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Preparing the Future of European Space Transportation: Reusable Technologies and Demonstrators

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Abstract

The Future Launchers Preparatory Programme (FLPP) of ESA Space Transportation Directorate delivers new technologies providing lower cost, higher performance, larger mission versatility and reduced time to market to the evolutions of operational launchers, based on the investigation of future services and advanced concepts in space transportation. FLPP is structured around the permanent interaction of three disciplines: advanced technologies are matured up to their integration into flagship demonstrators, in coherence with services/system studies identifying and assessing their interest for future applications, including commercially driven space transportation services. FLPP investigates in particular reusability through flagship demonstrators and advanced technologies applicable across multiple domains related to reusable launchers. This paper positions the programme and details a selection of current demonstrators and advanced technology activities, pushing the limits of European industry in space transportation research and technology to deliver innovative and attractive solutions for more competitive services in European space transportation.

1. Introduction

At the Ministerial Conference of ESA in 2016, Member States subscribed extensively to the FLPP "New Economic Opportunities" (NEO) period, with the goal of framing and developing a portfolio of flagship demonstrators and associated technologies to ensure a short time to market of price-competitive innovations for possible evolutions of European launchers. This investment in the preparation of future European launchers puts the focus on the following main objectives :

- Significantly reduce the recurrent cost of European launch solutions.
- Increase the flexibility and versatility of missions provided by European launch solutions to provide services for all existing and emerging markets.
- Enable high reactivity to opportunities and threats by shortening the development cycles and reducing the time to market for new launch capabilities.
- Prepare further evolutions and ruptures towards a more service-centric approach.
- Open the way for spin-ins and COTS applications.
- Secure unrestricted access to new and critical technologies, safeguarding innovation and engineering competences in Europe.
- Reinforce competitiveness of industrial partners.
- Propose business opportunities for newcomers.

In front of the increasing competition pressure, the system, advanced technologies and demonstrators 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

Such demonstration of reusability for access to space may also extend later on to other components of the launcher (e.g. upper stage or fairing) or to other types of launchers (e.g. microlaunchers).

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The European reusability roadmap for Ariane is illustrated as below:

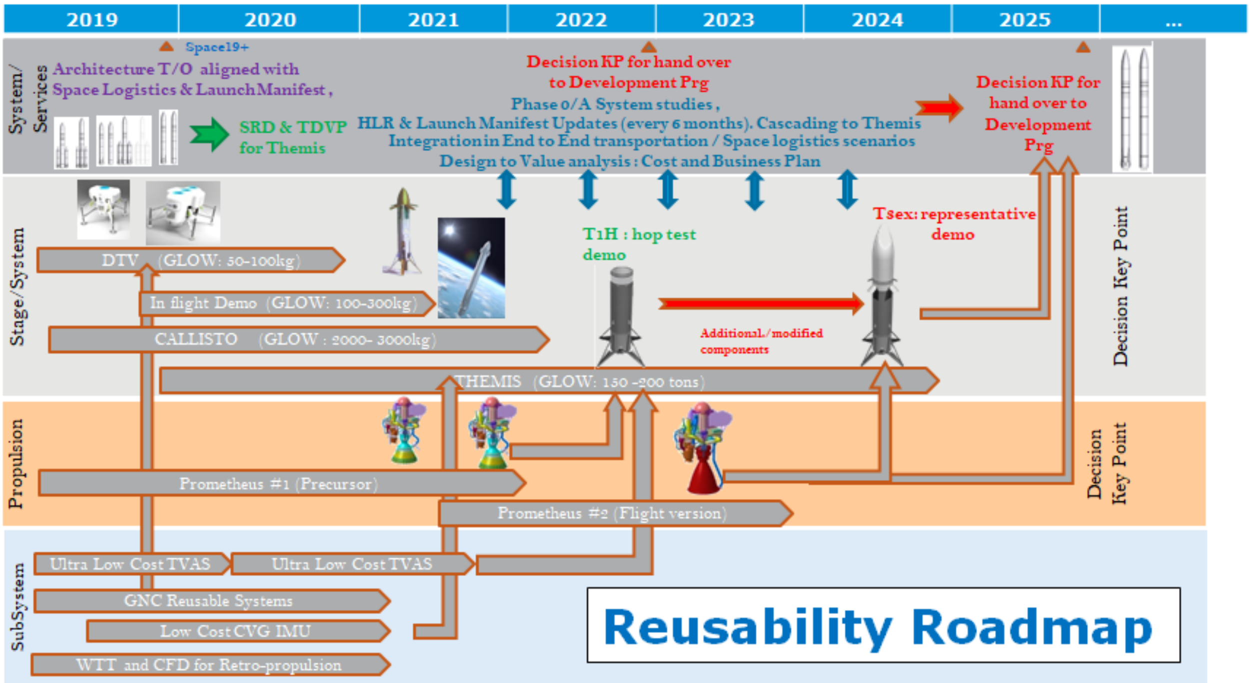

Figure 1 : Reusability Roadmap

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 [2]). Early demonstrators will de-risk overall design, lift-off and landing phases, then toss-back manoeuvers as well as ground operations.

The FLPP **System activities** related to reusability are specifically addressed in [1].

As detailed in the following sections of this paper, FLPP is investigating reusability through **flagship demonstrators** (Chapter 2). These demonstrator projects are underpinned by the identification and maturation of **advanced technologies** applicable across multiple domains, such as : Avionics, GNC and Flight SW (Chapter 3), Propulsion (Chapter 4), Mechanisms (Chapter 5), WTT and CFD techniques for retro-propulsion (Chapter 6), or Recovery concepts for reusable launcher components (e.g. payload fairing, Chapter 7).

In addition to these domains, the **Prometheus engine** project, originally started by the French Space Agency CNES, has been successfully transferred to ESA and is now managed by FLPP . This project is specifically addressed in [2].

Mid- and long-term objectives that could frame future FLPP activity in the field of reusability (e.g. reusability for transport in space and returning from space, reusability in terms of in-orbit infrastructures …) are briefly addressed at the end of this paper.

2. Flagship demonstrators

Reusable launch systems are inherently more complex than expendable launchers, from both technical and operational perspectives. This increased complexity adds risks on reliability and on safety. It is therefore crucial to address reusability demonstration with an incremental test approach, in order to tackle the technical challenges step by step.

The first step of the ESA demonstrator program towards the reusability of launcher first stages is the **Demonstrator for Technology Validation**, with INCAS (Romania). The project consists in designing, building and flying in the atmosphere a fully re-usable vertical take-off and vertical landing (VTVL) vehicle, in order to test and mature guidance, navigation & control (GNC) technologies, related avionics (hardware and software) and fault detection, isolation & recovery (FDIR). The DTV is propelled by a turbojet engine (0.9 kN class) in two configurations: the one-engine version, and an upgraded version propelled by three turbojet engines. It will offer up to 30 minutes endurance flight at 3 km altitude for up to 75 kg of payload.

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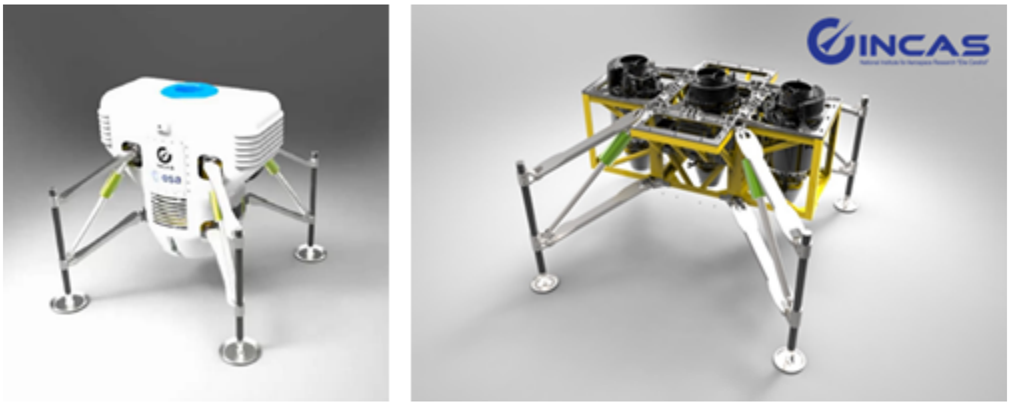

