DOI: 10.13009/EUCASS2019-971

LAUNCH VEHICLES SYSTEM STUDIES IN THE "FUTURE LAUNCHERS PREPARATORY PROGRAMME":

THE REUSABILITY OPTION FOR ARIANE EVOLUTIONS.

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ABSTRACT:

The European launchers shall answer the evolutions of the payloads and their mission profiles. Ariane 6 and Vega-C programmes are the next step "short term" answers. But beyond that, the Future Launchers Preparatory Programme (FLPP) managed by ESA, prepares the future launcher system architectures and the enabling technologies through demonstrators.

Concerning the future of Ariane, and in front of the increasing competition pressure, the system and technology activities in FLPP/NEO shall prepare the options that will ensure sustainable competitiveness. Part of these activities, the in-flight reusable vehicle demonstration aims to contribute to the following targets:

- Ariane Recurring Cost decrease with a target of -50% compared to Ariane 6 Baseline
- Reusability to reduce investment in production means (CAPEX)
- Acquisition of the reusability key competences not available in Europe

The reusability option, for the future liquid boosters and/or lower stage, is under evaluation through Ariane Group studies currently ongoing. Design to cost and time to market are critical issues to be treated, but those studies shall also put emphasis on a coherent approach w.r.t. the current Ariane 6 launcher design. They pave the way for the evolutions of Ariane at 2025 horizon, and for possible subsequent evolutions of Ariane configuration by 2030.

The present paper will focus on the way the reusability option is treated in the FLPP system studies, which also includes the preparation of a demonstrator for reusability (THEMIS).

✓ At launch vehicle system level, a trade-off has been addressed with different modes of return (such as toss-back, or rocket boost glide back) for the different phases, including the reusability flight phases (flip manoeuver, braking process for atmospheric re-entry if needed, approach and landing processes). In front of the agreed selection criteria, the Toss-Back return mode was finally selected as the most relevant one.

✓ Among the activities related to technologies, a concept analysis is undergoing for a possible reusable liquid booster and/or lower stage demonstrator, equipped with LOx/LCH4 multi engine bay using Prometheus engines.

This demonstrator concept will be the result of different Trade-Offs (number of engines, layouts, structural materials, avionics & all subsystems required for reusability). The current study includes the definition of the demonstration plan considering the selected recovery mode, the architectural & layout definition with the reusable scheme decided in launch system studies, and the verification of the attainable flight envelope.

DOI: 10.13009/EUCASS2019-971

This paper will highlight the main outcomes of these studies.

KEYWORDS: e.g. reusability, launch system, Ariane evolutions, Future Launchers Preparatory Programme (FLPP)

1. INTRODUCTION AND CONTEXT

Since its beginning, the Ariane 5 launcher has been a remarkable success. To date, the European launcher has completed a series of 83 successful consecutive launches. Ariane 5, while guaranteeing independent access to space for European states, managed to capture 50% of the open market for launch services. As early as 2020, Ariane 6 will continue this success at a cost twice as low as Ariane 5.

While Ariane 6 and Vega C, thanks to their reduced cost and versatile capabilities, will ensure the competitiveness of the European launchers in the short term, additional efforts must be invested in a longer-term view to prepare for a sustainable long-term future of the European launcher family in an ever more competitive worldwide space transportation marketplace.

ESA, in the frame of its Future Launchers Preparatory Programme (FLPP), prepares the enabling technologies for future launcher system architectures through advanced technologies and demonstrators activities [7], addressing innovative solutions in manufacturing process, low cost avionics and in particular low cost liquid propulsion [3].

Concerning the future of Ariane, and in front of the increasing competition pressure, the system activities in FLPP/NEO shall prepare the options that will ensure sustainable competitiveness, for instance aiming a launch cost reduction by a factor of two compared to Ariane 6 as illustrated in Figure 1.

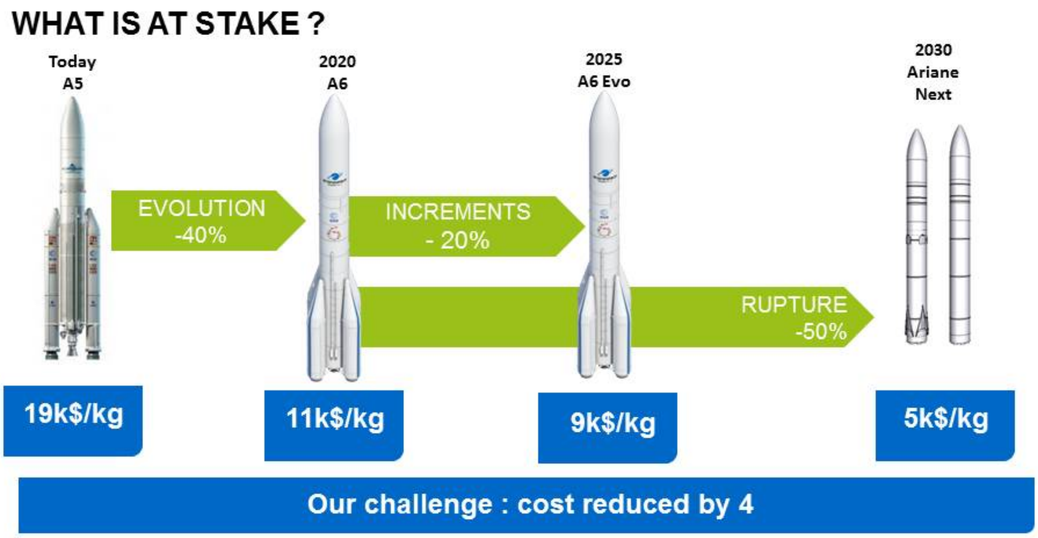

Figure 1. Objectives for Ariane launch price reduction (GTO mission)

The Space transportation System Investigation (STSI) studies, performed in FLPP NEO Core framework, were initiated in April 2018 (up to early 2020) with the following objectives:

- Propose a robustness file for the Ariane evolutions incremental roadmap
- Contribute to ESA Programme File for Technology and Demonstrators that will support the different selected concepts justified in the robustness file
- Deliver the architecture (to derive requirements for demonstrators):
  - for the launcher in view of the Upper Stage/ PHOEBUS demonstrator
  - for the launcher in view of the reusable booster/lower stage demonstrator

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Managed by ESA FLPP, with CNES and DLR technical assistance, studies are performed by ArianeGroup, interacting with main European actors.

