Key Technologies for Retro Propulsive Vertical Descent and Landing
– RETALT –
an Overview

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ABSTRACT

Since SpaceX successfully demonstrated the vertical landing of launcher first stages and made this way of returning them to earth a routine operation with over 100 successful landings after 6 years, the interest in Europe to develop the key technologies for this approach has drastically increased. It not only promises large cost savings, but also reduces space debris and is more environmentally friendly as no debris parts fall back to the earth' surface.

The first project funded by the EU commission to investigate key technologies for reusable launch vehicles applying retro propulsion is RETALT (RETro propulsion Assisted Landing Technologies) which received a funding of 3 million Euros in the frame of Horizon 2020.

The consortium consists of the German Aerospace Center (DLR), CFS Engineering (CFSE), DEIMOS Space, MT Aerospace, Almatech and Amorim Cork Composites. The key technologies studied in detail are Aerodynamics, Aerothermodynamics, Flight Dynamics and GNC, Structures, Mechanisms, TVC, and TPS.

Detailed wind tunnel test series were performed at DLR and were combined with Computational Fluid Dynamics (CFD) studies by DLR and CFSE to generate a sound basis for the understanding of the complex aerodynamic and aerothermodynamic phenomena at play for such configurations. MT Aerospace designed the structure of the aerodynamic control surfaces and landing legs, and closely worked together with Almatech who designed the mechanisms for these applications. Demonstrators were built in a scale of 1/5 of the aerodynamic control surface and the landing leg, and the landing leg was tested in a drop tower. Amorim Cork Composites developed a new cork based TPS material specifically for the application on retro propulsive landing configurations with a focus on an easy applicability of the material. The material was tested in the arc heated facility L2K at DLR.

In this paper a detailed overview of the studied technologies will be given and the interplay between the different disciplines will be highlighted. Design challenges for launcher configurations descending and landing through a deceleration using the engines will be discussed. An outlook for the potential for future research and developments will be given.

Index Terms *— Retro Propulsion Assisted Landing Technologies, Vertical Take-off Vertical Landing, Reusable Launch Vehicle, RETALT*

1. INTRODUCTION

The successful demonstration of the vertical landing of the Falcon 9 launcher first stage by SpaceX in 2015 generated a large interest in reusable launch vehicles. The common opinion, reaching back to the Space Shuttle days, that reusability does not lead to costs savings was quickly transformed; leading to a number of research and development impulses all over the world. In Europe this new movement inspired a multitude of research projects, funded by different frameworks (national funding as well as ESA and EU funding), leading to several multinational collaborations.

System studies were performed in projects like Ariane Next [1] and ENTRAIN [2], small scale demonstrators for GNC development were developed in EAGLE [3], FROG [4] and DTV [5], wind tunnel experiments and CFD tools were validated for such applications in

RETPRO [6] and projects like CALLISTO [7] and Themis [8] focus on a large scale demonstrator; just to name a few.

On the EU side a call was opened in 2018 with the aim of funding research to maintain and foster European non-dependent autonomous, reliable and cost-effective access to space. In this frame the RETALT consortium applied to lay the foundations in Europe on the key technologies for landing launchers vertically with the aid of retro propulsion. Therefore, the project was named Retro Propulsion Assisted Landing Technologies (RETALT). Rather than focusing on one specific technology as in EAGLE, FROG, DTV and RETPRO or building a large-scale demonstrator as in CALLISTO and Themis, the aim was to focus on the key technologies necessary to develop Reusable Launch Vehicles (RLV) and to investigate their interaction between each other on representative reference configurations.

The project started in March 2019 and was funded by the European Union's Horizon 2020 research and innovation framework program under grant agreement No 821890. The project ends in August 2022. The key technologies investigated in the project are Aerodynamics, Aerothermodynamics, Flight Dynamics and Guidance Navigation and Control (GNC), Structures, Mechanisms, Thrust Vector Control and Thermal Protection Systems. A large demonstrator of a landing leg was manufactured and tested in a drop tower. A prototype of an aerodynamic control surface and its deployment mechanism were also manufactured. The aerodynamic properties of the vehicle were validated in wind tunnel experiments and the aerothermal behavior of the TPS material was validated in the arc-heated facility L2K at DLR.