Figure 2 : DTV in one-engine and three-engine configurations (Credits: INCAS)

The next step will be to develop **DTV+**, a subscale reusable vehicle with throttleable green rocket engine. The goal is to demonstrate the functions of a liquid propulsion vehicle capable of vertical take-off, exo-atmospheric flight, high-Mach deceleration manoeuvers and vertical landing. The main challenges assigned to the DTV+ flying platform are:

- To mature and validate, in representative flight conditions, the enabling technologies that will serve as building bricks for the subsequent steps of the launcher reusability demonstration roadmap (including GNC).
- To test, in representative flight conditions, rocket engines (in the 6-10kN class) under development.
- To master rocket engine-based descent and safe precision landing capability.
- To develop all ground infrastructures and procedures, that will serve as technology bricks for large-scale reusability demonstrators.

Another project towards reusability is the **Liquid Propellant Stage Recovery** (LPSR) demonstration, with PLD Space (Spain), consisting in a field demonstration of the recovery at sea of a hardware representative of the liquid propellant stage of a microlauncher.

Figure 3 : Demonstrator carried by Chinook (Credits: PLD Space)

On 11th April 2019, the drop test campaign of the first stage of the MIURA-5 rocket was successfully completed from El Arenosillo Experimentation Center (CEDEA) of INTA (Instituto Nacional de Técnica Aeroespacial). The demonstrator (15m long and 1.4m in diameter, representative of the MIURA-5 liquid propellant stage) was dropped by a Chinook CH-47 helicopter from an altitude of 5 km, decelerated by a series of three parachutes triggered by the on-board avionics system, and recovered after splashdown in a controlled area of the Atlantic Ocean.

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Figure 4 : Demonstrator under main parachute (Credits: PLD Space)

The objective of the LPSR activity is threefold:

- Qualify the sequence of parachute triggering and characterize the descent phase of the microlauncher first stage under parachute.
- Demonstrate the recovery operations of the stage after splashdown.
- After initial cleaning (removal of salt water), assess the effort and actions necessary to refurbish the stage for a re-launch.

3. Avionics, GNC and Flight Software

To increase the level of autonomy and responsiveness of future missions of reusable launchers, especially for the recovery flight phases, mission scenarios may rely in part on the use of On-Board Real-Time Trajectory Guidance Optimization [3]. The objective is to increase the mission performance robustness against uncertainties or re-planning, by using the on-board computational capability to resolve a complex optimization problem in real-time, as opposed to traditional design techniques using off-line design and tuning of the trajectory and of the Guidance laws. FLPP is developing such optimization techniques through a contract with Embotech (Switzerland). Based on a vertical take-off / vertical landing concept of demonstrator of reusable launcher, the on-going study puts the focus on the detailed design and the functional verification of the Guidance laws and on the coding and validation of the Guidance software. Next phases are in preparation with the goal to test the On-Board Real-Time Trajectory Guidance Optimization on flying test beds or demonstrators.