The study logic consists in iterative system loops, progressively increasing the depth of the analysis while reducing the number of launcher architecture as illustrated in Figure 2.

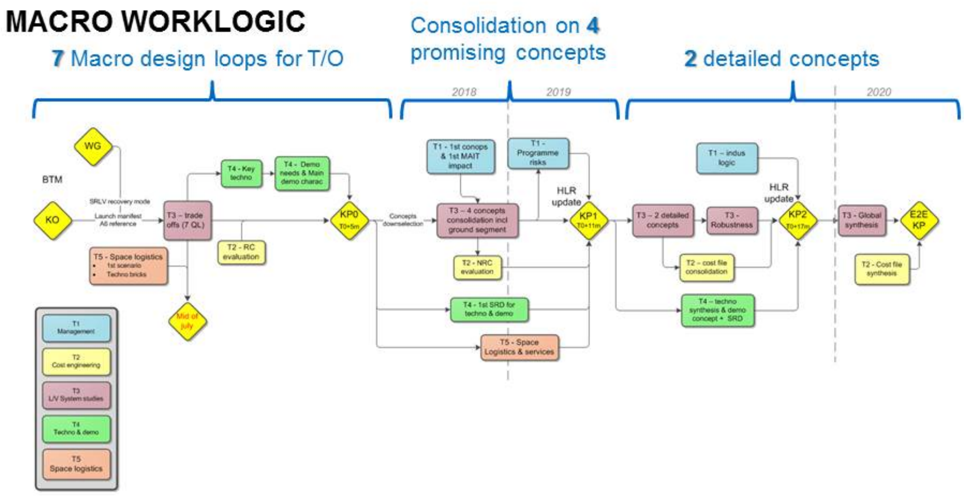

Figure 2. FLPP STSI study work logic

By combining timescale for technology maturation (2025 & 2030), architectures (boosted vs linear) and propulsion options (methane, hydrogen, solid), the trade-off tree is wide as illustrated in Figure 3.

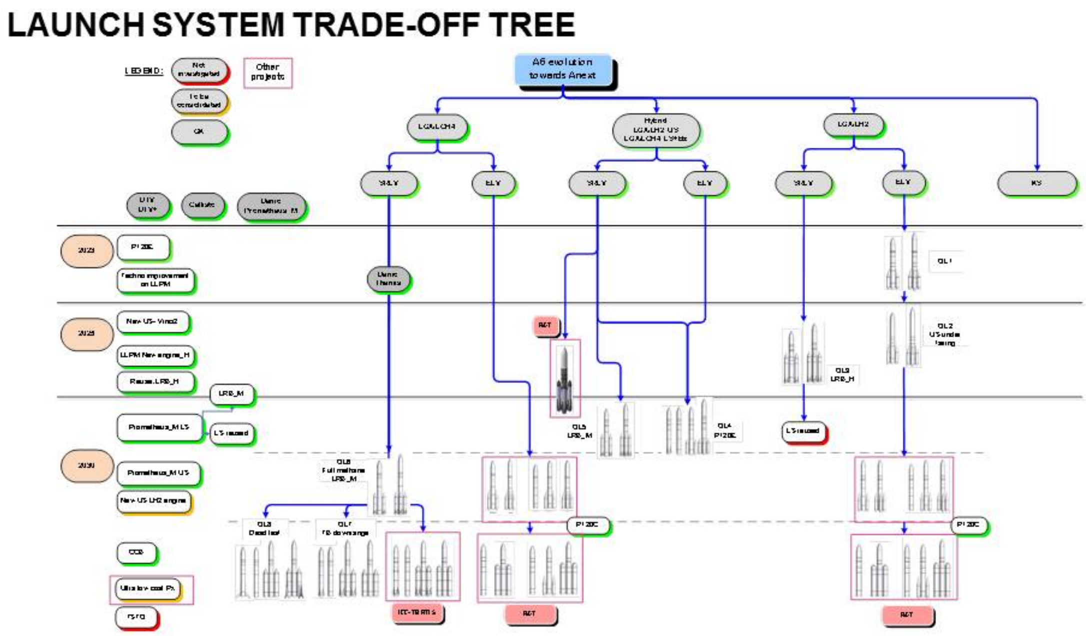

Figure 3. FLPP STSI trade-off tree

Furthermore, the reusability option, for the future liquid boosters and/or lower stage, is an additional variable for architecture trade-off. The previous ESA study (Launcher Evolution Elements) has shortlisted “Toss-Back”, the “Rocket Boost Glide Back” also called “Glider”, and the “Fly Back” modes among 19 variants (see Figure 4).

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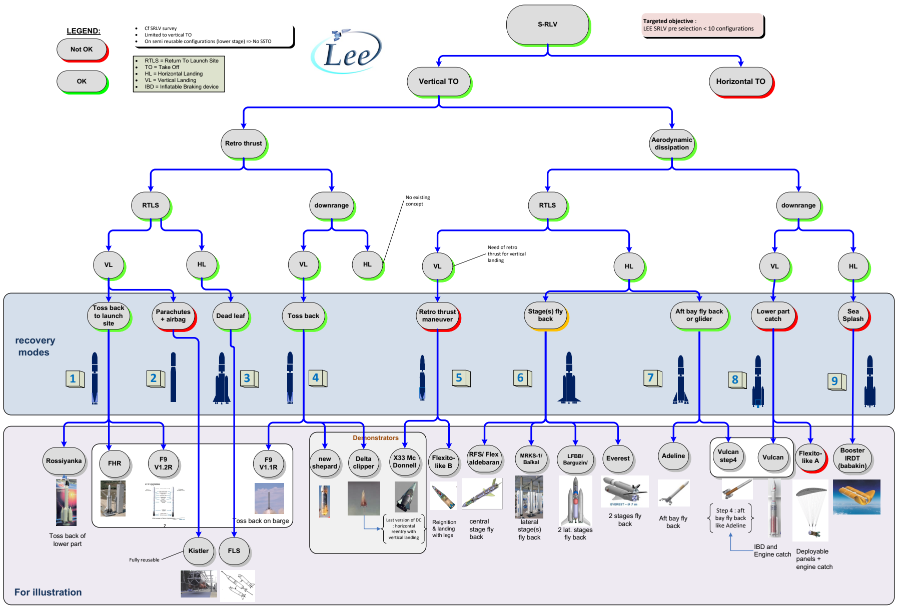

Figure 4. Recovery modes options tree

In order to limit the combination of architectures, the first phase of STSI study is dedicated to the selection of the reference recovery mode for reusable options.

