Acta Astronautica 170 (2020) 735–749

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Research paper

Ariane Next, a vision for the next generation of Ariane Launchers

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ARTICLE INFO

Keywords:
Launchers
Reusability
Demonstrators
Ariane

ABSTRACT

The development of Ariane 6 and Vega-C is well on track, both launchers should start their operational life by 2020. Combining enhanced capabilities, increased flexibility and reduced launch costs, the modernised fleet will be the backbone of the "European Space Access Strategy" for the next decade. Beyond these developments, a step forward must be prepared to further improve competitiveness and flexibility of European launchers.

In this context, CNES Launcher directorate, together with ArianeGroup, is currently assessing launch system definitions for the next generation of Ariane Launcher, so-called Ariane NEXT. The main goal is to further improve competitiveness in particular by halving the launch cost with respect to 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 rationalization of the production. The launch system studies also evaluate LOx-LCH4 interest, simpler to handle than LOx-LH2 and allowing for further tank communalization and simplification.

With the aim of enhancing flexibility and cost efficiency, new technologies in the fields of design, manufacturing and ground operations are involved. Moreover, the reusability is taken into account on the first stage as an option in launch system exploitation. Indeed, it is of prime interest to confirm the potential benefit of reusability from an economic and flexibility point of view in the face of unstable and different markets, including in our low-volume institutional market.

Some Ariane-Next breakthroughs are not yet mature in Europe and four key technological bricks have been identified:

- Callisto: a low scale recovery and reusability demonstrator;
- Prometheus: a low cost reusable engine precursor;
- Themis: a full scalelow cost and reusable stage demonstrator;
- PHOEBUS/ICARUS: a demonstrator of a light-weight upper stage.

This paper provides an overview of the current status of the Ariane NEXT launch system definition and economic analysis, as well as the main associated demonstrators development status.

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 modernised fleet will be the backbone of the "European Space Access Strategy" for the next decade. Beyond these developments, targeting the 2030's, 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

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https://doi.org/10.1016/j.actaastro.2020.02.003
Received 28 January 2020; Accepted 1 February 2020
Available online 08 February 2020
0094-5765/

Acronyms/abbreviations

AG	ArianeGroup;
CSG	Guyana Space center
CNES	Center National d'Etudes Spatiales, French space Agency
ESA	European Space Agency
ETID	Expander Technology Integrated Demonstrator
FLPP	Future Launcher Preparatory Program
ICARUS	Innovative Composite ARiane Upper Stage
MUSE	Multifunctional Upper Stage Express
ONERA	Office National d'Etudes et de Recherches Aerospatiales (French Aerospace Laboratory)
PoC	Proof of Concept
PHOEBUS	Prototype of a Highly Optimized Black Upper Stage
RTLS	Return To Launch Site;
TCA	Thrust Chamber Assembly
TRL	Technology Readiness Level
TP	Thermal Protection
TSTO	Two Stage to Orbit
ULPM	Upper Liquid Propulsion Module
ZL3	Zone de Lancement N° 3 (Launch Pad #3 @CSG)
ZLS	Zone de Lancement Soyuz (Soyuz Launch Pad)

launchers, so called Ariane NEXT. ESA/FLPP studies done by ArianeGroup and CNES studies proves to be convergent toward two stages concepts with the same goal to demonstrate a sustainable competitiveness in particular by enabling launch cost to be halved wrt Ariane 6 in the 2030s time frame.

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 communalization and simplification. Moreover, in order to enhance flexibility and cost efficiency, the reusability is taken into account on the first stage as it represents close to 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 or ArianeGroup.

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. In Section 6, Main demonstrators' roadmap is presented along with a description of the main steps deemed necessary to ensure a safe development of Ariane Next. 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 between 2028 and 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 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 European 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 markets scenarii can be designed:

- "Business as usual": in addition to institutional 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 15–17 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 26–29 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 10–11 missions per year.

2.2. High level requirements

In order to settle some main consideration about Ariane Next design, some main requirements have been anticipated, in Table 1 hereafter.

Table 1
Ariane Next launch system main requirements.

Preliminary	Requirements	Ariane Next
Time to market		*2028+*
Sustainable exploitation		*Bio sourced propellant, reusability, etc.*
Launch service	Payload volume	*Standard fairing: idem A62 short fairing*
Launch cost	*Launch cost @ 17 Missions/year*	*Average Launch cost of 35 M €/missions*
Launch rate	Launch rate	*17 Missions per year as ref. Up to 25 Missions per year*
Availability	Standard notice	< 12 months
	Reduced notice	< 3 months *for known satellite platforms*
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 (see Table 2) are then defined on the basis of market scenarios, with the following principles:

Table 2
Ariane Next Launch system performance requirements.

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

- 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 NG).

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.

Compared to LH2, Methane presents several opportunities for launchers:

- less constrained design thanks to soft-cryo temperature (112 K liquid)
- Allow synergies between LOX and CH4 components, as for instance identical equipped and insulated tanks
- easier safety conditions for reusable trajectories (in particular RTLS)
- better operability (GN2 compatible, thermic conditions, bio-

Methane opportunity),
- Methane is a key asset for space exploration

This is illustrated hereafter in Fig. 1.:

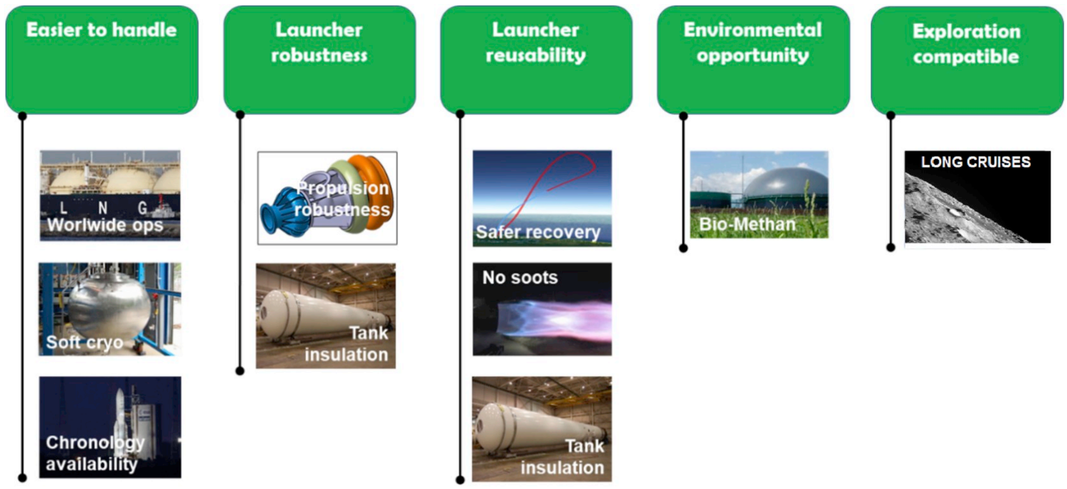

Fig. 1. LOx Methane opportunities.

