DOI: 10.13009/EUCASS2025-571
11TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS)

Contributions Towards a Future European Reusable Launch Vehicle

Ellerbeck, Moritz†; Ruhhammer, Florian*; Steinacher, Armin*; Thies, Christoph**
** MT Aerospace AG*
Franz-Josef-Strauß-Str. 5, 86153 Augsburg, GERMANY
eucass@mt-aerospace.de
† Corresponding Author

Abstract
This work presents recent advancements toward a reusable launch vehicle (RLV), focusing on key technologies for sustainable and cost-effective space transportation. Presented developments include reusable landing legs with deployment testing, oxide ceramic-based thermal protection with rapid turnaround, and stainless-steel propellant tanks emphasizing low-cost manufacturing and environmental benefits. Additionally, next-generation ground facilities are being developed with standardized, multi-user systems to meet future infrastructure demands. These efforts, partially carried out within EU funded SALTO project and ESA programs, aim to enable a flexible, efficient, and sustainable European space transportation ecosystem.

1. Introduction

In recent years, the development of reusable launch vehicles (RLVs) has become a central focus of space transportation initiatives worldwide. The motivation behind this development is based on the potential to significantly reduce launch costs, increase flight cadence, and enhance the sustainability of access to space. In line with this global trend, Europe has intensified its efforts to develop independent RLV capability that can ensure competitiveness and autonomy in the evolving space sector.

This paper summarizes a series of developments conducted by MT Aerospace AG within the EU funded SALTO project (reuSable strAtegic space Launcher Technologies & Operations), ESA FIRST! programs and ESA HYGUANE of which are strategic European efforts aimed at maturing reusable launch technologies. Specific contributions include:

- The design, manufacturing, and testing of reusable landing legs, with deployment mechanisms validated through hardware demonstrations and load characterization in collaboration with institutional partners;
- The development of a low-cost, oxide ceramic-based thermal protection system designed for reusability, fast attachment and rapid refurbishment cycles;
- A hardware-rich pathfinder approach to optimizing stainless-steel propellant tanks for RLV, focusing on robustness, manufacturability, and environmental impact mitigation;
- The conceptualization of next-generation ground facilities tailored to the needs of reusable systems, emphasizing standardization, multi-user support, and sustainable infrastructure.

Together, these efforts represent a significant step toward competitive and operationally flexible European reusable launch architecture.

2. Landing Legs

The reuSable strAtegic space Launcher Technologies & Operations (SALTO) European Union (EU) project aims at investigating launch system reusability technologies for a Vertical Take-off Vertical Landing (VTVL) launcher configuration. Within this context, MT Aerospace (MTA) develops a landing leg system for the T(HEMIS)3 launcher.

Copyright © 2025 by Moritz Ellerbeck. Posted online by the EUCASS association with permission.

DOI: 10.13009/EUCASS2025-571

Themis is an ongoing development technology demonstrator to maturate European RLV capabilities. Previous gained knowledge from the project RETALT (Retro Propulsion Assisted Landing) is transferred to a full-scale demonstrator, which is manufactured and finally tested.

2.1 Development Logic and Design

The development logic considers the following topics:

- Requirement screening and definition including functionality, interfaces, environment and loading
- Assessment of landing leg concepts (Figure 1) considering performance, kinematics, development risks.
- Costs. Integration aspects, reliability and manufacturing
- Design and analysis of the landing leg
- Manufacturing of the landing leg
- Deployment testing of the landing leg

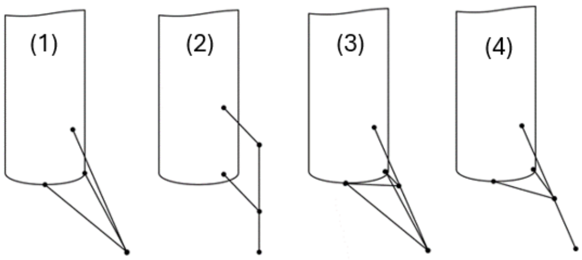


Figure 1: Kinematic Concepts for Landing Legs

The landing Leg (LL) consists of the Shock Absorber AssemblY (SAAY) with the locking mechanism, the damper system and the Land Leg AssemblY (LLAY) including load carrying structure with integrated aerodynamic cover (s. Figure 2). The key measurements of T(HEMIS)3 landing legs are:

