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The Reusability Flight Experiment – ReFEx: Details of the Protoflight-model Integration Campaign and Final Update Prior to Flight

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Abstract

The Reusability Flight Experiment (ReFEx), is a technology demonstration mission of the German Aerospace Center (DLR), aimed at validating key technologies for aerodynamically controlled reusable launch vehicle (RLV) stages. Scheduled for launch in 2026 from the Koonibba Test Range (KTR) in South Australia, ReFEx will be carried by a VSB-30 sounding rocket to a trajectory representative of a returning RLV first-stage.

The experiment seeks to autonomously guide the vehicle as far back as possible toward the launch site using only aerodynamic control surfaces, demonstrating fully autonomous flight control capable of critical heading changes and energy-efficient returns.ReFEx features a compact design, measuring 2.7 meters in length with foldable wings and a mass of approximately 400 kg. In the frame of the ReFEx project the advanced guidance, navigation, and control (GNC) systems, aerodynamic control strategies, and structural resilience under hypersonic and subsonic conditions shall be tested.

One key aspect of the project is a rigorous pre-flight verification campaign, including structural integrity tests, avionics integration, and environmental simulations. By collecting flight data to validate aerodynamic models and control algorithms, ReFEx aims to enhance the development of future European reusable launch vehicles, contributing to more sustainable and cost-effective space access. This paper, which is the latest addition in a long series of updates on the project, focuses on the efforts to bring the final proto-flight model (PFM) of the experimental vehicle to completion in the PFM integration campaign, currently underway at the DLR Institute of Space Systems in Bremen, Germany.

The work here was informed by the successful structural model (SM) campaign, which was completed at the end of 2023. Since then, lessons learned and modification from the SM campaign have been incorporated in the project. Once completed ReFEx will then be shipped to KTR, Australia and prepared for the flight experiment.

Keywords: RLV, hypersonic, flight experiment, AIV, integration

Acronyms/Abbreviations

ACE	Actuator Control Electronics
AIV	Assembly Integration and Verification
CALLISTO	Cooperative Action Leading to Launcher Innovation in Stage Toss back Operations
CoG	Centre of Gravity
CAST	Core Avionics System Testbed
DLR	German Aerospace Center
EI	Entry Interface
GNC	Guidance Navigation and Control
KTR	Koobibba Test Range
MoI	Moments of Intertia
MORABA	Mobile Rocket Base
PFM	Proto-Flight Model
RCS	Reaction Control System
ReFEx	Reusability Flight Experiment
RLV	Reusable Launch Vehicle
SM	Structural Model
VSB	Veículo de Sondagem Booster
VTHL	Vertical Take-Off horizontal landing
VTVL	Vertical Take-Off vertical landing

1 Introduction

The Reusability Flight Experiment (ReFEx) is a flight demonstrator mission of the German Aerospace Center (DLR) to validate key technologies required for future winged, aerodynamically controlled reusable launch vehicle (RLV) stages [1], [2]. Designed for a vertical take-off and horizontal landing (VTHL) profile, the experimental vehicle will be launched aboard a VSB-30 sounding rocket, from the Koonibba Test Range (KTR) in Southern Australia. The mission aims to demonstrate a fully autonomous return flight, transitioning from hypersonic to subsonic speeds, performing a controlled heading change exceeding 30°, and reaching a predefined terminal point using aerodynamic control surfaces. A small cold gas reaction control system (RCS) is also on-board to allow for attitude control in exo-atmospheric flight to achieve the correct orientation for re-entry [3], [4].

Since its inception in 2016 and first presentation at EUCASS 2017 [5] and IAC 2017 [6], ReFEx has advanced through several major design and development phases. Following the successful Preliminary Design Review (PDR) in 2019 and Critical Design Review (CDR) in 2021, the project transitioned into the Assembly, Integration, and Verification (AIV) phase. This phase has involved integration of all mission-critical subsystems including the Guidance, Navigation, and Control (GNC) system, avionics, power systems, sensors, and deployable aerodynamic surfaces such as wings, rudder, and canards [1], [7].

Due to the compact internal configuration of the 2.7-meter-long, 1.1-meter-span vehicle with a mass of approximately 400 kg, system integration posed considerable engineering challenges. Structural models, engineering models, and proto-flight hardware were employed to validate subsystem compatibility and mechanical interfaces [7]. One major milestone during this period was the completion of a full-scale structural shaker test campaign that verified the mechanical robustness of the assembled system under launch conditions. This included successful deployment testing of the fairing and folding wings under simulated flight loads [2], [7]. Additionally, a comprehensive system-level hardware-in-the-loop (HIL) test series was executed to validate mission software performance and functional behavior under real-time simulated flight scenarios[3].