In terms of resulting impact on the launcher cost, preliminary estimates do not allow to significantly differentiate LH2 from Methane: Methane 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 and so more engines. In the other hand it allows significant design simplification (for instance a unique turbo-pump on engines). This comparison needs to be consolidated in the future.

3.3. Prometheus operational engine

Prometheus operational engine 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 could allow a further optimization 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 1 200 kN in vacuum instead of 1 000 kN 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 targets cost efficiency as primary criteria, reusability can be an additional lever 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 (see section 5), 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 5.4 m, covering all identified needs as of today. At 2030 horizon, it is possible that 7 m 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 Fig. 2 hereafter.

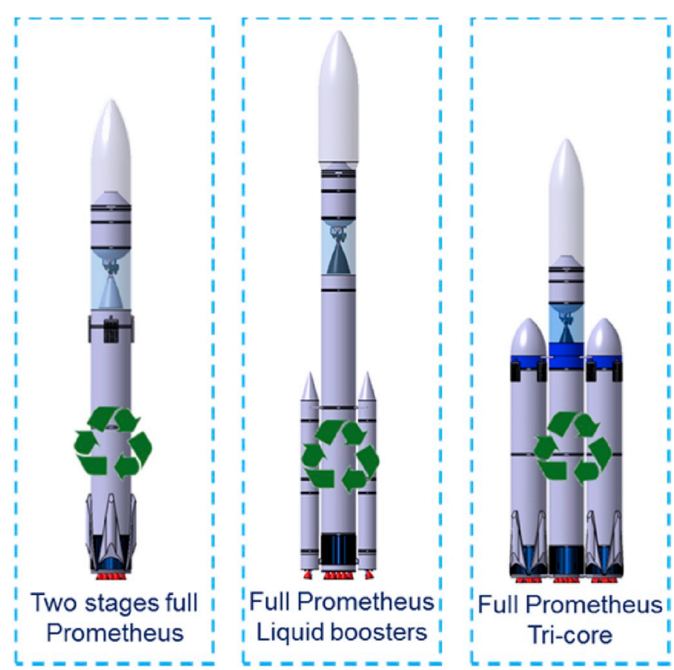

Fig. 2. Ariane Next configurations.

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

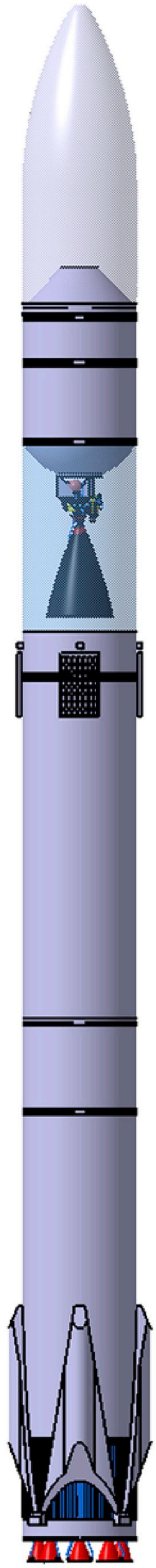

Fig. 3. Ariane Next C600-C126 configuration equipped with recovery kit.

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. Full performance configuration in LOX-CH4

With the objective of a two stage launcher able to launch up to 7t in GTO mission, the following launcher has been pre-designed: staging is made on the GTO 1800 m/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 1200 kN. 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 5.4 m.

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, Aluminum 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, Fig. 3.

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/ship that is able to withstand the landing of the stage, and all the relevant port facilities). Performances obtained are the following ones (see Table 3).

Table 3
Ariane Next performance results.

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

Performance results reach the target except for GTO 1 500 m/s where the configuration is 400 kg 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 (Fig. 4). In red and cyan propulsive and ballistic phases for ascent, in blue and red propulsive and ballistic phases for 1st stage return. On the return trajectory, one cans notice a quite important braking boost taken into account before heat flux peak.

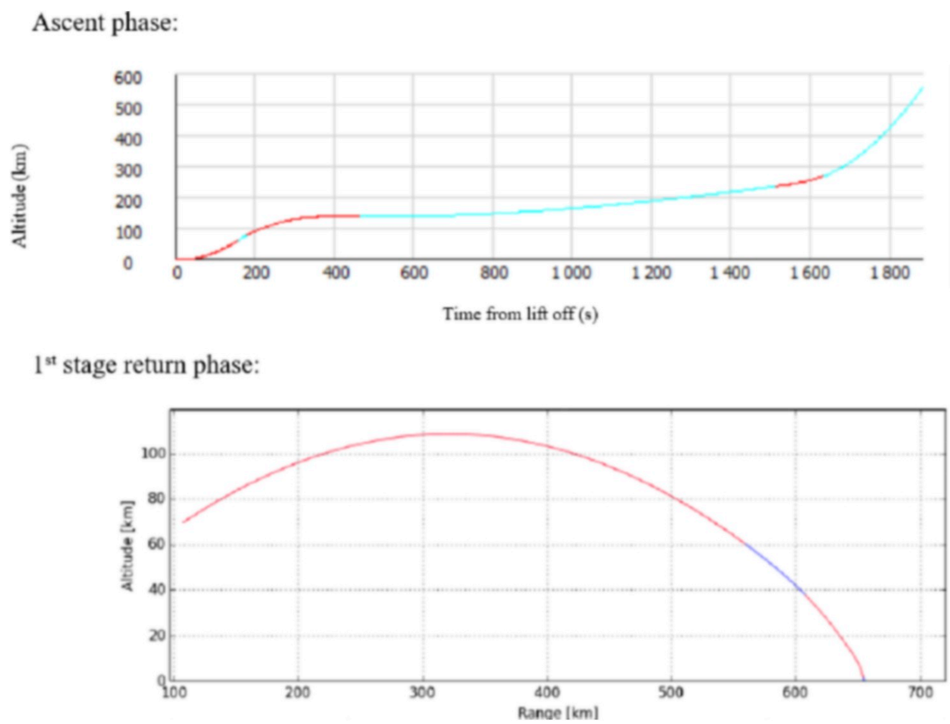

Fig. 4. Ariane Next C600-C126 trajectory profile.

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.

It is to be noted that current status of studies leaded by ArianeGroup within ESA/FLPP contract, lead to a similar design with a two stage configuration with 600 tons of propulsive propellant for the first stage and 140 tons for the second stage. The launcher is considered propelled by 9 Prometheus engines as well.

4.2. Alternative 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 1 500 m/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 1 200 kN.

