DOI: 10.13009/EUCASS2017-57

Ariane 6 launcher requirements for solid rocket motor

Fabrice MARTIN and Isabelle QUINQUIS***
**Solid Propulsion Engineer*
Airbus Safran Launchers, Route de Verneuil, 78133 Les Mureaux, France
***System Engineer*
Airbus Safran Launchers, Route de Verneuil, 78133 Les Mureaux, France

Abstract

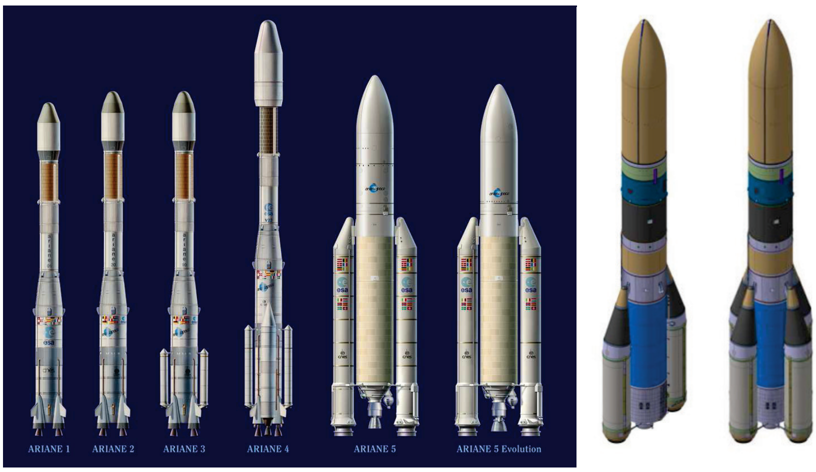
Soon Europe will acquire a new launcher called Ariane 6 in order to meet the new constraints of space market introduced by new comers like SpaceX, Blue Origin that declared they wanted to think space differently, especially with regard to costs.
Although looking roughly like Ariane 5, Ariane 6 will have a brand new booster, the biggest monolithic solid rocket motor in the world able to meet very stringent requirements in terms of performance, thrust imbalance, pressure/thrust oscillations, production rate as required by the System/Launcher teams.

Acronyms

AM	*Acoustic Mode*
CSG	*Centre Spatial Guyanais*
DIAS	*DIspositif ASsouplisseur (damping device)*
ESA	*European Space Agency*
ESR	*Equipped Solid Rocket (= booster)*
EUP	*EURoPropulsion company*
Fmean	*Mean thrust between two SRM*
Fx	*Instantaneous thrust of SRM #x*
MPS	*Moteur à Propergol Solide (SRM on Ariane 5)*
SRM	*Solid Rocket Motor*

1. The Ariane 6 launcher

The Ariane 6 launcher is based on a full cryogenic central core propelled by the Vulcain2.1 engine on the lower composite and by the Vinci engine on the upper part. As Ariane 6 has to be versatile with regard to the large missions be performed, and like its elder "sister" Ariane 4, two or four boosters will be able to be implemented.



Ariane 6

Figure 1: Ariane family and the Ariane 6 configurations (A62 on the left, A64 on the right)

