Present and Future Plans of INNOSPACE's Reusable Launch Vehicle

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***Abstract*— A reusable launch vehicle refers to a rocket designed to be reused either partially or entirely. Various organizations and companies around the world are actively engaged in researching and developing reusable launch technology to perform innovative space missions. In Korea, INNOSPACE successfully launched the HANBIT test launch vehicle (HANBIT-TLV) and is now focusing on researching the foundational technology for reusable launch vehicles using hybrid rockets. INNOSPACE's research and development efforts are centered on creating a demonstration model for reusable launch vehicles. This model, Reusable Launch Vehicle (RLV) demonstrator, is being rigorously tested and validated through various trials conducted at INNOSPACE's test facilities.**

This paper details the progress made by INNOSPACE in developing reusable launch vehicle technology. It presents the flight test results of both the 1-DoF altitude control test and the tethered flight test, providing insights into the performance and capabilities of the RLV demonstrator. Furthermore, it outlines future development plans and discusses how the verified technology will be applied to INNOSPACE's next generation launch vehicles. Through these efforts, INNOSPACE aims to contribute significantly to the advancement of reusable launch vehicle technology and make space exploration more accessible and sustainable.

Keywords*— *Reusable launch vehicle, System design, 1-DoF Altitude Control Flight Test, Tethered Flight Test, Vertical Takeoff and Vertical Landing(VTVL), Guidance, Control

I. Introduction

The concept of reusable launch vehicles, where a rocket launched into space is reused, has existed since the 1960s. This concept was first realized in NASA's Space Shuttle program. However, the Space Shuttle was not a fully reusable system, and due to the complexity of its systems, challenges in maintenance, low launch frequency, and safety issues, the program ended on July 21, 2011, with the return of the Space Shuttle Atlantis.

After the conclusion of the Space Shuttle program, reusable launch vehicle technology was pursued by private space companies. In December 2015, SpaceX successfully recovered the first stage of its Falcon 9 rocket. During this event, SpaceX demonstrated a new operational method called Vertical Takeoff Vertical Landing (VTVL), which is different from the operational concept of the Space Shuttle, by vertically landing the first stage of Falcon 9.

Initially, the idea of vertically landing a launched rocket was considered unrealistic, but as the stability of VTVL was proven, the reduction in operational costs and a significant increase in the reuse cycle of launch vehicles highlighted the efficiency and commercial potential of reusable rockets.

INNOSPACE has also begun developing the foundational technology for reusable launch vehicles while developing space launch vehicles using hybrid rocket engines. As an early achievement, a reusable launch vehicle VTVL demonstrator was developed, and through verification tests, the utility of vertical takeoff and landing using a hybrid rocket engine is being demonstrated.

II. Present of INNOSPACE's Launch Vehicle

INNOSPACE, a pioneering South Korean aerospace company, is developing its reusable launch vehicle technology with a focus on enhancing the accessibility and efficiency of space launches. INNOSPACE's key project, the HANBIT series, is designed to support both commercial and governmental satellite launches. As of now, the HANBIT-TLV, a suborbital test launch vehicle as shown in Fig. 1, has completed several critical tests, paving the way for future orbital launches. INNOSPACE is also exploring the use of hybrid rocket engines, which offer a balance between cost, safety, and performance.[1]

INNOSPACE has been working closely with global partners to streamline manufacturing processes and reduce launch costs, aiming to compete in the growing small satellite market. INNOSPACE's reusable technology aims to increase the frequency of launches while minimizing the environmental impact, contributing to the commercialization of space access.

Fig. 1. HANBIT-TLV Launch

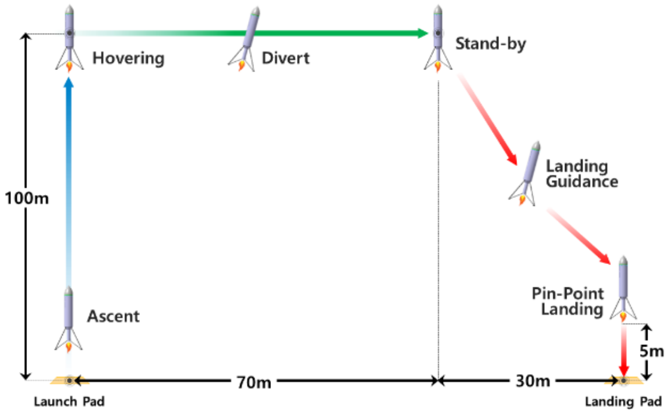

Fig. 2. Mission Configuration

TABLE I. MISSION REQUIREMENTS

REQUIREMENTS	
Flight Time	>60 sec.
Altitude	> 100m
Distance	>100m
Landing Velocity	<1.3m/s
Tracking Accuracy	<3m
Attitude Accuracy	<5deg
End Position Accuracy	<1m
Mission Status	Vertical take-off & Vertical landing