The same design optimization process was followed as for the full performance configuration. It leaded to a 4.6 m diameter on the 2 stages, allowing a significant mas saving wrt 5,4 m 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 (Fig. 5):

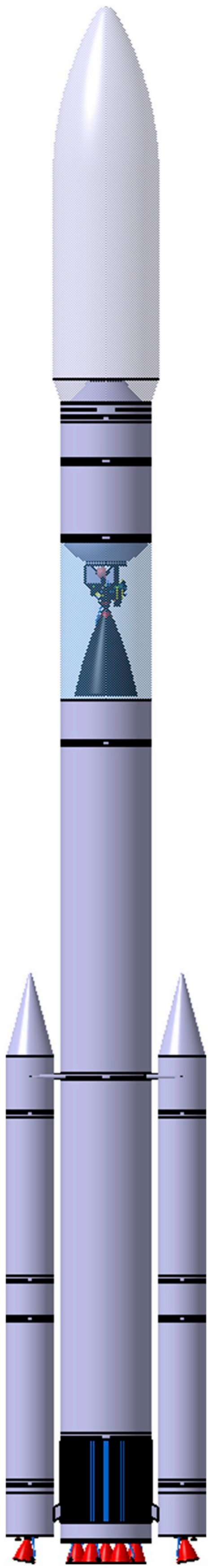

Fig. 5. Ariane Next C450-C103 configuration equipped with boosters.

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 2–4 liquid boosters

Performances obtained are the following ones (Table 4):

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

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

4.3. Growth potential

If deemed necessary, small strap on boosters or a kick-stage would allow to adapt the performance and mission domain. This could allow to comply with highly demanding missions, beyond the identified market (scenarios & HLR), in terms of performance and/or versatility:

- Kickstage: Orbital Kick stage for Additional Performance Increase (OKAPI): 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. With a 10 tons loading class and green storable propulsion, OKAPI would be able to ensure an additional lever of flexibility and versatility in orbit or ensure very long mission for solar system exploration.

The dimensioning target of OKAPI is to cover at least the performance losses when retrieving the first stage wrt to an expendable mission, thus optimizing economically the whole process.

- liquid or solid Boosters: As seen in the previous concepts boosters (60t loading class, solid or liquid based propulsion) 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 very much oriented toward 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 especially considering 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 in the beginning of a possible Ariane NEXT exploitation, as A6 will be in operations and so prohibits deep modification in the facilities .

The trade-off between the two sites 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. The various missions offered by Ariane NEXT implies to have a launch pad with large capability in terms of possible trajectories (SSO, GTO, MEO,..). Without any contest, the ZL3 is the one offering the most flexibility, for safety reasons due to its well centered location within CSG limits (as seen in Fig. 6).

Fig. 6. CSG facilities. Copyright: © 2016 CNES service communication/Optique vidéo du CSG.

Different integration scenarii have been preliminarily investigated as well, reusing as much as possible the ELA3 installation. Among them:

- complete horizontal scenario,
- horizontal scenario with a mobile gantry in ZL (as Ariane6),
- vertical scenario with a new assembly building

For the Ariane next launch complex, a complete horizontal scenario including upper part (vertical encapsulation possibly) is currently preferred, avoiding any mobile gantry on the launch pad, but only erection mean. These assumptions have to be consolidated in the next years.

As usual, characteristics of the launcher, of its ground/board interfaces and of its main operation for assembly phase (including recuperation and reuse topics) will be key factors for proposing a ground architecture in fulfilling all requirements. The sketches below (Figs. 7-8), illustrates a possible reuse of the ZL3 for Ariane NEXT:

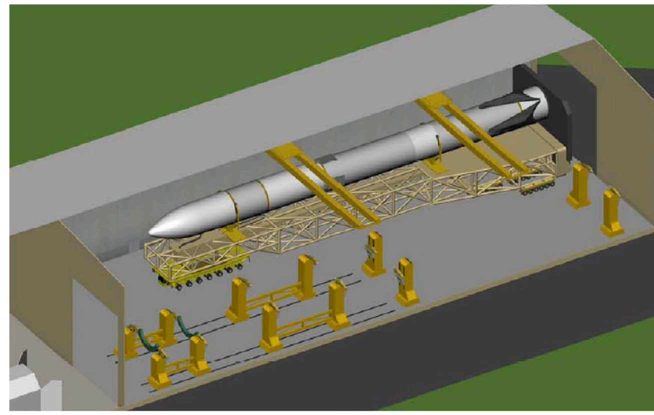

Fig. 7. Ground segment possibilities.

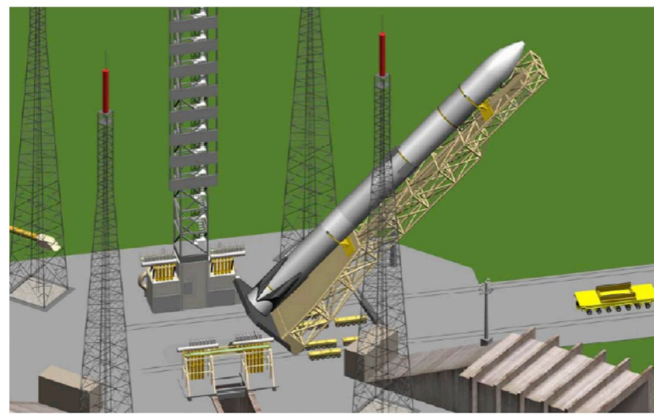

Fig. 8. Launch pad possibilities.

As Ariane NEXT shall be compliant to a sustainable exploitation, propellant production will be locally bio sourced. Inventory recently made tends to demonstrate that the potential resources will be available.

5. 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. Of course a dual launch approach could still be envisioned especially when considering growth potential of the configurations.

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 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 semi-reusability strategy is illustrated hereafter (Fig. 9), where recovered stages are preferentially reused on energetic or high performance missions:

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 35 M€ 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 a division by 2 wrt Ariane 6. This price would be, deemed competitive with respect to the today and future competition.

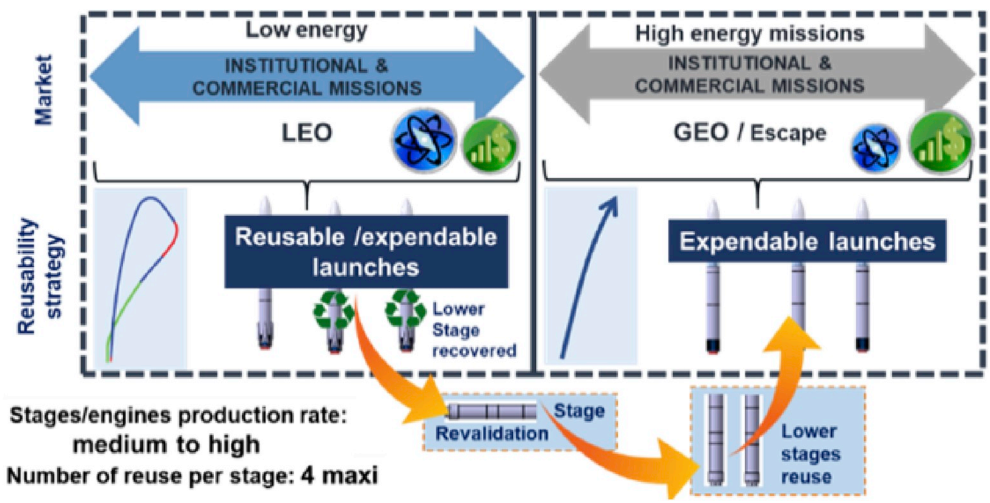

Fig. 9. Semi-reusability strategy.