The aim of this paper is to give an overview of the technical achievements in the different areas in the last years and to refer the interested reader to further literature published by the respective partners. Therefore, links are made to a special issue of the CEAS Space Journal on RETALT, and to papers on the specific areas presented at the FAR conference.

The paper is laid out as follows. First, a summary of the reference configurations will be given for a general understanding of the framework of the research in the project. Then, the various technological areas will be highlighted and summaries of the objective, methodology, status and main findings will be given. The paper will then close with a discussion on the plan of exploitation of the technologies developed in RETALT and an outlook of the remaining work in the last project phase.

2. REFERENCE CONFIGURATIONS

To investigate the technologies studied in the project two reference configurations were defined [9]:

- RETALT1: A heavy lift launcher configuration able to bring a payload of up to 14 tons into the Geostationary Transfer Orbit (GTO)
- RETALT2: A smaller Single Stage To Orbit (SSTO) configuration able to bring a payload of 500 kg into Low Earth Orbits (LEO)

These configurations have very different scales, such that the scalability of the developed technological solutions with the launchers size could be assessed. RETALT1 is a configuration more closely related to an application scenario which could be realized in Europe in the medium-term, while RETALT2 is to be seen more as a technology test bed due to its nature of being an SSTO configuration with a quite small payload. To give a perspective of the size of these two configurations, in Fig. 1 they are compared to various launchers based on a comparison shown on the website of Blue Origin [10]. Also the Grasshopper by SpaceX is shown, taken from [11]. One can see that RETALT1 is in the size class of New Glenn, while RETALT2 is smaller than the Grasshopper.

As the project focuses on the European access to space the configurations were based on existing European technologies. Hence, the RETALT1 configuration is using engines inspired heavily by the Vulcain 2, while RETALT2 is based on an engine adapted from the Vinci engine. Due to its higher relevance for European launchers in the medium-term, RETALT1 was investigated more in detail than RETALT2 in the project.

2.1. RETALT1

The mission concept or RETALT1 is depicted in Fig. 2 and the configuration layout is shown in Fig. 4. Similar to the Falcon 9 by SpaceX the RETALT1 configuration has 9 engines in the first stage and 1 engine in the second stage. The engines in the 1st stage are optimized for sea level conditions, while the second stage engine is optimized for vacuum conditions. As mentioned before the configuration is based on engines similar to Vulcain 2 engines, with LOX/LH2 (Liquid Oxygen / Liquid Hydrogen) as propellant combination.

As for the Falcon 9 a Return to Launch Site (RTLS) can be performed for missions with low orbits and payloads and a Down Range Landing (DRL) can be performed for more demanding missions (see Fig. 2).

A novel concept was studied for this configuration where segments of the interstage were meant to be used as aerodynamic control surfaces (ACS) (see Fig. 4a). This however, proved to be challenging due to high structural loads and high hinge moments, leading to unfeasibly high structures and actuator masses [12]. This is why also planar fins were investigated as ACS (Fig. 4c, d) alongside with grid fins (Fig. 4b) as reference for ACS operational to date (on the Falcon 9) [12][19]. As proposed in the CALLISTO project (see e.g. [16]) the planar fines are folded along the main body during ascent (see Fig. 4d).

2.2. RETALT2

The mission concept of RETALT2 is shown in Fig. 3 and the configuration layout in Fig. 5. The RETALT2 configuration is an SSTO with 9 engines similar to the Vinci engines, adapted for sea level conditions.

The RETALT2 configuration has a conical shape with a blunt surface area at the base. The intention is to reduce fuel consumption for the re-entry burn due to a larger aerodynamic deceleration, similar to re-entry capsules.

Therefore, it does only perform a Down Range Landing (DRL), were only a short de-orbit burn is necessary. No re-entry burn is performed as the deceleration is performed purely aerodynamically. Similar to RETALT1, the fairing segments for RETALT2 were intended to be used for the aerodynamic control of the vehicle (see Fig. 5).