- Height LLAY from ground [m] h2
- Height SAAY from ground [m] h1
- Diameter of launcher [m]
- LLAY length [m] [PB]
- SAAY length [m] [PT]
- LLAY width (fitting to fitting) [m]

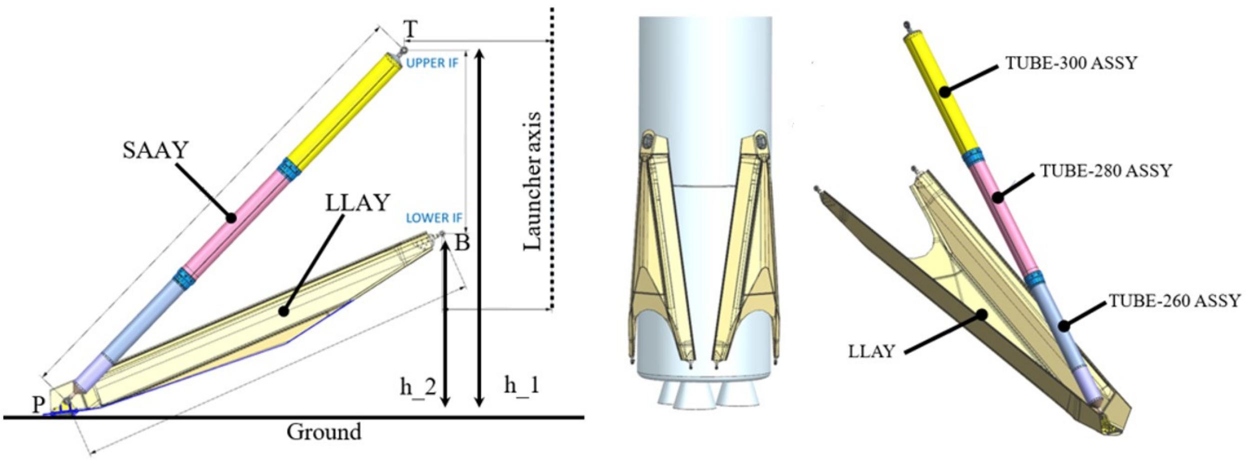


Figure 2: Sketch of Landing Leg

The analysis loop is represented by:

- QSL FEM analysis

DOI: 10.13009/EUCASS2025-571

- Stability investigations
- Dynamic (kinematic analysis) using Multi Body Dynamics (MBD)

The goal of the elasto-kinematic analysis is to determine the reaction forces during the deployment. The mathematical model includes:

- Rigid components: Application on complex components e.g. contact formulation
- Flexible bodies: Stiffness representation of SAAY and LLAY by Super Element Technique (SET) technique
- Structural mass points: To represent mass of inertia of components not represented in geometrical detail
- Spring elements: Representation of interface stiffness of the test rig

The deployment simulation is done under gravity loading without friction (minor effect on reaction forces). It represents the complete kinematic of unfolding from vertical position until the latching of the locking mechanism at deployed position. This resultant of the reaction forces at the interface B and T (s. Figure 2) is shown in Figure 3.

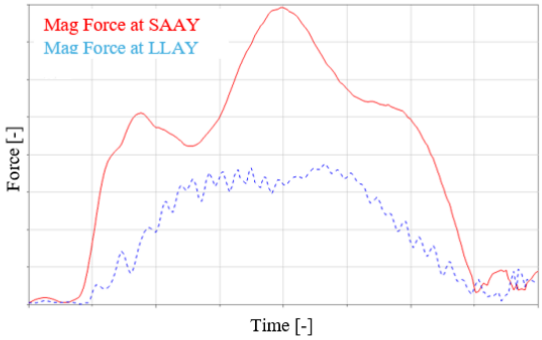


Figure 3: Result of MBD analysis representing reaction forces at the interfaces B and T

2.2 Manufacturing

The manufacturing of the landing leg is divided into:

- Integral LLAY and CFRP tube for the telescope SAAY by 8 x ¼”-tow Coriolis C1 Automated Fiber Placement (AFP), tooling made by CFRP additive manufacturing (AM) and curing in autoclave
- Ti-6-4 metallic components by 3D printing e.g. for the locking mechanism
- Integration and functional verification, e.g. sliding, locking

Figure 4: AFP layup of LLAY on AM tooling

DOI: 10.13009/EUCASS2025-571

The CFRP tubes of the telescope system (SAAY) were also produced by AFP. The advantages are the possibility to produce 0° dominated laminates with an extremely high outer surface quality within tight geometry tolerances, which is mandatory to meet the requirements of the telescope mechanism.

Furthermore, a test campaign under ambient conditions is performed to validate the kinematics and the locking mechanism as well as to demonstrate and assess the quality of the manufactured structures. Additionally, during post-test activities, the test results serve to verify the numerical analysis e.g. MBD- and FEM.

2.3 Testing

The main objectives for the test campaign were defined as follows:

- Applying the total kinetic energy
- Execution of the test matrix
- Measurement of strains and the kinematics of the LL
- Evaluation of test results corresponding to test prediction

Figure 5: Complete Landing Leg with optical measurement points

The instrumentation was realized by unidirectional strain gauges, optical instrumentation via ARAMIS, accelerometers (x-, y-, z-direction) and transducers (x-, y-direction). The strain gauges are applied in the highest loaded regions and in regions with low stress gradients. The optical measurement system consists of high-speed cameras and software, which visualizes the observed displacements over time. To track the structure, the components were marked with numbered reference points, realized by small patches (s. Figure 5).
The measured reaction force of the test is lower than predicted due to a lower stiffness of the test rig than assumed and uncertainties in the early stage of the FEM and MBD mathematical models. The analysis approaches delivered the input for the test campaign sufficiently and the deployment test could be conducted. Nevertheless, a detailed FEM test correlation must be done especially for stiffness. For the final test, it can be stated that the key characteristics such as latching, and the complete kinematics are tested successfully. [1]

3. Thermal Protection

Within ESA's FIRST, a novel thermal protection system (TPS) was successfully developed up to TRL 4/5 for re-usable future launcher by MT with contribution by DLR/Stuttgart.
Besides the design definition, its verification by manufacture (of flight-representative test hardware), analysis and breadboard tests, the effectiveness of this re-usable TPS was assessed by comparison with conventional non-re-usable, i.e. ablator-based TPS.

DOI: 10.13009/EUCASS2025-571

3.1 Requirements

The external surface of the launcher first stage's rear bay was selected as typical use-case because this component in general is a primary candidate for re-use, with its large surface area requiring thermal protection due to the expected environments, e.g. aerodynamic flow and engine plume.
For design definition and verification, technical requirements were specified based on available data for common expandable launcher and results regarding expected loadings of re-usable launcher during descent and landing. Emphasize was put on realistic but conservative load environments including vibration and thermal loadings secondly, on the most essential aspects of re-usability, e.g. number of re-uses, on-ground recovery, and thirdly criteria describing the competitiveness with ablative TPS (e.g. cost, mass, refurbishment).

3.2 Design Definition

The finally selected design concept is sketched in Figure 6. It is characterized by a rigid shell made of oxide ceramic material that provides thermal and mechanical stability to the external environments. For quick dis- and re-assembly, the TPS shell is connected to the cold structure via snap-fit connections to flexible stand-offs made of thermal-resistant alloy. Temperature increase of the cold structure by heat conduction and convection is limited by internal insulation made of pressed oxide ceramic wool and rigid seals mounted as barriers between adjacent TPS elements.

For cost efficiency, the design involves commercial off the shelf materials and parts, i.e. DLR's WHIPOX and OXIPOL aluminum-oxide based ceramic matrix composite (CMC) for the hot structure and rigid seals, trade-marked insulation mats as used in ground-based furnace and Inconel sheets for the manufacture of the flexible stand-offs.
Manufacture costs are furthermore decreased due to simple shaping of the individual components. The design of the TPS element is generic with several parameters that can be adapted to the needs of the specific application (launcher, mission). This design flexibility is achieved by different grades of WHIPOX/OXIPOL and insulation material, the size of the individual TPS elements that can be varied up to 300 x 300mm, its height that can be adjusted to the value required not exceeding the allowable temperature of the cold structure.