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 CNES 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 10–20% 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 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

6. Key technological demonstrators

Along with technological aspects, the direct route to the final system qualification going through a traditional model-based development V cycle will not allow for a complete minimization of system and sub-system margins where most of the room for improvement exist. Instead, a H/W-based spiral maturation cycle involving system demonstrators (Prometheus, Callisto, Themis, ICARUS) is deemed necessary. This will allow aiming to implement a new set of design rules and inputs as well as demonstrating the full set of new technologies necessary for Ariane NEXT.

The hereafter figure (Fig. 10) shows main demonstrators today forecasted. One has to note that it shows CNES leaded demonstrator Frog, multilateral cooperation with Callisto (CNES/JAXA/DLR), ESA demonstrators with Prometheus and Icarus, and ArianeWorks leaded Themis.

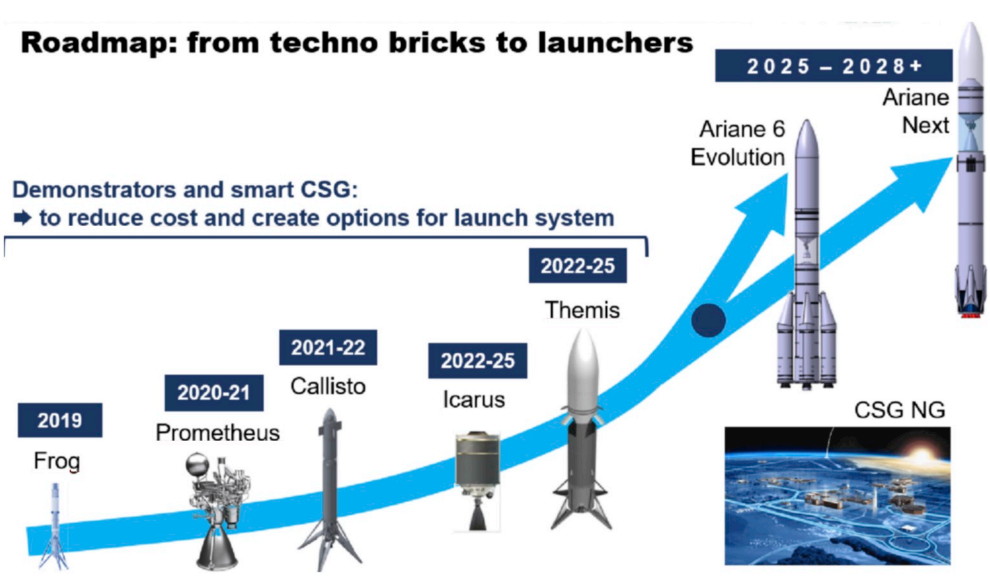

Fig. 10. Key technological demonstrators.

6.1. FROG

In the above roadmap, FROG demonstrator corresponds to the early sandbox approach [6]. As a matter of fact, among the required technologies for reusable rockets, GNC for landing is deemed to be one of the most challenging ones. This must not be studied only by simulation, but also with tests on demonstrators. For this purpose, FROG is a small scale vertical landing gear demonstrator that allows experiments to be carried out around the flight control chain and thrust control. The main objective is the implementation in flight tests of a control algorithm and an adaptive control system, in closed loop until landing, controlling thrust regulation and relying on one or more sensors. It enables to demonstrate guidance and control algorithms for vertical landing, quickly, at low cost, low risk and with high agility.

FROG is both a technology demonstrator and an agile project demonstrator. 2 steps are today in progress:

- FROG-T (see Fig. 11), already flying (tethered in June 2019 and in free flight in late 2019), with active guidance and control. FROG-T is powered via a small COTS kerosene turbojet engine. Control is mainly achieved via deflection of the exhaust gas through a steerable nozzle to mimic rocket actuation. The avionics is composed of one on-board computer, motor controllers, power control units and actuators. Several independent RF communication system are used for telemetry/telecommand (TM/TC), remote control, and safety link. In addition, various on-board sensors are used like several inertial measurement units, magnetometers, RTK GNSS receivers, laser rangefinder (LIDAR), contact sensors, etc. FROG flight operations relies only on on-board algorithm and sensors. The next step is to perform a free flight by the end of the year 2019.
- FROG-H aiming to be more representative of a launcher, will keep the same avionic and GNC architecture, but will feature a use a so-called “green propellant”: High Test Peroxide (HTP). Only the exothermic decomposition trigged by the contact of the HTP with a catalyst bed will be used to deliver a higher thrust than the turbojet engine used in FROG-T. In addition, this HTP engine will allow a much faster response time enabling a quicker and more accurate GNC. This characteristic will make it more representative with respect to launchers. FROG-H vehicle studies and, especially, propulsion system and associated CONOPS have reached a PDR maturity level. A development plan has been consolidated in which the first FROG-H tethered flight is planned for end of 2020.