III. DESIGN OF REUSABLE LAUNCH VEHICLE DEMONSTRATOR

A. *Design of RLV VTVL Mission*

INNOSPACE has been conducting research on reusable launch vehicle technology and perform the final mission configuration flight test of the demonstrator.[2]

The final mission configuration flight test of the RLV VTVL demonstrator is a simulated flight test for a reusable launch vehicle that performs a flight and re-landing. As shown in Fig. 2, the vehicle will ascend vertically to an altitude of 100 meters and then fly toward the landing site, located 100 meters away from the launch point, landing vertically at the precise target location. The target requirements for each flight phase of the final mission configuration flight test have been set as shown in Table 1.

B. *Design of RLV VTVL Demonstrator*

To develop reusable launch vehicle technology, a VTVL demonstrator was first designed to verify vertical takeoff and landing. The VTVL demonstrator is a test vehicle for verifying the guidance algorithms and control performance.[3] The structural design was carried out considering the inclusion of only the minimal components necessary for validation, such as the onboard computer, sequence control unit, control system and valve unit, fuel tank, fuel and combustion chamber, and flight termination system. The system configuration of each unit is shown in Fig. 3.

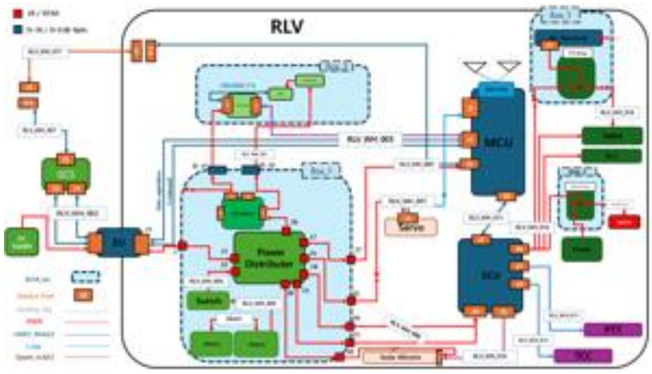

Fig. 3. System Configuration of VTVL Demonstrator

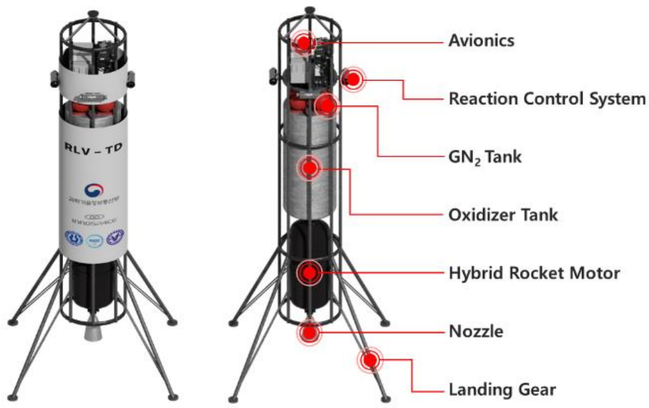

Fig. 4. Concept Design of VTVL Demonstrator

In the conceptual design of the reusable launch vehicle VTVL demonstrator covered in this paper, the layout was conceived as shown in Fig. 4 to initiate the design. The performance of the demonstrator was set to a size that allows for combustion tests and flight tests at INNOSPACE 's vertical static hot-fire test facility, with the specific values outlined in Table 2.

During the development process, the capacity of the oxidizer tank was increased to enhance control authority, and a satellite navigation system was added to obtain more precise positional and altitude data. The resulting design of the modified VTVL demonstrator is shown in Fig. 5. The components onboard the demonstrator were organized into sections according to their roles.

The VTVL demonstrator will verify the reusable transport capabilities of the vehicle through a series of validation tests. Control performance will be verified prior to flight through valve control tests, combustion tests, and thrust vector control tests. Additionally, altitude control tests and tethered flight tests will evaluate the application of VTVL technology to the launch vehicle.

This paper describes the process up to the tethered flight test. It explains how each validation test was conducted and discusses the significance of the tests in the overall verification process.