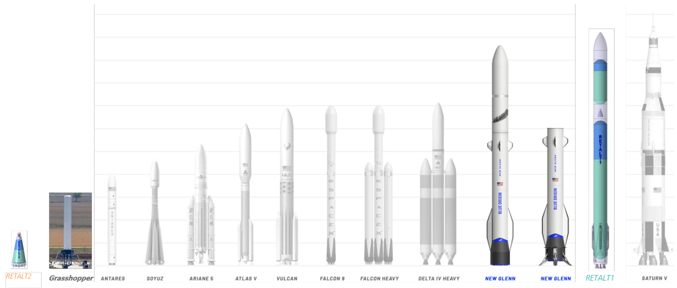


Fig. 1: Size comparison of RETALT1 and RETALT2 with various launchers (Launcher comparison taken from [10], image of Grasshopper taken from [11])

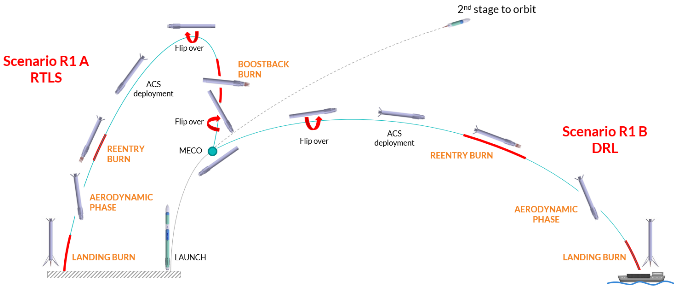


Fig. 2: RETALT1 return mission concept [15]

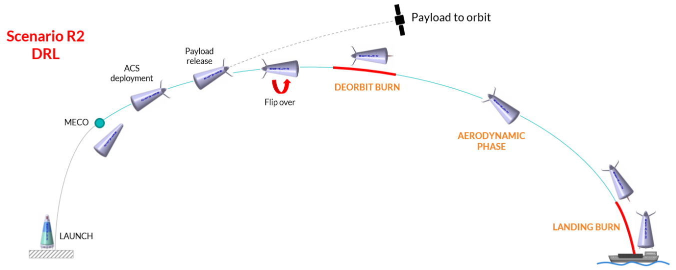
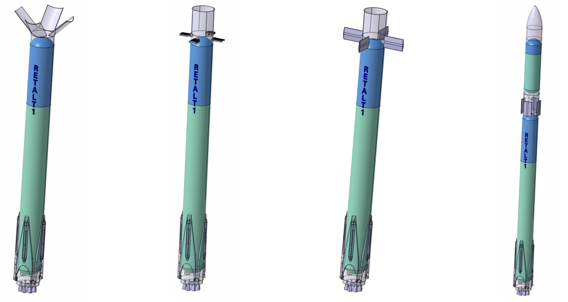


Fig. 3: RETALT2 return mission concept [9]



a) Configuration with Petals during descent

b) Configuration with grid fins during descent

c) Configuration with planar fins during descent

d) Configuration with folded planar fins during ascent

Fig. 4: RETALT1 configurations of aerodynamic control surfaces [12]

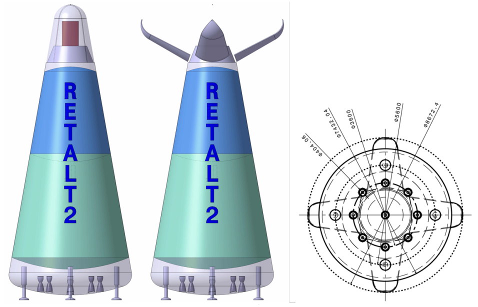


Fig. 5: RETALT2 configuration layout as presented in [9]

3. TECHNOLOGICAL ADVANCEMENTS IN THE RETALT PROJECT

As mentioned in the introduction the key technologies studied in RETALT are Aerodynamics, Aerothermodynamics, Flight Dynamics and Guidance Navigation and Control (GNC), Structures, Mechanisms, Thrust Vector Control and Thermal Protection Systems. An overview of the technological advancements in these areas and a summary of the objectives, methodology, status and main findings in each discipline is given in this section.