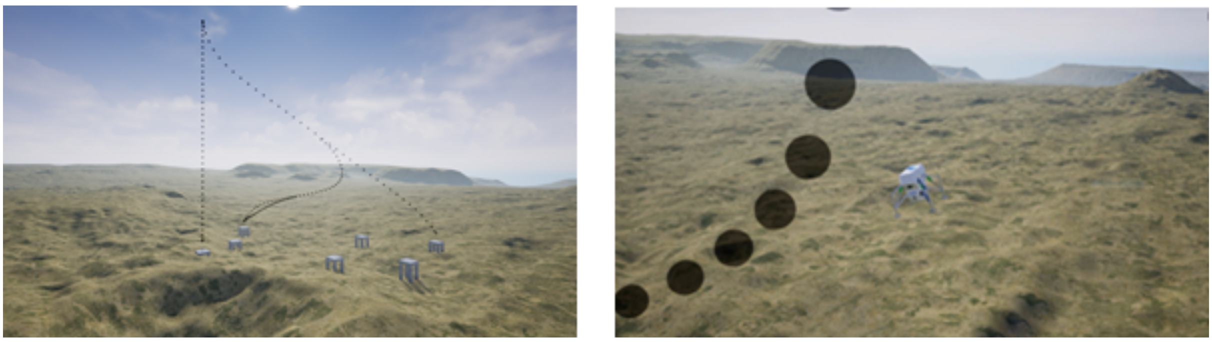

Figure 5 : Trajectory simulations with OBRTTG (Credits: Embotech)

As part of the cost reduction expected from the reuse of launch vehicles, it is also necessary to investigate the **reusability of COTS and low-cost avionics**. For this purpose, FLPP is taking the opportunity of its contribution to on-going projects of micro-launchers involving both low-cost avionics and reusability. For instance, in the frame of the **AVIOAR** project and together with GMV (Spain) [4], FLPP is co-funding the development and flight tests of the avionics system of a sounding rocket, which is designed for scale-up and re-use as avionics technology for other launchers, including small and micro-launchers. The goal is to reduce considerably the development and exploitation

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costs for the avionics system, which constitutes a significant part of the overall launcher system costs. Based primarily on the adaptation of technologies already consolidated in other domains and COTS available in the market, the activity targets the flight test of the sounding rocket MIURA-1 late 2019 / early 2020, including the recovery of the rocket to assess the post-flight status of the Avionics and its reusability.

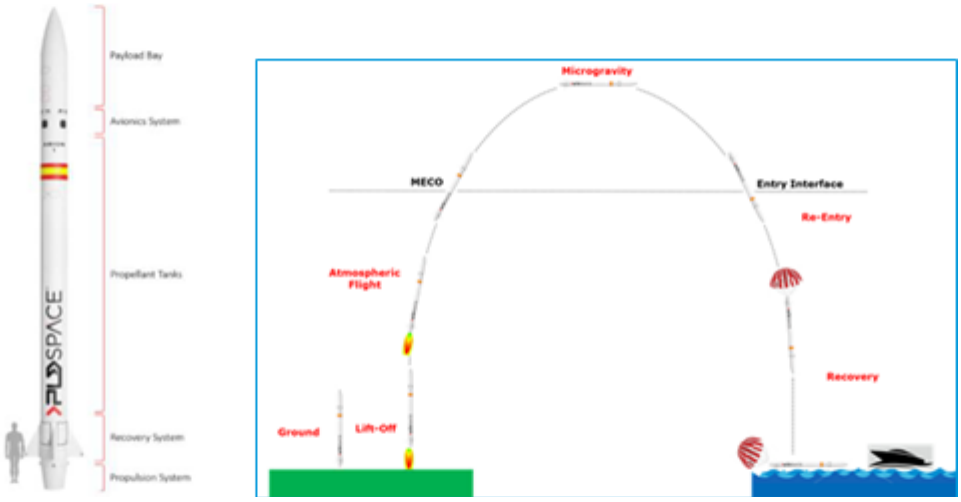

Figure 6 : MIURA1 configuration & mission profile (Credits: GMV)

A reusable launcher requires thinking **new ground operations** in all aspects. It is necessary to envisage new equipment qualification philosophies in order to take into account multiple use cycles seen by the equipment from a thermal and mechanical point of view (including re-pressurization during descent). Additionally, at vehicle level, new mission phases are to be defined (e.g. the on-board avionics has to manage the landing and to put the vehicle in safe state in order to allow it to be recovered).