2. TRADE OFF ON THE RETURN MODES

2.1. Objective and perimeter of the trade-off

At launch vehicle system level, a trade-off has been made with different modes of return of a first stage with a vertical lift off from Guyana Space Center. It included the “Toss-Back”, the “Rocket Boost Glide Back” also called “Glider”, and the “Fly Back” modes. And this trade-off tried to take into account the technical aspects for the different mission phases, but also the development risks, and the possible economy for the whole launch system. The objective was to compare the different return modes, and to progressively select the most promising ones for the next steps of the detailed FLPP/NEO system studies.

The following figures indicate the different return modes which have been compared.

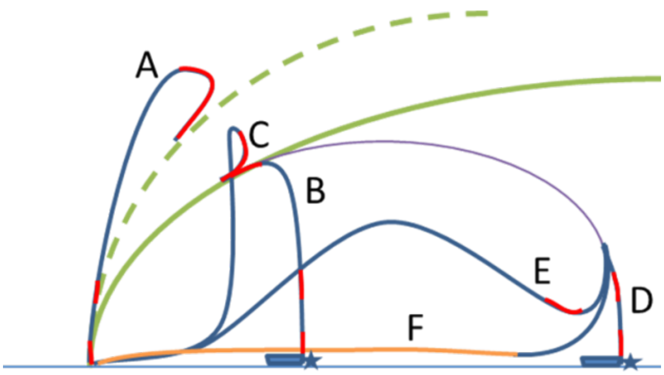

Figure 5: typical mission profiles for the preselected return modes

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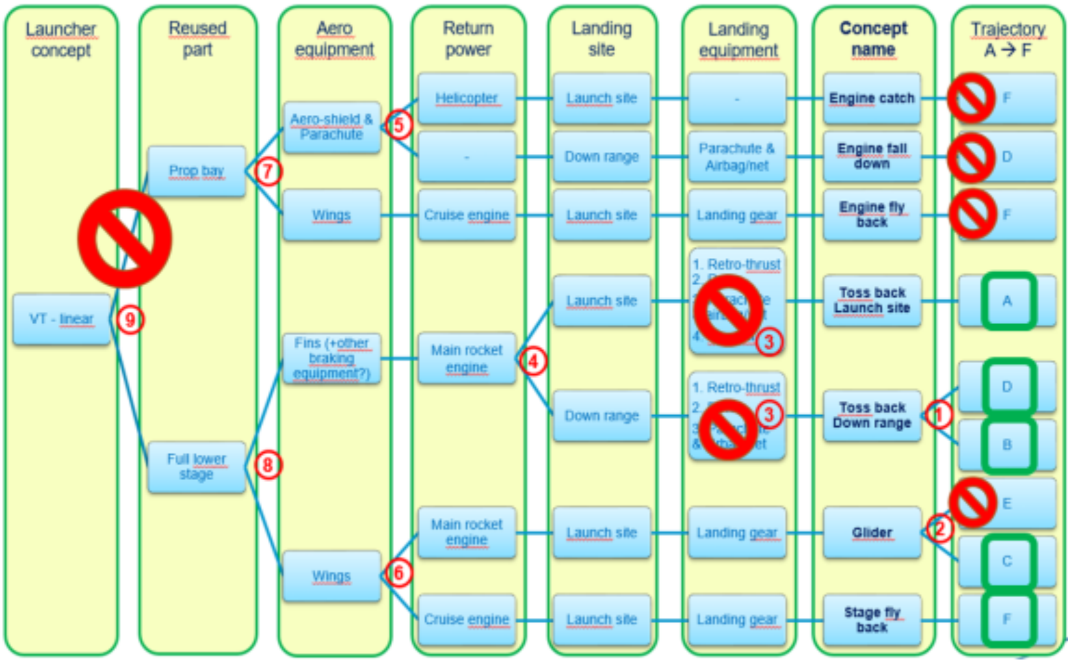

Figure 6: return modes preselection during FLPP/NEO system studies

Regarding the 1st stage reusable part, it has been admitted that the partial reusability (for instance focusing on the propulsion bay alone), shall be less attractive from the industrial and the economical points of view, compared to the full lower stage reusability. Therefore, this principle has not been retained.
An important retained principle, concerned the possible options to Return to The Launch Site (RTLS) or to allow landing Down Range (DR), for instance using a drone ship or a barge.

On figure 5, the “concept” names (more precisely: the “return modes” names) are associated to the typical 1st stage trajectory profiles: profile “A” stands for Toss Back RTLS, “B & D” for Toss Back DR, “C & E” for Glider (or RBGB), and “F” stands for Fly Back

For all the concepts, and especially for the wing’s concepts, a particular attention was paid in order to allow dismounting the selected devices through a “kit approach”. For instance, figure 7 shows a preliminary concept of a winged 1st stage, studied by ONERA [2]. As far as possible, the reusable elements shall be dismountable in order to switch from a reusable launch vehicle to an expendable one.