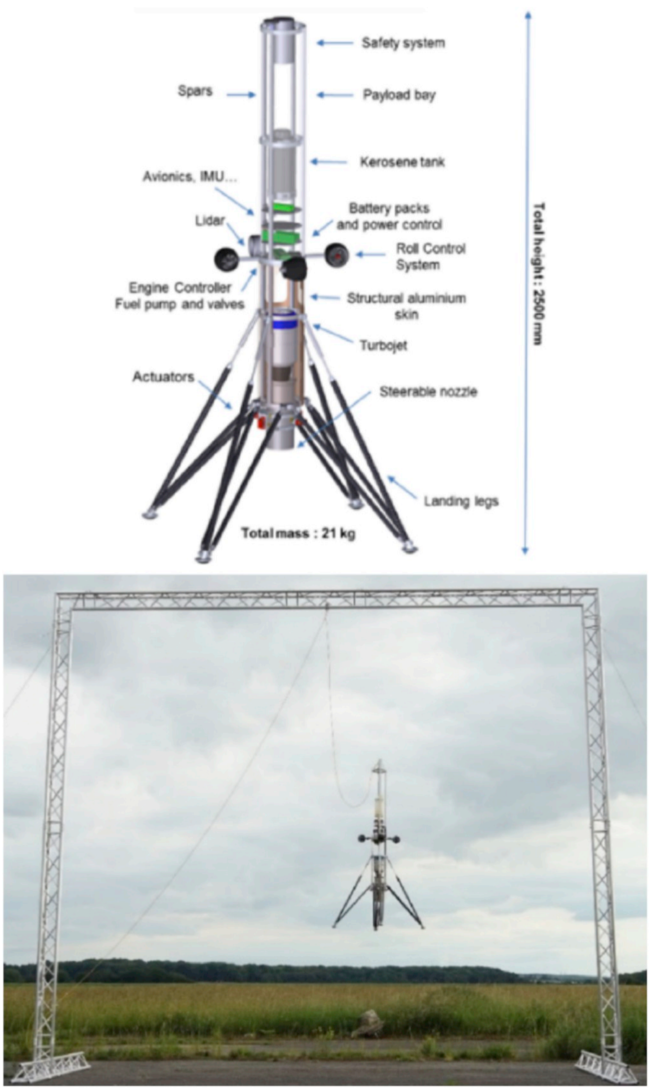

Fig. 11. FROG-T architecture, and tethered flight.

6.2. Prometheus

Prometheus (Precursor Reusable Oxygen METHane cost Effective propUlsion System) is the Precursor of a new liquid rocket Engine family designed for Ultra low-cost, flexibility and reusability.

This Project, undertaken through cooperation between CNES and Ariane Group, entered in ESA Future Launchers Preparatory Programme (FLPP) after the Ministerial Conference in December 2016, with Germany, Italy, Belgium, Sweden and Switzerland joining France in this Programme [4].

The aim of this project is to design, produce, and test an advanced low-cost 100-tons class LOx/LCH4 reusable Engine. Prometheus is a precursor aiming an ultra-low-cost engine target of 1 M€ recurrent cost (at a production rate of 50 units per year). Prometheus engine targets also flexibility in operation through variable thrust (high throttling capability from 110% down to 30%), multiple ignitions, compatibility to main and upper stage operation, and minimized ground operations before and after flight.

The engine cycle is a gas generator cycle well mastered in Europe and in line with the low cost target objective of this project and the achievement of overall good performance. As the engine shall be able to operate on a large thrust range an electric control & command is necessary to do it. Control of the engine regarding thrust domain is based on a full electrical valves actuation.

To reach those ambitious objectives, an extreme design-to-cost approach is mandatory, as well as innovative technologies and advanced industrial capabilities (design for manufacturing). For instance, the extensive recourse to Additive Manufacturing for the production of engine components.

The hot-fire tests at engine level are foreseen by end 2020 at P5 test bench, DLR Lampoldshausen (Fig. 12). P5 facility will be adapted to enable hot-fire tests of the Prometheus engine in LOx-Methane.

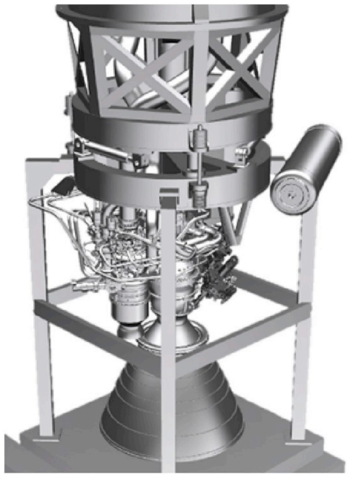

Fig. 12. Prometheus on test Bench (DLR Courtesy).

Throughout three major disruptive approaches.

- extreme Design-to-Cost approach,
- generalized agility,
- frugal innovation and development,

the program has already achieved important milestones to cope with the ambitious targets assigned to this engine.

The ambitious objectives for the coming years are very challenging for Europe. Prometheus project, success oriented, federates a new working methodology with the goal of preparing next ultra low-cost engine generation but also future European industry.

6.3. CALLISTO

CALLISTO (Cooperative Action Leading to Launcher Innovation for Stage Toss back Operation) project is a launcher first stage recovery and refly demonstration performed by CNES, DLR and JAXA agencies (see Refs. [8,9] for a more comprehensive description).

The general goal consists on learning on recovery with accuracy and necessary operations for reuse, of one single vehicle with several take-off and landing from Guiana Space Center. The results of the project will be used for technology and cost model validation for real scale launcher using reusable first stage.

Different kind of transient phases will be defined with possibly different trajectories of the test plan in order to explore different domains for vehicle demonstration: control at transonic during descent phase after a boost back maneuver, propulsion system mastering during attitude maneuver, and landing system mastering with a non-gravitational acceleration during landing.

The 3 partners have shared the work to be performed which can be globally summarized by the following: System Vehicle, safety, and ground Segment for CNES, Aeroscience and active control mechanisms for DLR, Rocket Propulsion System and project lead for JAXA. Each Partner have an interest with guidance and control and will have the opportunity to flight.

As seen in Fig. 13, the vehicle is about 12 m height, 1 m diameter, with in flight foldable landing legs and Aerosurface flight control, and a H202 Reaction Control System. The vehicle thrust is generated by the RSR2 JAXA engine which can have thrust modulation using liquid hydrogen and liquid oxygen propellants, capable of inflight re ignition.

The ground segment will propose one take off area and several landing areas for achieving the different objectives of the mission. The Concept of Operations, Maintenance & Repair requirements are set for reducing the duration and allowing flights from other launchers be operated from other launch sites in CSG. All Duration and type of operations will be recorded make it available in order at the end of the project to assess the cost and try to extrapolate to a launcher at real scale.

Fig. 13. CALLISTO Vehicle configuration fins and legs unfolded.

Safety studies and dedicated on board safety system, and specific vehicle architecture will enable to get the vehicle flight back and be operated around the vehicle.

Several flights are expected using the same vehicle, under a more and more energetic and demanding trajectory. Maximum altitude will be around 50 km, which will enable using components under low vacuum condition and without using radiative hardened components. Several class of flight tests have been defined (see Fig. 14).

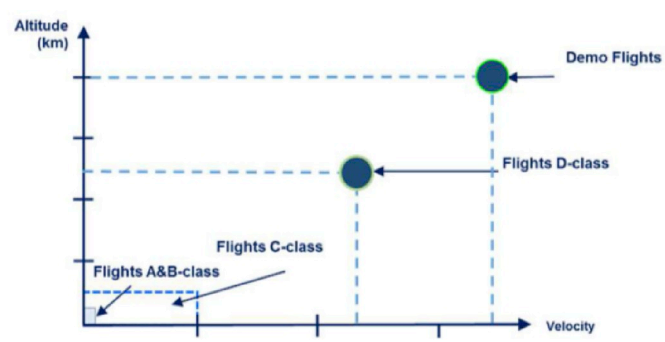

Fig. 14. Test flight envelope exploration logic.

