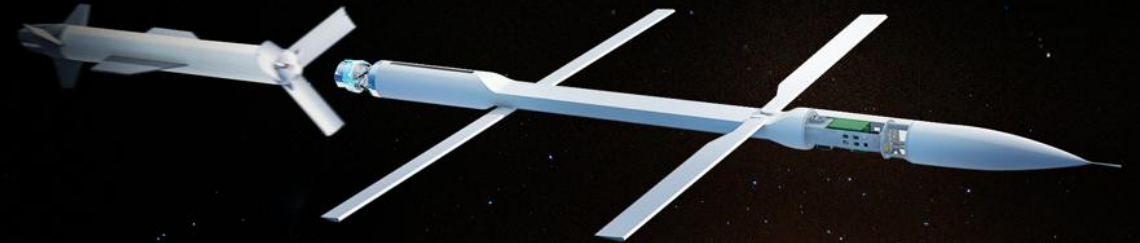




다목적 하이브리드 재진입 무인시스템 개발
Development of a Multipurpose Hybrid Reentry Unmanned System (HyRUS)

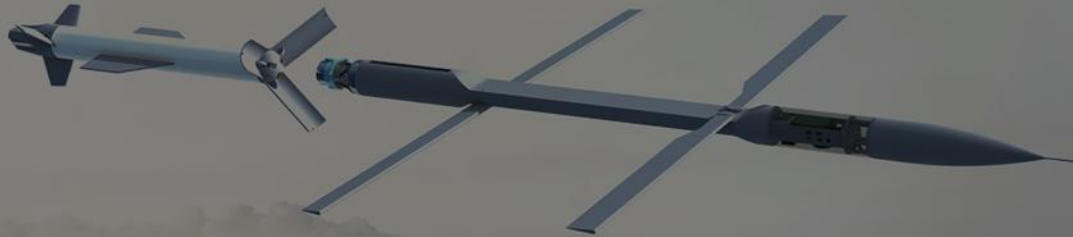
Assoc. Prof. Sunghun Jung
Dept. of Aerospace Engineering, Chosun University
CEO, Unmanned System



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SYSTEM** www.unmansys.com

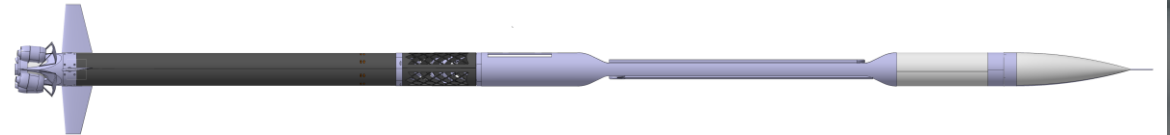


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| 04 | Test Equipment Development | ... | 시험 장비 개발 |
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Introduction

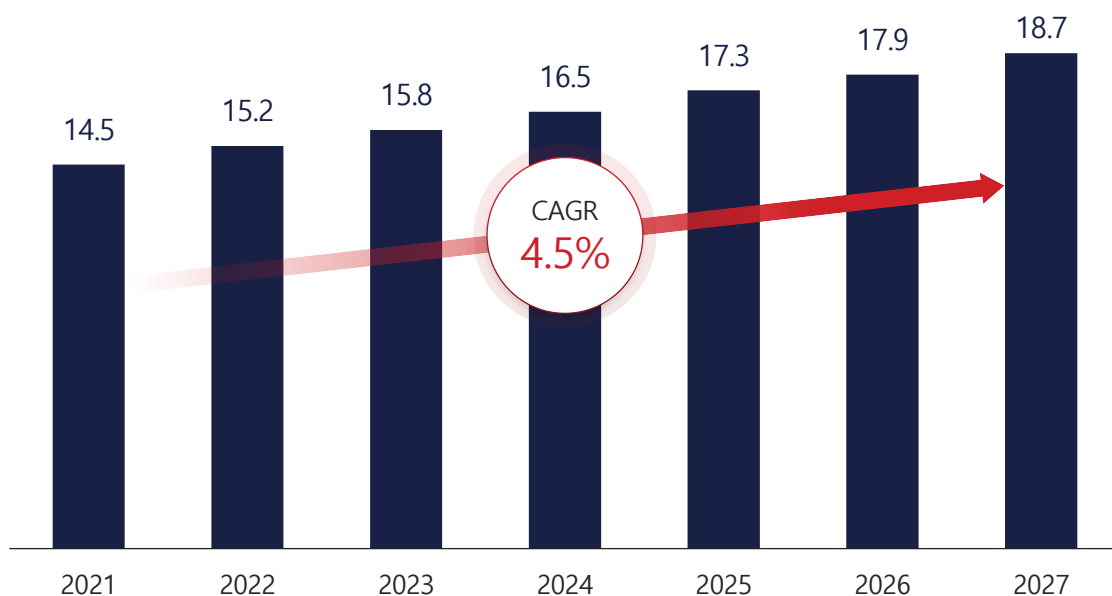
서론



Motivation #1

- The global environmental-monitoring market is growing from **USD 14.5 billion in 2021** to **USD 18.7 billion by 2027** (CAGR 4.5 %)

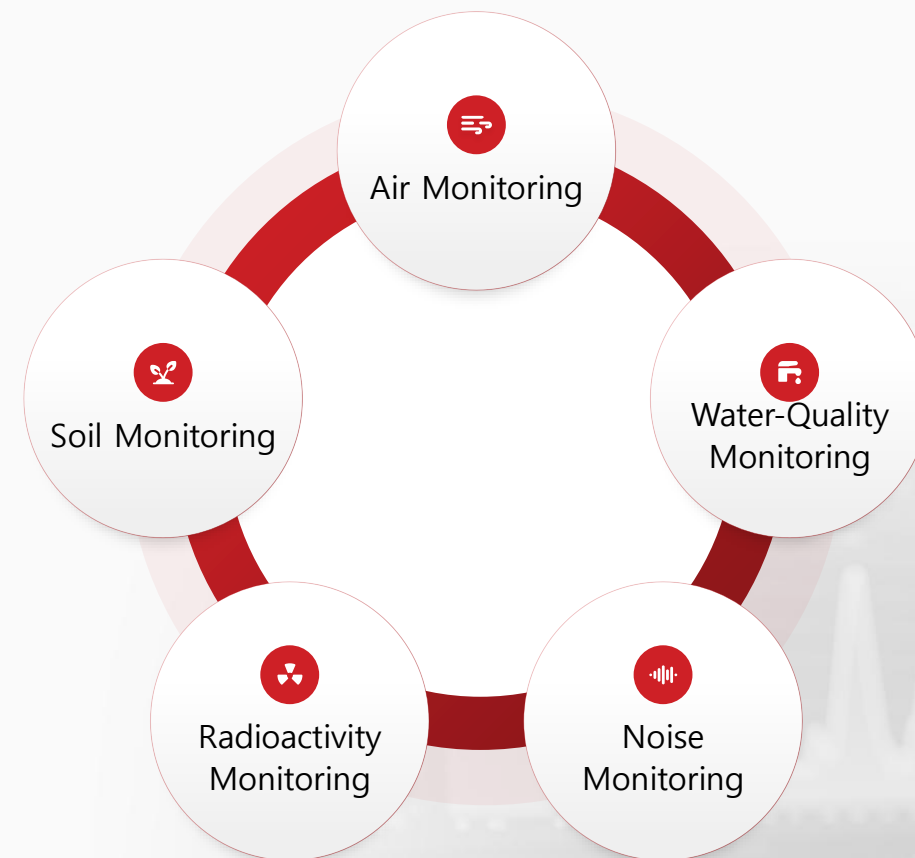
Global Environmental Monitoring Market

 (Unit : billion dollar)
 (단위: ×1.4조원)


✓ **North America** holds the largest share (50.6 %), followed by **Europe** (25.5 %).

✓ **Particulate-matter detection** (PM2.5 & PM10) accounts for 47.2 % of the total market.

Major Environmental-Monitoring Segments



Necessity of Environmental Data

- Fine dust (PM) and hazardous gases (NO_x , SO_x , etc.) disperse from power plants, industrial complexes, and agricultural zones via wind.
- Pollutants migrate into residential and neighboring areas, requiring close-range atmospheric monitoring of inflow, spread, and fluctuation.

Growing Demand

Accurate weather forecasting is increasingly critical in the era of global warming.

1

Remote-Sensing Gap

Satellite data, though continuous, must be periodically calibrated with in-situ observations.¹

2

In-Situ Constraints

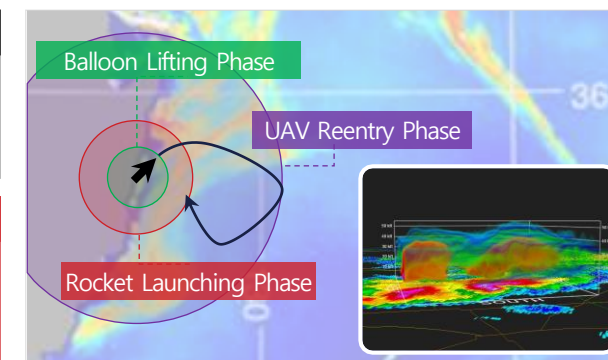
Accessing high altitudes for direct measurements is more expensive than using ground stations.

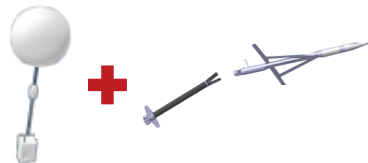
3

Proposed Solution

Combine the advantages of balloon, rocket, and UAV:
 a balloon-lifted, rocket-launched, hybrid reentry UAV*.

4



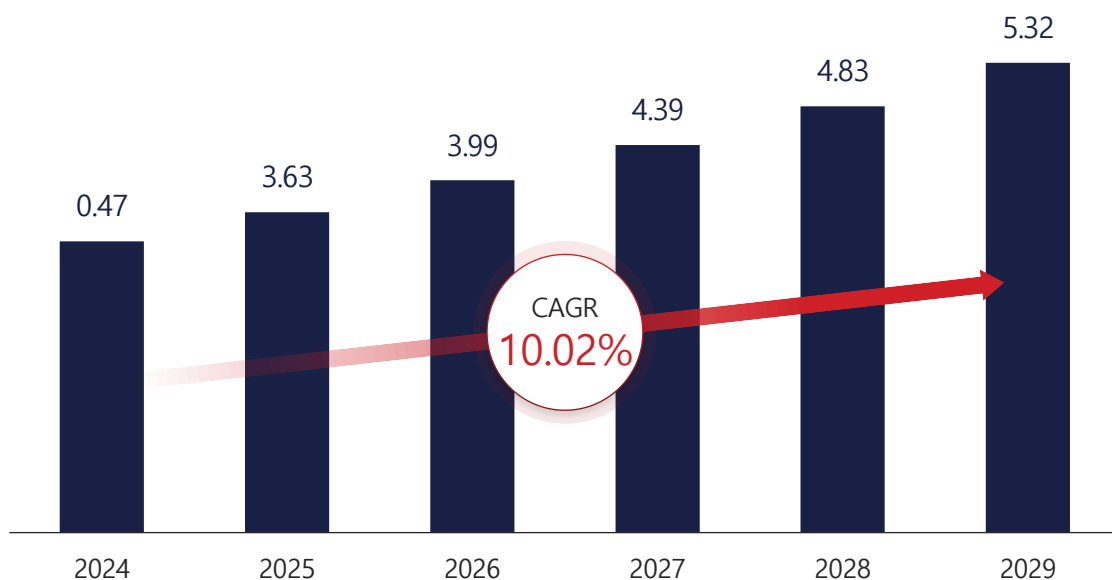
Platform	Observation Aircraft	Observation Balloon	Expendable Sounding Rocket	Reusable Sounding Rocket	*Proposed Method
					
Reusability	Yes	Limited	No	Yes	Yes
Operational Altitude	< 21 km	< 30 km	> 50 km	> 50 km	> 60 km
Station-Keeping	Yes	Limited	No	No	Yes
Precision Recovery	Yes	No	No	Yes	Yes

1. G. Balsamo et al., "Satellite and In situ Observations for Advancing Global Earth Surface Modelling : A review, "Remote Sensing, vol. 10, no. 12, pp. 2038-2109, Dec. 2018

Motivation #2

- The demand for cost-effective **suborbital microgravity** platforms (**60 ~ 80 km altitude**) is increasing for both scientific and industrial research.