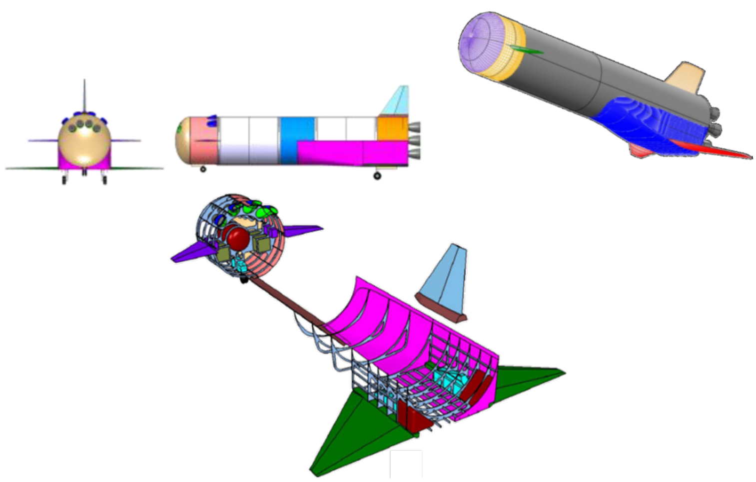

Figure 7: 1st stage winged concepts including a “kit approach” for RLV or ELV launch vehicle (@Onera)

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Regarding the return power, the winged "Fly Back" concepts are supposed to use turbojet engines which have to be qualified for "inflight" ignition. In their concept studies, ONERA proposed to integrate 4 EJ200 turbojets in the 1st stage front skirt, and about 7T kerosene propellant to feed them. The kerosene tanks are dispatched on the forward and on the rear parts of the stage. Still for the return power, the main rocket engines shall be used for the Toss Back and the Glider concepts. In the particular case of the Toss Back mode, the main engine rocket shall be qualified for a reduced thrust level during the landing phase. Anext system studies [3] gave some preliminary results concerning the required thrust modulation during the "soft landing" phases with the Toss Back mode: the requirement is about 30% of the nominal thrust level.

The Glider with E profile supposes a restart of the main engine after the 1st aerodynamic re-entry and the aerodynamic turn. But concerning the choice of the best strategy between C and E profiles, no performance benefit was identified with the E profile which was finally forgotten. The following figure shows the trajectory comparison between the Glider C and the Fly Back F profile.

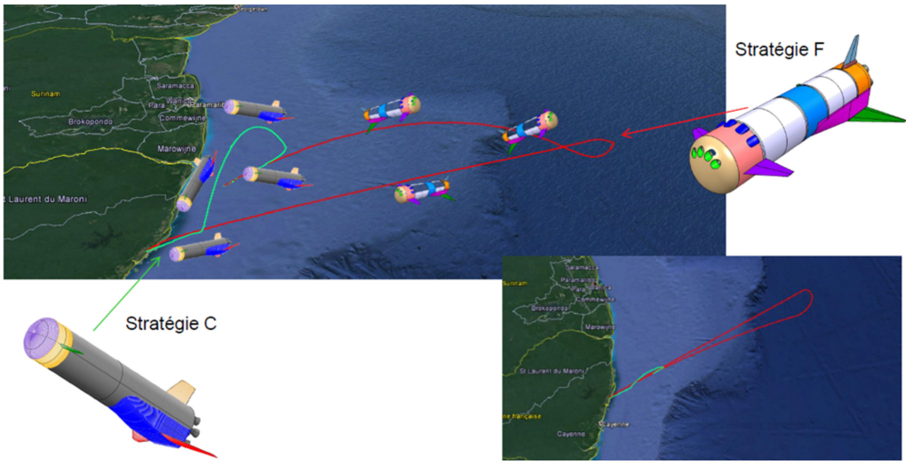

Figure 8: 1st stage winged concepts trajectories Glider and Fly Back (@Onera)

The Fly Back concept was found to be slightly more efficient then the Glider concept from a performance point of view. This was mainly the result of the high propulsion efficiency given by the turbojet engines for the return phase. But on an other hand, the Fly Back concept requires more subsystems, and the turbojets have to be adapted for spatial environment. This later point may induce high investments, for a limited production rate (system assumptions: the launch rate assumption is about 11 per year, and the 1st stage shall be reusable 5 times).
Finally, and due to the additional complexity of the Fly Back concept compared to the Glider concept, it was decided to focus the comparison analysis on the following return modes: Toss Back A (RTLS), Toss Back B or D (DR), and Glider C. In the following paragraph, the Toss Back (DR): with B or D profiles, are treated as a single concept.

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2.2. Results of the trade-off

2.2.1 Technical analysis per flight phase

The Toss Back concepts:

The ascent trajectory profile, in case of RTLS, shall be verticalised so as to minimize the performance loss due to the propellant consumption for the return phase. The impact of this "verticalisation" on the safety aspects shall be analyzed. This phase is also slightly affected by the protuberances due to the un-deployed systems (landing legs and re-entry aerodynamic control surface). All these aspects will be identified and mastered thanks to wind tunnel tests activities, and thanks to CALLISTO [1] return of experience.

During the 1st stage separation phase, a quick orientation will be needed, especially for the RTLS option more demanding compared to the DR case. This could be performed with an added Reaction Control System (for instance a cold gas system). At the end of the manoeuver, a restart of the main propulsion system is needed for mission profiles A & B. This engine capacity has been introduced in the requirements of PROMETHEUS [3] engine demonstrator, which is actually under development.

The next phase is the exo-atmospheric phase for which, the main open point concerns the management of the propellants in micro-gravity. Several options such as the possible use of Anti-Wetting Devices [4], are under study through National Research programs. Specific thrusters may also be used for propellant settling.

During the re-entry atmospheric phase, a re-boost action is needed to stay within the acceptable limits of aero thermal fluxes and dynamic pressures. The guidance and control functions shall be able to insure a proper return trajectory down to the landing area. An aerodynamic control system will help reaching this challenge. CALLISTO [1] experience will contribute to the maturation of the associated technologies.

For the landing phase a precise management of the 1st stage altitude and velocity is required. The main engine shall allow a deep throttling capacity, which is identify as an important topic to be covered with PROMETHEUS [3]. Once the vehicle has landed, a passivation procedure has to be engaged, involving autonomous or remotely active passivation valves. For safety controls, UAV systems may be used [5].

The next steps correspond to the refurbishment, the revalidation and the reuse of the 1st stage. A Health Monitoring System shall drive the corresponding operations until the revalidation step.
The stage reusability shall be evaluated with a "RLV kit" option. But those topics are not specific to the Toss Back concepts.