By accompanying thermal and structural analyses, the applicability of the re-usable TPS design was demonstrated. From comparative assessment with an ablative TPS with similar performance, it is preliminarily concluded that the re-usable design becomes competitive for at least a number of ten re-uses.

3.3 Manufacturing and Testing

Design verification by test aimed to demonstrate the design robustness with respect to the harmonic and random vibration loads that become maximum at lift-off. These loads are considered most critical regarding potential failure of the novel snap-fit connections as it is also justified due to published failure events of comparable TPS elements in current launcher.

The test program comprised pre-tests on technological sample demonstrating the expected mechanical performance of the snap-fit connection followed by a series of shaker tests on two breadboards.
Each breadboard was built-up by an assembly of two adjacent TPS elements and thus is a flight representative cut-out of a typical TPS array integrated on the aft bay. The two breadboards only differed in terms of the tile material, i.e. OXIPOL and WHIPOX (s. Figure 7).

In general, both breadboards performed in similar way, the achievable load levels were not determined by the tile material but by the snap-connection. They proofed to be fully compliant with the specified out-of-plane excitations but showed deficiency at certain level of in-plane vibration loads that caused the spring elements gliding out of the eyelet in the TPS tile. This failure mode is attributed to in-sufficient manufacture tolerances and thus can be easily avoided by correspondingly adapted process parameters. In general, the TPS elements showed damage tolerant behavior, i.e. revealing not essential damage of ceramic components even in case of lost connections to the stand-offs. Additional, in course of sample integration, the practicability of the design concerning its easy dis-/re-assembly could be demonstrated, however, showing some potential for further improvements that can be achieved by minor design changes of the spring elements.