Global Microgravity Research Market

 (Unit : billion dollar)
 (단위: ×1.4조원)


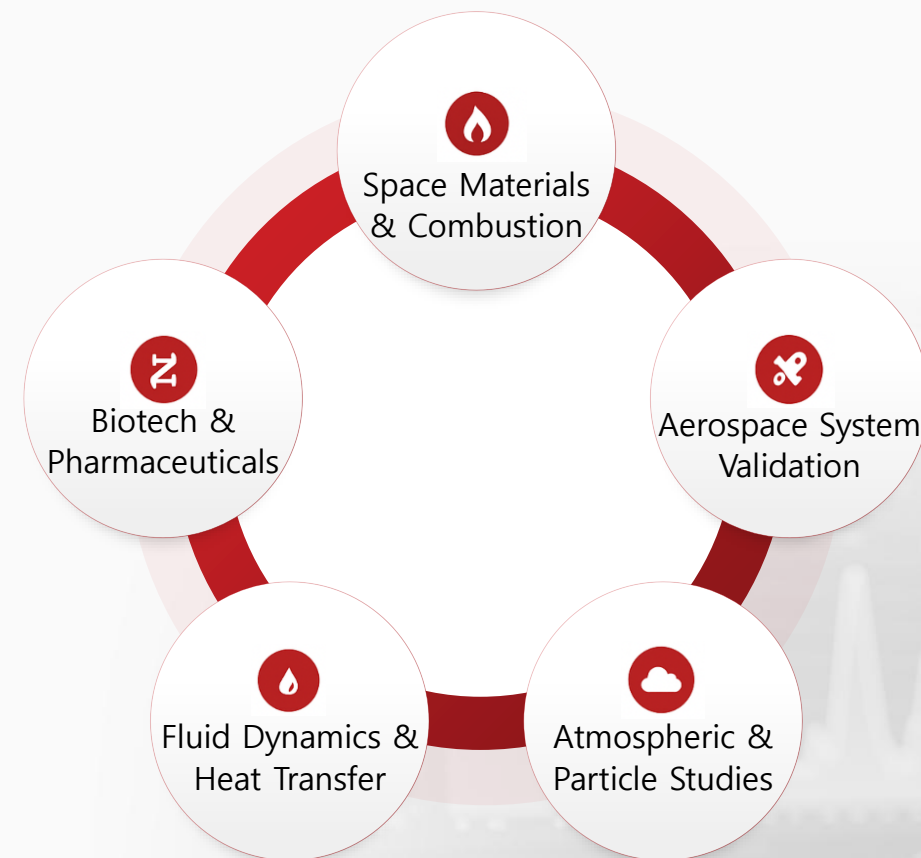
✓ **North America** expected to grow at a CAGR of $\approx 9.8\%$, with strong institutional and commercial microgravity-research activity.

✓ **Asia-Pacific** region leads in growth momentum, with a projected CAGR of $\approx 10.5\%$, driven by China and India

Source: The Business Research Company Report

<https://www.thebusinessresearchcompany.com/market-insights/microgravity-research-market-insights-2025>
<https://dataintel.com/report/microgravity-research-market>

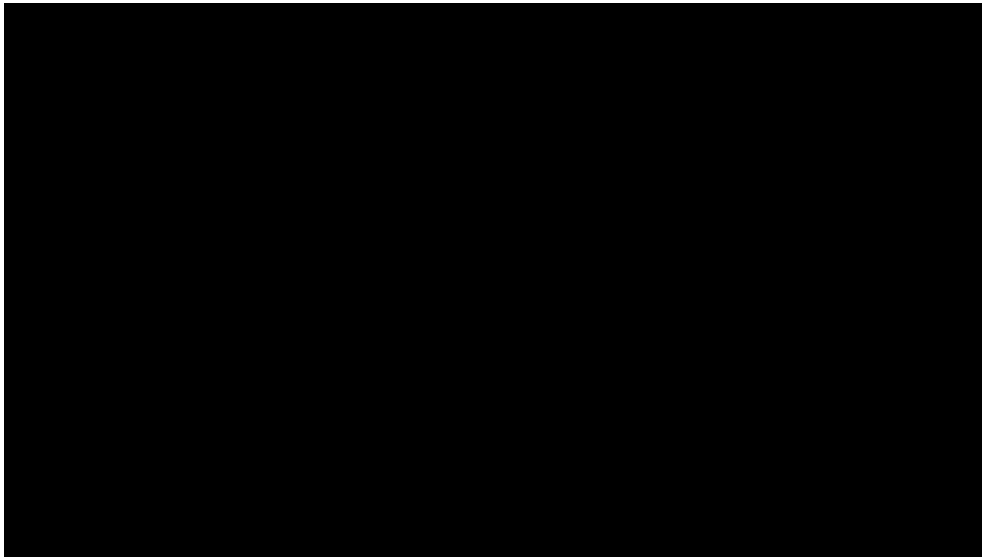
Major Suborbital Microgravity Segments



How to approach?

- **Rockoon:** Balloon-assisted rocket launch at high altitude (Stratospheric)

- ✓ A suborbital rocket is launched directly from a high-altitude balloon platform, utilizing near-space conditions with minimal aerodynamic drag.
- ✓ The Rockoon combines the lifting capability of a balloon with the propulsion of a rocket, enabling microgravity or upper-atmospheric experiments.



1. **Balloon-Rocket Integration:** A small rocket is mounted beneath a high-altitude balloon platform.
2. **Ascent Phase:** The combined system ascends to near-space altitude (~30–40 km) with stable lift.
3. **Mid-Air Launch:** Once the desired altitude is reached, the rocket is released and ignited in near-vacuum conditions to minimize aerodynamic losses (> 60 km Target).
4. **Scientific Operation:** Performs microgravity or upper-atmospheric experiments during the suborbital flight.

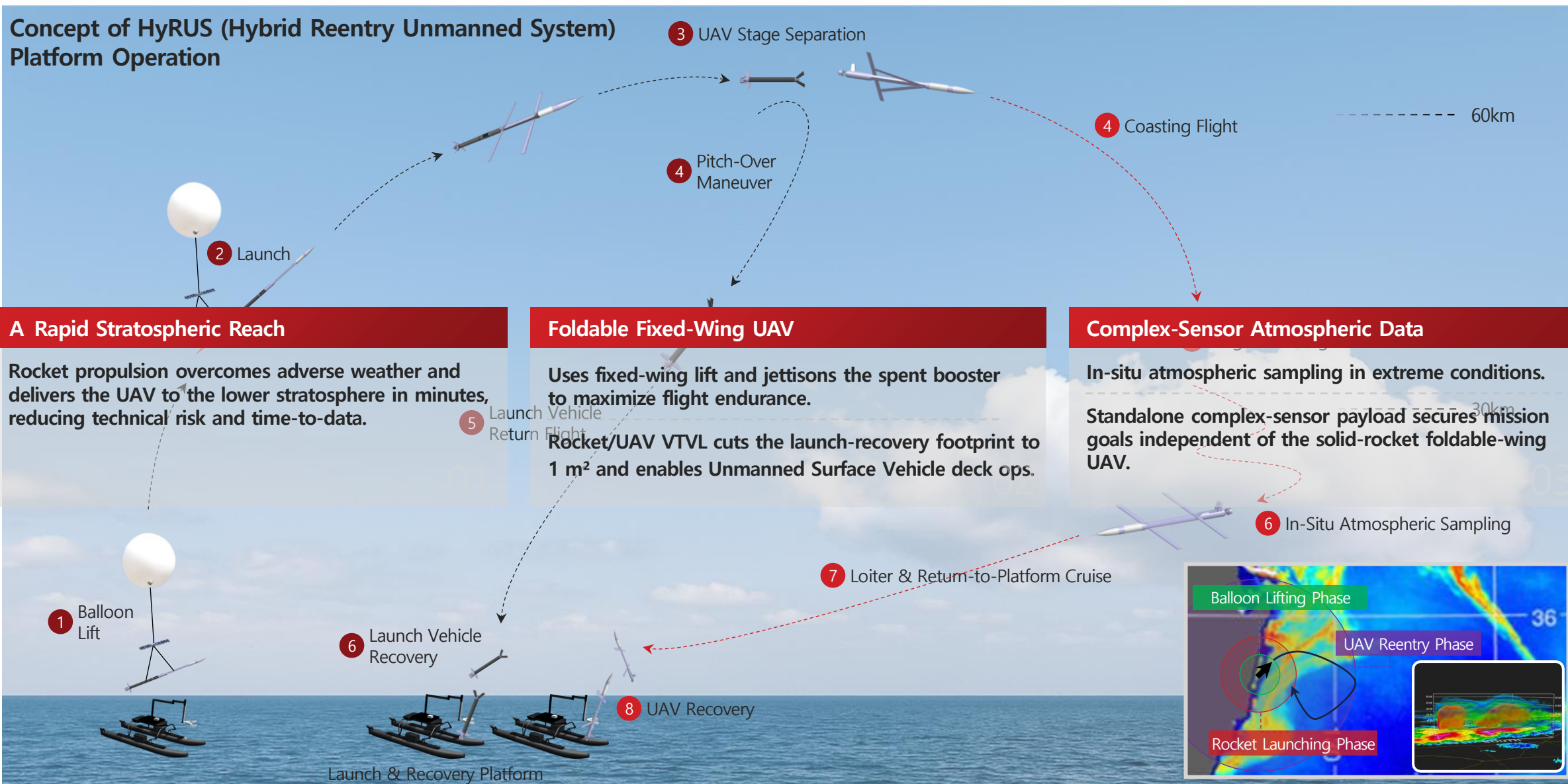
Where to start?

The first step toward a realizable "**Multipurpose Hybrid Reentry Unmanned System (HyRUS).**"

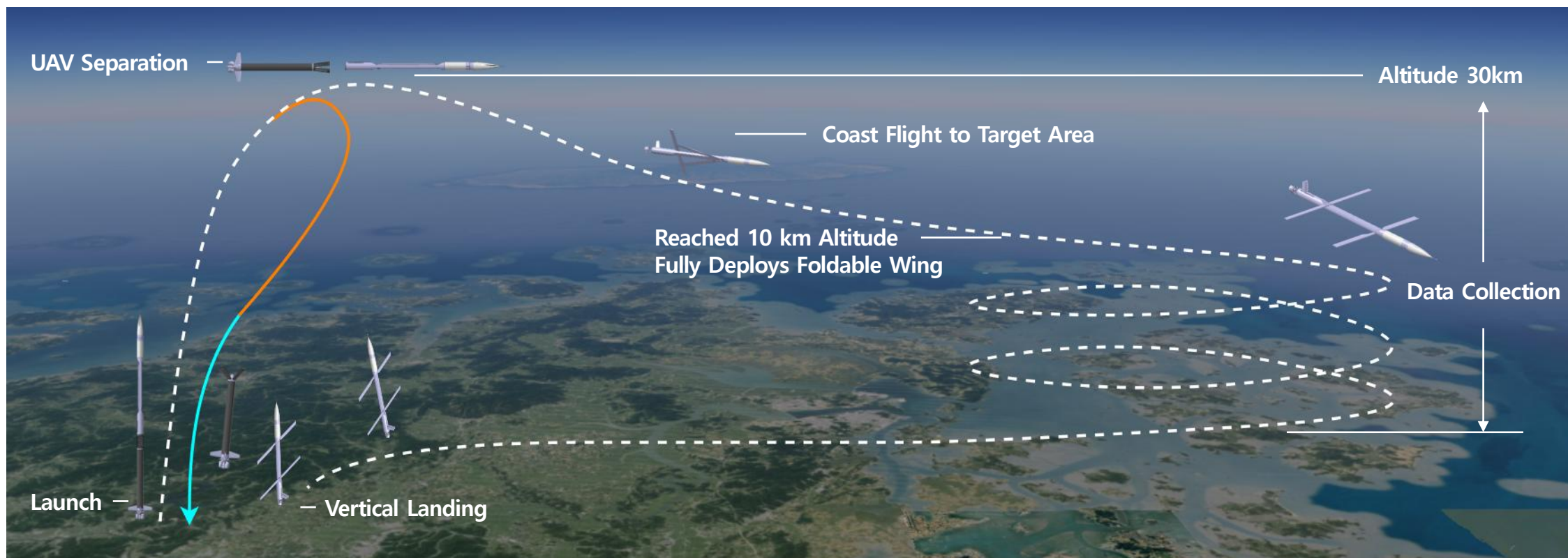


Solution: **Rapid Stratospheric Access** with a Rocket-Launched, Foldable-Wing UAV

Concept of HyRUS (Hybrid Reentry Unmanned System) Platform Operation



Current Status: Developing a Scaled RLV(Reusable Launch Vehicle) for the UAV



Demonstrating...