TABLE II. SPECIFICATIONS OF VTVL DEMONSTRATOR

SPECIFICATIONS	
Total Mass	300kg
Dry Mass	190kg
Max Thrust	390kgf
Total Impulse	1,580kgf/s
Length	3.5m
Diameter	0.6m
Landing Parts Length	1.5m

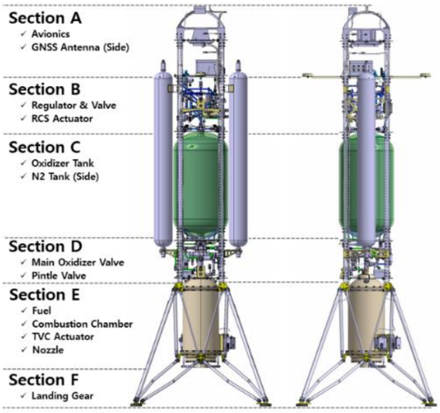

Fig. 5. Design of VTVL Demonstrator

IV. VERIFICATION OF REUSABLE LAUNCH VEHICLE

A. Avionics and Valve System Integration Test

The VTVL demonstrator performs various types of valve control. To ensure proper engine combustion, the pressure in the tanks and combustion chamber must be controlled. The internal piping pressure control of the demonstrator is managed through solenoid valve control via the sequence control unit.

To achieve VTVL, altitude must be controlled according to the takeoff, flight, and landing phases. Controlling altitude requires adjusting thrust, which is regulated by controlling the pintle valve that adjusts the oxidizer flow rate.

During flight, there are disturbance factors such as mechanical movements of the structure, thrust misalignment, and changes in the center of gravity due to combustion, which may cause rotation. Disturbances causing roll rotation during flight are counteracted by controlling the RCS valves, which stabilize the demonstrator’s attitude by expelling nitrogen gas to generate compensating thrust.

Valve unit tests and integration tests were conducted to verify the normal operation and performance of each valve. (Fig. 6, 7) In particular, during the integration tests, the opening and closing of valves were confirmed according to the flight sequence, verifying that the control commands for internal piping pressure control, thrust control, and attitude control reached and operated the respective valves.

Additionally, the pintle valve, which controls thrust, was not only subjected to operation tests but also to oxidizer filling tests to confirm that the oxidizer flow rate was properly controlled.

Fig. 6. Valve System Control Test

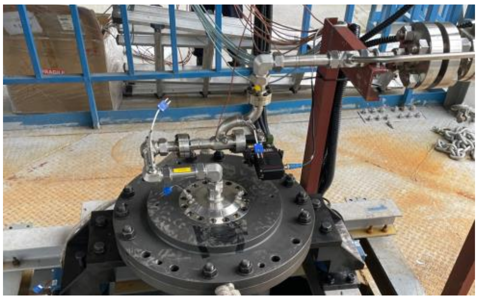

Fig. 7. Pintle Valve Control Test

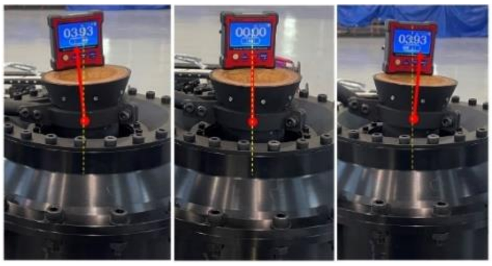

Fig. 8. Thrust Vector Control Test

Fig. 9. Thrust Vector Control Hot-firing Test

B. *Thrust Vector Control Hot-firing Test*

The VTVL demonstrator stabilizes its attitude during flight by controlling the thrust vector. By moving the nozzle through an actuator, the direction of thrust changes, which allows the VTVL demonstrator to generate torque in the pitch and yaw axes.

The thrust vector control test validates performance through both the nozzle actuation test and the thrust vector control test during combustion. The nozzle actuation test (Fig. 8) verifies the change in nozzle angle in response to actuator movement relative to the demonstrator's structure. During this test, the relationship between the actuator angle and the nozzle angle is measured and used accordingly.

The thrust vector control test during combustion controls the actuator to move the nozzle, changing the direction of thrust during the combustion process. Due to the nature of the hybrid engine, the position of the pivot point and the force required for actuation can change as the flexible seal compresses during combustion. The thrust vector control test during combustion (Fig. 9) confirms the relationship between the actuator angle and nozzle angle, which is then applied to flight simulations to validate flight performance.