Finally, the positive points, and the identified difficulties are summarized below:

Opportunities	Difficulties
✓ "Rocket approach" flight modes ✓ Possibility to have 2 locations of recovery: RTLS vs DR. ✓ Good reversibility (launcher and ground means) ✓ TRL 9 recovery mode today (world). And CALLISTO demonstration engaged to pave the way ✓ Possibility to test "as you fly" and as a secondary mission in production ✓ Robust return mode wrt development program	✓ Performance loss for RTLS modes ✓ High number of main engine restarts ✓ "Very vertical" ascent trajectory for RTLS ✓ Grounds means (barge , ships, harbour, cranes , transports)

Figure 9: Toss Back concept, summary of the opportunities and difficulties.

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The Glider concepts:

From the launch pad accommodation to the ascent phase, the system will be affected by the wings protuberances. This has a high impact on the mass budget of the launcher. It will generate lateral load factors during the flight, depending on the wind's profiles.

During the separation phase, the collision avoidance manoeuver may be more critical due to the wings, compared to the Toss Back concepts. It will also depend on the residual dynamic pressure at the separation altitude. The vehicle orientation can be performed with an added Reaction Control System. And at the end of the manoeuver, a restart of the main propulsion system is needed. This engine capacity has been introduced in the requirements of PROMETHEUS [3].

Next phase is the exo-atmospheric phase for which, the main point concerns the management of the propellants in micro-gravity. Same as for the Toss Back concepts, several options can be proposed [4].

During the re-entry atmospheric phase, the selected aerodynamic shape, associated to the guidance and control functions shall be able to insure a proper return trajectory down to the landing area. REFEX [6] experience will contribute to the maturation of the required technologies.

The landing phase is associated to the precise management of the 1st stage altitude and velocity. The flight profile and the energy management can use similar solutions as the "Terminal Area Energy Management" (TAEM).
One important point is the amount of investments for the development of an airstrip, runways and all the required facilities for the operations of a winged concept.

Once the vehicle has landed, a passivation procedure has to be engaged, same as for the toss Back concepts. And UAV systems can be used for safety controls.
The next steps correspond to the refurbishment, the revalidation and the reuse of the 1st stage. And as for the Toss Back concepts, a Health Monitoring System shall drive the corresponding operations until the revalidation step. The stage reusability shall be evaluated with a "RLV kit".

Finally, the positive points, and the identified difficulties are summarized below:

Opportunities	Difficulties
✓ Low delta performance wrt to Toss Back RTLS ✓ Good reversibility with a kit approach. ✓ TRL 9 in the past for glider approach, and Development progress with REFEX to pave the way ✓ Possibility to test "as you fly" and as a secondary mission in production	✓ Kit approach for wing concepts and impact on the launch system. ✓ Use of wings AND restart of main rocket propulsion. ✓ RTLS only option ✓ Ground means: airstrip + runways ✓ Less robust wrt development progress (links between aero shape - propulsion – performance).

Figure 10: Glider concept, summary of the opportunities and difficulties.

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2.2.2 Quotation matrix between the preselected return modes.

The ranking is performed in relative way between Toss Back RTLS, Toss Back DR and Glider. A limited number of criteria have been agreed in relation with the launch vehicle fleet derived from each possible “return mode” concepts: the recurring cost, the development costs and risks, the adaptability to the spacecraft market, and the robustness towards possible contingencies. It is important to notice that the interest of the 1st stage reusability, is not only linked to the recurring cost, but reusability can also bring some advantages regarding the production flexibility, and the robustness towards the market evolutions.

For the recurring cost criteria, the results from previous FLPP studies are used. They have shown a delta around 10 to 20% between Toss Back-RTLS and Glider concepts which are more expensive. In addition, a launch system optimized around a Toss Back DR return mode, will be slightly cheaper compared to the case of a Toss Back RTLS mode.

For the development costs, regarding the time target, THEMIS (see §4: 1st stage RLV system demonstrator) shall fly around 2025, which is also an important date for an eventual Ariane Next development decision.

- Time to market: the target is more accessible to the Toss Back, compared to the winged concepts for which the design loops optimization, including an aero shape, is more complex. And the Toss Back RTLS concepts are more accessible than DR ones due to the need of a barge.
- Adaptability to Ariane infrastructures (buildings, launch pad…): The Toss Back RTLS concept is quite close to a classical Launch vehicle design, so the potential adaptation of existing infrastructures shall be limited. Perhaps for the launch pad due to multiengine aft bay, but this concerns all the return modes concepts. Still for the Toss Back RTLS concept, the landing area will be limited compared to the runway (or the barge) needed for the other concepts.
- Safety aspects: The Toss Back DR solutions don’t need a verticalisation of the ascent trajectory. Then, it is comparable to a classical launch vehicle during the ascent phase; and the return phase on a barge has no safety impact. The other return modes have safety impact during ascent phase due to verticalisation need. With a Glider concept, during the landing phase, the debris area should be limited. These phase is supposed to be less critical with a Glider concept compared to a Toss Back RTLS one.
- Family potential: this criterion addresses the possibility to derive a launch vehicle family. Considering an "RLV Kit» easily dismountable whatever the return mode concepts, the Toss Back or the Glider have the same “family potential”: we can create a fleet which address the market scenario and allow commonalities in all the cases.

For the Adaptability to market:

- Versatility: For instance, several orbit may be asked with the same configuration, within the fleet (GTO/GEO, LEO, SSO…). Toss Back fleet allows a wide range of performance especially if we can address both RTLS and DR capacities. Glider solution is more limited.
- Availability: this covers for instance, the potential impact of reusability and recovery mode on the launch date (or on the launch cadence). From a global point of view, the availability will be better with a RTLS concept than with a concept using a barge, which may induce additional constraints due to potential waves.

With regard to Robustness towards some contingencies:

- Concept scalability and robustness: What are the constraints induced on the launch vehicle architecture due to the selected return mode concept? Does it allow for possible launch vehicle evolutions? The winged configurations are less adaptable as the aero shape is optimized for a given reference launch vehicle. The Toss Back concepts are more adaptable, being closer to classical launch vehicle systems.