VTVL(vertical take-off and vertical landing) recovery.

To demonstrate vertical take-off-and-landing recovery, development of a small-scale launch vehicle scaled for 150 m altitude was required.

01

Validating...

Control feasibility under rocket-jet propulsion.

To maximize in-atmosphere fuel efficiency, a synergistically integrated rocket-jet propulsion system is proposed, and its vertical-take-off-and-landing control feasibility requires verification.

02

Providing...

An in-flight environment for UAV separation testing.

A test environment is needed to demonstrate effective in-air UAV separation and evaluate collision-avoidance control during the coasting-flight phase.

03



Vehicle Development

기체 개발 →

System Requirements of the Original RLV and the UAV

Requirements

Category	Requirement	Notes
Mission Altitude	Target: 30 km	Peak altitude with payloads
Maximum Size	- Width, Depth, Hight: $\leq 0.3\text{ m}$, $\leq 0.3\text{ m}$, $\leq 5\text{ m}$ - Weight: $< 25\text{ kg}$	Derived requirements—most notably the need for a small, easily transportable UAV to support logistics and deployment
Payload	- Complex-sensor suite (PM2.5/PM10, NO_x/SO_x, Temperature, Humidity, Pressure, Location) $\leq 3\text{ kg}$, $\leq 3\text{ m}$ length, $= 0.1\text{ m}$ Diameter @ folded	Self-powered, autonomous data downlink
Propulsion	- Rocket thrust: 3 kN peak, ~30 s burn - Turbojet cruise: 250 N @ 1 km	Hybrid integration for fuel efficiency
VTVL & Recovery	- VTVL footprint $\leq 1\text{ m}^2$ - Deck ops on unmanned surface vessel	Control autorotation & propulsive landing
Environmental Tolerance of Avionics	- Temperature: $-60\text{ }^{\circ}\text{C}$ to $+60\text{ }^{\circ}\text{C}$ - Pressure: 0.01 – 1 atm - Wind gusts up to 12 m/s	Stratospheric low-pressure chamber tested
Autonomy & Comm.	- In-flight separation actuation - Data downlink. via SAT, LTE - Autonomous recovery with USV(Unmanned Surface Vehicle)	YOLO-based recovery vision on USV, autonomous recovery

System Requirements of the Scaled RLV and the UAV

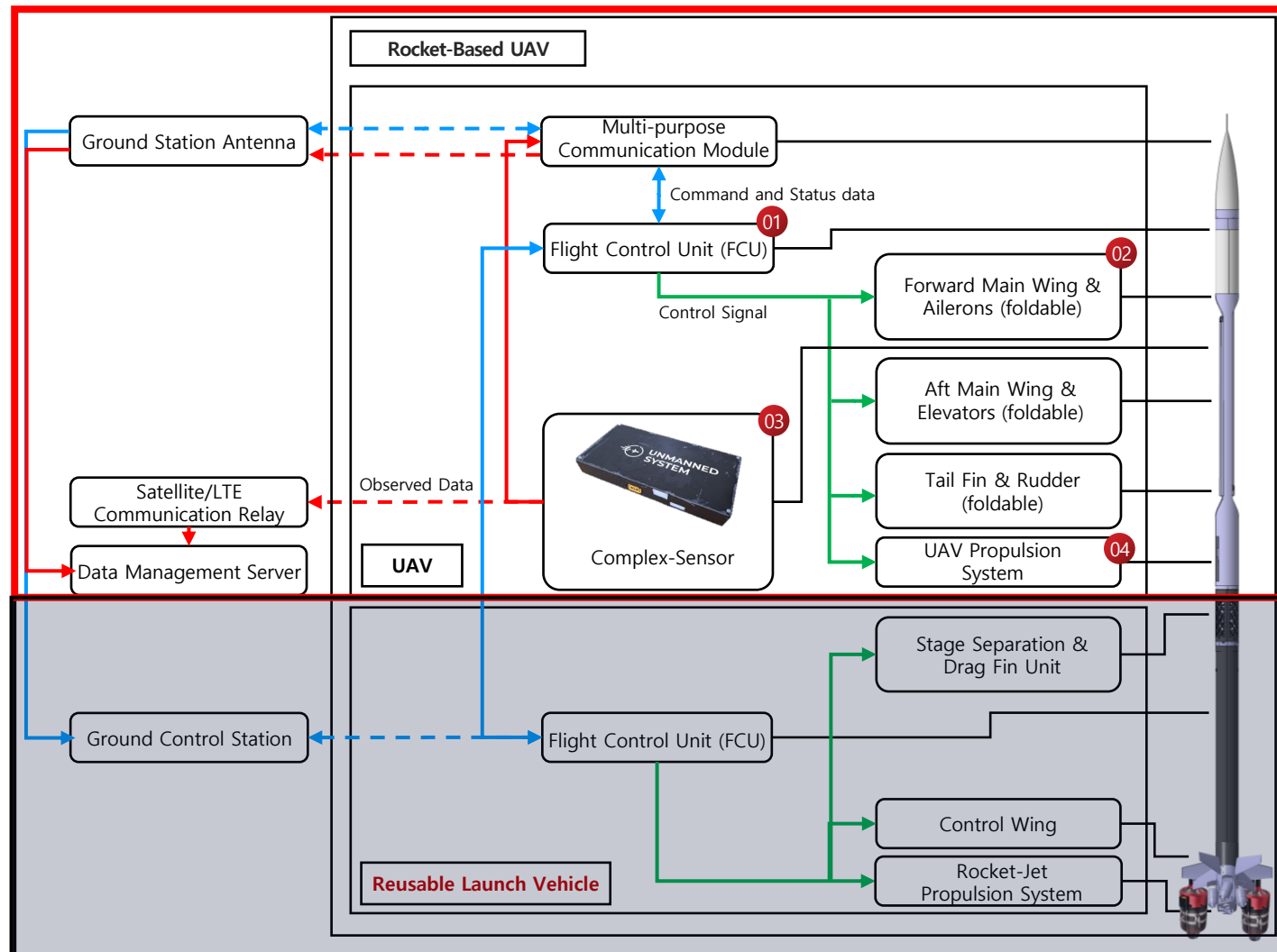
Requirements

Category	Requirement	Notes
Mission Altitude	Target: 150 m	150 m scale-down for VTVL validation
Maximum Size	- Width, Depth, Hight: $\leq 0.3\text{ m}$, $\leq 0.3\text{ m}$, $\leq 5\text{m}$ - Weight: $< 10\text{ kg}$	Derived requirements—most notably the need for a small, easily transportable UAV to support logistics and deployment
Payload	- Mockup UAV $\leq 3\text{ kg}$, $\leq 3\text{ m}$ length, $= 0.1\text{ m}$ Diameter	Dummy payload mass and data-acquisition instrumentation for investigating UAV separation dynamics
Propulsion	- Rocket thrust: 100 N peak, ~3 s burn - Turbojet cruise: 250 N @ 1 km	Hybrid integration for fuel efficiency
VTVL & Recovery	VTVL footprint $\leq 1\text{ m}^2$	Demonstrate propulsive landing without platform
Environmental Tolerance of Avionics	- Temperature: $-60\text{ }^{\circ}\text{C}$ to $+60\text{ }^{\circ}\text{C}$ - Pressure: 0.01 – 1 atm - Wind gusts up to 12 m/s	Stratospheric low-pressure chamber tested
Autonomy & Comm.	- In-flight separation actuation - Real-time telemetry. via 433mHz Radio	Telemetry and manual override capability for contingencies



System Design of the UAV Mock-up

System Architecture



01 Flight Control Unit

- UAV guidance and flight control after rocket separation.
- Coast flight management toward mission area.
- Wing deployment timing determination.
- Flight control during mission execution.
- Return-to-launch-site guidance and landing control.

02 Foldable Wing

- Wings remain stowed during near-supersonic rocket-powered ascent to minimize aerodynamic drag.
- After RLV separation and deceleration to the optimal speed, wings deploy to generate lift and transition to aerodynamic flight.

03 Complex-Sensor

- Combines gas, temperature/humidity, and pressure sensors in a single atmospheric data acquisition module.
- Continuously streams data to ground via satellite and LTE.

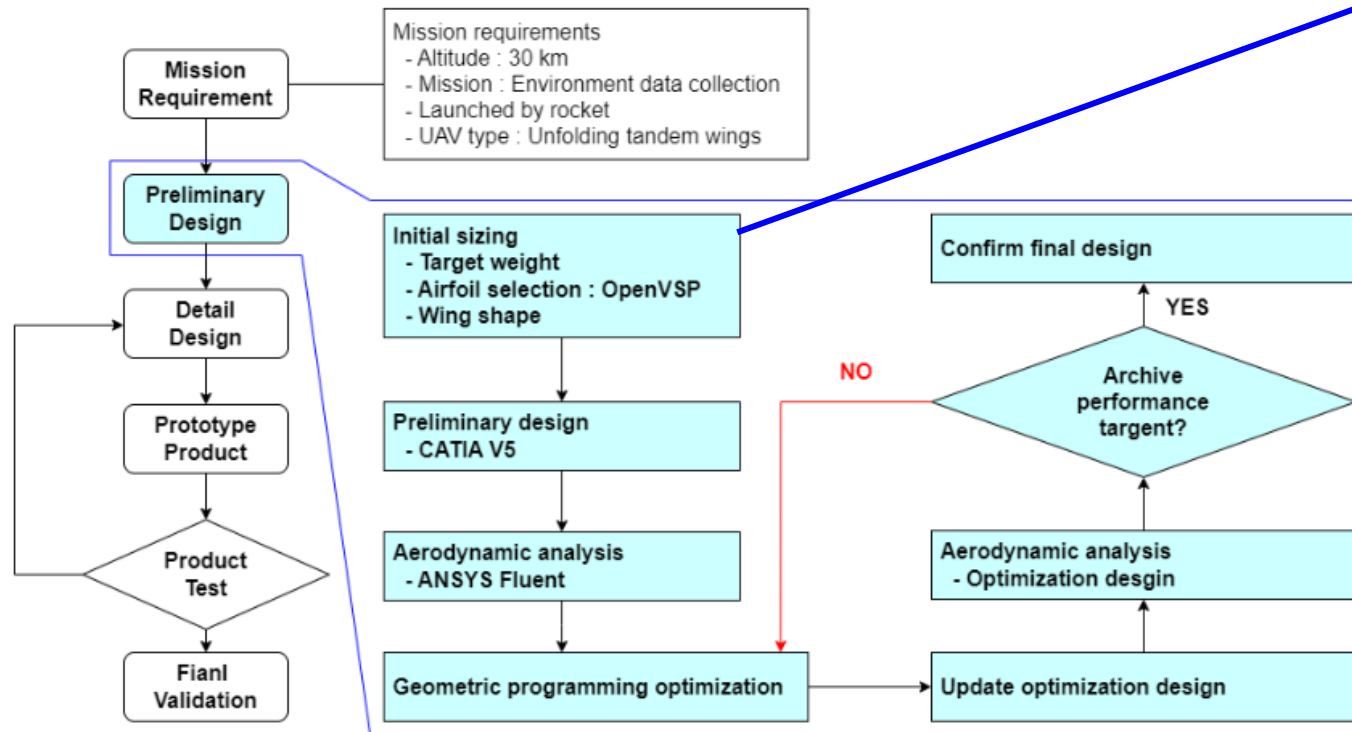
04 UAV Propulsion system

- Selected a jet engine to deliver high-density thrust for high-altitude, high-speed flight and reverse-thrust vertical landing capabilities.
- Glide flight conserves fuel, while thrust-vector control is primarily reserved for reversing flight direction during vertical-landing recovery.



