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Ariane Next, a vision for a reusable cost efficient European rocket

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Abstract

Ariane 6 and Vega-C is well on track and will start their operational life by 2020. In this context, CNES Launcher directorate, is currently evaluating launch system definitions for the next generation of Ariane launchers, so called Ariane NEXT. The main goal is to demonstrate a sustainable competitiveness in particular by enabling launch cost to be halved. In order to limit technical risks, Ariane NEXT launch system studies follow a design approach considering a highly standardized architecture and also evaluate LOX-CH4 interest. The reusability is taken into account on the first stage and only as an option in launch system exploitation. An overview of the current status of the Ariane NEXT launch system definition and some of its main subsystems is provided, including those dedicated to stage recovery. It will also discuss the added value of reusability in the European context.

1. Introduction

The development of Ariane 6 and Vega-C is well on track, and both launchers should start their operational life by 2020. Combining enhanced capabilities, increased flexibility and reduced launch costs, the modernized fleet will be the backbone of the "European Space Access Strategy" for the next decade. Beyond these developments, a step forward must be achieved to improve cost and flexibility of European launchers. By definition, market forecasts are uncertain, and new disruptive approach could be necessary to better address both institutional and commercial satellite market [1].

In this context, and in parallel of ArianeGroup launch system studies in the frame of ESA/FLPP [2], CNES Launcher directorate, is currently evaluating launch system definitions for the next generation of Ariane launchers, so called Ariane NEXT. The main goal is to demonstrate a sustainable competitiveness in particular by enabling launch cost to be halved wrt Ariane 6. In order to limit technical risks, Ariane NEXT launch system studies follow a design approach considering a highly standardized architecture as it will allow for a significant reduction in the development and operating cost. The launch system studies also evaluate LOX-CH4 interest, simpler to handle than LOX-LH2 and allowing for further tank communalisation and simplification. Moreover, in order to enhance flexibility and cost efficiency, the reusability is taken into account on the first stage as it represents ~50% of launcher cost, and only as an option in launch system exploitation. Different concepts of stage recovery are studied including Toss-back, winged concepts with and without aeronautical propulsion in partnership with ONERA [3] but this paper will address only the current reference Toss-back recovery mode (retro-propulsion and vertical landing) considered at CNES.

The paper is organized as follows. In section 2, consideration on market projections at 2030 horizon and the scenarios that will be addressed in the studies are presented along with the main launch system requirement application. In Section 3, main loops objectives are summarized, giving a global view of launch system studies objectives. In section 4, design loops main results in terms of staging, architectures and performances will be addressed. In Section 5, main exploitation scenario and overview of launch cost efficiency levers is presented. Finally, in conclusion, is given a summary and some perspectives on the following activities.

2. Market and High level requirements for Ariane Next

2.1 Market scenarios

Ariane Next system studies considers a horizon of 2030 as first launch date. Predicting market at this time frame is by definition very hazardous. The goal here is then to submit the different launcher configurations to different market

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scenarios in order to judge the robustness of different concepts to market hypothesis. Allowing, in the end, quantifying the best configuration given the hypothesis.
One can assume the satellite market defined by the sum of institutional market and commercial market.

- institutional market stands for governmental/military satellites, scientific missions, navigation needs, Earth observation, etc.
- Commercial market can be summarized in three different types: GEO, Non GEO and constellations. These three types impose very different mission types and launch frequencies.

Depending on the future tendencies, 3 market scenario can be designed:

- "Business as usual": in addition to institutionnal market forecast, GEO demand and share stay within actual number (excluding 2017 "gap"), the equivalent to one big constellation is launched by Ariane Next representing 20t by plane and year during 6 years. Non GEO stay relatively limited and represent 5 missions per year. "Business as usual" represents roughly 19 missions per year.

- "Space Economics Expansion": in addition to a more exhaustive institutional market, this scenario is to be divided into variants. Indeed, 2 cases could be envisioned considering the commercial success of constellation. As the constellation grow GEO market could be limited and reciprocally. Launcher concepts may not respond in a similar way for the two cases and so each variant have to be considered. In this scenario market shares increases substantially, which gives a total number of about 24 missions per year.

- "Robustness case": Institutional market is limited to renewing of existing services, commercial market is very limited. The consideration for this market lead to a number of 10 missions per year.

2.2 High level requirement

In order to settle some main consideration about Ariane Next design, some main requirements have been anticipated.