3.1. Aerodynamics and Aerothermodynamics

The aerodynamic work performed in the RETALT project can roughly be split into three sections: 1) The study of the aerodynamic behavior of the vehicles in wind tunnels at DLR in Cologne, 2) the aerodynamic study of the vehicle and the aerodynamic control surface efficiency, as well as the extrapolation from wind tunnel to flight, mainly performed by CFSE and 3) the aerothermal assessment of the vehicles performed at the DLR in Göttingen. The aerodynamic data was gathered in an Aerodynamic Data Base published in [13] for RETALT1 and [14] for RETALT2.

3.1.1. Aerodynamic Wind Tunnel Tests

The wind tunnel experiments were performed at the Supersonic and Hypersonic Technologies Department at DLR in Cologne. The aim of the study was the characterization of the aerodynamic behavior of the vehicles in the flight phases experienced during descent and landing and the understanding of the complex steady and unsteady flow fields and resulting loads on the vehicle. Also the aerodynamic data base was partly based on wind tunnel test results.

The flight phases of the vehicle were rebuilt in the wind tunnels in the following way:

- In the Hypersonic Wind Tunnel Cologne (H2K) the hypersonic re-entry burn was modeled with a cold gas jet simulating one or three active engines (see Fig. 6) [21]
- In the Trisonic Wind Tunnel Cologne (TMK) the aerodynamic phase of the vehicles was rebuilt. Force and moment measurements were performed to assess the aerodynamic behavior of the vehicle and to compare the efficiency of the petals and planar fins against each other. [12] [20] [22]
- In the Vertical Free-Jet Facility Cologne (VMK) the landing burn is simulated with a cold gas jet and further with hot combustion of oxygen and hydrogen [22]
- In the Arc Heated Facility L2K the cork TPS material developed in RETALT by Amorim Cork Composites was

tested for the most critical heat loads during the descent trajectory. [23]

The wind tunnel tests helped to understand the physical phenomena at play during retro propulsion descent and landing of launcher first stages and their impact on the loads on the vehicles. In the remaining project life time a detailed analysis of the final landing approach in the VMK will be performed. Furthermore, the flow dynamics during the hypersonic re-entry burn shall be investigated further by a more detailed modal and frequency analysis.

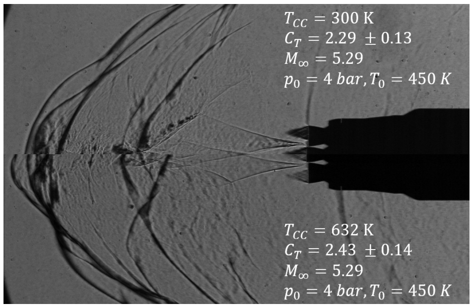


Fig. 6: Re-entry burn with three active engines tested in H2K with air at ambient temperature (upper image part) and heated air (lower image part) [21]

3.1.2. Aerodynamic CFD

The objectives of the CFD simulations with focus on the aerodynamics were:

- Investigation of the aerodynamic control surfaces (planar fins, petals, grid fins) for RETALT1 [19]
- Generation of the Aerodynamic data bases for use in the GNC analysis
- Rebuilding of Wind Tunnel Experiments at DLR Cologne for RETALT1 [24] and for RETALT2
- Extrapolation of wind tunnel results to flight conditions

A large number of CFD simulations were made using the NSMB CFD solver. For some conditions cross reference calculations were made using the TAU CFD solver.

Concerning the choice of aerodynamic control surfaces, it was found that using petals as control surfaces generated too high loads on the structure [19], and for this reason planar fins were selected as control surfaces for RETALT1. Using planar fins more than 300 CFD simulations were made to populate the Aerodynamic database for RETALT1.

Rebuilding wind tunnel experiments for RETALT1 showed some differences in the measured and computed shock stand-off distance. But a good agreement between NSMB and TAU CFD results was observed. Comparison of measured pressures with computed pressures from both NSMB and TAU showed a good agreement along the body, but large differences in the base region. In flow in this region is complex and many flow separations exists. In some of the experiments flow unsteadiness was observed, which was not the case in the CFD simulations [24].

Fig. 7 shows a comparison of a Schlieren picture with the CFD results for 1 active engine. As can be seen the overall flow structure is well captured, but there is a small difference in measured and computed shock stand-off distance.