Preliminary Design of Foldable-Wing UAV

Design Process of UAV



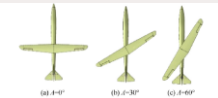
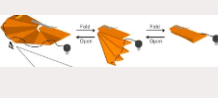
Initial Sizing for UAV

Specification	Value	Note.
Maximum Takeoff Weight (MTOW)	≤ 4 kg	- Structure : 1.54 kg - Propulsion : 1.43 kg - Avionics : 1.02 kg
Wingspan	2 m	- Min. length of UAV - Single wing
Wing Area	0.2 m ²	- Cord length constraints by body diameter
Stall Speed	24.3 m/s	- Initial derivation from constraints
Cruise Speed	38.8 m/s	- Initial derivation from constraints
Wing Loading	196.2 kg/m ²	- Initial derivation from constraints
Airfoil	E387	- Selected by aerodynamic



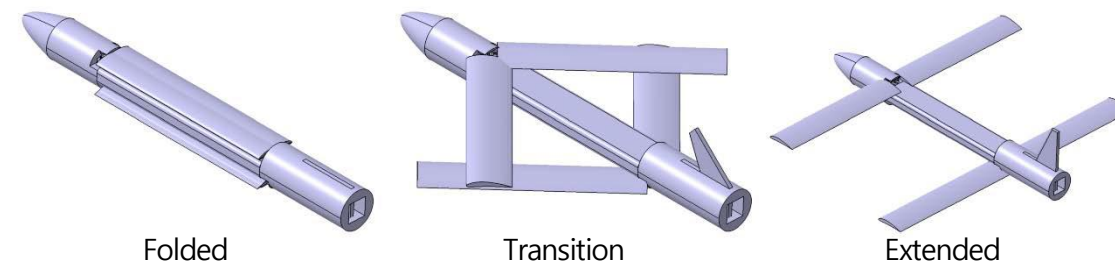
Preliminary Design of Foldable-Wing UAV

Folding Method Selection

Wings Type	Advantages	Disadvantages
Tandem 	- Highly compact for stowage - Proven in tube-launched UAVs	- Aerodynamic complexity - More structure - Potential efficiency loss
Switchblade 	- Very compact storage - Rapid deployment - Simplified mechanism	- Wing size constrained by tube - Hinge stress point - No in-flight adaptability
Telescopic 	- Expanded span on demand - Good packing - Morphing capability	- Mechanical complexity - Joint weakness - Weight penalty
Hinged Folding 	- Simple and reliable - Very compact folding - Rigid when locked:	- Added weight & cost - Multiple failure points - Minor aero penalties - No in-flight adaptability
Wrap-Around 	- Extreme compactness - Instant, passive deployment - Gust tolerance	- Structural limits - No conventional controls - Special materials needed
Origami-Based 	- Maximized wing area - Sophisticated deployment - Innovative potential	- High complexity - Structural reinforcement needed - Unproven at scale

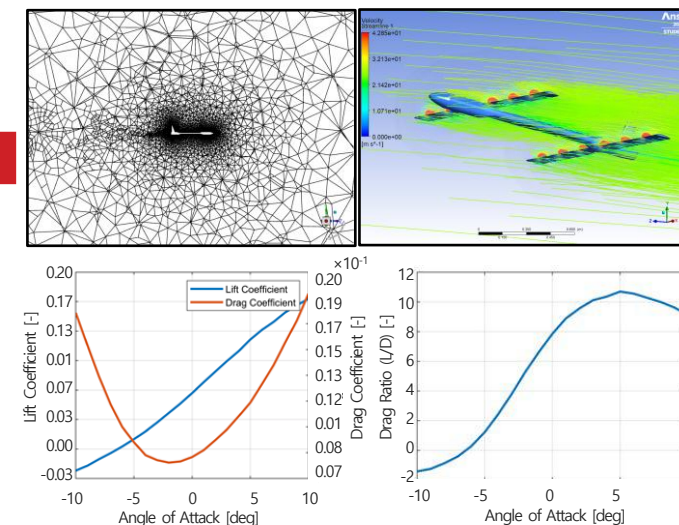
Critical items highlighted

Preliminary Design for Tandem wing



Aerodynamic Analysis

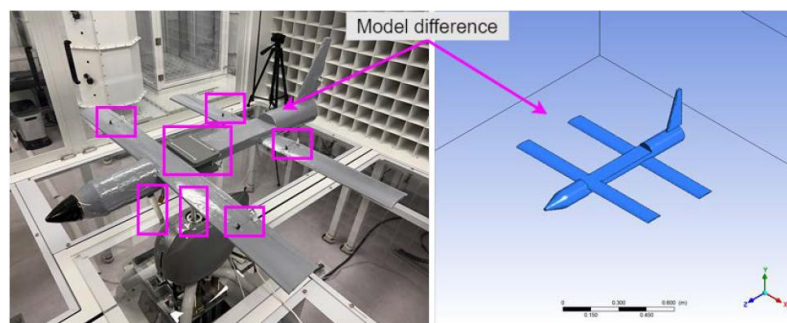
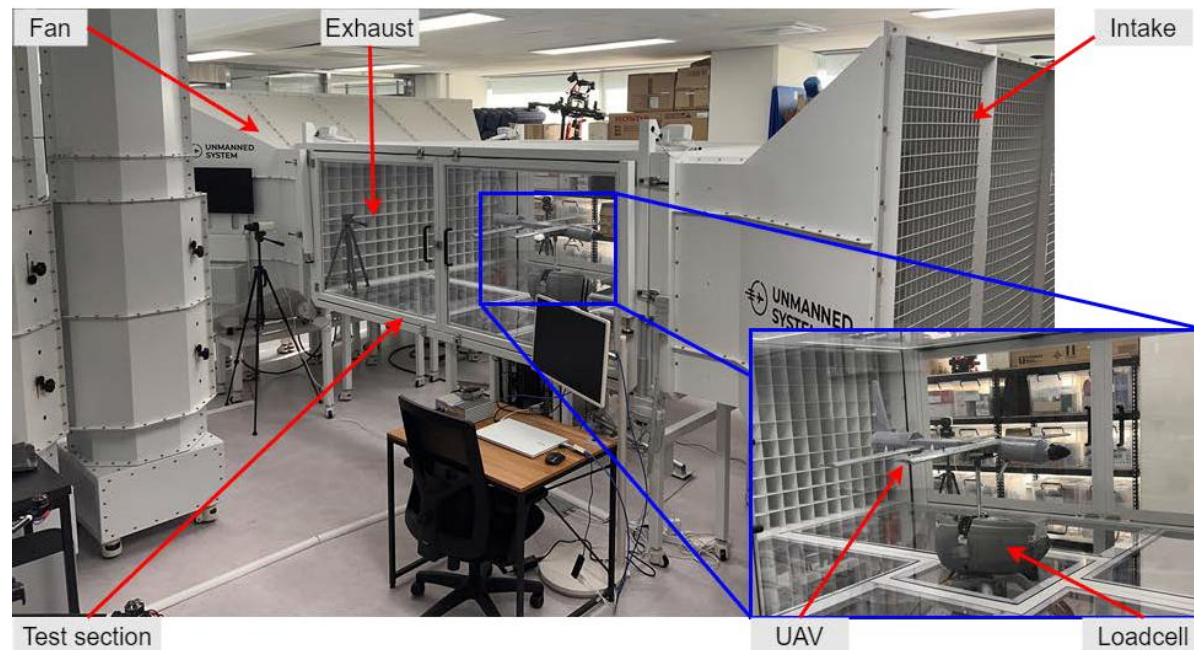
Specification	Value
Total Wingspan	4 m
Total Wing Area	0.4 m ²
Lift Coefficient @ max L/D	0.12
Drag Coefficient @ max L/D	0.01
Wingspan	2 m
Wing Area	0.2 m ²



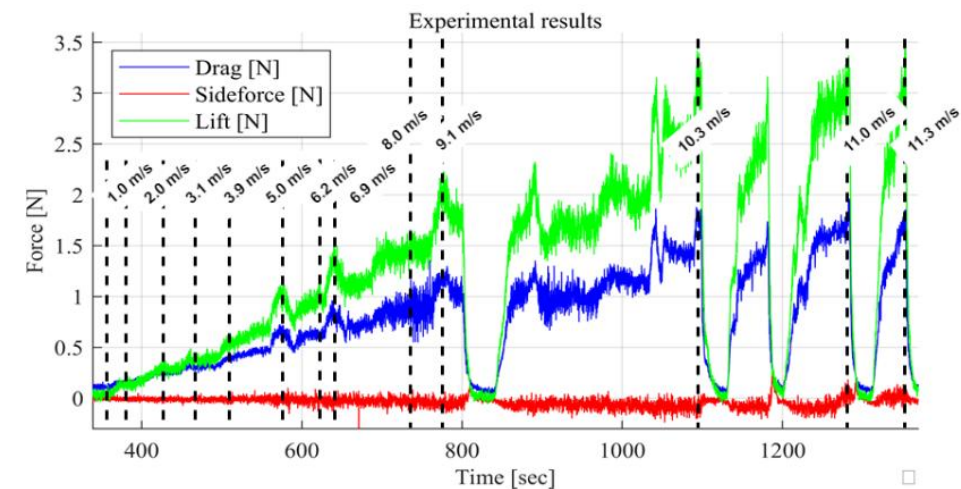
Preliminary Design of Foldable-Wing UAV



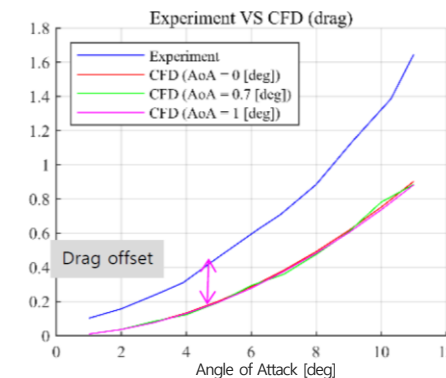
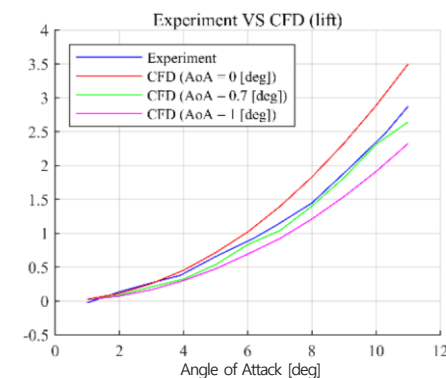
Wind Tunnel Validation



Experimental data



Results



- Experimentally measured lift closely matches CFD predictions, but drag consistently shows a small offset.
- This offset is attributed to unmodeled drag contributions from test-rig (with mock-up UAV) components; ongoing work aims to improve this.



UAV Design Improvement & Optimization Plan



Geometry Programming Optimization

- Utilizing GP's global optimum guarantee to rapidly derive globally optimal initial concepts in multidisciplinary design.
- Leveraging GP's fast convergence speed for developing dynamic geometry optimization that responds to real-time mission changes.
- Using GP's rapid alternative analysis combined with AI to expand design space through high-speed validation and optimization of AI-generated novel geometries.