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- Reversibility: This criterion corresponds to the capacity to easily switch from a launch vehicle fleet, including some RLV configurations, to a “full ELV” fleet, and vice versa. If the launch vehicle fleet is optimized on the Toss Back DR return mode, then the performance penalty with this return mode, will be low compared to the ELV case. This provides a small advantage. In all the cases, the “RLV dismountable Kit” is supposed to be efficient.

The table below summarizes the comparison of the different return mode concepts.

Main criteria	Topics	Objective	Best return mode concepts
Recurring Cost	Recurring cost evaluation	as low as possible	1. Toss Back DR 2. Toss Back RTLS 3. Glider
Dev. costs and risks	Time to market / TRL	as soon as possible	1.Toss Back RTLS 2.Toss Back DR 3. Glider
	Adaptability to Ariane “environment”	high commonality	1. Toss Back RTLS 2. Toss Back DR & Glider
	Safety impact		1.Toss Back DR 2. Glider 3.Toss Back RTLS
	Family potential	high potential	Toss Back = Glider
Adaptability to market	Versatility	Wide capacity of orbits	1. Toss Back DR (combined with RTLS) 2. Glider
	Availability	as high as possible	1.Toss Back RTLS or Glider 2.Toss Back DR
Robustness towards possible Contingencies	Concept scalability, robustness	high capacity, as high as possible	1. Toss Back 2. Glider
	Reversibility	high capacity, as high as possible	1.Toss Back DR 2 Toss Back RTLS & Glider

Figure 11: Global comparison of the different “return mode” concepts

2.3. Conclusion of the trade-off

At the end of this selection process, the Toss Back (Down Range) return mode was chosen as the reference case for the next step of the FLPP system analyses. The Glider concept has been kept, for a short time, as a back-up solution. But finally, the cost analyses didn’t show any advantage to keep it any longer in the system studies. Despite all, the winged concepts are still under analyses through the National Research Programs.

3. REUSABILITY IN THE SYSTEM STUDIES

System Studies compare different Launch System architectures addressing the same launch manifest (sensitivities to launch manifest are performed to check the robustness to market evolutions).

During the first phase, concluded by Key Point 0 in December 2018, reusability options were applied on the following architectures:

- Full Hydrogen (QL3): A6 central core with LOX/LH2 reusable booster (hydrogen version of Prometheus engine)

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- Mixed (QL5): LOX/Methane lower stage and reusable booster + LOX/Hydrogen upper stage
- Full Methane:
  - LOX/Methane lower and upper Stages + 2 or 4 small reusable LOX/Methane boosters (QL6)
  - LOX/Methane lower and upper Stages (lower stage reusable or expendable) + 2 large reusable LOX/Methane booster for Heavy version → comparison between Toss-Back (QL7) and Glider (or Dead-Leaf = QL8) recovery modes

All launch systems are sized to reach 13 t GTO net performance with the Heavy variant. Reusable versions are illustrated in Figure 12.

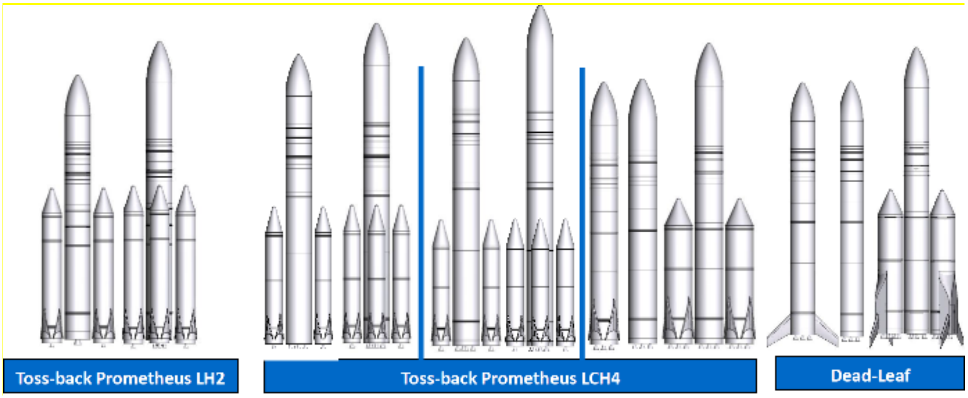

Figure 12. Ariane Next fleet with reusable stage as investigated in the frame of ESA FLPP

Launch rates scenarios investigation was performed to define 3 launch manifests in addition to Ariane 6 reference manifest, as illustrated in the table below:

Launch rate	A6_like	Min	Average	Max
Total / year	11	7	14	27

With respect to the 50% cost reduction versus Ariane 6, results for reusable options are the following ones:

- Annual exploitation cost :

Total yearly cost	A6_like	Min	Average	Max
QL3	+	+	+	+
QL5	+	+	+	+
QL6	++	++	++	++
QL7	+++	+++	+++	+++
QL8	+++	+++	+++	+++

- Cost per kg in GTO on Heavy version
  -

Cost per GTO kg	A6_like	Min	Average	Max
QL3	+	NA	+	+
QL5	+	NA	+	+
QL6	++	NA	++	++
QL7	+++	NA	+++	+++
QL8	+++	NA	+++	+++

Nota: no GTO dual launch then no Heavy variant in Min launch manifest

The QL7 case provides the highest cost reductions whatever the launch manifest, consisting in a highly robust option.

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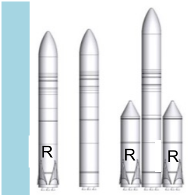
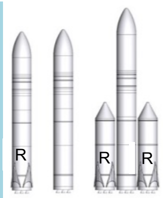
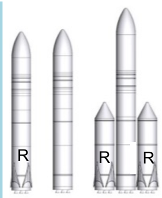
Economic performance is slightly better than Dead Leaf (Glider) architecture and was preferred after a dedicated trade-off (see §2). Reference recovery scenario is Toss Back Down Range (barge landing) with Toss Back Return To Launch Site as a variant when maximal performance is not required.