DOI: 10.13009/EUCASS2025-571

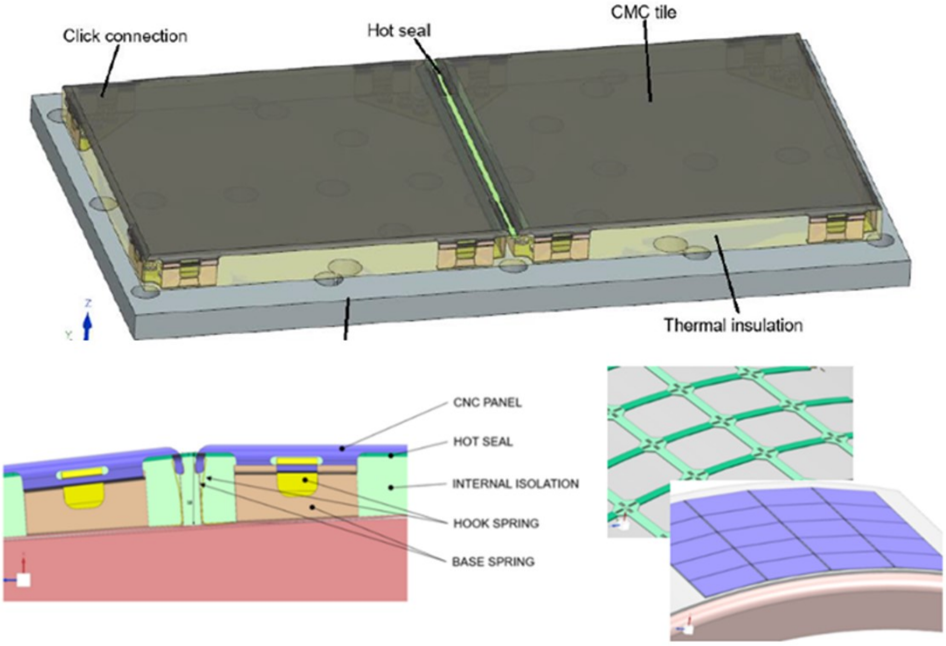


Figure 6: Design Concept of TPS Element

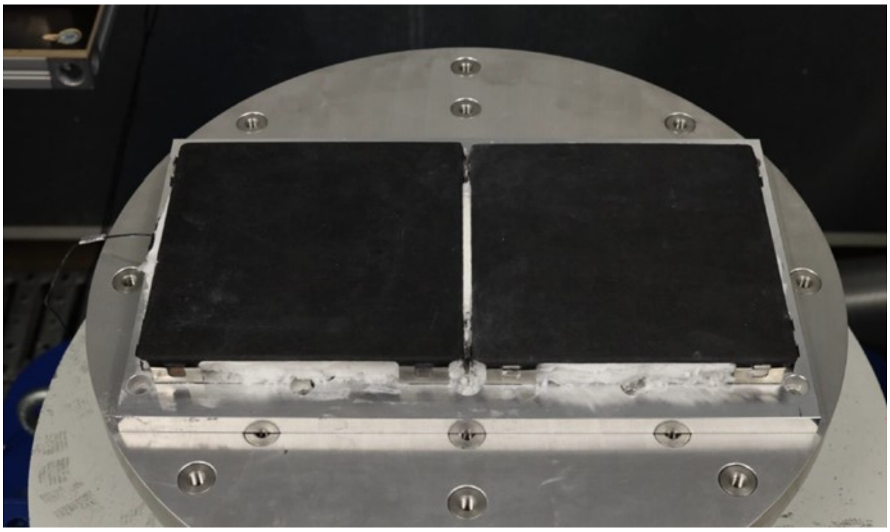


Figure 7: Breadboard-Test on Shaker

4. Stainless Steel Tank

Contributing to the above-mentioned SALTO program furthermore, a robust and cost efficient lightweight stainless-steel booster tank is developed and built to support future European RLV technologies.

4.1 Scope and Objectives

The major scope of this activity is to investigate design and manufacturing approaches for future reusable launch vehicle cryogenic propellant tanks and to provide optimized hardware for flight tests to raise the maturity level of a European reusable system. Furthermore, the following objectives are included:

- Demonstrating the viability of stainless steel as a cost-effective and robust solution for reusable launch vehicle propellant tanks.

DOI: 10.13009/EUCASS2025-571

- Reducing environmental impact by promoting sustainable material use and manufacturing techniques.
- Establishing hardware-driven insights to guide the next iterations of tank design for reusable launch systems.

4.2 Development Approach

One of the major aspects of achieving the above-mentioned objectives is to combine conventional industrial approaches with its established supply chains and manufacturing means together with aerospace needs and regulations. This refers to industrial available raw materials, semi-finished products, manufacturing capabilities as well as welding and NDI methods. Different regulations and approaches are compared and commonalities as well as extensions are elaborated to cover specific aerospace requirements.

In a hardware rich development approach, sub-scale as well as full-scale sample parts for selected design characteristics are manufactured, investigated and tested. As an example of this approach a selection of those samples are shown in Figure 8 and described below.