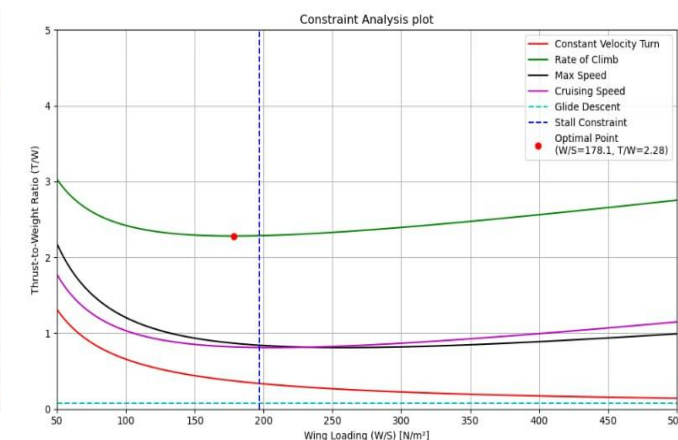
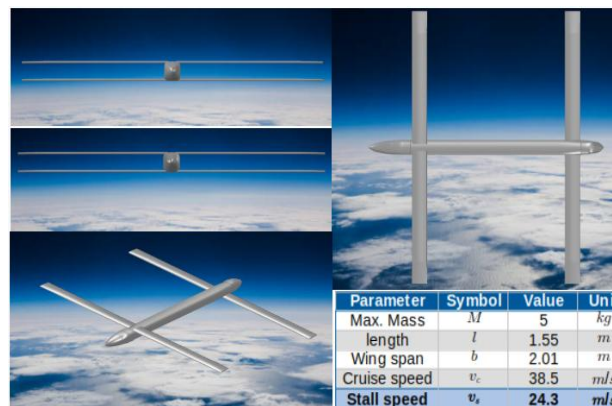
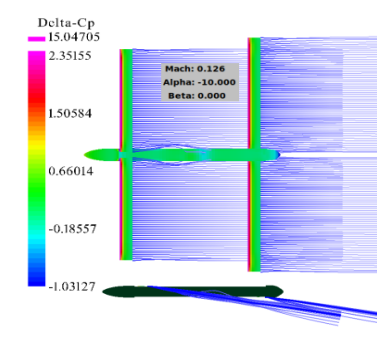
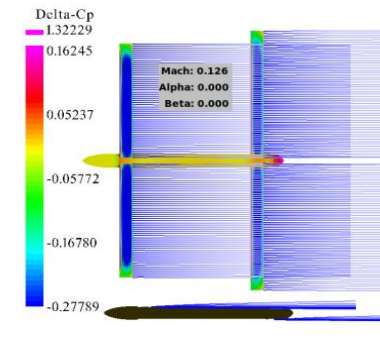
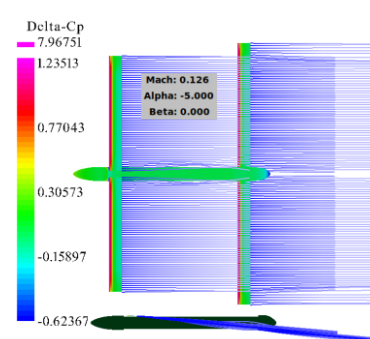
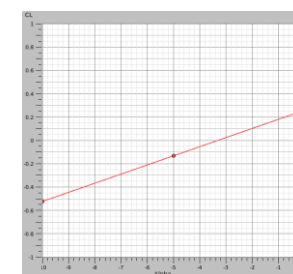
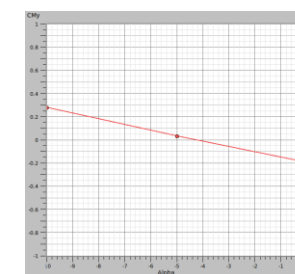
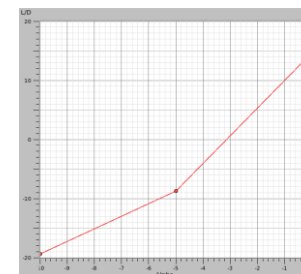
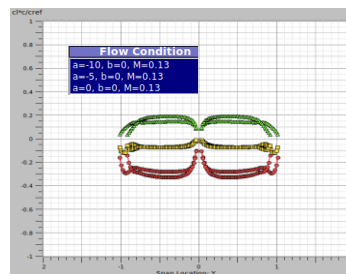
Trajectory-Based Multidisciplinary Design Optimization

- Exploiting its real-time path optimization potential to develop algorithms for adaptively re-searching optimal paths in unpredictable dynamic environments.
- Leveraging its energy-efficiency-focused optimization characteristic for research on integrated trajectory design to maximize mission endurance.



Design Margin Optimization

- Utilizing the flexibility of initial safety factor buffers.
- Research converting buffers into actual performance enhancements after phased development verification.





Foldable Tandem-Wing UAV: Wing Deployment Angle Optimization

Design trade-off between flight stability and aerodynamic efficiency

Mission & Problem Definition

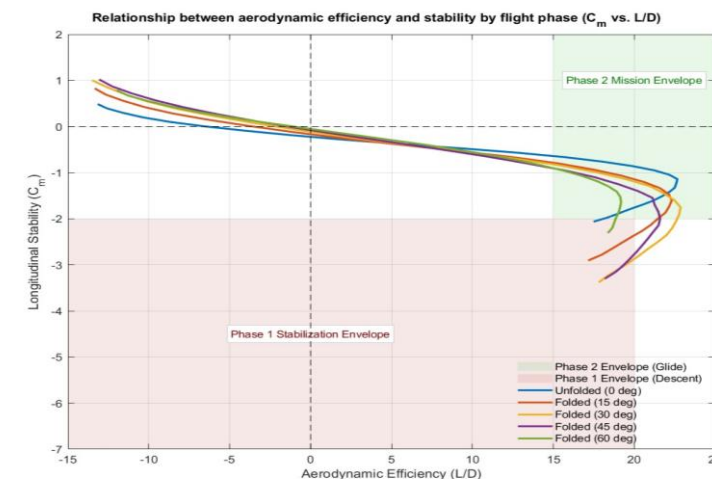
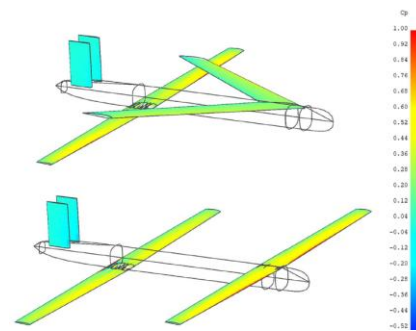
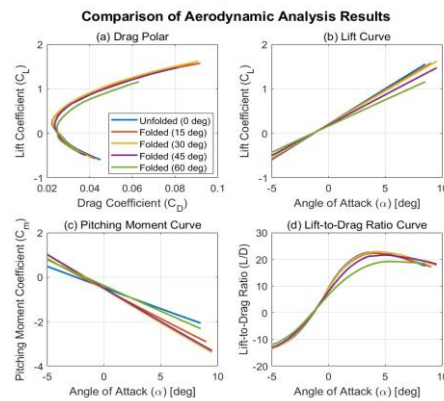
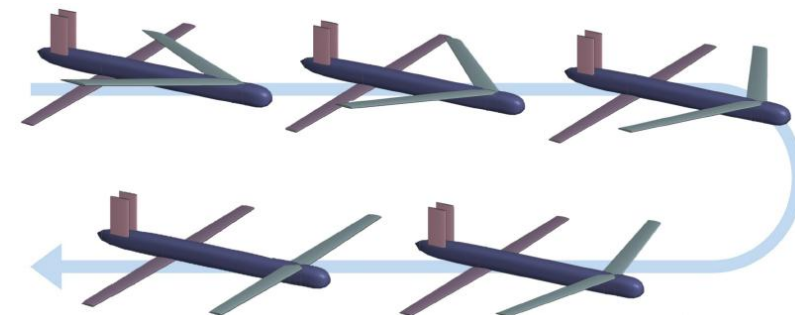
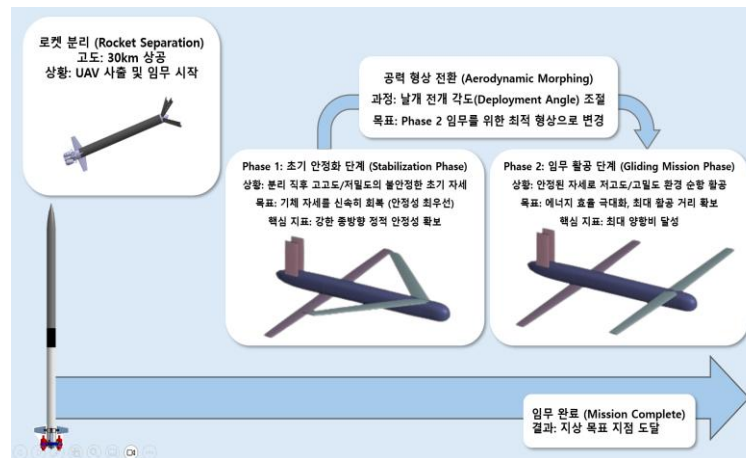
- Rocket-assisted release at ~30 km altitude
- Conflicting requirements during mission:
 - ✓ Early phase: flight stability
 - ✓ Later phase: aerodynamic efficiency
- Fixed wing configuration is not optimal

Method & Design Space

- Design variable: wing deployment angle:
 - ✓ 0° / 15° / 30° / 45° / 60°
- Aerodynamic analysis using XFLR5
- Key metrics:
 - ✓ Pitching moment (C_m)
 - ✓ Lift-to-drag ratio (L/D)

Key Findings & Design Insight

- Maximum efficiency at 30° deployment
- Improved stability at 30°–45°
- Intermediate deployment angle balances:
 - ✓ Stability and efficiency



Intermediate wing deployment enables multi-phase mission optimization.



Foldable Tandem-Wing UAV: Wing Deployment-Aware Dynamic Modeling & Optimization

From nonlinear dynamics to mission-adaptive wing deployment strategy



Mission & Problem Definition

- Tandem-wing UAV with in-flight wing deployment for multi-phase missions
- Wing deployment introduces time-varying inertia, control effectiveness, and aerodynamic coupling
- Conventional fixed-wing or constant-inertia models cannot represent transient dynamics
- Deployment-aware modeling is required for optimal control and angle selection



Design Insight & Implication

- Wing deployment angle is a key design and control parameter
- Intermediate deployment enables a stability-efficiency trade-off
- Provides a foundation for:
 - ✓ Convex / NMPC controller design
 - ✓ CFD-based aerodynamic integration
 - ✓ Future flight-test validation



Method & Modeling Framework

- Nonlinear 6-DoF dynamic model
- Wing deployment angle treated as a state variable
- Time-varying inertia tensor (parallel axis theorem)
- Deployment-dependent control surface moment arms
- Implemented in MATLAB/Simulink
- Validation via roll, pitch, yaw simulations ($\theta = 0^\circ, 15^\circ, 30^\circ$)

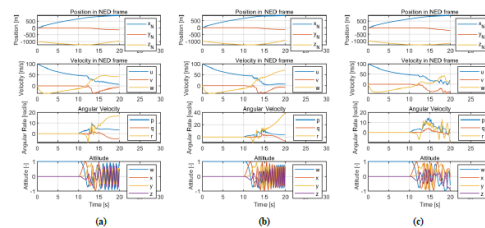


Fig. 3. Rolling scenario in (a) $\theta = 0^\circ$; (b) $\theta = 15^\circ$; (c) $\theta = 30^\circ$

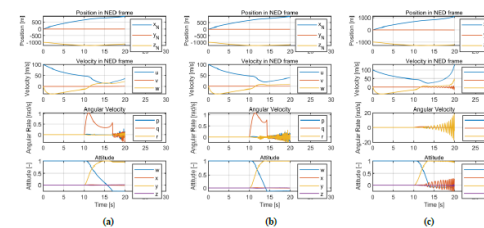


Fig. 4. Pitching scenario in (a) $\theta = 0^\circ$; (b) $\theta = 15^\circ$; (c) $\theta = 30^\circ$

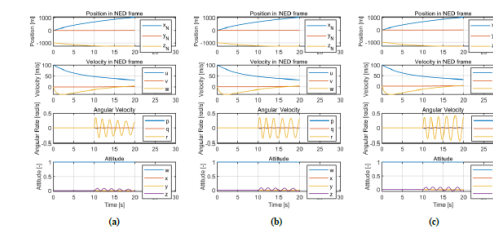
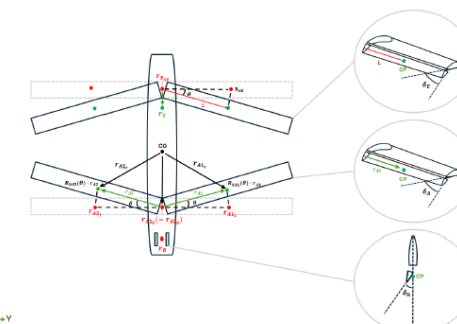
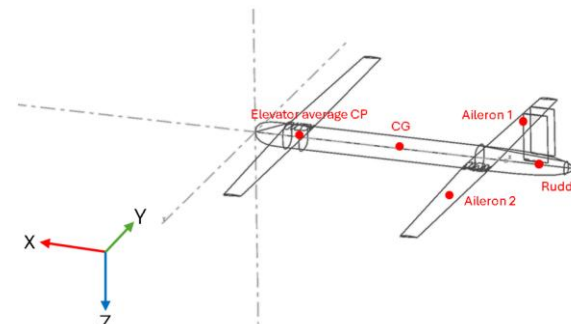


Fig. 5. Yawing scenario in (a) $\theta = 0^\circ$; (b) $\theta = 15^\circ$; (c) $\theta = 30^\circ$



Key Analysis & Validation Results

- Deployment angle significantly affects rotational dynamics and control sensitivity
- Larger angles cause inertia coupling and nonlinear cross-axis responses
- Simulations verify physically valid transient behavior and correct input-output trends
- Confirms necessity of deployment-aware modeling for reliable control design