DOI: 10.13009/EUCASS2017-57

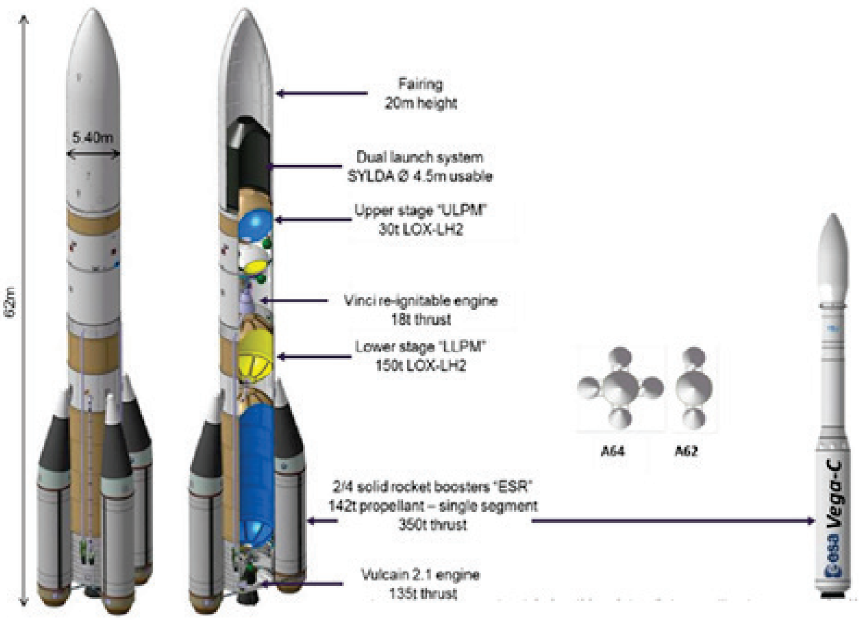


Figure 2: Ariane 6 description

1.1 Origin of the P120C SRM

Without entering in detail, the retained industrial organization is globally the same as the Ariane5/MPS one but with evolutions, i.e.

- AIRBUS SAFRAN LAUNCHERS and ELV are in charge of System activities for their own launcher and define the requirements for the SRM,
- EUROPROPULSION is the Design Definition Authority that means its responsibility is increased with regard to the SRM good operation and EUP is the supplier of SRM's. That also means no general requirements are initially proposed by the Ariane 6 System, but the Motorist has to define its own specification reference to be accepted by the System
  Moreover, EUP relies on two main sub-contractors that are AVIO and AIRBUS SAFRAN LAUNCHERS with a complete technical sharing of the development activities.

Due to a short schedule to develop such a solid rocket motor, co-engineering loops have been put in place in order to reduce the information exchange as much as possible between the Product and the System.
The final P120C SRM has been the result of an intense co-engineering activity between both Systems for Ariane 6 and VEGA C and the Motorist EUP:

- starting from a PPH configuration: a launcher including three identical solid rocket motors as first stage, another same SRM and a cryogenic stage with Vinci engine,
- a configuration change decided for a PHH launcher configuration, the solid propulsion being used as boosters,
- until the final convergence on the biggest SRM able to be manufactured with the current casting tools and pits, which led to a SRM having around 3.4 m diameter and 13.5 m total length.

1.2 The Ariane 6 ESR

The booster (also called Equipped Solid Rocket) implemented on the launcher is constituted of:

- a rear skirt that allows the launcher to stand on the launch pad,
- the P120C solid rocket motor,
- the upper cone that allows the thrust transmission to the rest of the launcher

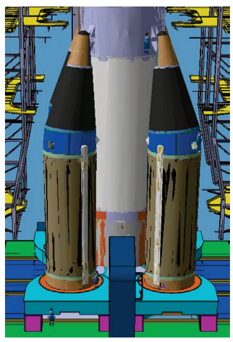


Figure 3: ESR view during launcher integration

DOI: 10.13009/EUCASS2017-57

2. Ariane 6 requirements for the SRM

2.1 Performance

In terms of performance, the requirements deal with the SRM mass, thrust laws constraints and thrust impulse. The next table presents the mass specifications and the Figure 3 shows the thrust law constraints.

Table 1: mass requirements

	Value
Minimum propellant mass (kg)	140000
Maximum SRM inert mass at ignition (kg)	11900
Maximum SRM inert mass at separation (kg)	11300