These efforts form a crucial part of DLR's broader strategy to mature reusable space transportation technologies and gain operational insights into both VTVL and VTHL vehicle concepts. Alongside CALLISTO—DLR's VTVL demonstrator—ReFEx contributes to a unique dual-path exploration of RLV technologies in Europe [2].

The paper at hand focuses specifically on the proto-flight model AIV campaign. It presents an overview and current status of the integration workflow, discusses the challenges in mechanical, electrical, and software interfacing, and highlights the verification steps to qualify the integrated vehicle for flight.

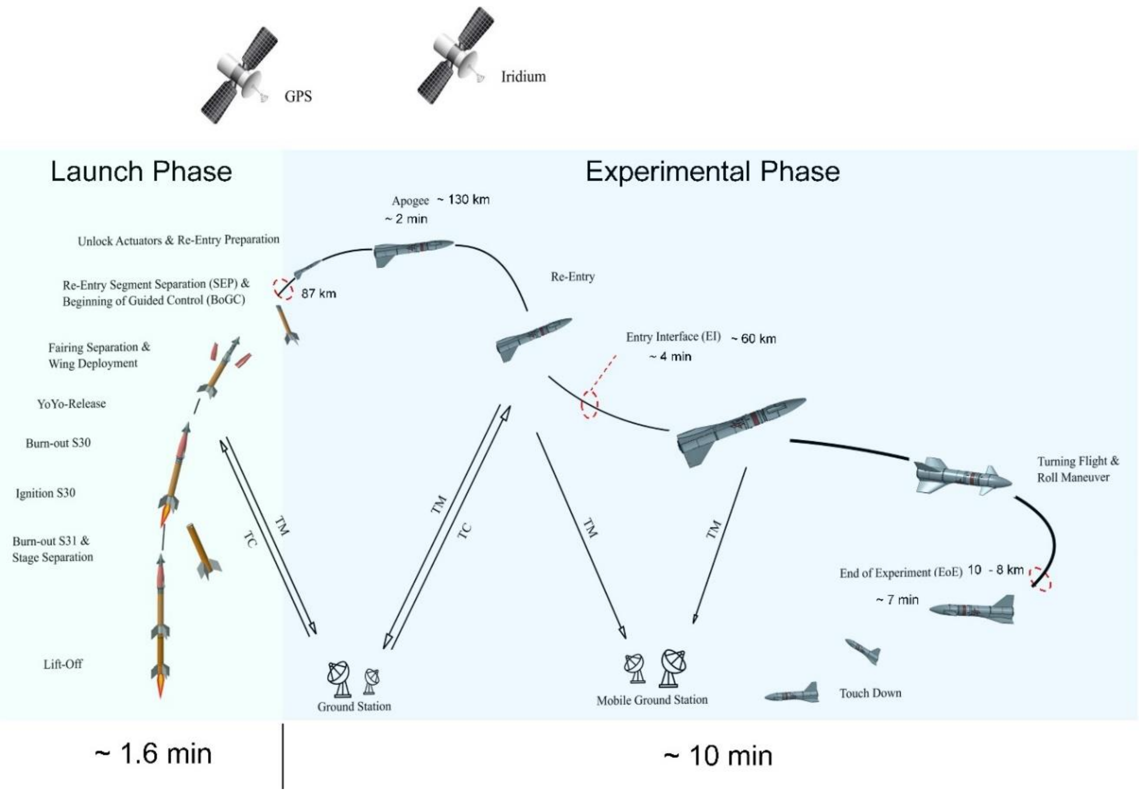

Fig. 1: ReFEx mission flight events and timeline

1.1 Flight Events

The ReFEx mission (see Fig. 1) will be launched on a Brazilian VSB-30 two-stage sounding rocket from the Koonibba Test Range (KTR) in Southern Australia. The flight sequence begins with a vertical lift-off of the launch vehicle, during which the ReFEx payload is enclosed within a triple-split glass-fibre fairing to preserve electromagnetic transparency, aerodynamic symmetry and ensure launch stability. In addition, the fairing is covered in cork for thermal protection during ascent. The VSB-30 rocket is passively stabilized and unguided, which introduces initial trajectory dispersion that must be compensated for later in the mission[2], [4], [7], [8].

Following ignition, the first stage (S31) burns for approximately 14 seconds before separation. The second stage (S30) then ignites and continues to accelerate the payload to apogee, reaching altitudes around 135 km and velocities just above Mach 5. Once burnout occurs around 49 seconds after launch, the Yo-Yo de-spin system is activated to reduce the spin induced for stabilization during ascent [9].