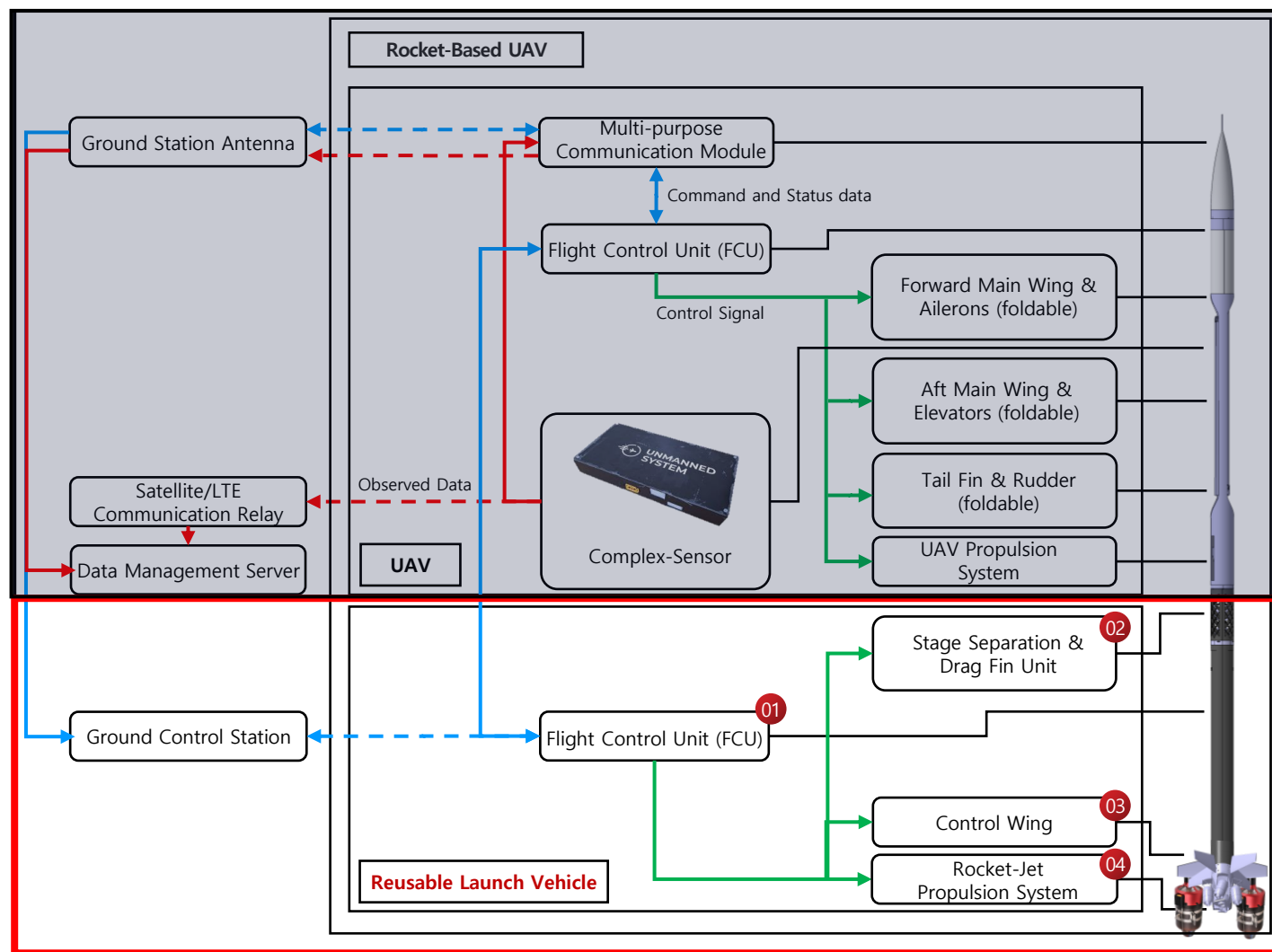


Deployment-aware nonlinear modeling is essential for optimal control of foldable tandem-wing UAVs.

System Design of the Scaled RLV



System Architecture



01 Flight Control Unit

- Performs state estimation by fusing data from multiple onboard sensors.
- Determines mission phase and commands ascent, UAV separation, return, and landing.

02 Stage Separation & Drag Fin Unit

- Consolidates UAV attachment/release, engine-module stowage, and drag-fin deployment into a single mechanism.
- Reduces overall system mass by replacing three separate subsystems with one integrated unit.

03 Control Wing

- Provide attitude control during unpowered coasting flight.
- Remain inactive when the thrust-vectoring jet engine is operating.

04 Rocket-Jet Propulsion System

- Solid rocket motor delivers high-density thrust pulses for rapid acceleration.
- Turbojet engine's air-breathing intake minimizes onboard oxidizer mass requirements.
- Jet thrust and thrust-vector control enable precise trajectory tracking and propulsive landing.

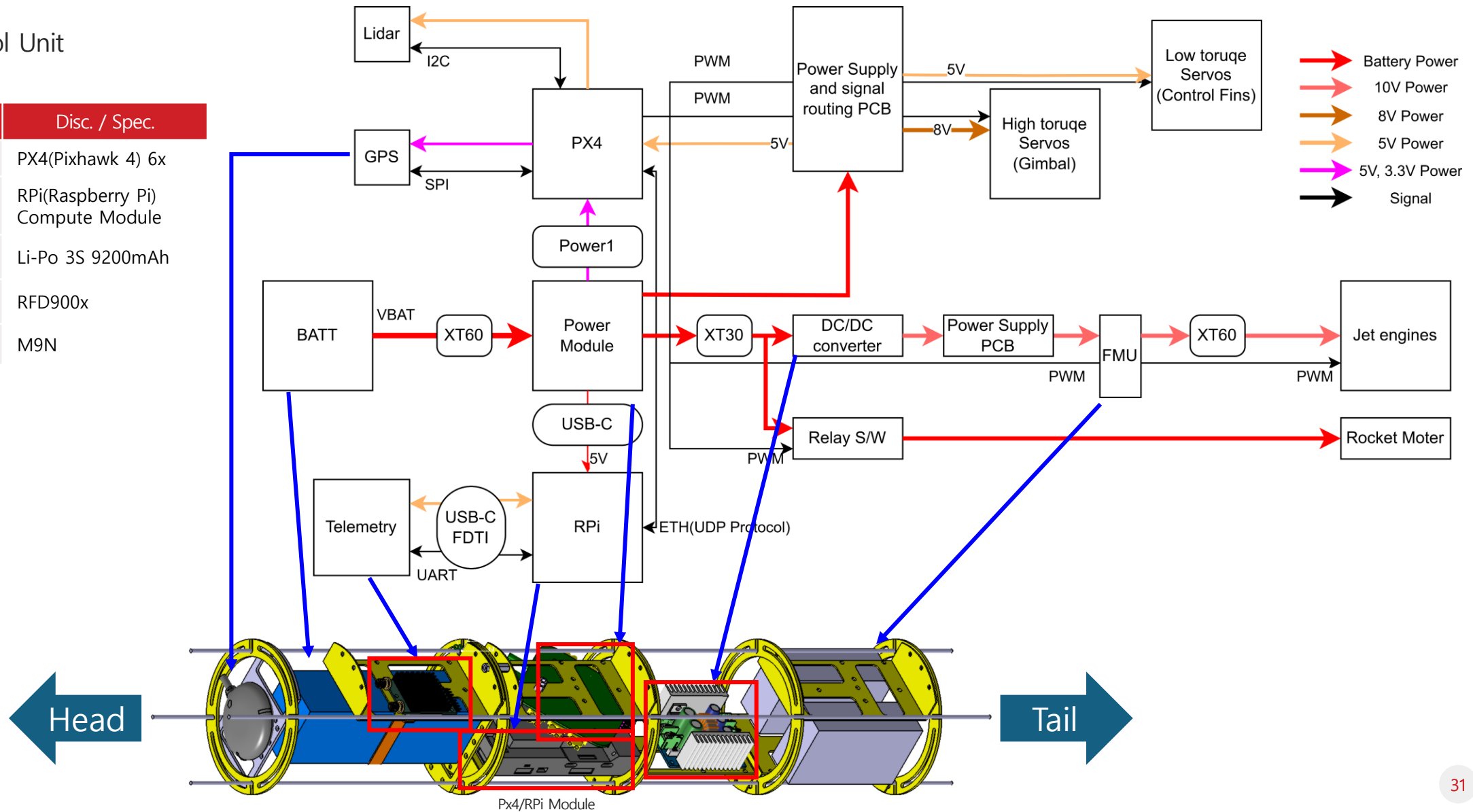


System Development: Flight Control Unit



Flight Control Unit

Category	Disc. / Spec.
Flight Computer	PX4(Pixhawk 4) 6x
Mission Computer	RPi(Raspberry Pi) Compute Module
Battery Capacity	Li-Po 3S 9200mAh
Telemetry	RFD900x
GPS	M9N





System Development: Stage Separation & Drag Fin Unit



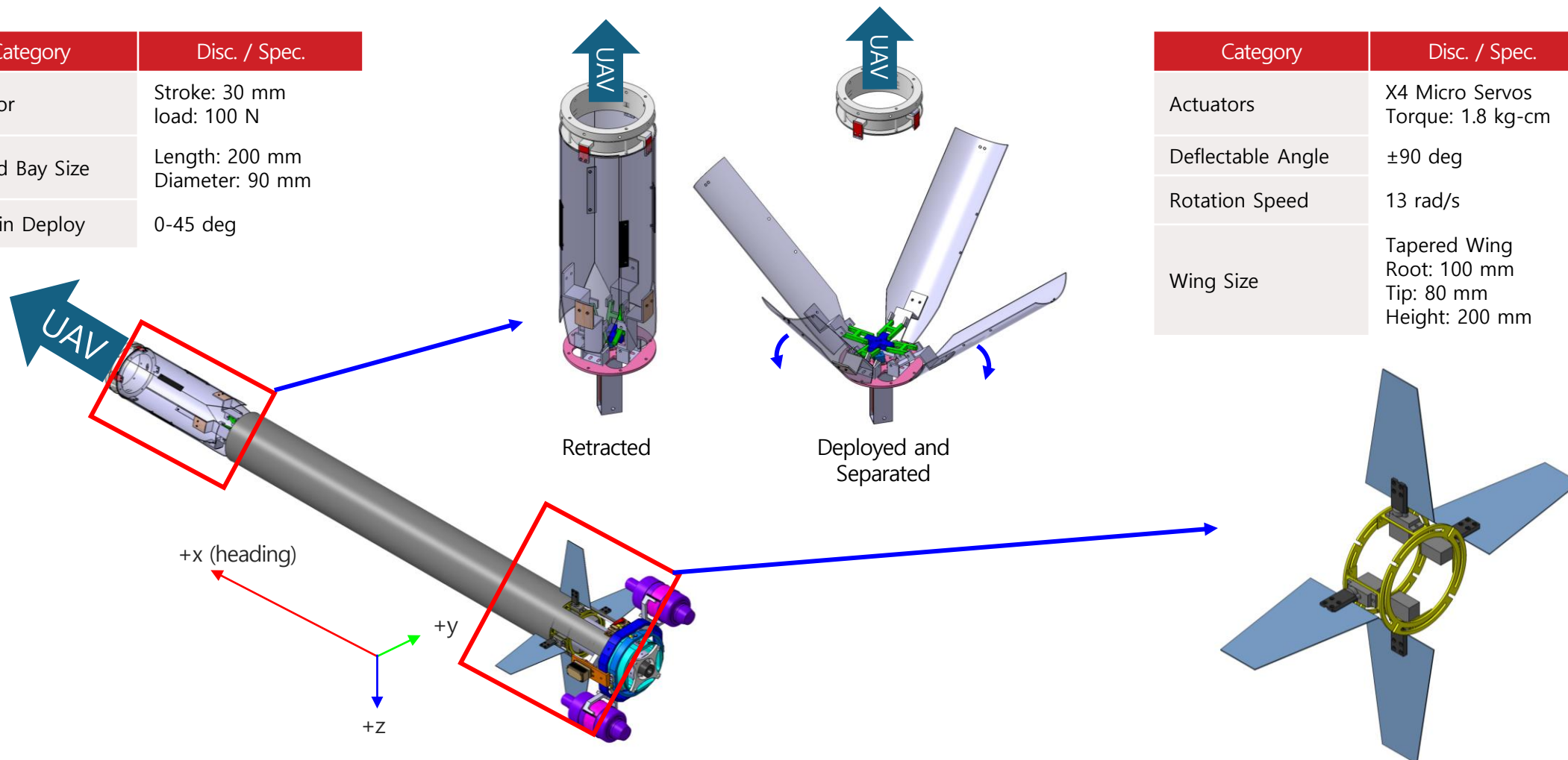
Stage Separation & Drag Fin Unit (Under Development)