With a unique type of engine, present in large numbers (8 for linear version, 19 for boosted version), production of stage and engine remain significant even with a high reuse rate. The following table illustrates the sensitivity to reuse rate.

Launch rate	7 / year (ref = 7 A62 + 0 A64)			11 / year (ref = 6 A62 + 5 A64)			14 / year (ref = 7 A62 + 7 A64)		
Annual Fleet Distribution (R = Reusable) (x6 = 6 exemplaries of the version)	 x1	x6	x0	 x4	x2	x5	 x1	x6	x7
Nb reuse (0=expendable)	0	4	9	0	4	9	0	4	9
Lower stage production (/year)	7	6	6	**21**	10	8	**28**	16	14
Prometheus engine production (/year)	56	50	50	**143**	65	55	**189**	**105**	94

Minimal scenario with limited application of reuse is naturally not sensitive to reuse rate when A6-like or average scenario can double the gains granted by propulsion and stage standardization thanks to reuse. This type of architecture are even hardly conceivable in expendable version (0 reuse), requiring high CAPEX for producing huge number of stages and engines.

On top of providing 15 to 20% additional cost reduction, reusability allows some flexibility in launch rate (including punctually for constellations deployment) through adjustement of reuse rate (manufacturing means not sized on production peak).

This architecture was down-selected for the on-going next phase that will be concluded by Key Point 1 review mid-July 2019. Work logic for the consolidation phase is presented in Figure 13.

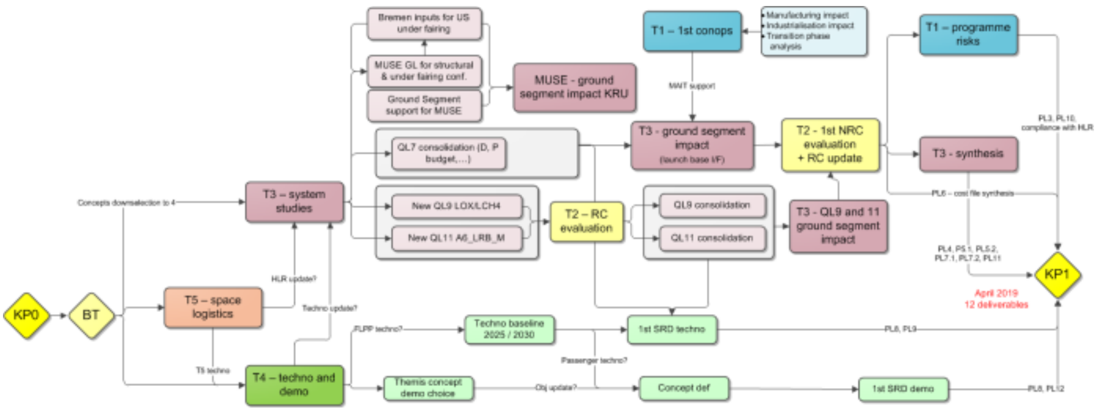


Figure 13. FLPP STSI work logic for phase 2

Two new reusable architectures were introduced in phase 2:

- Full Methane linear (QL9): Two Stage To Orbit, reusable version for institutional needs, expendable version for commercial needs, can be completed by an optional storable propellant kick stage for high performance missions (close to 13 t GTO).

- LOX Methane reusable boosters on Ariane 6 central core (QL11)

Current status of designs is illustrated in Figure 14.

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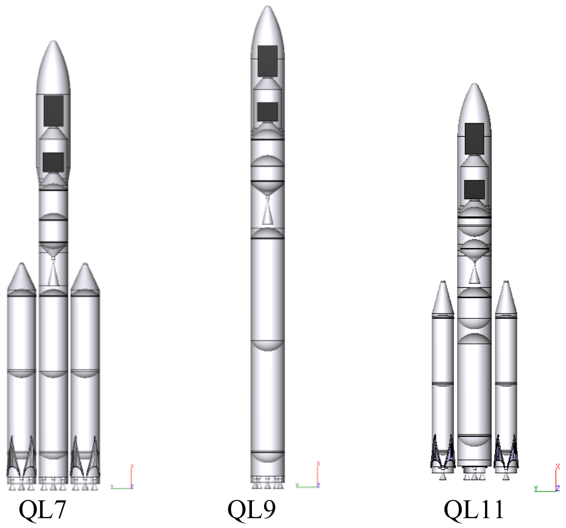

Figure 14. Reusable concepts architectures for phase 2

Economic performance is currently assessed to check if the 50% reduction target is met.

The cost reduction associated to reusability is highly dependent of 3 parameters:
- The reliability of the recovery
- The number of reuse
- The cost to fly again (recovery, inspection and refurbishment if necessary)

Overall performance is also linked to the efficiency of the recovery:
- Mass penalty for re-ignition
- Deceleration efficiency
- Hard landing capacity
- Control efficiency (low angle of attack)
- Guidance and navigation precision
- Low shock at landing
- Compatibility with high thermal and mechanical loads at re-entry

A specific demonstration programme (called Themis) is proposed for next Ministerial Conference (November 2019) to characterize all these parameters.

4. THEMIS, A TECHNOLOGICAL DEMONSTRATOR FOR REUSABILITY

European reusability roadmap is illustrated in Figure 15.

