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ESA Technology Strategy to support the Space Transportation Sector in Europe

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Abstract

The present paper provides an early view of the technical elements currently under elaboration and consolidation by ESA with its stakeholders to support the preparation of the future Space Transportation sector in Europe.

It highlights the evolutions of the current context calling for a shared European Vision for the future of this sector, based on cooperation and cross-sustainment among ESA's Member States. It also describes the main elements of a possible future European Space Transportation Infrastructure, and it derives a Technological Roadmap enabling the maturation of the most critical technologies with a set of ambitious and rapid In-Flight Demonstrations.

1. Introduction

In the past years, the Space Transportation sector worldwide has undergone major changes, with the growing diversification of the use of space and a booming new space economy, driving a strong-paced evolution of the market for launch services with an increased competition for the reduction of the cost of access to space challenging the European Space Transportation sector.

Furthermore, as the USA, China, Russia and India are accelerating their developments for human space exploration, Europe is also investigating the technical, programmatic, social, economic and political relevance of developing, in the future, European-made human-rated Space Transportation solutions, which would strengthen sovereignty, while expanding the accessible space economy .

Moreover, the recent events at Europe's borders are now stressing, more than ever, the importance for Europe to move towards self-reliance in crucial sectors such as space, ensuring autonomy and freedom of action in support to European ambitions, and securing critical space services for strategic needs.

In this context, the European Space Agency (ESA) is elaborating a Vision for the future of the Space Transportation sector in Europe, targeting a competitive infrastructure, and identifying technological priorities..

This paper presents the elements constituting the current status of such a Vision, and describes a Technology Roadmap which would enable to fill the technology gaps identified to achieve the development of competitive European Space Transportation services in this timeframe.

2. A Vision of 2030+ for European Space Transportation

The Vision of 2030+ for European Space Transportation currently elaborated builds on the main pillars and family of products summarised hereafter.

- **<u>Main Pillars:</u>**

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  - **Strategic Autonomy**: guarantying autonomous European-made capability in routine access to space, also enabling "transport in" and "return from" space, including the outlook of manned Space Transportation capability should this be required in the future.
  - **Affordability and Competitiveness**: maximising synergies, commonalities and balanced cross-sustainment of technology building blocks across European products, either institutionally, or privately funded.
  - **Industrial Diversity**: capitalising from the dynamic European ecosystem, scientific and industrial, relying on skills and means (production or tests facilities, hardware) from available industrial excellence of legacy players, as well as new actors.
  - **Commercialisation**: taking maximum advantage from the fast-growing commercialisation of the use of space, sharing public skills and ground infrastructures within Europe, focusing the role of ESA and National Institutions as Enablers for de-risking technological activities, and Anchor Customers for procuring future services.
  - **Innovation for competitiveness**: fostering innovation and the introduction of breakthrough technologies to increase competitiveness, assuming and incentivising a calculated level of risks, improving environmental compatibility towards carbon neutrality.
  - **Efficiency**: relying on agile/lean programme management methods based on collaborative work between a diversity of actors, either institutional, academic or industrial, newcomers or experienced.
  - **Cooperation**: fostering Member States cross-sustainment and European cooperation at the maximum extent possible, with a competitive but inclusive and collaborative approach across Europe, joining forces by building on the heritage and excellence of the available industrial expertise while offering opportunities to new industrial actors.

- **A Family of European Products with the following set of characteristics:**
  - **Two stages to orbit** to push the competitiveness, decreasing the number of stages and the complexity of the launch systems.
  - **Maximising synergies** among launch systems, implementing extensive modularity through **common building blocks** at components, engines and stages levels.
  - **Fully liquid propulsion** based on complementary thrust-classes of engines, and a single propellant pair for both first and upper stages.
  - **Fully reusable** for increased competitiveness and launch service flexibility, with focus on both lower and upper stages reusability to leapfrog the worldwide competition.
  - **Performance ranges** of Vega C and Ariane 64, with potential for Human Space Transportation.

The family of launch systems is complemented by a family of Mission Extension Modules compatible with the whole family of launch systems, from multiple payloads adapter to kick stages, for:

- **The extension of the range of launch services** targeting a wide range of spacecrafts, from micro to heavy, injected with precision and performance on multiple orbits.
- **The extension of the access to new markets in Space Transportation**, enabling in-orbit services or exploration needs.