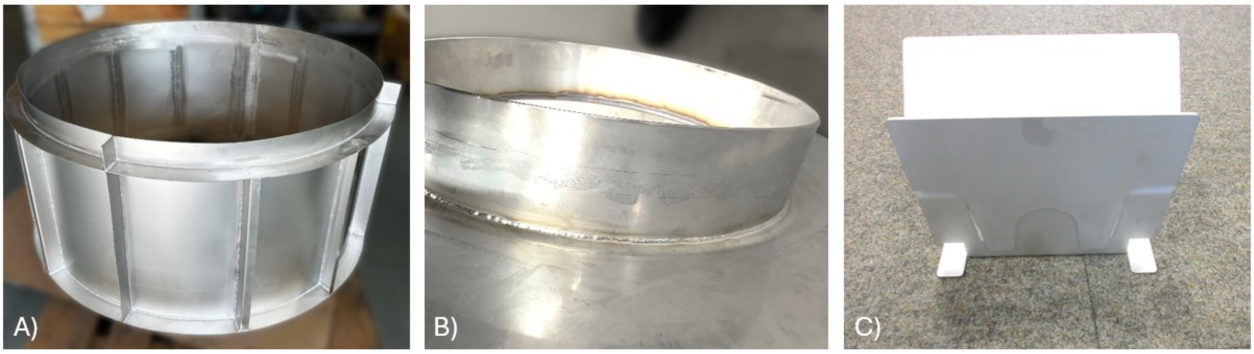


Figure 8: Hardware Samples for Hardware-Richt-Development Approach

Example A) To investigate the manufacturing approach of a stiffened cylinder segment, a cylinder section was manufactured and non-destructive tested. The gathered knowledge was directly applied improve analysis models, welding procedures and NDI methods. In B) industrial approaches to establish flange connections were investigated on full-scale parts. This test was established to identify manufacturing limitations and material characteristics. For C) full-scale samples of welded connections are manufactured and tested.

For the dome manufacturing various dome shapes were compared and ranked regarding stress, mass and geometrical complexity with a classical spherical head (s. Figure 9). The focus was on the potential performances of industrial available standard tank heads and custom designed torispherical dome with multiple radii.

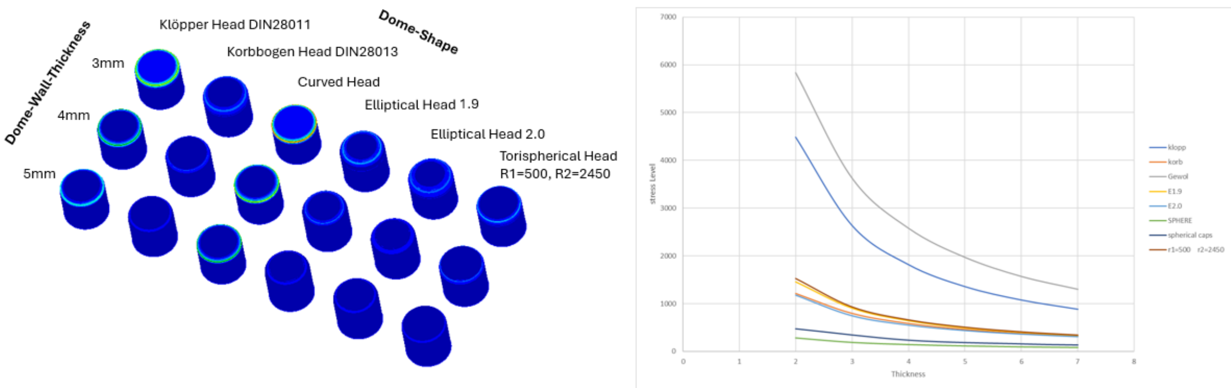


Figure 9: Dome Shape Comparison

DOI: 10.13009/EUCASS2025-571

4.3 Current Status

Various trade-offs and assessments have been accomplished to merge industrial standard approaches and aerospace needs as well as to comply to system prime requirements, interfaces and loads.

A requirements full-filling tank concept was elaborated and justified according to provide input and harmonized manufacturing methods. The stainless-steel tank separates the LCH4 and LOX tank-compartments with a common bulkhead in-between. The cylinder section of the tank is reinforced with a set of welded stringers and houses a several predefined interfaces for internal and external fluid-lines, electrical harness and further equipment. A central feed crossing-line though the lower tank-compartment is used to provide upper tank-compartment fluid toward the multi-engine bay. A sketch of the tank concept is shown in Figure 10 below.

Several stainless-steel alloys were subjected to trade-offs with a focus on performance and availability. As baseline material a 300 series stainless-steel alloy was selected. Stainless-steel has a large potential to reduce the environmental impact of launch vehicle manufacturing in comparison to e.g. aluminum alloys or composites. [2]

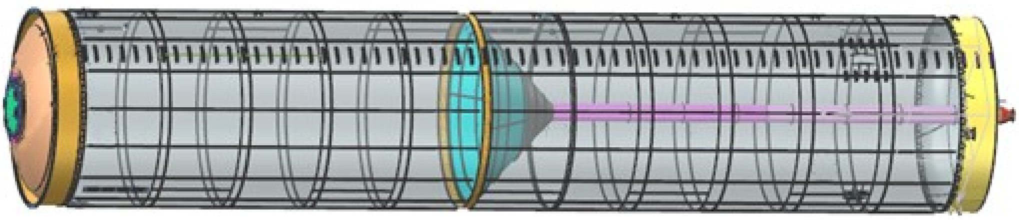


Figure 10: Draft Sketch of the Stainless-Steel Double Tank

The critical design review has been passed and manufacturing of flight hardware has been started.