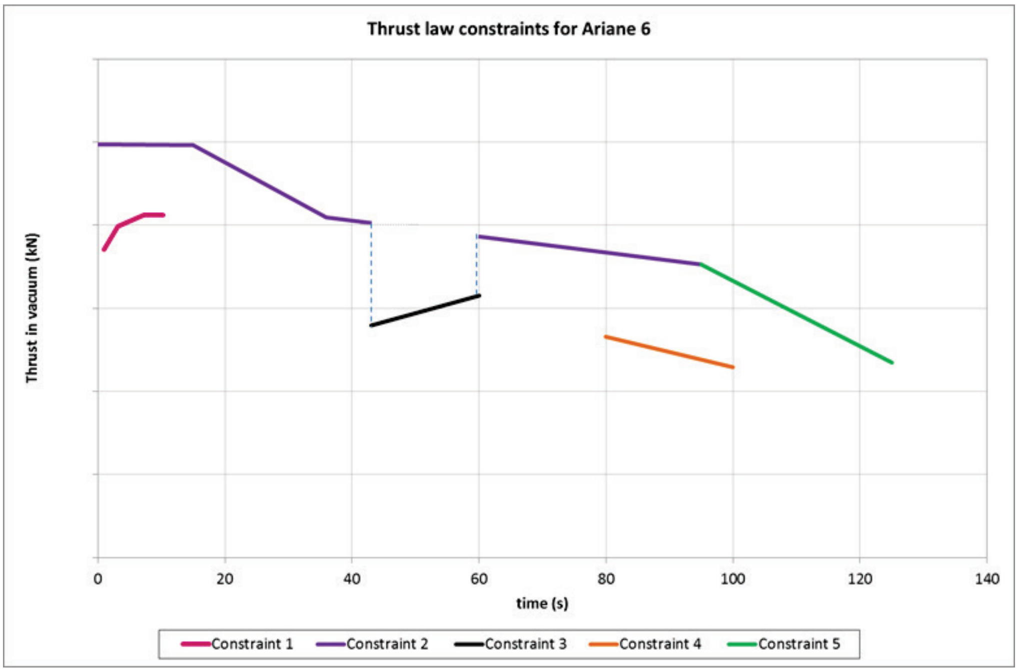


Figure 4: System constraints on thrust law

These constraints have to:

- guarantee a minimal acceleration at lift-off (constraint 1),
- be under a maximum limit with regards to general loads and structures sizing, including the maximum dynamic pressure phase (constraints 2 and 3),
- to re-accelerate after the dynamic pressure phase above constraint 4 in order to maximise the launcher performance,
- limit the final acceleration because of payload comfort (constraint 5).

In addition of these constraints, some other requirements have been defined to help the Motorist to optimize its thrust curve through thrust impulse values as described in the next table.

Table 2: other thrust requirements

	Value	*Objective*
Burning time range (s)	130-136	To ensure a minimum launcher performance
Minimum total impulse in vacuum (MN.s)	380	
Maximum Partial impulse à t=t0+43 s (MN.s)	161	To limit the ejected mass before Pdyn phase

DOI: 10.13009/EUCASS2017-57

2.2 Thrust imbalance

As on Ariane 5, the boosters have to operate simultaneously and in these conditions they have to be as reproducible as possible during all the SRM phases.
In addition, as the P120C SRM is a one grain motor, it is shorter than the MPS of Ariane 5 inducing a center of gravity much lower than on Ariane 5, especially in configuration with 4 boosters. The controllability of the Ariane 6 launcher is then degraded and thrust imbalance constitutes requirements that have to be absolutely met by the SRM to warrant the Ariane 6 feasibility and robustness.
Thus the following diagrams illustrate the different acceptable thrust imbalance versus SRM operation phases.

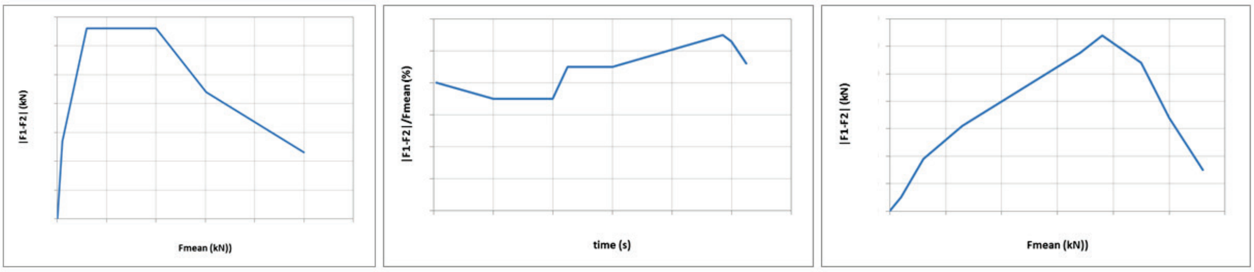


Figure 5: Acceptable thrust dissymmetry (on the left, during lift-off, in the center: on steady-state, on the right: during tail-off)

During dynamic pressure phase, the thrust imbalance needs to remain as low as possible because contrary to Ariane 5 where this phase is quite short (peak form), on Ariane 6, the assessment indicates that this phase would last several seconds, as shown in the next diagram, leading to a critical phase for the launcher controllability.