3. A European Space Transportation Infrastructure for 2030+

A possible future **European Space Transportation Infrastructure** is being identified, meant as a common and coherent technical answer to the Vision for 2030+, independent from any pre-existing programmatic frame, be it institutionally or privately funded.

The elements of such an infrastructure are identified to cover the Space Transportation services foreseeable in 2030+, streamlining products and associated services across European industrial capabilities, including the possibility for man-rated Space Transportation services, with:

- A family of Two-Stages-To-Orbit Launch Systems, fully based on liquid propulsion and fully reusable for increased competitiveness;
- A family of Mission Extension Modules, to extend the market capture;
- A Crew Transportation System, enabling Human Space Transportation;
- The associated Ground Infrastructure.

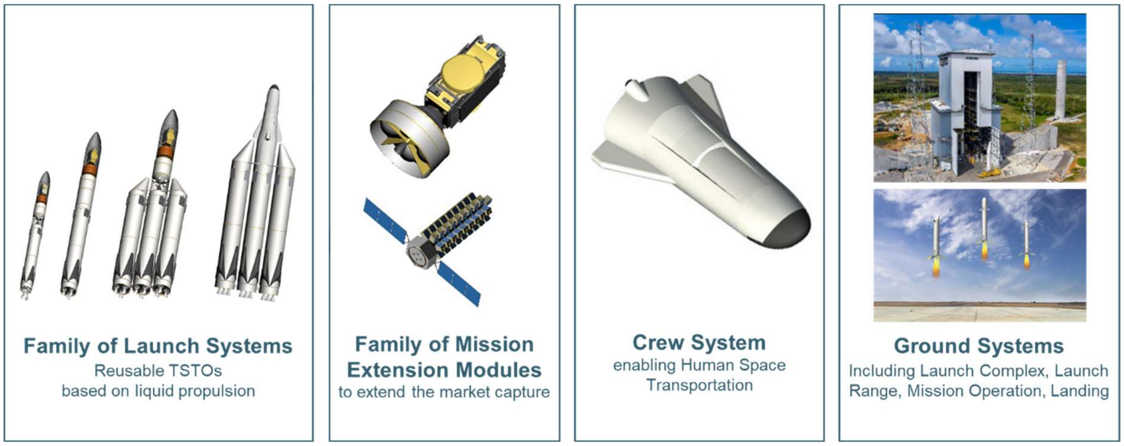

Figure 1: A potential European Space Transportation Infrastructure for 2030+

The architecture of this Infrastructure is being based on building blocks, with the objective to avoid unnecessary duplications and to optimise the available European resources, increasing the production cadence, minimising the production costs, maximising competitiveness, while at the same time improving the resilience of the Infrastructure.

The following building blocks levels are being identified:

- At stage level for launcher systems, and at modules level for mission extensions (e.g. motorised dispensers, orbital transfer vehicles, …), focusing on complementary common stages and modules across the whole infrastructure, fostering modularity/standardization of the stages sub-systems;
- At engine level, focusing on complementary common liquid propulsion engines across the whole Infrastructure (launchers systems, mission extension modules…), based on three complementary classes of thrust (with engines throttle-ability ranges to be consolidated towards flexibility and complementarity):
    - heavy class: 60-120+ tons, building on Prometheus engine;
    - medium class: 10-50+ tons, building on M10 engine;
    - small class: 1 ton+, building on Berta engine;

  assuming that lower levels of thrust are covered by spacecraft technologies, and that higher levels (e.g. 300 tons class) could be investigated if the need is confirmed for super-heavy applications, potentially targeting human space transportation;
- At components level, focusing on complementary common equipment (propulsion, avionics, mechanisms, structures…) across the whole Infrastructure.