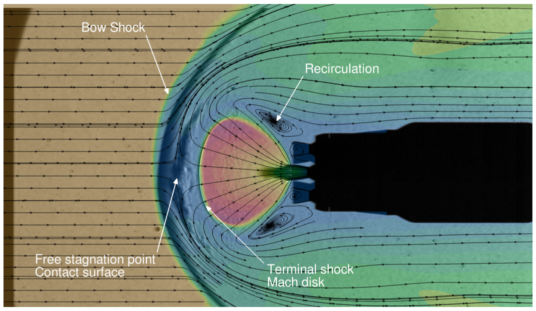


Fig. 7: Flow structure with central engine active. [24]

3.1.3. Aerothermodynamic CFD

The accurate prediction of the thermal loads which the vehicle is exposed to during its atmospheric flight is an essential prerequisite for the design and the sizing of the Thermal Protection System (TPS) and other important structural parts like the Aerodynamic Control Surfaces (ACS) and landing legs.

These analyses rely on Computational Fluid Dynamics (CFD) simulations. The DLR - Institute of Aerodynamics and Flow Technology in Göttingen is in charge for CFD based aerothermal load predictions, aerothermal database generation and application for the RETALT1 and RETALT2 configurations.

The surface heat fluxes resulting from a set of steady-state CFD simulations performed at characteristic trajectory points, operational conditions of the engines and surface temperatures, are organized in Aero-Thermal Data Bases (ATDBs). The computational matrixes are chosen in order to cover the entire flight trajectories in particular the flight regimes characterized by significant thermal loads or high dynamic pressure. The ATDB represents a fast response surrogate aerothermodynamic heating model that allows to evaluate the heat flux on each point of the rocket surface as function of flight time and local surface temperature thanks to the implementation of interpolation algorithms. The aero-thermal data base can be easily coupled to a structural response model to estimate the temperature history in each location on the vehicle surface during the entire trajectory [17][18].

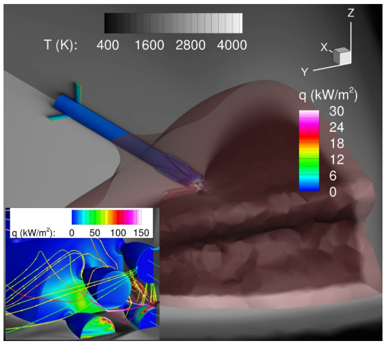


Fig. 8: RETALT1 descent flight, high altitude, beginning of retro-propulsion [17]

The CFD simulations are performed with the hybrid structured-unstructured DLR Navier–Stokes solver TAU and aim also at investigating the typical phenomena which affect the aerothermodynamic heating of the vehicle during both the ascent and descent trajectory. Results show that at high altitudes the ambient pressure is low and the plumes significantly spread out resulting in strong plume-plume interaction. The vehicle is fully immersed in a hot exhausted gases atmosphere but, thanks to the low flow field density, the heat loads on the rocket surface are limited, see Fig. 8. The accuracy of numerical results is validated by means of the comparison with wind tunnel data for sub-scale models of RETALT1 and RETALT2. A good agreement in terms of flow field representation and pressure in the sensors locations has been observed [18][24].

3.2. Flight Dynamics and GNC

To enable the reusability of a launcher it is necessary to assess its capability to perform a return mission and therefore be recovered. In the context of RETALT, Deimos developed a methodology to carry out the mission engineering of the return mission of the considered configurations. At first, the flight envelope during the descent is explored to identify mission and maneuverability needs and therefore define a Concept of Operations (CONOPS, see Fig. 9). Flight domains in which a feasible return mission can be defined were identified for the different RETALT1 configurations, and the associated propellant budget was estimated. In this way, a performance map can be created that maps the best recovery solution, if any, with respect to the ascent mission characteristics (see Fig. 9). The feasible flight domains identified supported also the identification of mission and GNC requirements, as well as the sizing of the actuators. In parallel, flight mechanics analyses assessed the flight characteristics for the different phases, to assure the capability of the configurations considered to perform a stable and controllable flight in order to recover the launcher. Eventually, the mission engineering is completed with consolidation of the mission design for the scenarios considered and the definition of reference trajectories, that were consolidated at each update of the aerodynamic dataset [25].