The development logic is based on several validation steps in Europe and Japan. The vehicle rocket propulsion system will be tested in Japan while the main other components and avionic will be tested in Europe. Final integration in French Guiana will be concluded by specific combined test involving the ground segment, the vehicle and the interfaces.

The idea to develop CALLISTO was first proposed in 2015. After a preparatory phase in 2016, the project reached a first milestone with the signature of the trilateral agreement between JAXA, CNES and DLR in June 2017 giving the start of a feasibility phase concluded by a System Requirement Review in March 2018. The project is ongoing with a System Preliminary Design Review expected for the end of 2019.

6.4. PHOEBUS/ICARUS: a demonstrator of light-weight upper stage

The Black Upper Stage ICARUS (Innovative Composite ARiane Upper Stage) and Vinci Evo are major contributors to fulfill various objectives toward A6 Evolution or Ariane NEXT: lower cost, higher versatility and increased payload performance. The combined approach Stage/Engine illustrated in Fig. 15 offers global optimization potential on upper stage level.

The further optimization of the entire upper stage architecture and the implementation of other innovations like reduction of non-useable propellant, wireless sensors, ALM, innovative interface techniques etc. will even increase the total mass saving by up to another 1.000 kg.

Various technology projects supported by DLR and within the ESA FLPP programme have recently been launched to provide the technical foundations for the ICARUS programme. The Black Stage Technology Demonstrator project will bundle them into a scale one stage demonstrator. PHOEBUS was initiated in March 2019 and will run over approximately 3 years. This warrants a seamless transition into a Black Stage Development Programme, if released by ESA Ministerial Conference.

The goal of PHOEBUS (see Fig. 16) is to mature the relevant technologies (TRL) and at the same time to raise the integration readiness (IRL). At the end, AG and its partner MT-A will deliver an integrated scale-one technology ground demonstrator consisting of LOX and LH2 tanks, filling and draining lines, primary structures and Electronics/Fluidics Ground Support Equipment for closed loop regulation simulation and testing. PHOEBUS will validate the technology selection in a representative environment, hence consolidating and enhancing the expected stage performance for the black upper stage programme implementation phase.

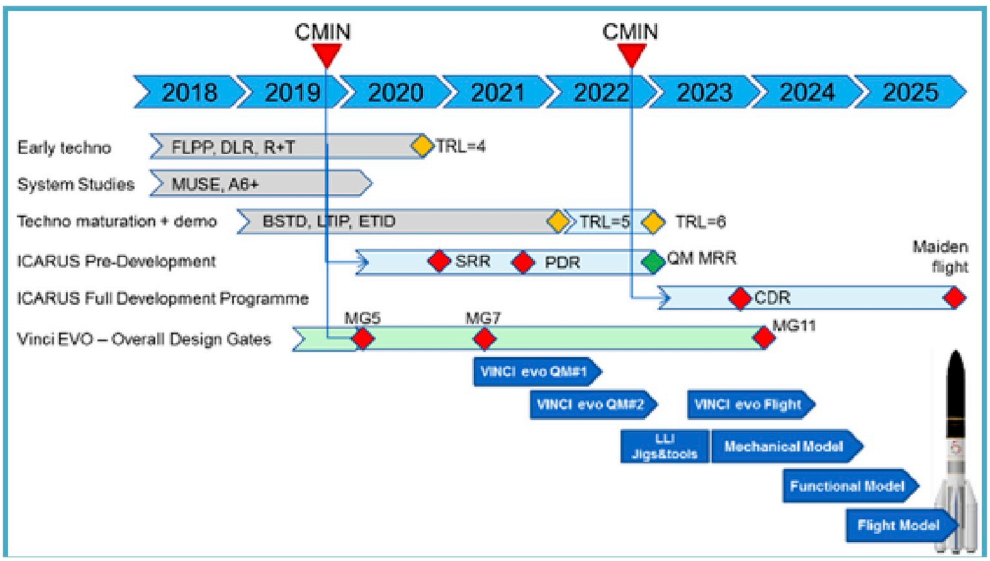

Fig. 15. ICARUS & Vinci Evo combined development logic.

Ariane 6 upper stage ULPM (Upper Liquid Propulsion Module) is being developed using mostly metallic tanks and structural elements. With the ULPM, Ariane 6 will have a reliable, versatile, modern and cost optimized upper stage. However, a further significant reduction of the ULPM inert mass in the range of 1–2 tons could become more and more desirable at same or even reduced costs. Ariane Next concepts, as mentioned earlier, also requires very low structural indexes to be competitive.

A large part of this reduction is achievable with the introduction of composite materials for the upper stage, in particular, for the tanks containing the cryogenic propellants (liquid hydrogen and oxygen) and for other primary and secondary structures. Cryogenic composite materials, in addition, can enable new stage architectures and combinations of functions, which are not possible using metallic materials.

As and intermediate step before Ariane Next, ArianeGroup Germany and MT Aerospace have therefore elaborated the vision to target an European, commercially useable cryogenic upper stage for Ariane 6 with a reasonably high ratio of carbon composite ("Black Stage") and a competitive dry mass and cost figure. The maiden flight could be targeted for 2025.

ICARUS programme includes, in particular, the maturation of the necessary technologies for a composite cryogenic tank (CCT), the development of a black stage concept that is more than just a replacement of several metallic subsystems/components and the detailed analysis and assessment of the potential benefits and necessary solutions.

Preliminary estimations performed for Ariane 6 upper stage covering replacement of metallic tank structure, primary and secondary stage structure identify significant mass savings in the order of 1.000 kg

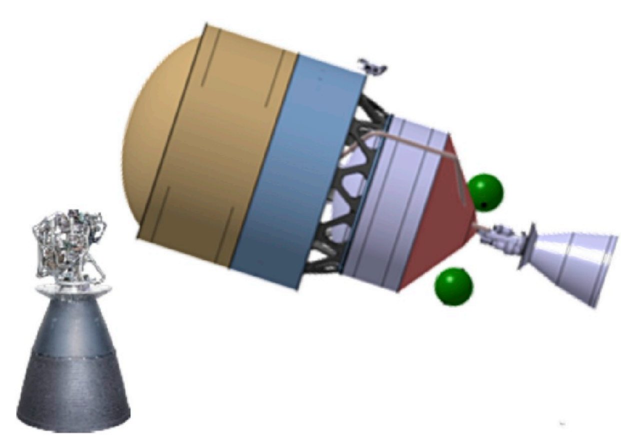

Fig. 16. Black Stage Demonstrator (PHOEBUS, Prototype of a Highly Optimized Black Upper Stage).