Infrastructure	Elements	Main subsystems based on common building blocks
Family of Launcher Systems	**- Mini/Micro-Launchers - Medium Launcher - Heavy Launcher - Man-Rated Launcher**	Engines, including reusability
		1st Stage, including reusability
		2nd Stage, including reusability
		Fairing, avionics, structures, tanks, …
Mission Extension Modules	**- Smart Dispenser**	Multiple payloads adapters
		Motorised dispenser (electrical and/or chemical green propulsion)
	- Kick Stage	In-Space Transport (chemical propulsion)
	- Orbital Transfer Module	Transfer / Tug modules, in-space transport for space logistics (electric and/or chemical green propulsion)
	- Re-entry Module	Re-entry, landing, payload recovery
Crew Transportation System	**- Crew module**	Pressurised module, man-rated re-entry
	- Support module	Crew life-support, energy, thermal control, propulsion
	- Launch Abort System	Distancing rockets, landing
Ground Segment	**- Launch Complex**	Launch base, spaceports
	- Launch Range	Launch control centre, downrange telemetry stations, communication networks, …
	- Mission Operation	In-orbit/re-entry/descent/landing control centres, telemetry stations, communication networks, …
	- Landing Sites	Landing facilities

Table 1: European Space Transportation Infrastructure elements and building blocks

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4. A Technological Roadmap to prepare European Space Transportation for 2030+

A Technological Roadmap is being elaborated, enabling the implementation of the Vision for 2030+ in a coherent and consistent way, encompassing the building blocks constituting the future European Space Transportation Infrastructure, including ground and flight aspects, for:

- access to space, transport in space, and return from space, through the family of Launch Systems and Mission Extension Modules, based on common building blocks,
- up to the opportunity of human Space Transportation, through man-rating of the launch system and the crew transportation system fulfilling the needs for human space exploration.

With the objective to ensure the end-to-end implementation of the Vision, the proposed roadmap includes:

1. A core of **system-level studies,** updating the Vision including potential prospects of market evolution by 2030+, refining the whole European Space Transportation Infrastructure, with concepts and architectures for the future family of launch systems and mission extension modules:
   - building on common building blocks, allowing to maximise the synergies between systems, subsystems, and components;
   - encompassing man-rating aspects, enabling autonomous European Human Space Transportation and Exploration.
2. A set of representative **in-flight demonstrators**, whose objectives and specifications tackle the most critical technological challenges and are derived from the system-level studies to ensure the compliance with the common building blocks.
3. **Early maturation for long-lead key critical/enabling technologies**, identifying such low TRL technologies through gaps analysis and consolidated selection criteria (e.g. compliance with the vision, criticality, potential, lead time for maturation, market potential, etc.).

4.1. Designing the future Space Transportation Infrastructure Building Blocks

System studies would characterize the European Space Transportation Infrastructure based on the common building blocks approach, capitalizing on technologies, existing or in development, in line with the shared Vision for 2030+, potentially updating it, and including:

- A family of Launch Systems, including reusability of the stages as key-driver;
- A set of Mission Extension Modules, for maximum market capture;
- A Crew Transportation System, to enable human space transportation;
- A Ground Infrastructure.

These studies would consolidate the objectives and commonalities across the different elements of the European Space Transportation Infrastructure, extracting a set of main building blocks at stage level (launcher stages, extension modules, crew module), meant to be intimately interconnected with the In-Flight Demonstrations, to be feeding the definition of the demonstrators objectives and specifications, and to be benefiting from the In-Flight Demonstration results to improve the robustness of the design of the future European Space Transportation Infrastructure.

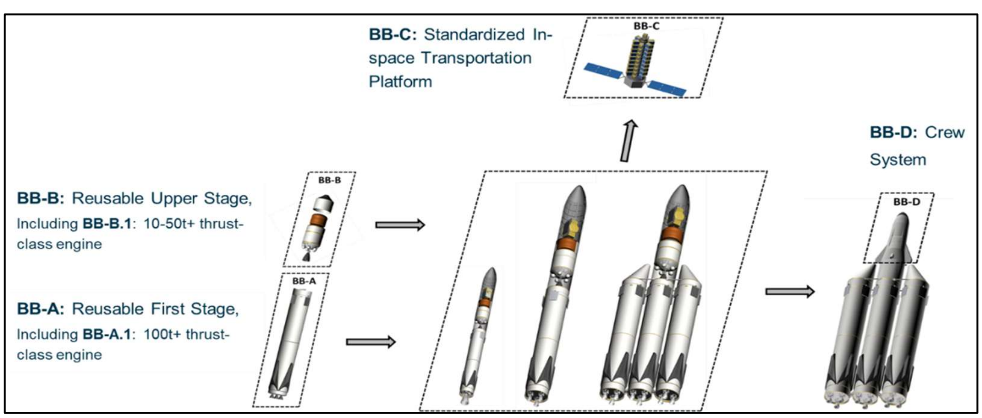

Figure 2: Possible Building Blocks of the European Space Transportation Infrastructure for 2030+

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Special attention will be given to the environmental sustainability of the future European Space Transportation Infrastructure, defining and taking into account eco-design rules based on full life cycle analysis (including manufacturing, propellant production, ground and flight operations, up to disposal of the elements) when performing trade-off or design choices.