At approximately 84 seconds into the flight, the fairing is jettisoned, and the ReFEx re-entry segment is separated after which the folding wings are deployed and locked into position. During the ballistic coast phase in near-vacuum conditions the vehicle attitude is controlled by a cold gas Reaction Control System (RCS), as aerodynamic surfaces are not yet effective.[4]

Entry Interface (EI) is defined by a dynamic pressure threshold at which the atmosphere becomes dense enough to enable aerodynamic control. For ReFEx this is at approximately 60 km altitude, since EI is dependent on both vehicle velocity and altitude [4]. ReFEx reaches the EI in inverted orientation contrary to classical operational vehicles for aerodynamic control reasons [2], [4]. From this point on, ReFEx transitions into a guided re-entry phase. The canards and rudder manage aerodynamic control, and the vehicle performs a lateral heading change of more than 30° while simultaneously re-orienting into a classical belly-down position. Especially the large heading change is a key mission objective representing return manoeuvres typical for reusable first-stage vehicles [10].

As the vehicle descends from hypersonic to subsonic velocities, it autonomously follows a pre-optimized trajectory toward a predefined End of Experiment (EoE) point. The mission concludes with an unpowered hard landing—no parachute or landing gear is employed—within the designated safety zone in the Woomera Prohibited Area. Onboard data recorders are designed to resist the impact to enable comprehensive post-flight analysis [7], [11].

1.2 Building the Flight Experiment

The PFM integration campaign of the Re-Entry Flight Experiment did start in 2025 alongside some early state environmental verification processes, that are addressed in the following chapters. Since then, many parts of the vehicle have been assembled following the overall AIV-Plan.
Since most of the systems are the first of their kind and are supplied by DLR institutes throughout Germany, each with their own development challenges, an exact delivery date is often very difficult to predict. This can lead to bottlenecks in the supply chain. Besides these difficulties and others like occurring non-conformances, the AIV campaign was able keep momentum and overcome blocking points by changing focus from one module to the other. This agility was only possible due to the flexible design of the Re-Entry segment based on separate modules which can be mechanically assembled separately, see Figure 1.

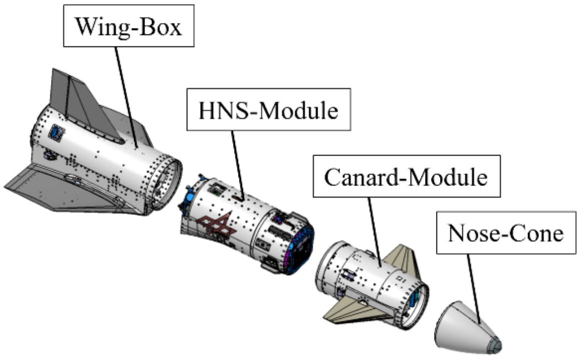

Figure 1: Schematic overview of the Re-Entry segments architecture

1.3 **System Verification**

System verification is being conducted in a two-step approach and follows the methodology applied in the verification of space systems rather than e.g. sounding rockets.

The first step in every hardware deployment is a stand-alone test (SET) in which the health status and function of the hardware is verified against its specification and its own GSE. The hardware is then integrated into the so-called Core Avionics System Testbed (CAST) and thus becomes part of the Flatsat. In this way, a complete functional replica of the vehicle is created step by step.

In the second step, Integrated Equipment Tests (IET) are carried out in the CAST itself. The individual subsystems are no longer tested against their GSE, but in combination, integrated with the other subsystems. In addition to the flight units, the CAST also consists of a dSpace system for simulating environmental parameters and missing hardware elements, as well as the power checkout equipment and several servers for connecting to the ground station and end users.

As soon as the ReFEx flight models (FM) are available, they are subjected to a SET in the same way as the EMs. An FM is then subjected to an IET instead of its EM in the CAST and verified in this way, insofar as this is physically and functionally possible.

In the last step, the functional components are finally removed from the CAST and integrated into the secondary or primary structure.

In ReFEx, it was not possible to apply the same modelling philosophy for all subsystems. As individual key components cannot be removed from the CAST without impairing the function of the CAST itself, the corresponding FM component installed in the Nose Cone, Canard Module, HNS-Segment or Wingbox in turn becomes part of the CAST.