In complement, a full exploitation of the technology portfolio on the liquid propulsion domain is envisaged to increase the competitiveness of Ariane 6 and prepare Ariane NEXT. Transferring technologies from FLPP ETID and Prometheus programme to Ariane 6 CIP is a key enabler to achieve the challenging cost reductions necessary latest in the year 2025 (see Fig. 17). Leveraging recent achievements, an evolution of Vinci is contemplated in synchronization with the new ICARUS upper stage. Respective interactions are ongoing in close connection covering Mission analysis, Launch Vehicle, Upper Stage and Engine aspects (e.g. Stage Loading, Thrust level).

selective application of innovative manufacturing processes, as well as, the stringent pursuit of a design-to-cost approach will be performed for the TCA parts.

In parallel of the maturation process, the composite solution is continuously traded against the metallic benchmark along Upper Stage system studies as FLPP/MUSE project. The composite technology is naturally considered for Ariane Next Upper Stages, in LOx/LH2 as well as LOx/LCH4 configurations.

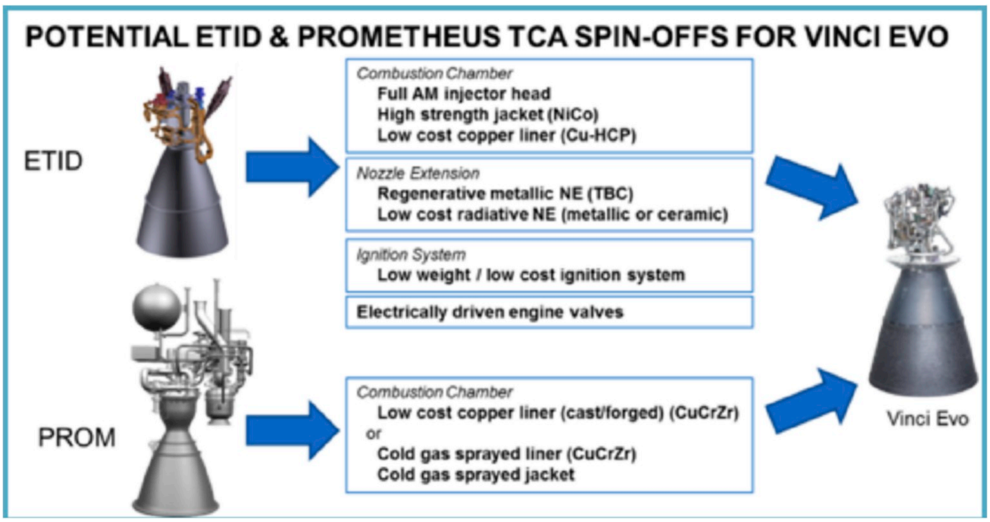

Fig. 17. ETID & PROMETHEUS spin-offs for Vinci-Evo.

Main improvement for Vinci Evo will be an all new design of the thrust chamber assembly (TCA). The lessons learned drawn from the ETID hot fire-test and the outcomes of the Prometheus technology maturation programme are the basis for the TCA design trade-offs. A

6.5. *Themis: a full scale low cost and reusable stage demonstrator*

As presented in Ref. [2], Themis demonstrator is the cornerstone of the European reusability roadmap illustrated in Fig. 18.

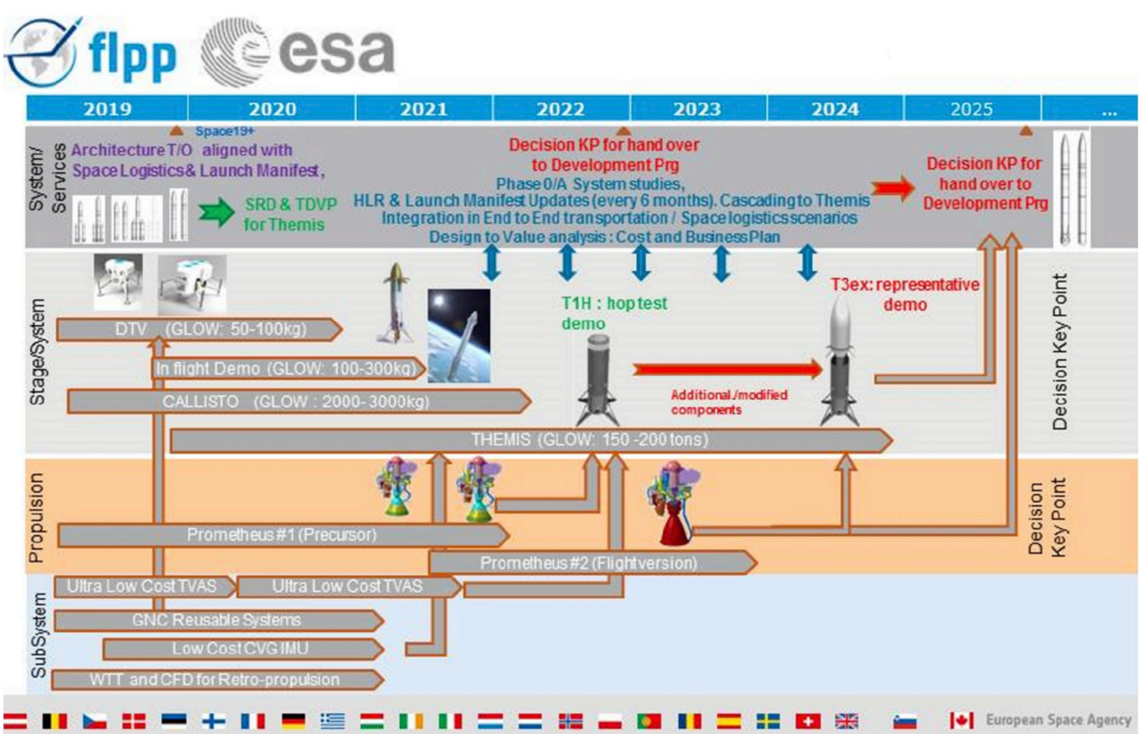

Fig. 18. European reusability roadmap.

This roadmap includes demonstrators of increasing size and complexity, starting with small scale, low altitude/low speed turbo-jet vehicles (FROG-T, DTV) and rocket version (FROG-H, In Flight Demo), medium size vehicle (CALLISTO) and finally a large scale demonstrator (Themis) with a representative flight domain and propulsion (Prometheus engine). Early demonstrators will de-risk overall design, lift-off and landing phases, then toss-back manoeuvers as well as ground operations. The flight domain extension is illustrated in Fig. 19.