4.2. In-Flight Demonstrations

A set of de-risking In-Flight Demonstrations (IFDs) activities is being identified, targeting the critical technological domains with the lowest maturity in Europe.

These IFDs are meant to be representative – both in terms of design and in-flight test specifications – of the building blocks end-applications, in order to:

- Accelerate the availability of the future Space Transportation Infrastructure,
- Lower the technological risks,
- Decrease the product/service development cost building on the results of the activities of the IFDs,

The IFDs activities would include the maturation of all enabling technologies required for the flight demonstration, including without being limited to, the significant efforts required for the completion of the building blocks at engine level (with maturation up to ground testing of Prometheus-derived engine, M10-derived engine, …).

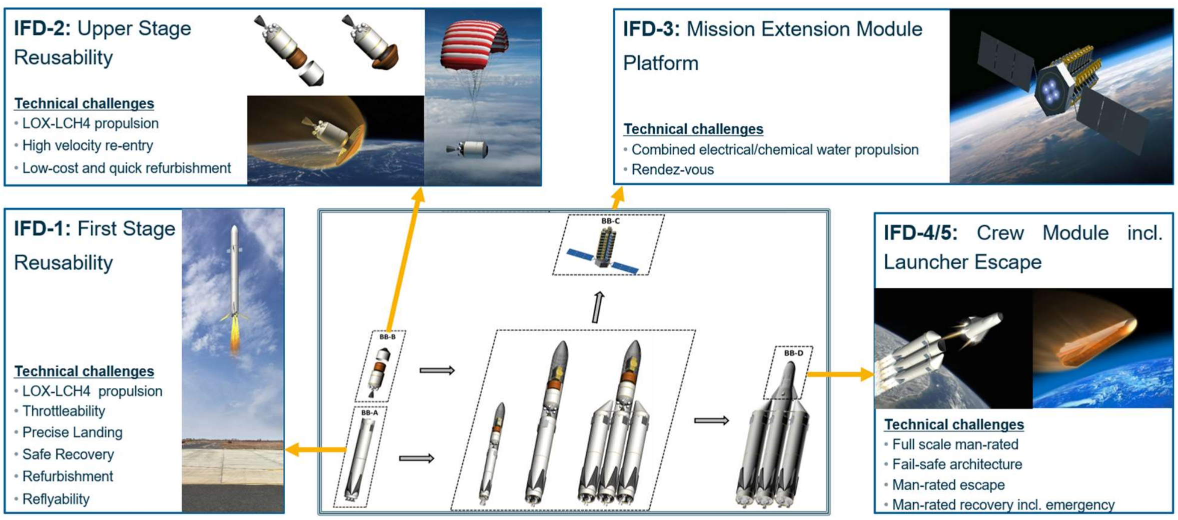

Figure 3: Building Blocks In-Flight Demonstrations

The IFDs activities are also meant to embrace New Space actors, therefore implementing privately funded approaches, in full or in part, while maintaining coherence with the Vision for 2030+. In this respect, the definition of a consistent and shared European Vision for 2030+, with a shared infrastructure and roadmap, would also provide a stimulus for private initiatives searching for elements representing future business.

Family of Launch Systems

For launch systems, reusability for lower and upper stages is identified as a rupture where Europe needs to de-risk new technological bricks to be ready to propose competitive launch services answering the demand for the growing diversification of the use of space, also contributing to improve environmental compatibility towards carbon neutrality.

Additionally, not presuming any definitive choice by industry of propellant for the future European operational launcher systems, as LOX-LH2 can rely on decades of extensive operational experience in Europe, LOX-LCH4 propulsion is prioritized for maturation on in-flight stages demonstrators. Indeed, this propellant combination also presents a high potential for cost reduction and as enabler for reusability, while still at low TRL in Europe.