Table 1 : Ariane Next Launch system Main requirements

Preliminary Requirements		**Ariane Next**
Time to market		*2028+*
Launch service	Payload volume	*Standard fairing: idem A62 short fairing* *Large fairing: 7m external diameter (growth potential)*
Launch cost	*Launch cost @ 13 payloads/year*	*50% cost reduction wrt A6 for commercial missions*
Launch rate	Launch rate	*19 Payloads per year as ref.* *Up to 25 launches per year*
Availability	Standard notice	*< 12 months*
	Reduced notice	*< 3 months*
Reliability, payload comfort		*Idem A5 / A6 / Vega*
Launch pad (in Guyana Space Center)		*ELA3 or ELS (refurbished)*

Along with theses preliminary requirements, from a performance point of view, a certain number of mission have been considered. Compatibility with GTO missions is mandatory for institutional needs, along with Galileo future generation. Earth observation is normally covered in terms of payload mass by GTO performance.
Performance objectives are then defined on the basis of market scenarios, with the following principles:

- The objectives in expendable missions represent the maximum requirements identified in terms of payload mass for the most energetic missions GTO and MEO;
- The objectives for recoverable missions (where the 1st stage is recovered in order to be reused on a following mission) are defined in such a way as to target at least 50% of missions with recovery of the 1st stage on a flat-rate basis (significant threshold allowing the reuse of stages for each of the missions to be performed as expendables, and thus reducing the launch cost). This leads to down range or RTLS operations;
- LEO and constellation missions are not considered with a specific target (except Galileo).

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Table 2: Ariane Next Launch system performance requirements

Mission	Recovery mode	Payload performance (tons)
GTO 1800m/s	Down Range	> 4.50
GTO 1500m/s	Expandable	> 7.00
SSO 800km	RTLS	> 4.50
MTO 7000km circ. 58° (Galileo NG)	Expandable	> 4.75
MTO	Down Range	> 2.50
L2	Expandable	> 2.00

It is to be noted that there are many other missions that are not identified here whereas to be considered in the flight domain, such as Low Earth Orbit missions, escape missions, multiplane missions, etc. On these missions there is not, as of today, requirements of performance due to the current level of detail of the system studies.

3. Ariane Next main design drivers

Current system studies at CNES/DLA aims to consolidate a certain number of path and concepts toward the goal of a low cost launcher. One can consider the main following ones:

3.1 A highly efficient and standardized architecture

From a launcher perspective, the main objective being the reduction of costs, the result is an important driver which is the communalization of the different components of the launcher along with the minimization of parts. This quest for synergy must be combined with high level design principles to limit the negative effect on the performance. Indeed, the need for performance combined with poor structural indexes for instance could lead to an increase of propellant loading.

Therefore, one can settle the main architectural characteristics as follow:

- A single diameter for all the launcher (fairing may be excluded from this constraint),
- Limitation of singular, or one stage only equipment. Sub-system technology shall be repeated as much as possible between stages.
- Two stage to orbit launcher, with as few as possible optional measures to comply with all missions required.

3.2 LOX-CH4 or LOX-LH2

LOX-CH4, as opposed to LOX-LH2, is considered in Ariane NEXT system studies as a means of enabling the synergies between tanks, the application of technologies such as low cost engines, composites, common bulkheads and simplifying launch operations as well as thermal management for long or multi boost missions. Of course, this comes with the main disadvantage that the theoretical Isp obtained with LOX and LCH4 is far less than LOX-LH2 combustion. This will lead to heavier launchers, requiring more thrust to lift-off.

3.3 Prometheus

Prometheus is the key foundation of Ariane NEXT concepts by the offered capacities of such engine [4][5]. The operation in cluster of engines allows single stick configurations (aka without side boosters to ensure lift off). The possibility to derive the same engine both on first and second stage will allow a further optimisation and synergies on the subsystems.

However, the level of thrust remains an important hypothesis for launcher staging as the two stages configurations are very sensitive to this particular parameter. For the last iteration of design loops Ariane NEXT feature a nominal thrust of 1 200kN in vacuum instead of 1 000kN in the current Prometheus loops, the impacts on the design is currently assessed [4].

3.4 Stage recovery and Reusability

Assuming that the launcher design proves itself as efficient as possible, reusability is key to further improve the cost targets. Ariane Next system studies considers the recovery of the first stage using retro propulsion and possible designs options for second stage recovery.
As a consequence of the semi-reusability targeted exploitation scheme, the first stage design modification for recovery is targeting to have minimal impact to the expendable configuration and is foreseen as a kit, mounted only in the case of an attempt to recover the stage.