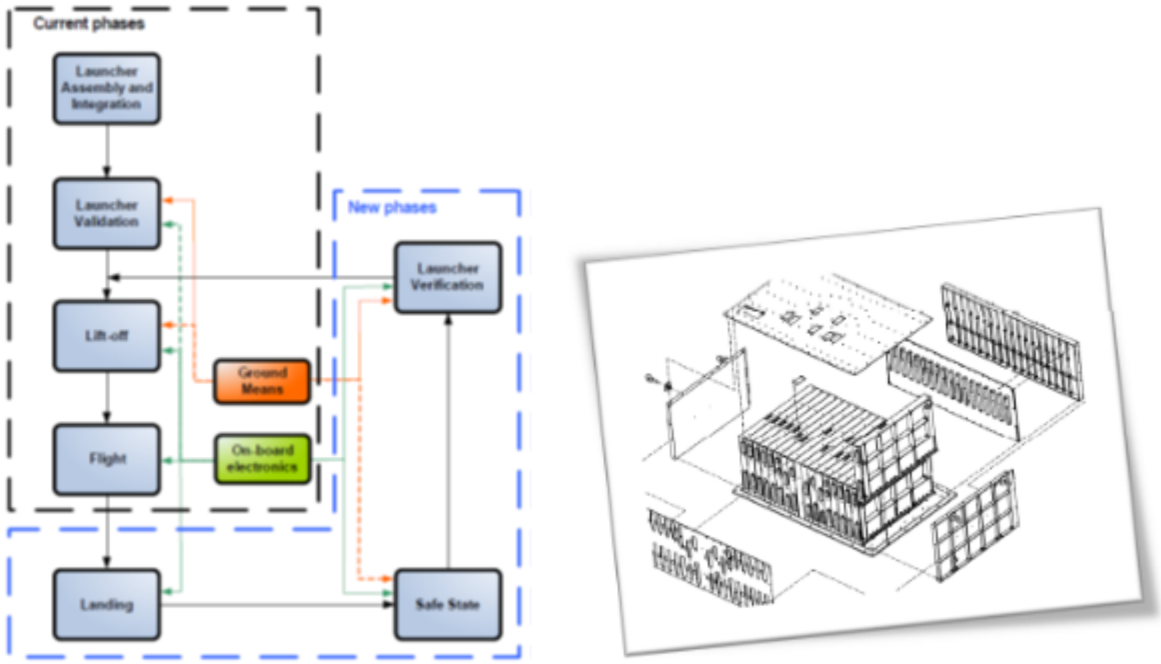

Figure 7 : Avionics reuse : multiple cycles & new flight phases wrt expendable launchers (Credits: Thales)

An ongoing study with Thales (Belgium) investigates the **impact of reusability on avionics**, with the aim to analyze the optimal refurbishment of a re-usable launcher avionics and how to demonstrate the flightworthiness of avionics equipment in case of re-use, while limiting operations cost. The analysis focus on following avionics aspects;

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- Packaging and access: in order to limit impact on electrical system (loss of qualification status) as well as on the amount of ground operations, the packaging has to allow easy replacement of avionic equipment (in case of failure for example).
- Testability: The avionic equipment must allow verification that each mission-critical functions are still working for reuse, without having to dismount any part. To do this, Built-In Test (BIT) functions are necessary at the right level of the avionic equipment. The right level means that the electronic circuits added to make auto-test do not decrease equipment reliability, but also that tests performed are more efficient made on-board instead of by ground means.
- Health Report: In the same idea as for BIT, an efficient Health Monitoring System should make possible the simplification of Ground means and Assembly, Integration & Test (AIT) operations.

4 - Propulsion

The recently completed hot-firing tests as part of the ESA-led activity **Expander Cycle Technology Integrated Demonstrator** (ETID) has proven propulsion technologies in a move towards ‘intelligent’ engines to power the next-generation launchers. Two different electrical igniters, laser and direct spark, were shown to reignite the engines multiple times, and the electrically operated valves showed excellent repeatability, aiding the engine startup. In the first step towards an ‘intelligent’ engine, there is a fault-tolerant controller associated with the valves. If any electrical component fails, the control system automatically compensates so there is no functional impact.

