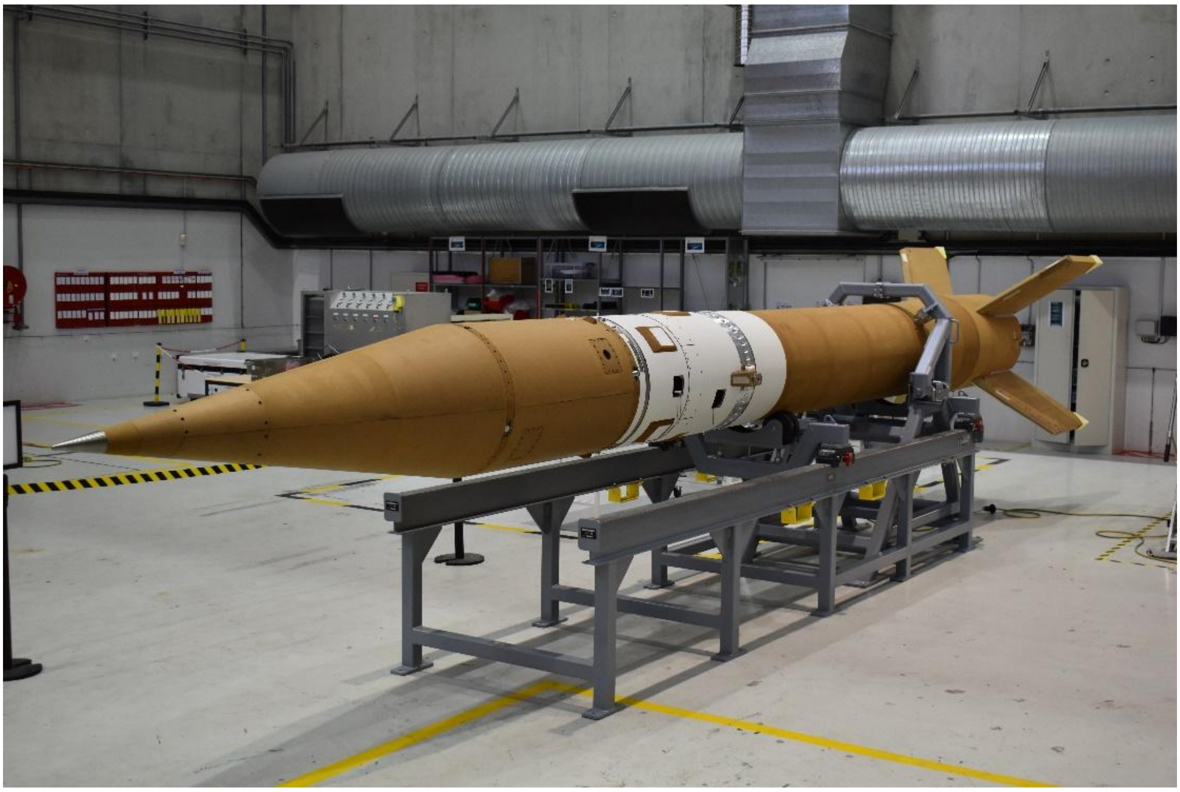


Fig 22 : SyLEx "DEMO1" ready for flight

4. SYLEX Manifest and next Challenges

Following the first BLOCK1 flight, ArianeGroup is currently working on the next challenges:

- SyLEx Block 2+ first DEMO flight
- Component manufacturing for next SyLEx sounding rockets : 2 Block2 to be launched in 2026
- Production schedule and manufacturing set up to fulfill a production rate of 3 to 4 Spark motors and 2 SyLEx per year (single stage and dual stage version)
- Addition of new featuring:
    - Camera implementation
    - Recovery system

And this is not the end of the story…