3.5 Fairing diameter

Reference diameter for the faring is currently set at 5.4m, covering all identified needs as of today. At 2030 horizon, it is possible that 7m diameter fairing becomes gradually a new standard, enabling either the launch of heavy payloads or the aggregation of multiple medium payloads. The compatibility of the launch system to a larger fairing shall then be assessed to be able to determine possible technological lockouts.

4. Ariane Next design loops

The current system studies are currently addressing different configurations. One can summarize the different possibilities with the following figure.

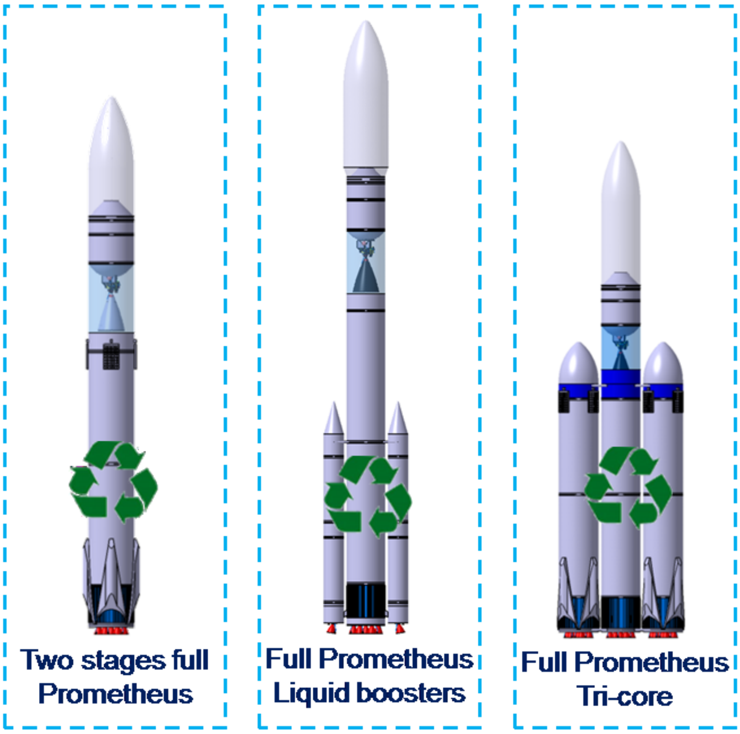

Figure 1: Ariane Next configurations

Different options are currently explored in order to maximize flexibility and cost efficiency, and answer to emerging satellite markets. Actual considerations go from only one launcher answering to whole market, creating flexibility with recovery of the first stage and/or additional small boosters, or replicating the first stage in order to create a launch family from single stick to heavy configurations.

It is to be noted that aside from all methane configurations, a TSTO using hydrogen is also under evaluation. This concept would use a Prometheus derived hydrogen engine. Apart from this (huge) difference the main architectural key parameters are the same.

The following part will describe the first two configurations using Methane propellant, detailing architecture principles, performance results and a preview of trajectory results.

4.1 Addressing the launch market with a single launcher: full performance configuration in LOX-CH4

Limiting the number of pieces, and streamlining the integration process lead to simplify the launch system at its outmost. Therefore, addressing all type of missions can be done with a large two stage launcher able to launch up to 7t in GTO mission down to 500kg in LEO missions.
Following this principle, the following launcher has been pre-designed: staging is made on the GTO 1800m/s mission with the first stage recovery.

Complying with the performance target for this missions leads to the following staging. 600 tons of propellant for the first stage and 126 tons for the second stage. The launcher is considered propelled by 9 Prometheus engines with a nominal vacuum thrust of 1200kN. All stages are at the same diameter, which is determined by the management of different constraints, such as launchers height, ability to integrate all Prometheus engines in the aft bay and optimum diameter for the two stages. For this configuration the diameter is then selected to 5.4m.

Structural indexes are key parameter for a TSTO configuration. Common bulkheads, large through feed lines, and short thrust frames are considered in order to target the lowest possible structural indexes (around 5%). Tanks materials are still subject to trade-off between Steel, Aluminium and Composites. Pre-sizing of the stage takes into account reinforcement and placeholders for recovery specific hardware, this hardware is only mounted on the stage for missions with first stage recovery.