V. VALIDATION OF REUSABLE LAUNCH VEHICLE

A. *1-DoF Altitude Control Flight Test*

The 1-DoF altitude control flight test is a flight test designed to verify stable thrust control. It tests the takeoff and landing of the demonstrator under constrained conditions, with only vertical freedom of motion, as shown in Fig. 10. Since this test involves only vertical motion, there is no need for attitude control, simplifying the guidance and control process. Successfully achieving stable thrust control through the 1-DoF altitude control test ensures the performance of the VTVL demonstrator required for flight tests.

The altitude graph in Fig. 11 shows that while an overshoot occurred around the 6-second mark, the altitude converged to the target. Additionally, during the landing process, the altitude sequentially decreased according to the guidance profile.

In the vertical velocity graph of Fig. 12, the flight velocity converged below the required speed during flight, and the landing was successfully completed with the velocity maintained below the landing speed requirement.

Through the 1-DoF altitude control flight test, the demonstrator reached the intended target altitude via thrust control, and the altitude was maintained according to the guidance profile, even with changes in mass and moment of inertia due to propellant consumption.

This test verified the performance of the thrust control and algorithm of the reusable launch vehicle.

B. *Tethered Flight Test*

The tethered flight test is designed to verify not only stable thrust control but also stable attitude control. As shown in Fig. 13, the rails used to constrain movement in the altitude control flight test are removed, allowing for 6 degrees of freedom. However, the demonstrator's position is limited by wires to prevent collision with the vertical tower. This test ensures the stability of both translational and rotational movements of the reusable launch vehicle.

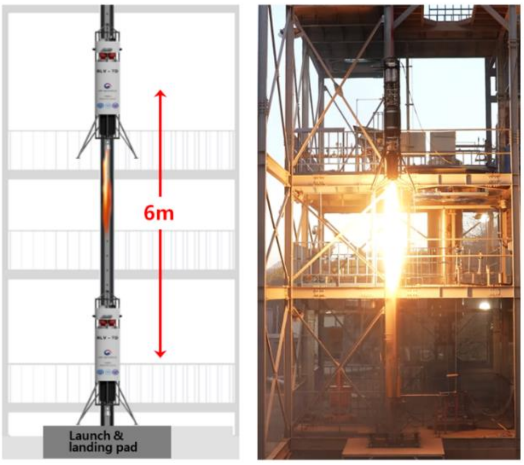

Fig. 10. 1-DoF Altitude Control Flight Test

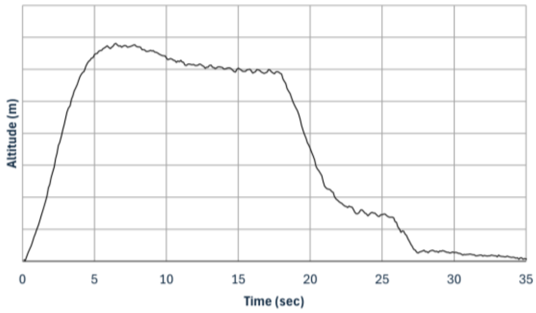

Fig. 11. 1-DoF Altitude Control Result (Altitude)

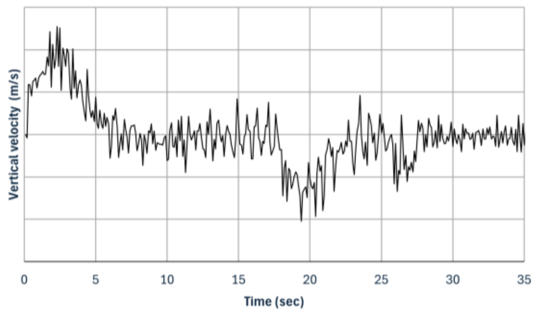

Fig. 12. 1-DoF Altitude Control Result (Vertical Velocity)