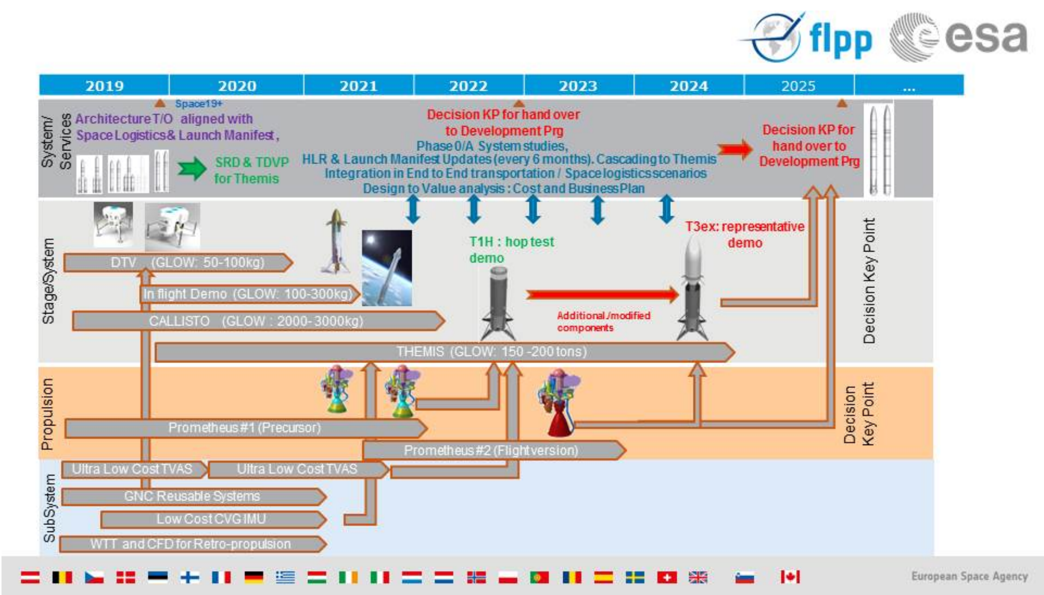

Figure 15. ESA/FLPP Reusability Roadmap

DOI: 10.13009/EUCASS2019-971

This roadmap includes demonstrators of increasing size and complexity, starting with small scale, low altitude/low speed turbo-jet vehicles (DTV) and rocket version (In Flight Demo), medium size vehicle (CALLISTO) and finally a large scale demonstrator (Themis) with a representative flight domain and propulsion (Prometheus engine, see [3]). 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 Figure 16.

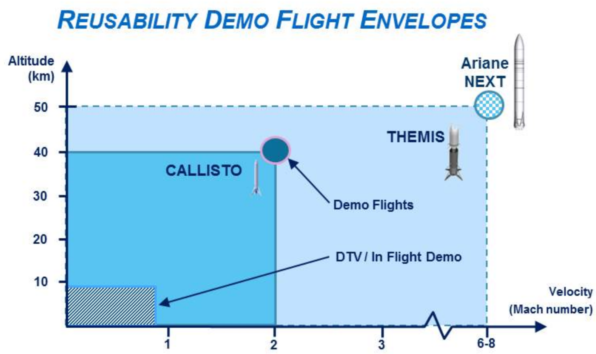

Figure 16. Reusability Demo Flight Envelopes

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:

- Common bulkhead tank
- Crossing feedlines
- LOX/Methane stage without cold thermal protections
- 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 (QL7, QL9 or QL11 described in §3). 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)

High Level Requirements for Themis final demonstration were defined and prioritized as illustrated below:

DOI: 10.13009/EUCASS2019-971

Priority level	HLR number	Description
P1	DEMO_HLR1	The budget of DEMO demonstration, for full perimeter, shall not exceed 200 M€. This notably derives in AGILE development methodologies.
P1	DEMO_HLR2	DEMO demonstration shall allow to validate PROMETHEUS LOX-LCH4 engine, and LOX-LCH4 stage, in a re-usable mission: capability of PROMETHEUS and FPS to ensure required specific functionalities and performances during full flight up to landing and passivation, and capability of one same PROMETHEUS engine to perform at least two consecutive flights.
P1	DEMO_HLR3	DEMO demonstration shall be representative of operational target during reentry phase: RTLS mission and possibility of DR: ~Mach 6, 100kPa, thermal flux TBD, altitude > 100km (figures TBC).
P1	DEMO_HLR4	DEMO demonstration shall allow demonstrating recovery and re-use (refurbishment and then re-fly), and allow characterizing the end-to-end cost of a re-usable Launcher.

Priority level	HLR number	Description
P2	DEMO_HLR5	DEMO shall be a System demonstrator of operational stage and shall serve as a test bed for technologies & architecture features (e.g. re-usable fairing, common bulkheads, crossing feed lines, GOX pressurization, etc…). See note 2.
P2	DEMO_HLR6	DEMO demonstration shall contribute to increase TRL of technologies required to achieve recovery and re-usability objectives: Engine throttlability in operation, Landing System, Grid Fins, Avionics & GNC for RTLS, Autonomous safeguard, HMS,…
P3	DEMO_HLR7	DEMO shall demonstrate technical feasibility of multi-engine architecture, in terms of lay-out in a constrained environment (limited diameter), and of functional behavior.
P3	DEMO_HLR8	DEMO demonstration shall be the opportunity to experiment innovative industrial organization.
P3	DEMO_HLR9	DEMO shall contribute to the industrial tool maturation for reusable liquid boosters or reusable lower stages
P3	DEMO_HLR10	Demo shall support agency and industry communication

Themis is in early definition phase as illustrated in Figure 17. Current characteristics are:

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

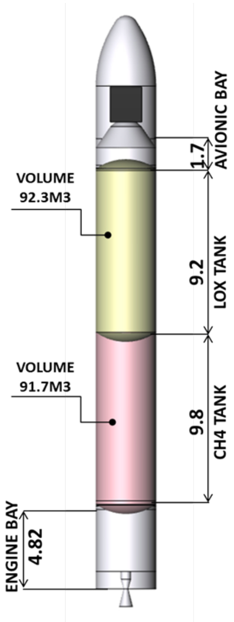

Figure 17. Themis early definition

Analysis and design consolidation of Themis demonstrator will continue through FLPP/STSI until the beginning of the development early 2020 (after a positive decision at Space19+).

DOI: 10.13009/EUCASS2019-971

5. CONCLUSION

ESA FLPP Space Transportation System Investigation is preparing Space19+ Ministerial Conference through System Studies aiming at defining:

- A reference concept for recovery and reusability
- Robust Ariane evolutions scenarii for 2025 and 2030 timeframes (for expendable and reusable launch systems)
- A roadmap towards reusability demonstration consistent with European technology maturation programmes

6. ACKNOWLEDGEMENTS

The authors thank all the people from all entities directly or indirectly involved in FLPP NEO Core Space Transportation System Investigation for their contribution to this paper.

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