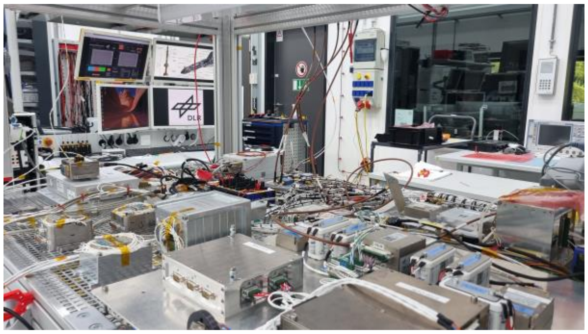

Figure 2: ReFEx CAST Setup

Each module, as mentioned above, contains a harness system that connects the components and subsystems within it. The harness is then routed towards separation points, where the harness from the next module can be attached via separation connectors or components still on the CAST can be connected and tested. This design allows full functional checkouts per module without the necessity of every module being completed. Each missing component or module can be exchanged by a flat-sat build or skipped completely if not needed for a specific checkout.

This strategy is a major advantage when it comes to full functional tests of actuator systems that have multiple actuators and Actuator Control Electronic (ACE) boxes integrated in different modules. This is true for the canard actuators, placed in the canard module and rudder actuator, placed in the wing-box, as they have three separate ACEs where one is set as a termination resistance. The complete system can only check out as a whole. Since the HNS module cannot been used during this checkout, the whole module can easily be replaced by the flat-sat system.

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1.4 Physical Properties Verification

Proper knowledge of the systems, mass, center of gravity and inertia is key to a successful flight. These must be kept within small tolerances due to the combination of a fast ascent with a sounding rocket, the high demands placed on the GNC, and the aerodynamics during the descent All those physical properties will be measured via the high-end mass properties measurement solution by Resonic, called Resonic F. The measurement system consists of a horizontal spring suspended platform with six degrees of freedom to guide the device under test. The springs also contain force sensors that give information about the systems movements in combination with the known spring stiffness in order to calculate the physical properties [12]. This technology was used to measure and verify the mass properties of the Structural Model (SM), see Figure 3.

Figure 3: Mass Properties Measurement by Resonic (SM)

After the final integration of the Flight Model (FM), the maximum deviation from the central axis will be measured during the so-called coning test. Therefore, the FM will be centered on a rotating platform with several measurement points along its central axis. The constant measurement over a full rotation of the system will give the maximum deviation, which is a critical information for the flight control and stability.

1.5 Environmental Verification

The environmental verification on system level will be performed via a vibration campaign, that simulates the vibration loads expected during the ascent of the sounding rocket. The campaign is scheduled for Q1 2026. During the test all systems of the Re-Entry Segment will be fully operational in order to test a flight like configuration.

1.6 Functional Performance - Mechanisms

1.6.1 Wing Load test

During the re-entry in the Earth’s atmosphere each wing will experience load of up to 3.5 kN. These loads need to be tested with a safety factor of 1.25, leading to a test load of 4,5 kN per Wing. In order to bring a combined load of 9 kN onto the system a test special test rig was build up, see Figure 4.

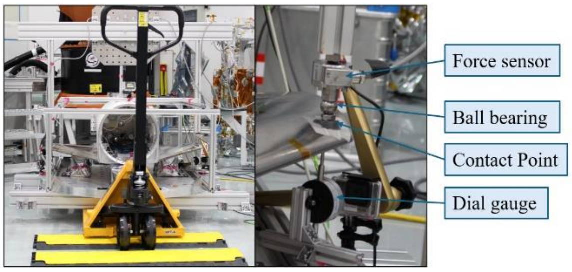

Figure 4: Test rig for the wing load test

Special jigs were designed to enable to force the wings with the expected flight loads. In addition, force sensors were used for monitoring the loads in real time. Underneath the wings dial gauges were placed to measure the displacement. The load is carried into the system via a hydraulic pump represented by a fork lift. A KUKA robot was used as an anchor, carefully placed in the correct position while carrying the force sensors, see Figure 4 (right). This way the load was increased slowly and it was possible to inspect the system behavior instantly.

1.6.2 Fairing deployment

The fairing deployment was tested initially during the SM vibration campaign. All three parts of the fairing were separated at once and caught using a net system. The test did proof the functionality of the three-piece fairing.

Another fairing deployment test is planned after the final PFM vibration test campaign. Previous to this campaign the fairing was placed and trimmed to be as close to the center of gravity as possible. The manual reintegration of the fairing afterwards will be done with the greatest possible offset to the center of gravity. A final measurement of the mass and inertia properties of the system will then show that the manual rebuild of the fairing will not lead into an unbalanced system.