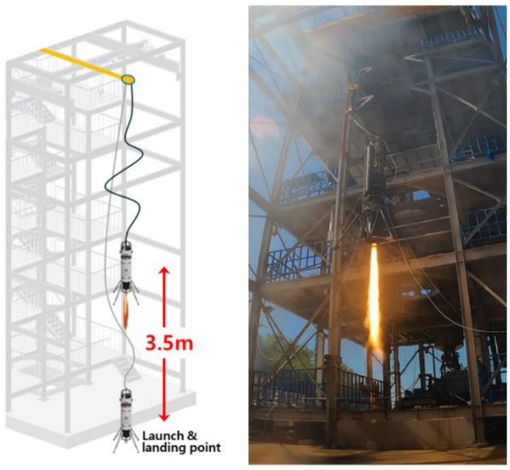

Fig. 13. Tethered Flight Test

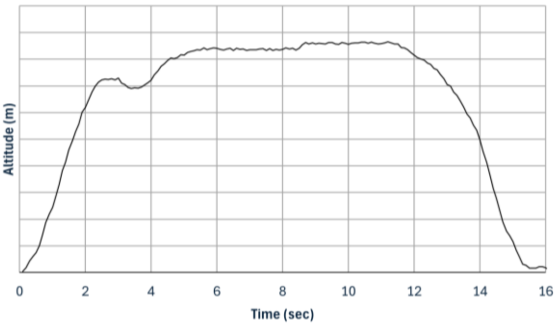

Fig. 14. Tethered Result (Altitude)

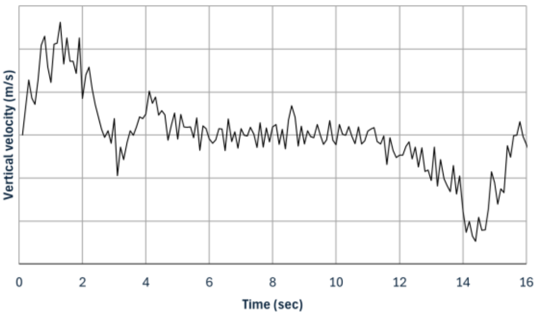

Fig. 15. Tethered Result (Vertical Velocity)

In the altitude graph in Fig. 14, after 3 seconds, the thrust vector control activates to maintain attitude control, causing a brief fluctuation in altitude. However, the attitude quickly stabilizes, and the altitude control system works to maintain the target altitude. While some error in altitude control was observed, the system overall maintained stability.

In the vertical velocity graph in Fig. 15, descent begins after 12 seconds, and the descent velocity reaches its maximum at 14 seconds. After 14 seconds, the velocity quickly decreases, reaching the required landing speed by 15 seconds, and the demonstrator successfully lands after 15 seconds.

The success of the tethered flight test verifies that the demonstrator can stably control translational and rotational movements along all axes during flight, confirming the effectiveness of the reusable launch vehicle's control systems.

VI. FUTURE PLANS OF INNOSPACE

In the future, INNOSPACE plans to advance this RLV technology by scaling up the capabilities of the HANBIT series to handle larger payloads and longer missions. The ultimate goal is to develop a fully reusable launch system, where both the first and second stages can be recovered and reused.

This would significantly cut down launch costs, making frequent and low-cost access to space a reality. Additionally, INNOSPACE aims to establish itself as a key player in the international space launch market, leveraging their advancements in hybrid engine technology and reusable systems to offer competitive solutions for a wide range of customers.

Fig. 16. HANBIT Line-ups

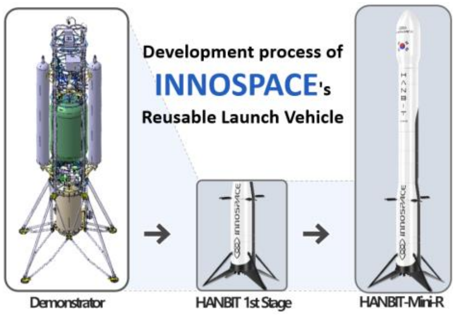

Fig. 17. Development Process of RLV

VII. CONCLUSION

This study describes the design of a RLV VTVL demonstrator and the validation tests conducted to verify reusable launch vehicle technology. Using the designed VTVL demonstrator, the 1-DoF altitude control test and tethered flight test were performed to verify and analyze the guidance and control algorithms, valve control performance, thrust control, and thrust vector control performance.

To prepare for the upcoming final mission configuration flight test, the demonstrator will be redesigned with improved real-time guidance and control performance, followed by further flight testing.

The development and flight test results of the reusable launch vehicle demonstrator will serve as foundational research for the future reuse of the HANBIT space launch vehicle.

The VTVL demonstrator is planned to be applied to the HANBIT launch vehicle, as shown in Fig. 16 and 17. This technology marks a significant step in advancing reusable launch vehicles, which will contribute to reducing launch costs and increasing the frequency of missions. Furthermore, as INNOSPACE continues to develop and refine this technology, it is expected to play a key role in the future of the space industry, enabling more accessible and sustainable space exploration and commercialization.

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