A visual of the launcher configuration is given below:

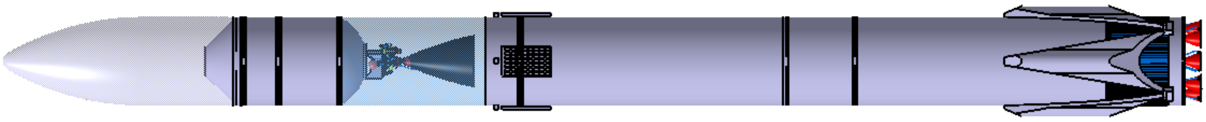

Figure 2: Ariane Next C600-C126 configuration equipped with recovery kit

For this configuration, two return sites are envisioned, depending on the required performance for a particular mission. Return To Launch Site (at Guyana Space Center) is the most challenging in terms of flight manoeuvers and leads to halve the performance. Down-Range return mode of the first stage, aka close to the nominal ballistic impact point at first stage separation, makes the return phase more accessible in terms of performance degradation and flight maneuvers but it is significantly more demanding toward aerothermal and aerodynamical fluxes and infrastructures required (floating device that is able to withstand the landing of the stage, and all the relevant port facilities).

Performances obtained are the following ones,

Table 3 : Ariane Next Launch system performance results

Mission	Recovery mode	Payload performance (tons)
GTO 1 800m/s	Down Range	4.5
GTO 1 800m/s	Expandable	8.5
GTO 1 500m/s	Expandable	6.6
SSO 800km	RTLS	5.5
MTO 7 000km circ. 58°	Expandable	6.6
MTO 7 000km circ. 58	Down Range	3.0
L2	Expandable	3.1

Performance results reach the target except for GTO 1 500m/s where the configuration is 400kg short. Addressing larger than 6.6t payloads could anyway be done by increase the amount of deltaV done by the payload to reach its operational orbit.

A typical trajectory altitude profile for a GTO Mission with down range recovery of the first stage can be seen hereafter. In red and cyan propulsive and ballistic phases for ascent, in blue and red propulsive and ballistic phases for 1st stage

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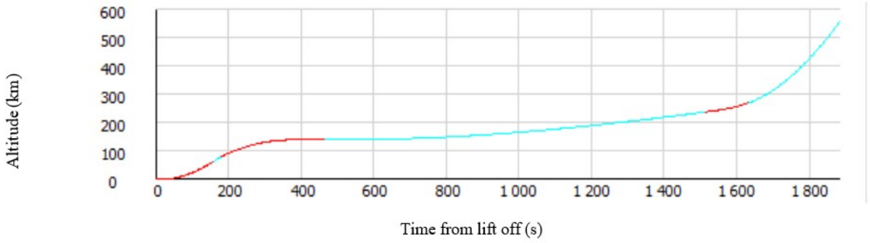
return. On the return trajectory, one cans notice a quite important braking boost taken into account before heat flux peak.

Ascent phase:



1st stage return phase:

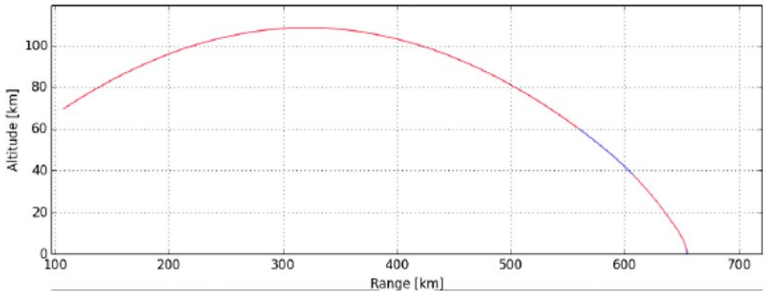


Figure 3: Ariane Next C600-C126 trajectory profile

One can notice that the mission profile features a two boosts injection scheme. This particular scheme is optimum to set the perigee argument close to 180°. This can be explained by the very short duration of propulsive flight (around 600s) that would imply to bend quite intensively the trajectory to reach equator line in order to align nodes line to apsides line of the final orbit.

4.2 concurrent designs - LOX-CH4

An alternative approach to the full performance configuration is to set an intermediate target for the two stage linear version and then to address high performance missions with additional boosters.

Setting the dimensioning mission of GTO 1 500m/s expendable at 4.5t lead then to a lighter launcher. The staging obtained is around 450t of propellant for 1st stage and 103 tons for second stage. The launcher is considered propelled by 7 Prometheus engines with a nominal vacuum thrust of 1 200kN.

The same design optimization process was followed as for the full performance configuration. It leaded to a 4.6m diameter on the 2 stages, allowing a significant mas saving wrt 5,4m diameter.
One can then design a booster able to be fitted between aft bay and intertank section. Loading of such booster was set to 60tons of propellant, featuring a single Prometheus engine.