5. Ground Facilities

5.1 Harmonization and Standardization

Today’s globalization would not be possible without the accessibility and availability of the diver’s airliners. This success would not be possible without the standardization between aircrafts and airports, enabling low-cost and fast turnaround services while still ensuring high quality.

Our vision is to push harmonization and standardization of launch systems to enable a similar success of airliners for future Ariane and commercial launchers. The state-of-the-art of the European launch system’s ground segment are unique and expendable solutions.

They are tailored for the specific need of each individual launcher leading to important RC and NRC needs to ensure its operational availability. Furthermore, those solutions, are not tailored to be used for any reusable launch system. Particularly no ground segment supporting the launcher last mile delivery (from landing, through inspection back to the launch pad) is yet existing.

In contradiction to the increase of total launcher developments, the needed ground segment interface has not yet evolved in the same way to answer the fast-growing demand on launch capacity. It is aimed to achieve standardization between launcher and ground segment, to strive for operational excellence, and to take advantage of economies of scale. [3]

Identified key drivers for the realization of multi-user launch complex are:

- Expansion of the commercial space industry across boarders
- Increase of launch frequencies per launch site
- Efficient, reusable and reliable standardized launch infrastructure

DOI: 10.13009/EUCASS2025-571

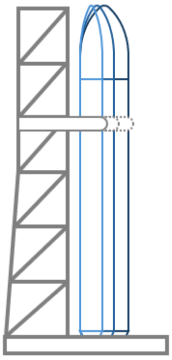
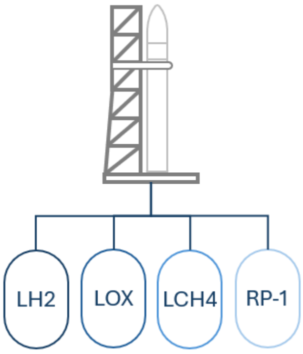
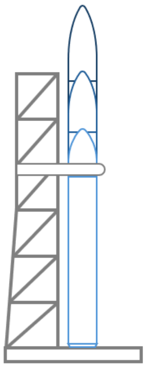
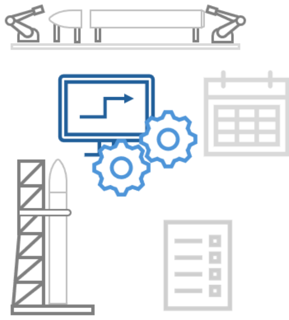
- Interoperability for various launch service providers

The main benefits resulting from a multi-user complex are:

- Reduction of important infrastructure investments traditionally required for single-user launch complexes
- Enabling LSPs to focus their resources on vehicle development rather than site construction.

The main enablers are presented in the table below.

Table 1: Main enablers

			
Modular Launch Pads, being capable of welcoming different launcher main stages diameters	Flexible Fueling Systems, being capable of providing different propellants and feedline pressure envelopes.	Multi-vehicle support, being capable of welcoming different launcher heights	Automation (operations & scheduling), being capable of managing effectively delays and priorities.

5.2 Sustainability for Ground Facilities and Services

The ESA HYGUANE project is an industrial pilot under development that stands for the production and usage of renewable hydrogen in the CSG and the French Guiana territory. Firstly, HYGUANE aims to decarbonize the hydrogen used for Ariane launchers (resilience and independence), secondly, it will develop a ground-breaking H2 ecosystem on the French Guiana territory with the introduction of H2 heavy road transport (truck, coach, and bus) for CSG & French Guiana citizens (mobility usage), the implementation of H2 fuel cells (stationary usage) replacement of diesel generators and the ultimate electrical back-up at the CSG (s. Figure 11).

Interest was shown and proposed to contribute competences for the development of a Hydrogen Competences Centre (HCC) which will host maintenance and training activities for H2 stationary & mobility usages. As a project partner different types of fuel cell electric vehicles, so-called H2 rolling stock heavy mobility, will be provided.