In addition to recovery and reusability demonstrations, Themis is featuring low mass and low cost technologies for liquid propulsion booster/lower stages applicable to both expendable and reusable stages as:

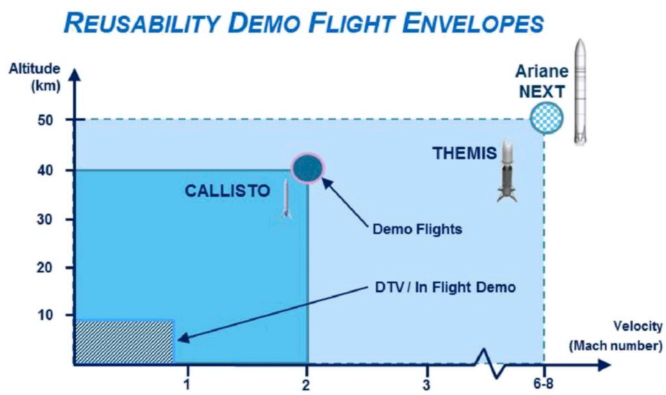

Fig. 19. Reusability demo flight envelopes.

- Common bulkhead tank
- Crossing feedlines
- LOX/Methane stage without cold TP
- Multi-engines aft bay
- Autogenous pressurization
- Ultra-Low Cost Actuation Systems

Thanks to similitude analysis, Themis size and characteristics are providing a robust path with a high representativity level, whatever the operational launch systems (see §4). Main similitude criteria are:

- Form factor (Length/Diameter)
- Centering and inertia
- Mach
- Reynolds
- Apparent load factor
- Froude
- Thermal peak flux
- Integral of flux
- Ballistic coefficient (Section/Mass)

The demonstration logic includes two steps:

- 2020–2022: concluded by a hop test in mono-engine configuration (T1: use of Prometheus precursor)
- 2023–2024: full coverage of flight domain and demo objectives with 3-engines configuration (T3: use of Prometheus flight models)

Themis is in early definition phase as illustrated in Fig. 20. Current characteristics are:

- 3 Prometheus engines of 1000 kN each
- Lift-off mass of 150 tons
- Diameter ~3,5 m
- Length ~30 m

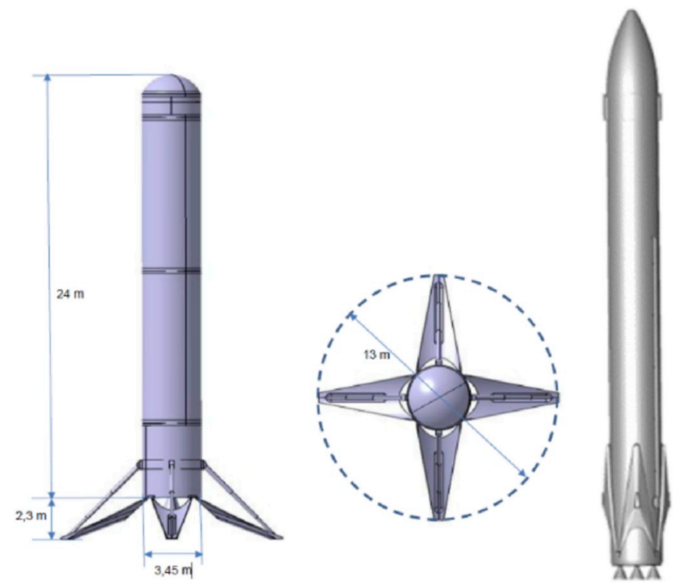

Fig. 20. Themis early definition. Left: Themis 1 Prometheus engine (Hop test) Right: Themis 3 Prometheus engines (full flight domain).

Analysis and design consolidation of Themis demonstrator will continue through ArianeWorks, the innovation accelerator created in February 2019 by CNES and ArianeGroup, until the beginning of the development early 2020 (after a positive decision at Space19+).

The 3 levers deployed by ArianeWorks for accelerating Themis can be described as follows (see details in Ref. [7]):

- Empowered management: operating somewhat between a start-up or a skunkworks, ArianeWorks is a flexible and agile setup with shortened and knowledgeable decision making chain, possibly enabling a more dynamic "rocket ecosystem" in Europe.
- Agile development logic: unlike earlier attempts to elaborate Themis development logic, proposed way forward is not built around a phase A/B/C/D sequencing (=make it perfect right from the first time). Instead, the pace of the project is made by yearly hardware testing milestones, allowing to enter a virtuous test/redesign spiral loop as soon as we can (= build and learn as you walk) as illustrated in Fig. 21.

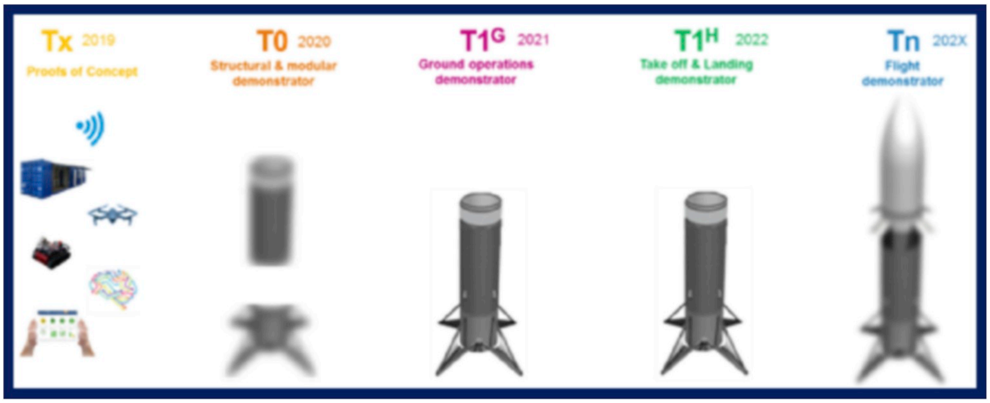

Fig. 21. - *MVP/Agile approach as proposed to Themis development.*

- Proof of Concept catalysts approach: there are a number of areas where high risk/high gain smart ideas have been worked recently in engineering design offices (be it CNES or throughout Ariane industrial base) but would not reach sufficient TRL mark for embarking in a standard space project baseline. In those situations, attempts are made to "leapfrog" the technology maturation process by undertaking proof of concept actions, possibly allowing to shorten innovation cycles. The first PoC of ArianeWorks was consisting in testing (at 1/10th scale) a ground-based solution for Themis landing function (as alternative to landing legs), see Fig. 22.

Fig. 22. PoC Smart Catcher on Themis alternative landing system.

7. Conclusion

The current system studies leaded by CNES for Ariane Next or done by ArianeGroup in the frame of ESA/STS FLPP contracts shows 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/Phoebus (lightweight stage) are the main demonstrators that will pave the way to a more competitive 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]. Prospective dialogues with national space agencies will be also required to build European consensus. Decision Key point to be held in 2022 shall orientate European launchers product policy.

Acknowledgements

The authors thank all the people from all entities involved in the frame of Ariane Next studies and especially in the technical directorate of CNES/DLA, ArianeWorks, and ArianeGroup for their contribution to this paper.

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