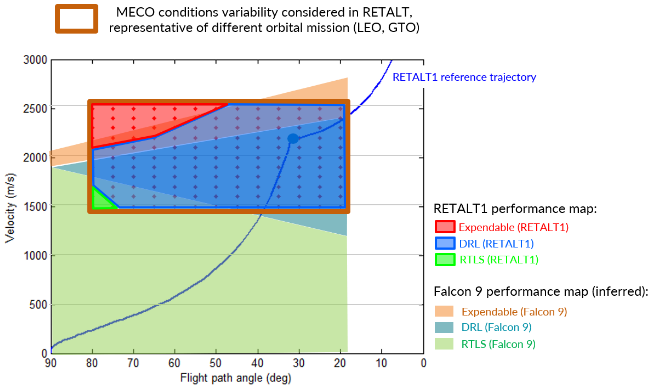


Fig. 9: Feasibility map for the recovery of RETALT1 (and comparison with reconstructed Falcon 9 performance [27])

To enable recovery and thus reusability it is also critical to define a GNC solution able to guarantee pinpoint landing for RETALT1 while compensation the dispersions accumulated during the return flight of the launcher. To achieve the required precision in a very uncertainty environment, Deimos developed a Guidance solution based on online trajectory optimization. Optimization of the fuel consumption during the retro propulsion phase, while providing convergence guarantees, is also important to increase the feasibility of the return mission and the affordability of the recovery. The recovery GNC solution was completed with state-of-the-art hybrid Navigation techniques and multi-mode scheduled controllers designed and verified using modern robust control techniques, such as H-infinity and mu-synthesis/analysis. The proposed GNC solution was assessed in a high-fidelity Functional Engineering Simulator to reach a Technology Readiness Level (TRL) of 3, and the performance obtained are considered very promising. The recovery GNC solution developed for RETALT is presented in detail in [26].

3.3. Structures

Structures are developed for landing legs and aerodynamic control surfaces (ACS).

The design ACS is represented in Fig. 10 and shows an overview of the whole control surface at its full-scale. The structure of the fin itself can be seen, is state of the art in terms of manufacturing of the metallic and composite components. The intended titanium root fitting however, represent an increased degree of complexity. MT Aerospace will consider the viability of producing the part using metallic additive manufacture (MAM). The final scaled manufactured ACS is shown in Fig. 11. The complex root fitting is conventional manufactured for the demonstrator and made of aluminium.

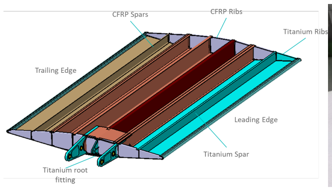


Fig. 10: Overview of aerodynamic control surface

Fig. 11: Aerodynamic control surface demonstrator

The layout and system analysis of reusable launch vehicle include major challenges related to the application of a robust, light-weight, inexpensive and serviceable landing gear. This consists mainly of a damper system and a high strength performance chassis frame to compensate compression and tension forces. The correct sizing of such a system relies on an accurate determination of dimensioning dynamic loads which occur during the touch down landing of the launch vehicle [28].

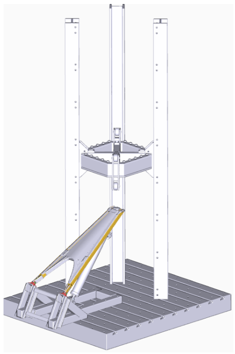


Fig. 12: Drop test setup (drop mass, guide rail and test field) with landing leg, test rig and absorber

A drop test is performed and evaluated by MTA, which simulates the dynamic shock loading on the 1:5 scaled landing structure, the kinematic behaviour of its damper system and the strength resistance of the frames during landing. The drop test consists of a large mass which is mounted on a fall tower. This impact energy leads to high forces in the landing leg of the launcher. The results will be represented in [29].

Correlation of mathematical models with test data will enable MT-Aerospace to improve the accuracy of the prediction of a landing scenario for full-scale RETALT launchers and similar reusable launch vehicles.