A visual of the launcher in boosted configuration is provided hereafter:

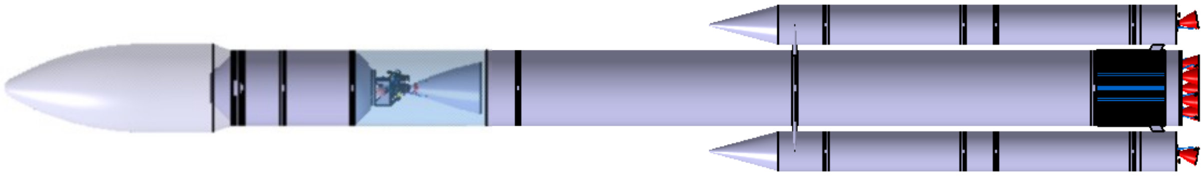


Figure 4: Ariane Next C450-C103 configuration equipped with boosters

The configuration would then address:

- Small performance mission with the recovery of the first stage
- Medium performance in expendable configuration
- High performance in expendable mission with the addition of 2 to 4 liquid boosters

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Performances obtained are the following ones:

Table 4 : Ariane Next Launch system - alternate configuration - performance results

Mission	**Launcher configuration**	**Payload performance (tons)**
GTO 1 500m/s	No boosters Expandable	4.0
GTO 1 500m/s	2 boosters Expandable	6.2
GTO 1 500m/s	4 boosters Expandable	8.3
SSO 800km	No boosters RTLS	4.1
MTO 7 000km circ. 58°	No boosters Expandable	4.3
MTO 7 000km circ. 58	2 boosters Expandable	6.5
L2	4 boosters Expandable	4.9

4.3 Growth potential

On all configurations, if an increase of performance is needed, different solutions can be studied

- Kickstage:

Kickstage is a particularly efficient way to gain some performance considering the two stage to orbit architectures presented. The two stage will would end its mission on a low orbit separate the kickstage and payload assembly and then be deorbited. The kickstage would then be in charge to raise this orbit to reach altitude and velocity of desired orbit. Kickstage would also be a practical way to address multi-plane constellations with a relatively small and versatile stage. Depending on added performance, the first stage could also be recovered, thus optimizing economically the whole process.

- Boosters:

As seen in the previous concepts boosters could be used to increase the maximal performance. However, the main drawback is that the presence of boosters penalizes heavily the ability of the 1st stage to be recovered. Therefore, is it a great way to have a good adaptation of performance but for an increased expandable exploitation.

- Tri-core

Replication of the first stage is tempting as booster, however one can note that the central core would have to particularized in order to sustain the loads generated by the sides cores. One can assume that if taken as a possibility from the start of the development, a cutting edge factory could be adaptable enough to produce the two different cores but it does add some complexity for a potentially limited number of launches in the European market.

4.4 Ground segment

In these studies, the horizon set for Ariane Next first launch date is in 2028+. This time frame is compatible with the reuse of either ELA3 or ELS (see Table 1) as A5 and Soyuz would then be decommissioned since a few years. The reuse of ELA4 is not foreseen as A6 will be in operations and so prohibits deep modification in the facilities. The trade-off between the two sites is ongoing. It considers different criterions such as existing facilities compatibilities for instance flame ducts, integration building volumes, danger zones, etc. There will also be some required adaptations given the differences in height of the launcher and some new buildings might be required depending on the selected assembly scheme.

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5. Recovery subsystems design

A set of design studies are currently performed at CNES and ArianeGroup for addressing following main design topics of Ariane Next.

5.1 Flip-over maneuver

The purpose of this study made in partnership with ArianeGroup is to define and select a Flip-over propulsion system for the recovery of the stage in the particular case of RTLS recovery mission.

Of all the possible systems, only dedicated ACS or the main engine were considered possible. Other means, such as the use of residual aerodynamics or the effects of jets from the upper stage were considered as possible opportunities but could not constitute the only means of turning the stage. The study of these opportunities has shown that jet effects are not negligible, and could constitute a significant part of the rotation of the stage.

The Trade-off performed between all possible ACS types and the main engine concludes with the choice of a dedicated ACS system using nitrogen. It benefits from simplicity (low cost), is decoupled from the total system (low risk), show a good potential of scalability (easy to reduce or expand), and low performance impact. Much more the use of nitrogen is already foreseen at stage level therefore the possibilities of synergies gives an additional advantage to this solution.