1.6.3 Nose Cone Integration

The Nose Cone module, see Figure 1, is especially challenging when it comes to the merging of primary and secondary structure. Firstly, the cone shaped form of the primary structure without any handling points and a mass of 27 kg complicates the handling of the structure. Secondly, the module consists of three parts, the cone as primary structure, the tip, which is installed from the top and closes the system from one side, and the secondary structure, that carries all the electronic boxes and harness and closes the system from the other side. The tip also contains pressure sensors with fragile pipes, that need to be connected to the secondary structure after both parts are merged. Thirdly, the secondary structure needs to be installed into the cone after the tip in a specific orientation, without touching the pressure sensor pipes. The high mass of the secondary structure of about 14 kg also makes handling it difficult, considering the limited space available. Lastly, the inner part of the module contains many sensors with connection cables that need to be fitted through the secondary structure while it is merged into the cone.

In order to deal with the listed difficulties, a specialized handling cage was designed that can be attached to the industrial robot arm (see also [7]) used to aid the integration campaign, see Figure 5.

Figure 5: Nose Cone in MGSE cage (left), attached to the robot arm (right)

The cage is designed to hold the nose cone in place using a form fit, rather than screws while keeping the bottom rim of the structure free. With this design the same cage can be used later to attach the nose cone to the Canard module.

The assistance and the flexibility of the robot arm during this integration process was essential for multiple steps. The merging of primary and secondary structure with exact positioning, the glueing process, that requires a resting period of eight hours, where the robot could hold the structure in place, see Figure 5 and the outfitting of the cone after the tip was installed, in an ergonomic position, see Figure 6.

Figure 6: Robot assisted tip integration at the Nose Cone

1.7 Physical Properties – Campaign progress

As it is stated in 1.4, the knowledge of the physical properties is very important for a successful flight and reliant manoeuvring of the Re-Entry segment. During the PFM campaign the physical properties will be measured multiple times. Initially after the final integration of all modules including the fairing with a focus on balancing the system by installing trim masses. The second measurement will be performed after the environmental verification campaign and manual deploying and re-integration of the fairing. Finally, a third measurement will be performed using a different measurement technique to verify the first two measurements as the technique used here has good heritage in previous missions.

The first two measurements will be performed using the Resonic-F technology mentioned in 1.4. There the whole Re-Entry segment is placed on a movable table, which carefully moves the system while taking data in order to calculate the centre of gravity, see Figure 3 [7]. After performing the measurement in all three coordinate axes, the systems mass, centre of gravity and inertia is known. The method used here has several advantages. The test stand is small and flexible to have a short setup time and the system is portable and the measurements can be performed in house without moving the system from one place to the other.

The third measurement method is planned to be performed at the AIRBUS test facility in Ottobrunn near Munich. This facility is used by MORABA on a regular basis and provides measurement methods which are standard for the sounding rocket flight business. These include spin balancing as well as measurements of mass, moments of inertia, center of gravity and vibration tests if needed.

In contrast to the Resonic measurement method, the spin balancing is done using a rate table. During the rotation of the table the nose tip off can be measured, too. The device with the rotating table extracts mass and angle values for the trim masses to be adjusted. Several iterations may be needed to fulfill the requirements. The spinning table can measure static and dynamic imbalances, the rotation frequency usually ranges between 0.5Hz and 4 Hz, depending on the vehicle to be measured.

For mass measurement a crane scale with a tolerance <0,2% and range between 10kg and 1000kg is available and sufficient. The Center of Gravity is measured on a Schenck AUD 14 CoG scale.

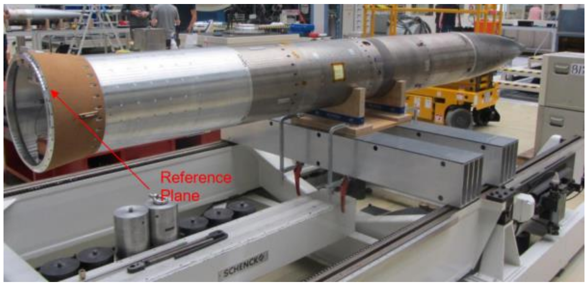

Figure 7: PMWE 3 CoG measurement on Schenck scale (example image)

2 Conclusions

The present paper gives an update of the status Reusability Flight Experiment, ReFEx, which aims to demonstrate key technologies for mainly aerodynamically controlled stages. The PFM campaign of ReFEx is currently ongoing in the Institute of Space Systems in Bremen. Some verification and testing activities during this campaign are shown and highlight the complexities of bringing technology demonstrator to flight. The vehicle is currently in final assembly at the DLR Institute for Space Systems and once complete will run through the final acceptance review before being shipped to the designated launch range, Koonibba Test Range, in Southern Australia. Here the flight experiment will be conducted, gaining valuable flight data for model validation of aerodynamically controlled RLV stages.

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