3.4. Mechanisms and TVC

Reusability of the launch vehicle necessitates specialized mechanism to be able to return the vehicle and carry out safe landing. Almatech has explored and traded-off several mechanism concepts that answer functional requirements of the RETALT1 launch vehicle, working closely with structures and with inputs from other disciplines of the consortium. The most promising concepts were developed in further detail, and demonstrators were designed to verify their functionality [30].

The two main mechanisms are those of the aerodynamic control surfaces and landing legs. Additionally, Almatech performed a trade-off on thrust vector control solutions to define a high-level-concept and a corresponding analytical evaluation framework, including gimbal kinematics as schematized in Fig. 13, in which the design space can be further assessed.

The aerodynamic control surfaces are foldable fins. Mechanisms retain the fins until their deployment, carry out the deployment itself, lock the fins into their nominal deployed position, and operate them during the launch vehicle return phase. A control surface mechanism demonstrator, shown in Fig. 15, was built accommodating a 1/5th scale, 1m span fin to verify these functionalities.

Landing leg mechanisms have several functions. The landing legs are retained in a compact folded position. When commanded, the legs fully deploy, and the deployed position is locked. Upon touchdown, leg attenuation mechanisms protect the vehicle by dissipating the impact energy. Two scaled demonstrators are prepared. A demonstrator of the shock attenuator is attached to a 1/5th scale landing leg. The configuration is tested in a drop tower to verify mechanism functionality. In addition, a 1/10th scale deployment demonstrator (shown in Fig. 14) is prepared to verify deployment kinematics, facilitate the preliminary assessment of the deployment dynamics [31].

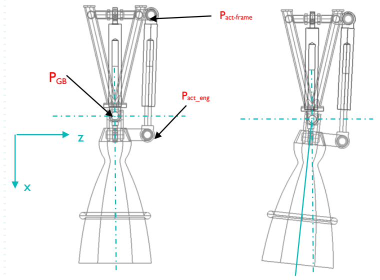


Fig. 13: Schematics of thrust vector control actuation kinematics.

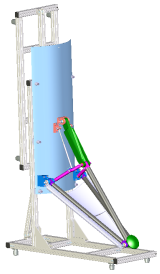


Fig. 14: Landing leg scaled deployment demonstrator

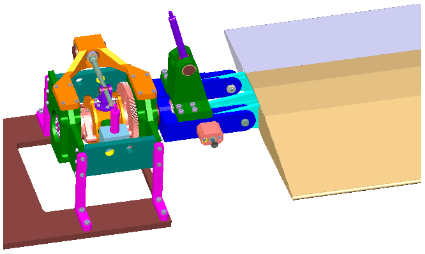


Fig. 15: Scaled demonstrator of deployment-actuation mechanism of aerodynamic control surfaces.

3.5. TPS Developments

In the framework of the RETALT project, a novel Thermal Protection System (TPS) was designed and manufactured, with the objective of being applied *in situ* while guaranteeing structural stability.

Amorim Cork Composites, developed a new trowelable cork composite material, applicable in structures with complex geometries and able to cure at room temperature.

The material development went through different stages, starting by research about TPS state of art, raw materials and processes procurement, types of resins compatible with cork and its processing conditions and additives to confer thermal properties required by aerospace applications.

Thereafter, the formulation design was studied, combining the raw materials selected and by iterative optimization of the material to ensure its applicability and its ablative properties.

All formulations were tested through different stages of thermal tests, starting with a butane torch pre-characterization process, at Amorim Cork Composites facilities, followed by a Cone Calorimeter test, of the most promising formulations. The final material (TPS05) was finally tested in the L2K arc heated facility at DLR, in comparison with P50, a TPS material by Amorim Cork Composites with large heritage in aerospace applications. Fig. 16 shows the TPS05 before and after L2K test.

The material development process and the testing at the facilities at Amorim Cork Composites was described in [32], the test results of the L2K tests and their indications for the material are presented in [23] and [33].

Fig. 16: Novel cork TPS material (TPS05) before (left) and after (right) test in L2K at DLR. Top: profile view, Below: surface view.

4. EXPLOITATION OF RESULTS

As mentioned in the introduction, the aim of the RETALT project was to investigate key technologies for the vertical landing of launchers with the aid of retro propulsion. The project was planned in view of a possible in orbit demonstration or in orbit validation of these technologies as a next step, and with the vision to implement them and reach a European reusable vertically landing launcher within four years after the end of the project. The Exploitation timeline which was defined in the grant agreement for the project outcomes is shown in Fig. 17.