The ESA HYGUANE project thus will be a key element for the decarbonization of the overall launch system and ensuring its sustainability in the future.

DOI: 10.13009/EUCASS2025-571

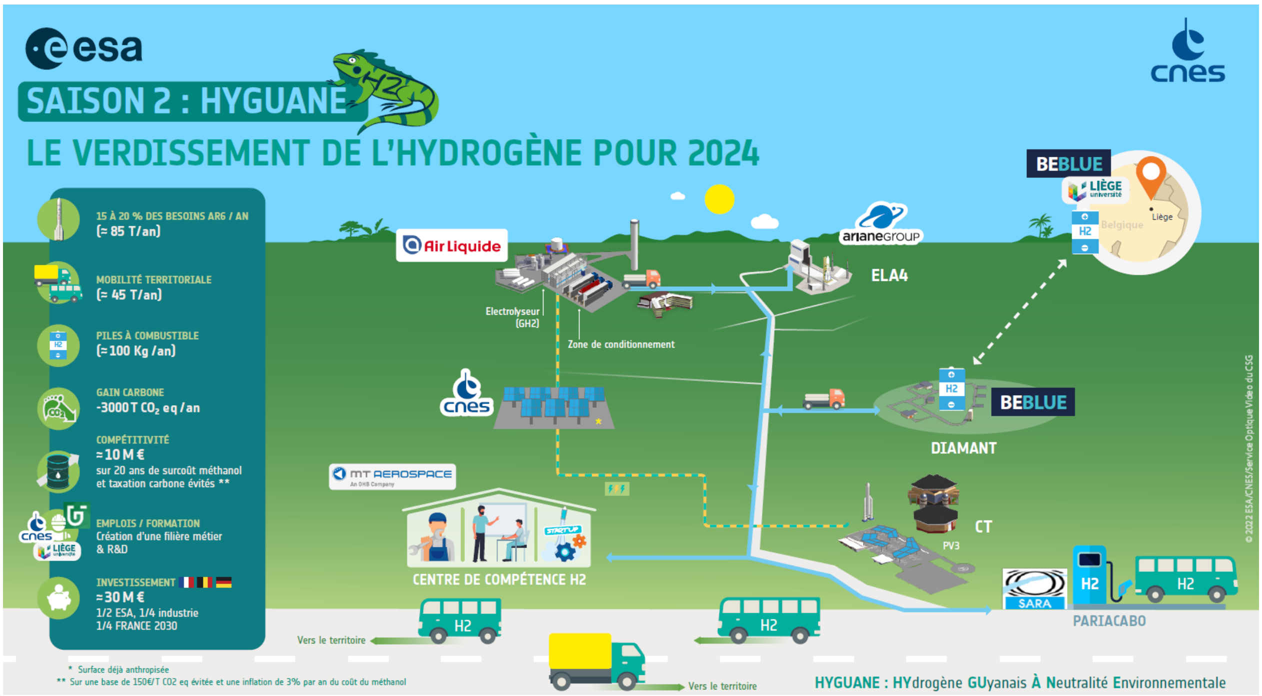


Figure 11: HYGUANE Saison 2 overview poster (© ESA/CNES/Service Optique Video du CSG 2022)

References

[1] Thies, Ch., P. Ortmann, C. Modén, T. Zenker. 2024. Development and Manufacturing of a Landing Leg System for Reusable Launchers T(HMIS)3 in the SALTO Project. In: *ECSSMAT2024* - European Conference on Spacecraft Structures, Materials and Environmental Testing.

[2] Ellerbeck, M., K.-N. Jurke, J. Petzold, F. Rossberg, Ch. Thies. 2023. A liquid reusable strap-on booster system discussion for future European launch vehicles. In: *Aerospace Europe Conference 2023 – 10TH EUCASS,* DOI: 10.13009/EUCASS2023-746

[3] Ruhhammer, F. 2024. Ground Facilities and Services - The past and the future of MT Aerospace AG at the spaceport. In: *75th International Astronautical Congress*, IAC-24-D2.2.7.82716