Therefore, two (2) major functional and operational In-Flight Demonstrations (IFD-1, IFD-2) are considered:

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- Addressing the technological maturation of LOX-LCH4 propulsion, through both Prometheus-derived and M10-derived engines, up to in-flight verification (engine development and operation, ground and in-flight LCH4 propellant management…).
- Including the necessary technologies to fill the gaps and prepare the maturation of reusability for launchers on a representative flight domain (landing systems, engine throttling operation, maintenance, …).
- Building on previous achievements, implementing improvements on test articles and stage or engine configurations as necessary, with the overall goal to demonstrate in flight all critical technologies enabling the realisation at limited risks of a future European family of reusable TSTO launch systems for access to space, competitive in the worldwide market
- Bringing special attention to environmental sustainability, in line with the outcome of the System Studies, building from eco-design rules and considering the full life cycle assessment of environmental impacts (including manufacturing, propellant production, ground and flight operations, up to disposal of the elements) when performing trade-off or design choices.

The definition and objectives of the two IFDs is being supported by detailed launch systems family staging analysis and studies, ensuring the representativeness of the demonstration campaigns in terms of building blocks and test specifications, and maximizing the design commonalities with the targeted building blocks.

Building Blocks	De-risking IFD	Objectives	Mission Description	Technology / System Focus
BB-A Reusable 1st Stage **BB-A.1** Reusable class 100t+ LCH4 engine	IFD-1	1. First stage recovery 2. First stage reusability	First stage launch; first stage return and landing on a barge and/or back to launch site; altitude < 100km tbc	• First stage aerodynamic flight phase; • Landing phase, including throttling in multi-engine bay; • LCH4 propellant management; • In-flight propellant settling for lower stage • Deployable landing legs or gears; • Refurbishment, logistics, lifecycles management aspects.
BB-B Reusable 2nd Stage **BB-B.1** Reusable class 10t+ LCH4 engine	IFD-2	1. Upper stage re-entry, descent and landing from orbit 2. Upper stage reusability 3. Full launch system reusability	Upper stage into orbit and return	All the above, plus: • Upper stage aerodynamic flight phase; • In-flight / in-space propellant settling for upper stages; • Re-entry and landing system for upper stages • LCH4 propellant management; • Thermal conditioning; • Long orbital mission. • Fully reusable launch system integration and operations; • Refurbishment, logistics, lifecycles management aspects.

Table 2: In-Flight Demonstration Objectives for Lower and Upper Stage Reusability

These IFDs final design will result from an iterative/incremental process based on the system studies output. The table above highlights the end-results that should be delivered and not the way to achieve it. Harmonisation between IFD-1 and IFD-2 activities would also be ensured to maximize technological synergies and commonalities at the maximum extent possible.

Family of Mission Extension Modules

The European Space Transportation Infrastructure includes a set of Mission Extension Modules to enable transportation “in-orbit” and return “from orbit”, based on the same principle of common building blocks, ensuring interfaces standardization as a benefit of using a common upper stage across the whole family of future launch systems.

Although most technologies have high maturation, with privately funded solutions already addressing commercial applications in some cases, one In-Flight Demonstration (IFD-3) activity is identified as enabler, of which detailed objectives and specifications would be consolidated by the system studies, including standardised interfaces ensuring full compatibility across the complete family of Launch Systems.

A combined electrical/chemical propulsion using water as propellant is under discussion, as such a promising technology is in need for maturation at propulsion system level for Space Transportation applications. In-orbit rendezvous is also identified as an objective for an in-flight demonstration, as well as opportunities for enabling several in-space logistics applications (refuelling, robotic arms, Active Debris Removal, etc), in coordination with the actors from the in-orbit servicing market.

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Building Block	De-risking IFD	Objectives	Mission Description	Technology / System Focus
BB-C Standardised Transport Platform	IFD-3	Modularity and Commonality for Value chain extension Modules	Orbital transfer capability to support in-space logistics	• Motorised dispenser with combined electrical/chemical water propulsion • Raising orbit and/or multiple payload deployment • Rendezvous. • Autonomous power capability • Interfaces standardization. • Platform for IoS demo: o Robotic arms o Refuelling connectors o Active Debris Removal

Table 3: In-Flight Demonstration for Extension Modules

Crew Transportation System

With the objective to support the preparation of a potential European-made Human Space Transportation System, an IFD-4 has been identified, maximizing synergies with building blocks for launchers or transport platforms for common technologies.