Figure 8 : ETID (Credits: AGG)

In support of the CALLISTO demonstrator project (led by CNES, DLR and JAXA), FLPP is undertaking the maturation of a latching type **Isolation Valve** making it attractive to re-use the hydrogen peroxide (H_2O_2) reaction control system in development by NAMMO (Norway) for the VEGA Roll & Attitude Control System (RACS). The use of a Propellant Isolation Valve instead of a Pyrotechnic device avoids replacing of the Isolation Valve after each flight. Moreover, there is a strong interest in developing such a valve at low cost in Europe, as Latch Valves are usually very expensive, and few European manufacturers exist.

These activities come in addition to the low cost and reusable engine “Prometheus” activities as described in [2].

5 - Mechanisms

In an effort to mature technologies for **Low Cost Actuation Systems**, targeting Thrust Vectoring Control (TVC), fin deployment and actuation mechanisms on launchers, FLPP is undertaking an activity with SABCA (Belgium). A target is to demonstrate the new actuation system on the CALLISTO demonstrator. The fin deployment mechanism shall allow the movement of the fins from folded position to active position, the fin and its actuator being securely locked before and after deployment. An actuator for each of the fins shall allow the dynamic control of the angular positions in deployed position of an aerodynamic structure. Another aspect of this activity is the maturation of a health monitoring system with the objective to establish a state of the art of health monitoring of TVC systems and to select a suitable strategy for flight control and re-usability.

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Figure 9 : CALLISTO

6 - WTT and CFD techniques for retro-propulsion

Although other solutions are possible and envisaged by various actors of the space sector, the existing reusable first stages of launchers having achieved real recovery flights consist of a reusable "vertical take-off / vertical landing" (VTVL) booster using retro-propulsion as the main braking device for its return flight, such as SpaceX's Falcon 9 or Blue Origin's New Shepard. In order to assess the feasibility and the potential interest of retro-propulsion for European reusable launchers, it is first necessary to demonstrate the validity of existing design tools in Europe, in particular Wind Tunnel Testing (WTT) & Computational Fluid Dynamics (CFD). FLPP is investigating this field through a contract with DLR with subcontractor Engits (Germany). The objective of the project is to validate WTT and CFD techniques for the specific application to the aerodynamics and aerothermodynamics of a launcher first stage flying back to the ground with the use of retro-propulsion to slow down its descent flight in a controlled fashion. The outputs expected from the activity will be primarily the **validated WTT & CFD techniques incorporating retro-propulsion**.

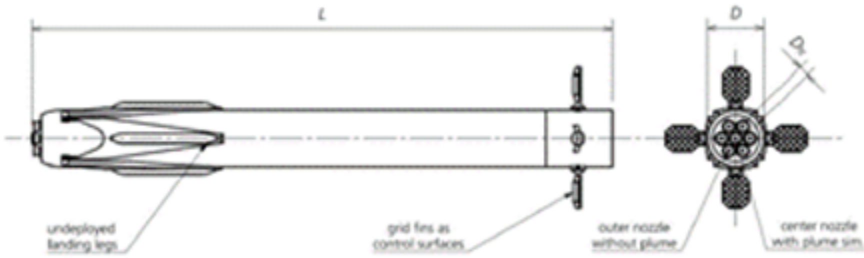

Figure 10 : RETPRO preliminary model configuration (Credits: DLR)

7 - Recovery concepts for reusable launcher components

Not only the launch vehicle itself, but also its jettisonable components may be candidate for recovery and reuse, such as the **payload fairing**. SpaceX for instance has been working for a while on recovering the fairings of Falcon 9 and assessing their reusability, and is poised to reuse the recovered fairings on future missions. FLPP is investigating the options for exploring the design and development of recoverable and reusable payload fairings at an attractive market price.

In terms of technology maturation, the first step in maturing the reuse process is the recovery of the payload fairing from the launch flight, in a state as intact as possible to re-fly it with the minimum possible amount of refurbishment. The recovery flight of the fairing starts after the jettisoning of the fairing by the launcher, typically at an altitude around 120 km and a velocity between 2500 and 5000 m/s (Mach 6 to 15). The fairing is to re-enter the atmosphere through the hypersonic, supersonic, transonic and subsonic flight regimes, before deploying parachutes for its final descent and landing phase. The fairing may land autonomously or be recovered in mid-air by an aircraft, before being retrieved and refurbished for its next launch flight.