In the last phase of the project (until August 2022), an exploitation plan will be worked out determining the development effort still to be performed to reach the Technology Readiness Level (TRL) of

8/9. To decrease the risks, the TRL of the technologies shall be raised in incremental development steps: 1) First the existing European launchers shall be evaluated regarding their potential for vertical landing and reusability; 2) In the next step the RETALT technologies need to be tailored to the selected launcher; 3) The launcher to which the RETALT technologies will be applied needs to be adapted for reusability (e.g. the structures supporting the ACS might need reinforcement). If the RETALT technologies are tailored for the specific launcher, they can already be tested partially in orbit. Simple functionalities, e.g. the deployment of the ACS could be tested first, as for these tests no complex GNC and aerodynamics are necessary; 4) In a further step a decent would be attempted, however, only with a sea splash down, such that no risk is taken by landing on a seagoing landing platform; 5) Finally, the lessons learned from the partial in-orbit tests shall be implemented and a final landing attempt on a sea going platform should be performed.

In parallel, technological, legal and safety requirements need to be assessed for the existing launch sites, and they need to be developed/adapted for the operation of vertical landing launchers. For down-range landing the seagoing landing platforms need to be built.

It should be mentioned that the exploitation plan summarized here was developed in view of an adaptation of an existing launcher to be (partially) reusable. However, an optimal solution for the implementation of these new technologies could also be reached through the development of a completely new generation of launchers, which could be tested in a similar manner of incremental steps of technology developments to decrease risk. For the development of a completely new generation of launchers, and to decrease the development time, it will be important to build this new design on technology bricks already available in Europe. This approach is followed by ESA as shown in the ESA technology reusability roadmap, presented e.g. in [34]. Risks can also be decreased through a development of the technologies based on a technology demonstrator. This demonstrator should be as representative of the flight vehicle as possible. This strategy is implemented by ESA, ArianeGroup, CNES and collaborating institutions in the Themis demonstrator that is based on Prometheus engines and aims for representative flight conditions [8].

This shows that the RETALT technologies fit well in the evolutions of the new launchers being currently developed and tested in Europe. Entailing a large potential for a rapid implementation of these technologies in collaboration with the European research and industry.

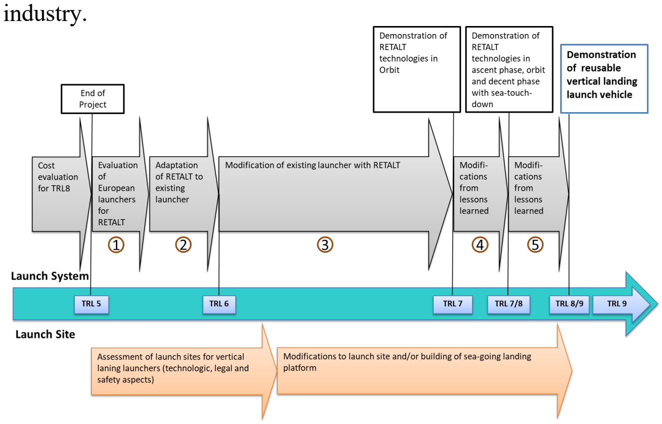


Fig. 17: Exploitation timeline with corresponding TRL

5. CONCLUSION

In this paper the advancements in technologies developed in the RETALT project have been highlighted. Key technologies for reusable launch vehicles which are descending and landing with the aid of retro-propulsion have been studied in detail. Aerodynamics and aerothermodynamics have been investigated extensively with CFD and with wind tunnel experiments, structures, i.e. landing legs and aerodynamic control surfaces have been designed manufactured and tested, as well as the mechanisms for those components. Mission analyzes have been performed and a GNC concept has been developed. A new cork based TPS material has been developed and tested in the arc heated facility at DLR in Cologne.

The RETALT project ends in August 2022. In the remaining project life time, last results will be evaluated and consolidated. The exploitation of the data and knowledge gathered in the project will be laid out and implemented.

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