There is indeed a clear need for a full-scale demonstration with the mission of a module representative of the crew transportation solution to be consolidated in the System Studies, encompassing all mission phases from orbit (e.g. rendezvous, docking, de-orbiting) to landing, including the re-entry and descent phases and the escape of the crew in case of emergency, with the specific technologies required to enable a safe recovery. Such a full-scale re-entry vehicle demonstration would address all technologies required to have it compatible with human operation (enabling off-nominal manual modes, habitat environment controlled in pressure and temperature, …) and man-rating safety (launch abort solution, reliability, …). The demonstrator would validate the most critical phases of the future mission, targeting representative environments during launch, in-space operation, re-entry and landing. The interfaces with the ground segment would also be validated with such a demonstration, especially for what concerns emergency escape and landing.

Building Block	De-risking IFD	Objectives	Mission Description	Technology / System Focus
BB-D Crew Transportatio n System	IFD-4	Man-rated re-entry and landing module for the crew including launch abort and emergency landing for the crew	Full scale and representative demonstration of crew module mission including feasibility at launch system level and launcher escape solutions	• Full scale pressurised module • Man-rated thermal control (thermal protections for re-entry…) • Man-rated fail-safe architecture, enabling off-nominal manual operations • Redundant communication systems • Crew module tracking, landing and recovery solutions including in emergency (parafoil, parachutes, landing systems…) • High thrust short-time reaction propulsion for escape • Crew emergency landing, tracking and recovery solutions • Ground interfaces for localisation and emergency landing.

Table 4: In-Flight Demonstration Objectives for Human Space Transportation

4.3. Early technology maturation

With the objective to pave the way for the future European Space Transportation Infrastructure by 2030+, five strategic domains are being currently identified, where early maturation should be conducted for critical enabling technologies, also including ground testing at component or subsystem level, either in preparation or complementary to In-Flight Demonstrations:

1. **Technologies for Reusability**, where dedicated and specific technologies are required;
2. **Technologies for Competitiveness**, where 4 axes are identified:
    - Low-cost innovative propulsion: acting on a significant part of the overall cost of the launcher;

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- Low-mass launch vehicle: with low structural index and yet high performance, key to achieve significant cost reduction at launch system level, with fewer components or even fewer stages (targeting two stages to orbit),
- Smart avionics: enabling lower launch costs and future reusable Space Transportation,
- Smart ground systems and spaceports: to reduce the cost associated to dedicated and expensive ground systems in spaceports, and to increase commonalities or building blocks (localisation, flight termination,…).

3. **Technologies for Environmental Compatibility**, engaging European Space Transportation systems towards future environmentally sustainable launch services.
4. **Technologies for enabling Value Chain Extension** beyond access to space:
    - Extending the range of launch services: to efficiently launch a wide range of spacecrafts (small to heavy, LEO and beyond, multiple payloads deployment, …),
    - Extending access to new markets in Space Transportation: to answer the growing diversification of the use of space, for in-orbit services or exploration needs.
5. **Technologies for preparing future Human Space Transportation** dedicated to man-rated Space Transportation systems.

5. Conclusion

In a context of aggressive worldwide competition to capture a booming market demand for a growing diversification of the use of space, Europe should stand for a coordinated approach when preparing the future of the Space Transportation sector.

A Vision of the future of Space Transportation in Europe for 2030+ is being proposed by ESA, and is currently under consolidation, identifying solutions to increase the competitiveness and resilience of European Space Transportation services on the worldwide market.

A reference Space Transportation Infrastructure answering the Vision is being elaborated, covering the Space Transportation services foreseeable in 2030+, including a man-rated Space Transportation capability, should this receive the necessary political consensus in the coming years. Such an architecture aims at maximising competitiveness through the implementation of extensive commonalities among elements, maximising the use of building blocks, avoiding unnecessary duplications and streamlining the production across European industrial capabilities.

An ambitious Technological Roadmap in support to the Infrastructure is also being elaborated, fostering rapid In-Flight Demonstrations, implementing leaner processes to accelerate the technology maturation and fill the main critical technological gaps, enabling faster developments for future European Space Transportation services, ensuring competitive and affordable solutions to maintain Europe’s autonomy in Space Transportation by 2030+.

The present paper provides an early view of the main technical elements currently under elaboration and consolidation by ESA with its stakeholders, including national institutions and industry, with the objective to ensure a coordinated preparation of the future in Europe, capitalising on the technological and financial potential of each single Member State, ensuring a strong role for Europe in the future at global scale.