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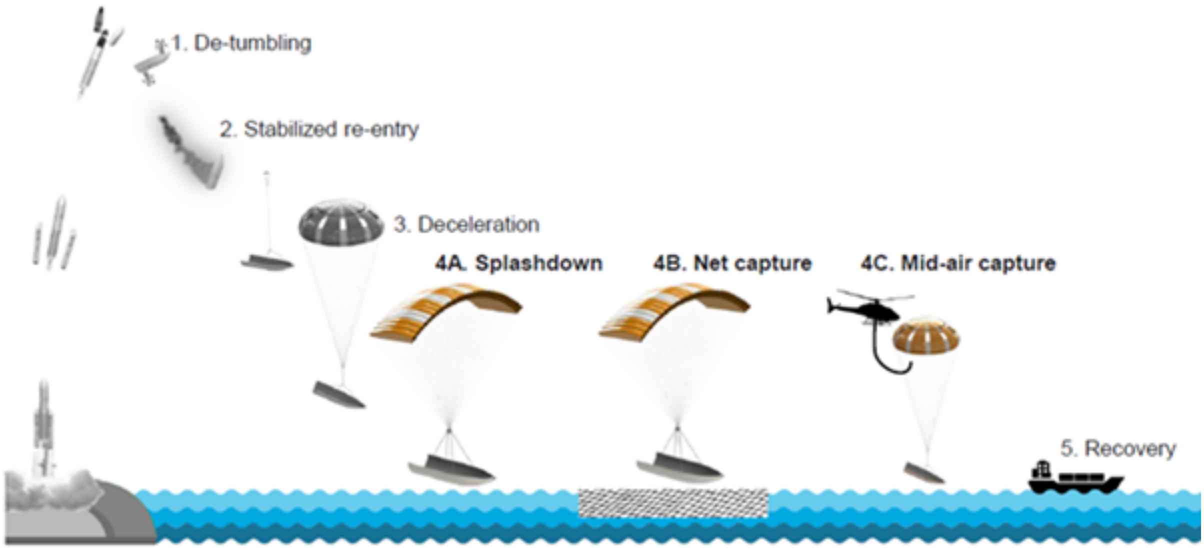

Figure 11 : Reusable Payload Fairing mission profile (Credits: RUAG)

As a continuation of in-house studies by RUAG (Switzerland) and Deimos (Spain) [5], the short-term objectives of a FLPP activity would be :

- to confirm the feasibility of the concept of fairing recovery and reusability,
- to perform the preliminary design of a recoverable and reusable fairing,
- to assess the potential savings of a reusable fairing in the total launch price.

Long-term objectives would be to develop and qualify for flight a complete demonstrator of recoverable and reusable fairing, including intermediate flight or drop tests as needed, and ending with a demonstration flight test of the complete system.

8 - Next steps for in-flight reusable vehicle demonstration in FLPP

As described in the previous sections, the short-term objectives, driving the on-going FLPP activity on reusability, consist mainly in demonstrating the reuse of the first stage of an Ariane-class launcher at the horizon 2025. The continuation and the completion of these activities shall form the basis of the reusability roadmap in preparation for the upcoming ESA Ministerial Conference Space19+ :

- System studies, vehicle design and technology development,
- Recovery operations and refurbishment,
- Regulations and business analysis.

The reusability roadmap for Space 19+ addresses also the reusability of other components of the launcher (e.g. payload fairing), the synergies with other types of launchers (e.g. microlaunchers) in the field of reusability and the identification of potential reusability for in-orbit or in-space infrastructure.

Building upon this short-term roadmap, mid-term reusability studies on the horizon beyond 2022 could cover :

- Follow-on demonstrations of first stage recovery and reuse, exploring innovative concepts with respect to current solutions,
- System and technology studies on reusability of launcher upper stages,
- Preliminary demonstration of in-orbit reusability,
- Continued effort on the maturation of enabling advanced technologies

Depending on the outcomes of current studies and on future market evolutions, long-term perspectives could encompass full-scale reusability demonstrations to/in/from Low Earth Orbit, as well as reusability extended to interplanetary missions.