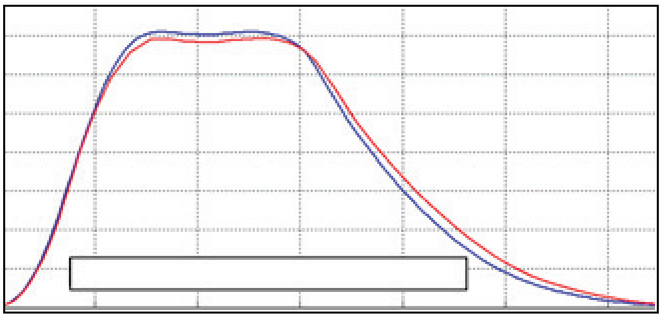


Figure 6: example of dynamic pressure assessment (and sensitivity) for Ariane 6 launcher

No SRM pairing is required by the Ariane 6 System, up to the Motorist to define the best solution in order to minimize the SRM costs and to meet these specifications.

3. Pressure oscillations

Ariane 6 aims to provide a payload comfort improved with regard to the Ariane 5 one. This comfort could be degraded when pressure oscillations occur and "shake" the launcher. Although promised without oscillations during the PPH launcher studies and so required as it for the P120C SRM, the current SRM architecture would be the center of significant pressure oscillations.
These environment being difficult to specify, a co-engineering activity has been performed in order to provide the best assessment of environment produced by the SRM and to analyse it at System level (see next figure).

DOI: 10.13009/EUCASS2017-57

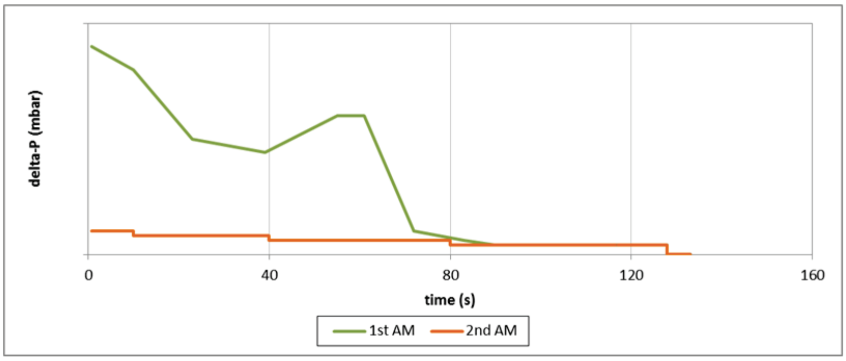


Figure 7: pressure oscillations domain in steady-state (source: EUP)

The analyses with FEM computations concluded that the upper cone of the ESR is a quite good filter regarding the source excitation. Besides, even if the levels are quite significant during the first part of the flight, the response at launcher level remains low because the SRM has still a lot of propellant. The critical phase is after 80 s when the SRM is quite empty and amplifies the excitations transmitted to the rest of the launcher. This is the point the Motorist has to characterize and above all it will have to define the maximum amplitude associated with the frequency range.

However a risk is remaining during tail-off where a blast could occur. Some damping devices have been analysed in case of the occurrence of higher environment than expected, like an equivalent of the current device implanted on Ariane 5 MPS (DIAS), or other concepts implemented either on the upper part of the ESR or directly on the Central Core / ESR attachment point.

The choice to implement or not this device on the Ariane 6 Launcher will be taken after the first static firing test of the P120C SRM, called DM and foreseen in the first semester of 2018.

4. Other commonalities

As declared previously, the SRM is common between the Ariane 6 and VEGA C launchers. As both of them are launched from the CSG in Kourou, Guiana, they have to meet the same safety requirements with regard not only to infrastructures and staff in the CSG, but also to sinking requirement.