5.2 Aerodynamics controls trade-offs

The return phase of the first stage will imply some control in aerodynamic phase. Indeed, the propulsive phases are to short and would not be efficient to recover injection or atmospheric uncertainties. In partnership with ArianeGroup, 3 alternates design are today envisioned for system studies:

- **Fins:** could be relevant if high level of L/D coefficient are required to compensate for uncertainties or to compensate for safety constraints.
- **Grid-fins:** the design is today flight proven on numerous flying objects operating in the Mach domain of Ariane Next first stage return phase and is to be studied as a reference.
- **Aerobrake:** this solution, even if not as efficient as fin or grid-fins, and necessitating high torque actuators can improve the overall launcher system efficiency by increasing drag during reentry therefor diminishing the aerothermal fluxes.

The tradeoff is actually on the way and the studies result will be integrated in the frame of the global system studies.

5.3 Landing system

Landing system is one of the key element for recovery and quite new for European space industry. A first assessment is made currently in partnership with ArianeGroup in order to validate the cost and mass budget of such system. The main functions and constraints have been enumerated, and some concurrent design evaluated. The possibilities are indeed very wide, going from “all ground systems” to “all on-board systems”. The first ones could be the less impacting solution on the launcher design, the second ones necessitate on the other hand less ground infrastructures and are more easily compatible with barge and ground landings. Considering the actual level of maturity, an on-board solution featuring legs on the launcher has been selected for current system studies. The subsystem pre-sizing including stability analysis is on the way.

6. Exploitation scenarios

Once the staging and performance have been determined it is essential to consider its efficiency toward each market scenarios. One as to notice that studied architectures are design for single launch mainly. This is a deliberate choice in CNES current studies in order to get rid of the exploitation constraint given by a dual launch strategy in a limited and diversified launch market.

In term of flexibility, the main principle considered for these type of configurations is a semi reusability scheme, where the launcher is made flexible with its capacity to diminish its own cost via the recovery of the first stage. After being

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refurbished the stage is reintroduced in the production and assembly circuit to be launched again. This lever is only accessible if the required performance is compatible with the performance of the configuration with the first stage recovery, therefore it varies depending from one side on the market scenario and one the other side on the capacity of the launcher.

The difficulty resides also in the optimization of: the production investments, the stage unitary cost which is dependent of production cadency, the number of reuse which from one side allows to benefit of a functional stage at the only cost of transport and storage infrastructures and maintenance, but from the other side will diminish new stage production (and then increase their unitary cost). The result of computations allows to show that substantial gains are to be expected starting from one reuse per produced stage if the maintenance cost do not exceed 10 to 20% of the stage cost. The high level of design and production synergies between first and second stage is a key factor in order to dynamically adapt the stages production to reuse scenario and therefore to overcome the fixed charges increase. More intensive reuse (up to 5) is not strictly necessary while favorable to make a substantial economy, and could allow a fast increase of cadence if needed, especially in the case of constellation deployments. The capacity of the Ariane family to rely of a relatively stable institutional market of 8 to 10 satellites per year is enough to implement semi reusability strategy.

The above presented configurations tend to diminish the number of stage even if it’s not the most optimized for global launcher performance. The intended effect is to maximize the ratio of recovered parts at each launch. The use of new technological elements such as Prometheus engines, the rationalization of launcher elements and the maximization of synergies should allow an aggressive cost target with respect to current European launchers designs.

At the horizon of 2030, a mean launch price of 35M€ is considered achievable for Ariane Next TSTO concept as presented before, allowing a smart pricing policy for the diverse markets addressed, in line with a target of 5 k$/kg on the GTO market and a division by 2 wrt Ariane 6. This price would be, deemed competitive with respect to the today and future competition.

7. Conclusion

The current system studies leaded by CNES for Ariane Next intend to show that a rationalized two stage to orbit architecture introducing Prometheus as engine and featuring a first stage recovery and reuse capacity can lead to a competitive launch system by 2030. Of course, there are challenges to be overcome, and innovative capacities have to be demonstrated. Prometheus, Callisto, Themis and Icarus (lightweight stage) are the main demonstrators that will pave the way to a future development for a reusable and cost efficient European Launcher.
System studies are in general the foundation of these potential future developments and many subsystems still need to be studied in depth before a comprehensive view of the launcher as a whole can be established. This will be done also in partnership with ESA/STS and ArianeGroup in the frame of future launchers projects [2].

8. Acknowledgements

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