Category	Disc. / Spec.
Actuator	Stroke: 30 mm load: 100 N
Payload Bay Size	Length: 200 mm Diameter: 90 mm
Drag Fin Deploy	0-45 deg



Control Wing

Category	Disc. / Spec.
Actuators	X4 Micro Servos Torque: 1.8 kg-cm
Deflectable Angle	± 90 deg
Rotation Speed	13 rad/s
Wing Size	Tapered Wing Root: 100 mm Tip: 80 mm Height: 200 mm



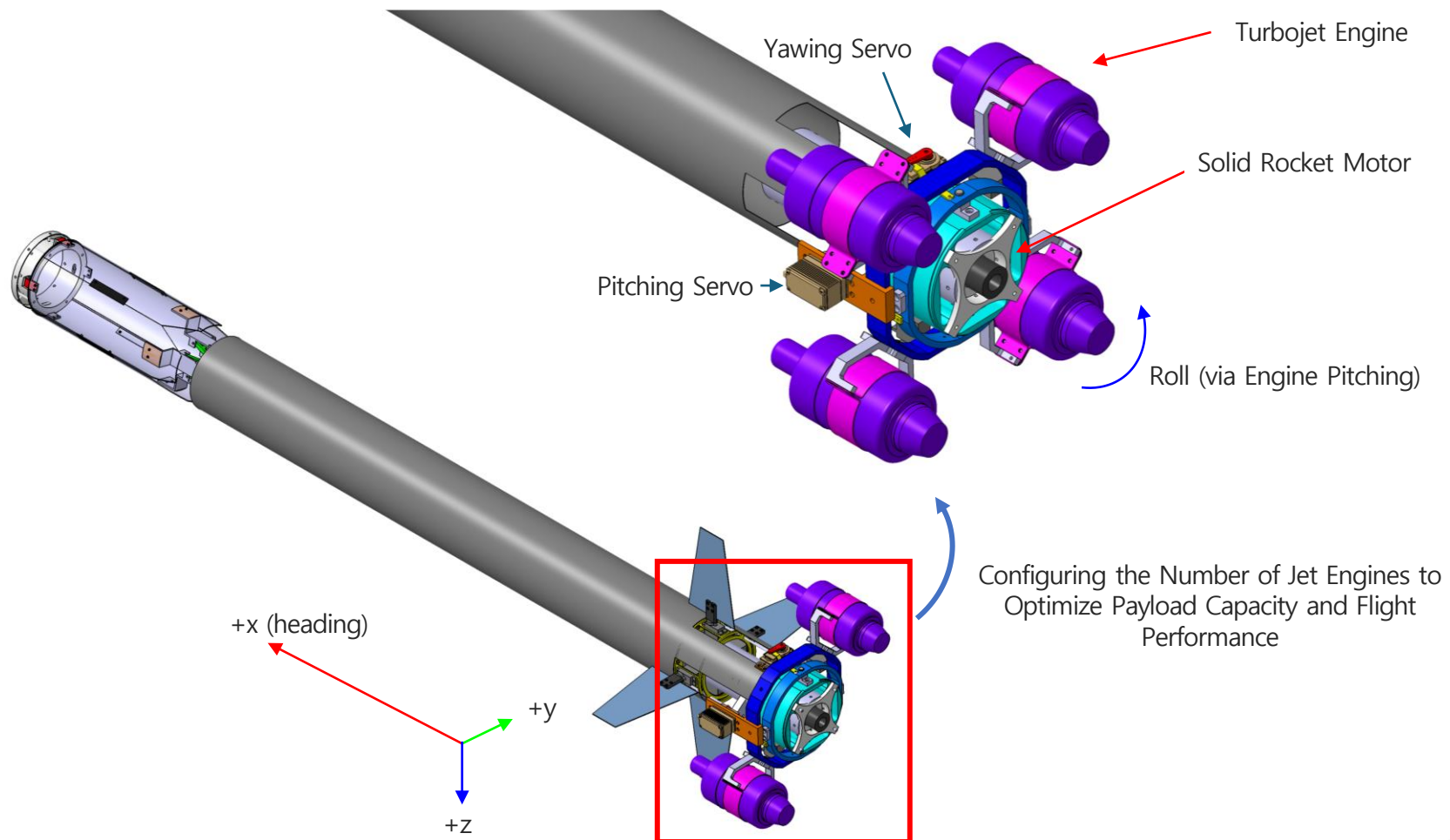


System Development: Rocket-Jet Propulsion System and Gimbal



Rocket-Jet Propulsion System

Category	Disc. / Spec.
Actuators	X4 Micro Servos Torque: 2.2 kg-cm X3 Servos Torque: 29 kg-cm
Rocket Motor	Solid Fuel and Oxidizer (KNSB) Specific Impulse: ~120 sec Max Thrust(Demo.): 120 N Burn Time: ~3 sec
Jet Engine	Liquid Fuel (Kerosene) Maximum Installation: 4 Engines Max Thrust: 30N/Engine Thrust Response Time: 1.5 sec Gimbal Enabled
Gimbal	Pitch Angle: ± 12 deg Yaw Angle: ± 12 deg Roll Angle(via Engine Pitching): ± 30 deg

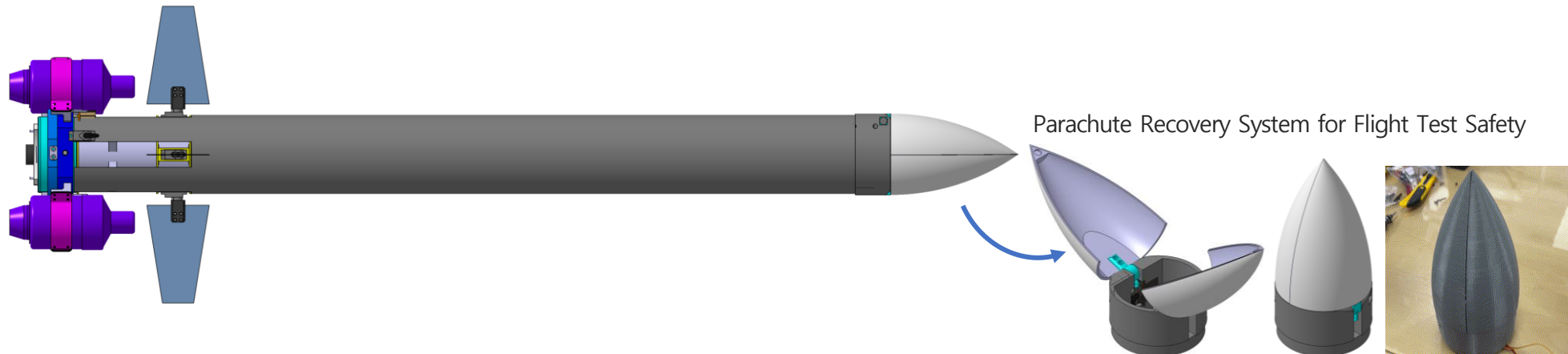


Staged Development Approach for VTVL Capability Verification

Stage 1 (Ongoing)

Powered Recovery

- Until the propulsive-landing recovery capability is verified, flight tests will be conducted safely in the lightest possible configuration, using a parachute recovery system.



Stage 2

Drag Fin Application

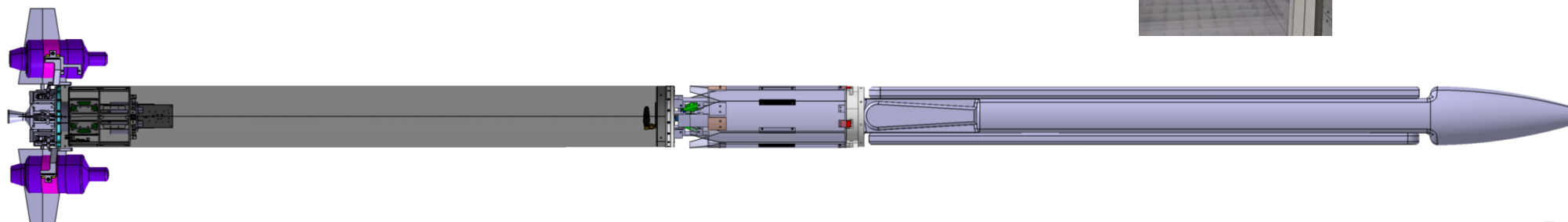
- Flight tests, conducted without the heavy UAV mock-up, verify the drag-fin system's functionality. The vehicle executes high-speed descents between 150 m and 10 km altitude to confirm effective aerodynamic braking.



Stage 3

RLV for UAV

- Validation of the final rocket configuration through comprehensive flight testing up to 30 km altitude.

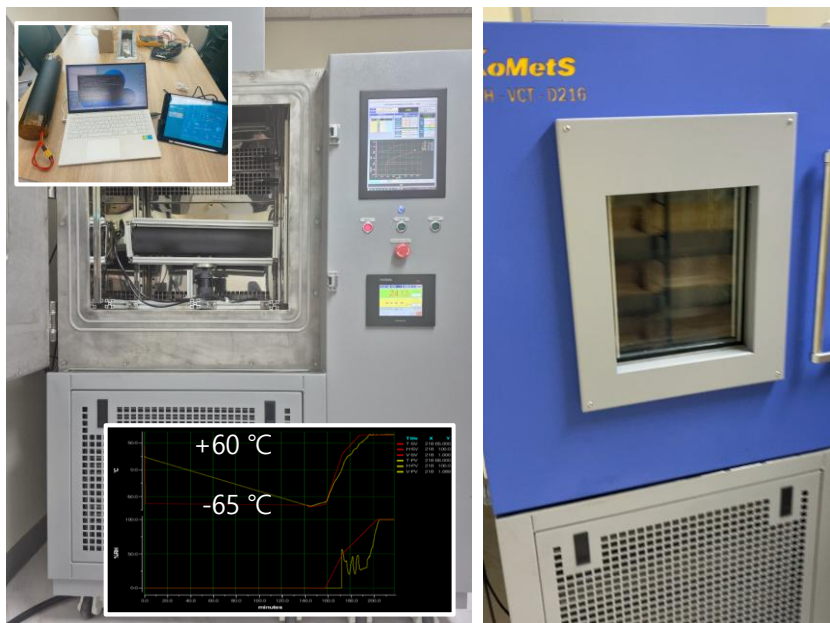


Current Rocket Manufacturing Status (Stage 1)

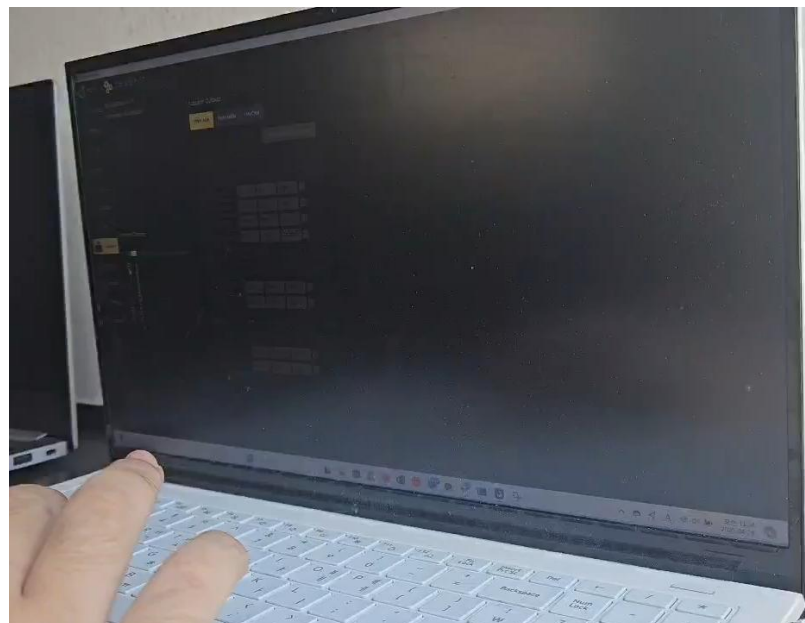
Requirement and Result

Category	Requirement	Result
Maximum Size	- Width, Depth, Height: $\leq 0.3\text{ m}$, $\leq 0.3\text{ m}$, $\leq 5\text{ m}$ - Weight: $\leq 10\text{ kg}$	- Width, Depth, Height: 0.24 m, 0.24 m, 1.24 m - Weight: 5 kg
Environmental Tolerance of Avionics	- Temperature: $-60\text{ }^{\circ}\text{C}$ to $+60\text{ }^{\circ}\text{C}$ - Pressure: $0.01 - 1\text{ atm}$ - Wind Gusts up to 12 m/s	Working over 1 Hour