Two devices have been required to ensure these functions:

- an anti-flight system device (a P80-like concept) that allows to prohibit the SRM self-propulsion with the burst out of the igniter mechanical link in case of untimely ignition. This device is changed in flight configuration few hours before lift-off,
- same pyro cord device that cut the SRM tank in case of launcher malfunctioning in flight and to open the SRM for sinking obligation

Linked to this topic of neutralization, the location of raceways (including cutting cords) have been subject of intense discussions between Systems and Motorist. From System point of view, on one hand a symmetry between raceways is required (VEGA C need), and on the other hand, a raceway with cutting cord needs to be diametrically opposed to central core, and the other raceway at 90 degrees for the first flight models (this latter being removed in final production, Ariane 6 need). The current convergence found between each party is to have both raceways almost symmetrical, slightly standing back from the central core.

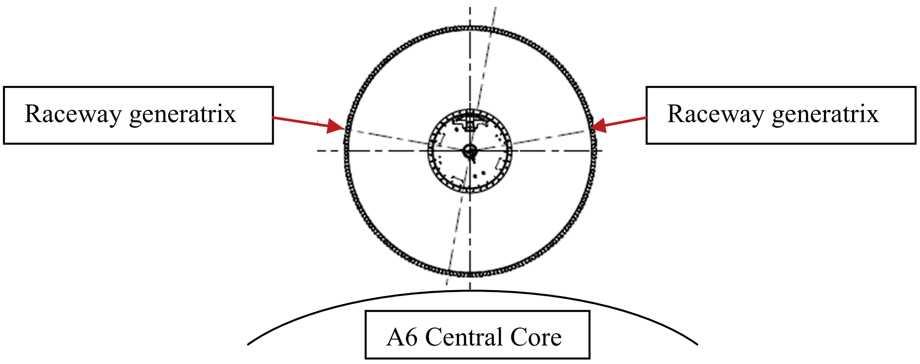


Figure 8: location of raceways on the SRM

DOI: 10.13009/EUCASS2017-57

At last, another common equipment is embarked on the ESR and on the VEGA C first stage: the nozzle actuators that allow to gimbal the nozzle up to 7 degrees. Indeed, to minimize the costs during development, it was decided to have the same hardware between both Systems, even if the complete TVC loops are different.

5. Integration and production

A substantial source of cost reduction is linked to the production rate and the ability of the Motorist and the System to integrate first the motor, and then the ESR in short duration.
To do this, ESA has to commit for a minimum of institutional launches and the other launchers shall be performed for commercial ones. The total number of Ariane 6 launches is expected at least 11 launches a year. At SRM level, the cadence is increased up to 35 motors (32 for Ariane 6 and 3 for VEGA C) annually, which is around 50% higher than the MPS cadence with 6 pairs of MPS a year, equivalent to 24 segments slightly smaller than the P120C SRM for the loaded motor case and a production increase of 200% for the nozzles and igniters (compared to the 12 nozzles and igniters on Ariane 5 MPS).
For integration, EUP chose the horizontal configuration minimizing the handling operations of the motor and its sub-components: the loaded motor case is placed on a skidder in the horizontal integration cell in the EUP premises in Kourou, the nozzle and the igniter being assembled one after the other, and then the SRM is controlled before final delivery.
Although not required by Ariane 6 System, it was decided to use this configuration to integrate the ESR and control it, once again to minimize integration costs and the lead time corresponding to these activities.

6. Conclusions

Because it has to meet requirements coming from two different Systems, for the time being the P120C SRM, which is a specific item fitting the needs of two different Launchers, is one of the most challenging developments given to solid propulsion industry in terms of:

- Performance objectives to ensure the same level as Ariane 5 in the first times,
- Thrust dissymmetry minimization for launcher controllability,
- Thrust oscillation reduction to increase Payload comfort,
- Cadence increase,
- And significant cost reduction in development and in production.

The first ground firing test will allow Motorist and Systems to check the good design of the motor and to better assess its behaviour in operation, hoping that no requirement will be put into question after it.
For System, this static firing test will be the very first tangible milestone of a short but intensive development period until the first flight of Ariane 6 foreseen in July 2020.