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Acronyms and Abbreviations

AIT	Assembly, Integration & Test
BIT	Built-In Test
CFD	Computational Fluid Dynamics
COTS	Commercial Off The Shelf
DTV	Demonstrator for Technology Validation
ESA	European Space Agency
ETID	Expander Cycle Technology Integrated Demonstrator
FDIR	Fault Detection, Isolation & Recovery
FLPP	Future Launchers Preparatory Programme
FLPP- NEO	FLPP - New Economic Opportunities
GNC	Guidance, Navigation & Control
LPSR	Liquid Propellant Stage Recovery
RACS	Roll & Attitude Control System
SW	Software
TVC	Thrust Vectoring Control
VTVL	Vertical Take-off and Vertical Landing
WTT	Wind Tunnel Tests

References

[1] GOGDET Olivier - ArianeGroup – France / MANSOURI Jamila - ESA FLPP – France / PATUREAU Antoine - CNES – France / LOUAAS Eric - CNES – France / BRETEAU Jérôme - ESA FLPP – France : "LAUNCH VEHICLES SYSTEM STUDIES IN THE "FUTURE LAUNCHERS PREPARATORY PROGRAMME": THE REUSABILITY OPTION FOR ARIANE EVOLUTIONS" (Paper #971 in EUCASS 2019)

[2] EDELINE Emmanuel - ArianeGroup - FRANCE / RAVIER Nicolas - ArianeGroup - FRANCE / SAGNIER Sebastien - ArianeGroup - FRANCE / SIMONTACCHI Pamela - ArianeGroup - FRANCE / BLASI Roland - ArianeGroup - FRANCE / ESPINOSA Amaya - ESA FLPP - FRANCE / BRETEAU Jérôme - ESA FLPP - FRANCE / ALTENHOFER Philipp - DLR Lampoldshausen – GERMANY : "PROMETHEUS: PRECURSOR OF LOW-COST ROCKET ENGINE" (Paper #743 in EUCASS 2019)

[3] PASCUCCI Carlo Alberto - embotech AG - SWITZERLAND / FERNANDEZ Alvaro - embotech AG - SWITZERLAND / JEREZ Juan - embotech AG - SWITZERLAND / BENNANI Samir - ESA ESTEC - NETHERLANDS / PREAUD Jean-Philippe - ESA FLPP - FRANCE / BRU Jorgen - ESA FLPP – France : "DESIGN SIMULATION AND SOFTWARE VALIDATION FOR ON-BOARD AND REAL-TIME OPTIMAL GUIDANCE" (Paper #698 in EUCASS 2019)

[4] MELARA Mariasole - GMV Aerospace and Defence S.A.U. - SPAIN / PACE Francesco - GMV Aerospace and Defence S.A.U. - SPAIN / DOMÍNGUEZ carlos - GMV Aerospace and Defence S.A.U. - SPAIN / CERCÓS Lorenzo - GMV Aerospace and Defence S.A.U. - SPAIN / GONZÁLEZ Eleazar - PLD Space – SPAIN : "MIURA 1 AVIONICS DEVELOPMENT AND QUALIFICATION" (Paper #688 in EUCASS 2019)

[5] BONETTI Davide - DEIMOS - SPAIN / MEDICI Giovanni - DEIMOS - SPAIN / BLANCO ARNAO Gonzalo - DEIMOS - SPAIN / SALVI Samuele - DEIMOS - SPAIN / FABRIZI Andrea - DEIMOS - SPAIN / KERR Murray - DEIMOS - SPAIN / SÁNCHEZ CEBRIAN Alberto - RUAG Schweiz AG - SWITZERLAND / MOLINARI Giulio - RUAG Schweiz AG - SWITZERLAND / GERNGROSS Tobias - RUAG Schweiz AG – SWITZERLAND : "REUSABLE PAYLOAD FAIRINGS: MISSION ENGINEERING AND GNC CHALLENGES" (Paper #638 in EUCASS 2019)