Experiment for Verification Environmental Tolerance of Avionics



Manufacturing & Experimental Test Flight for Parachute Recovery Validation

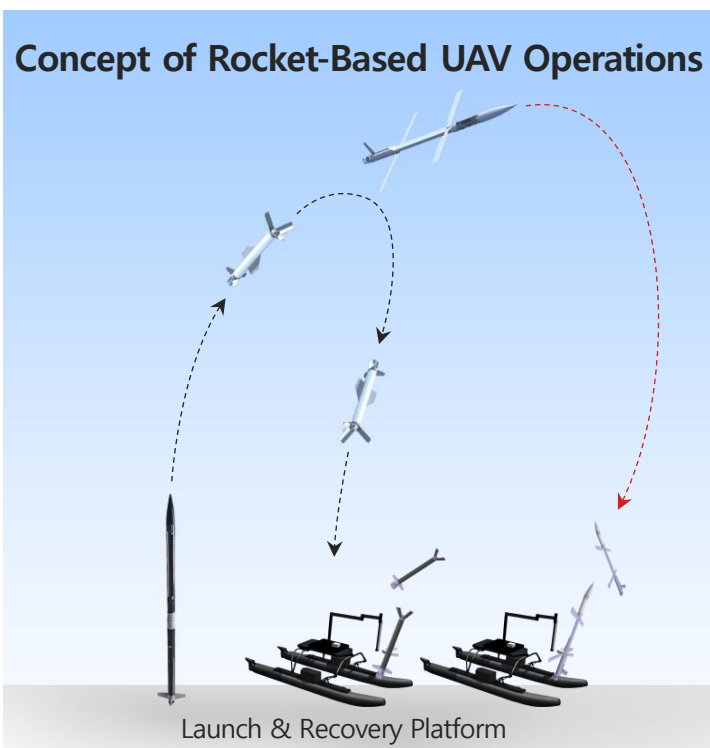




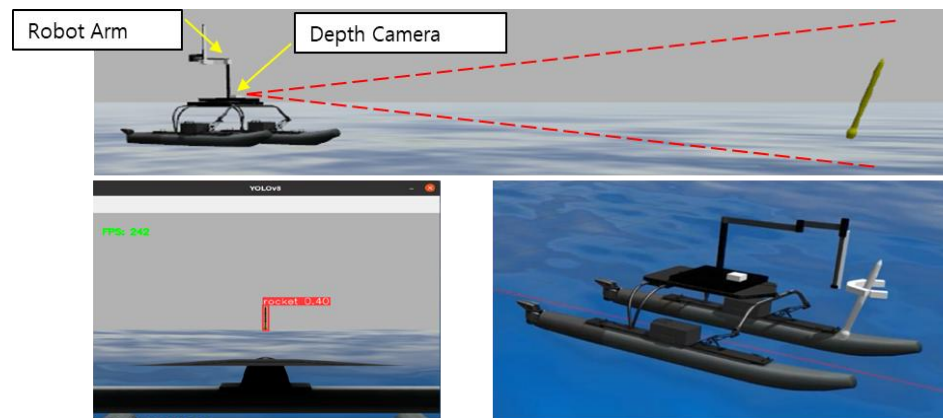
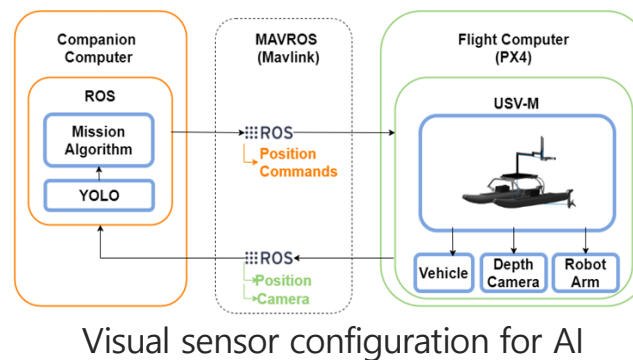
Detect & Recovery Capture with Unmanned Surface Vehicles at Sea



Detect Rocket and UAV Using YOLOv8 and a Depth Camera



Training Rocket Image Data



Applying YOLOv8 Algorithm to Trained Rocket Image Data

Detecting Rockets Using a Depth Camera and a YOLOv8 Algorithm Trained on data

Calculating the Position of Detected Rockets and Navigating the USV to the Target Site

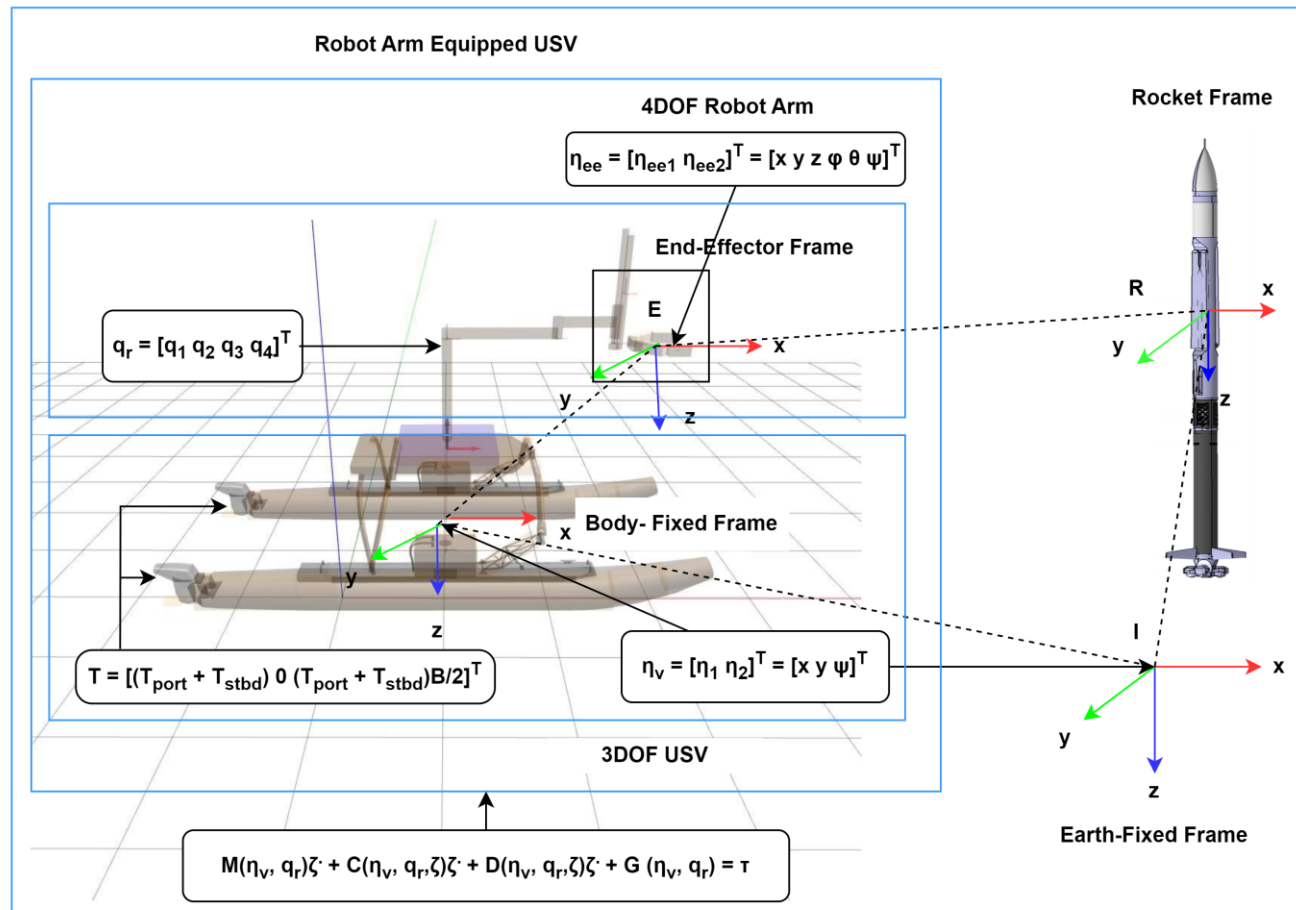
Recovering UAVs and Rockets Using the USV's **Robotic Arm**



USV Dynamic Model and Controller



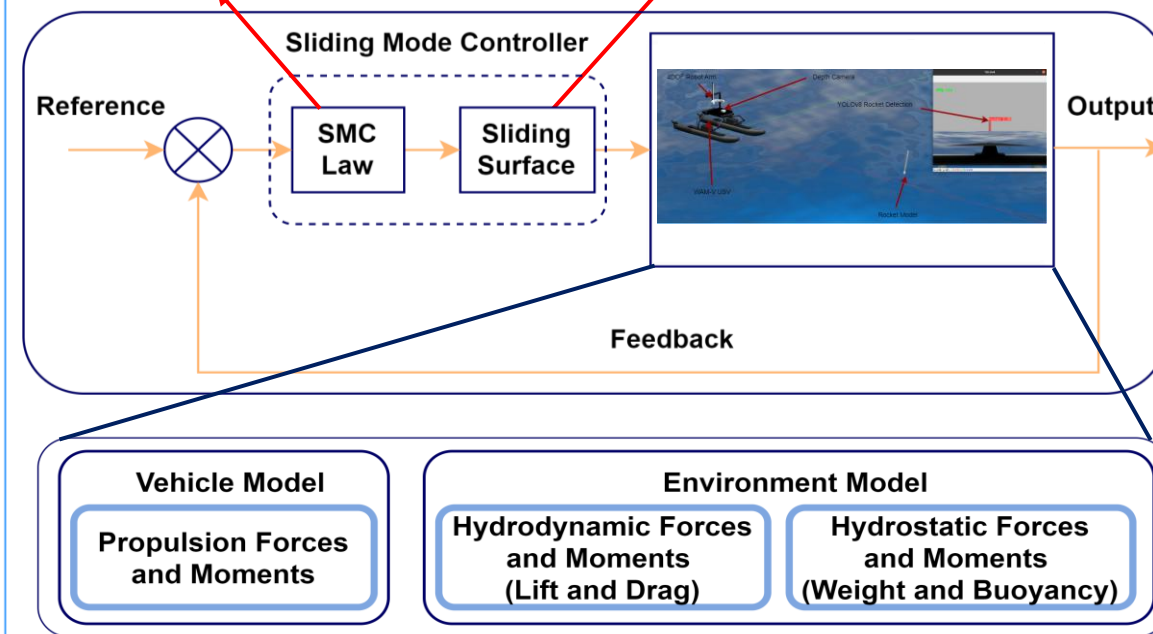
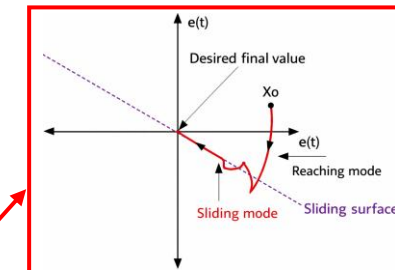
Reference Frames



SMC Controller Robust for Systems

- SMC control law in achieving precise position and trajectory tracking in USVs.

$$\tau_t = M(\eta_v, q_r)J(\eta_v)^{-1}(k\dot{e} + \ddot{\eta}_d - \dot{J}(\eta_v)\dot{\zeta} - \varepsilon \text{sat}\left(\frac{s}{\phi}\right) + C(\eta_v, q_r, \dot{\zeta})\dot{\zeta} + D(\eta_v, q_r, \dot{\zeta})\dot{\zeta} + G(\eta_v, q_r)$$



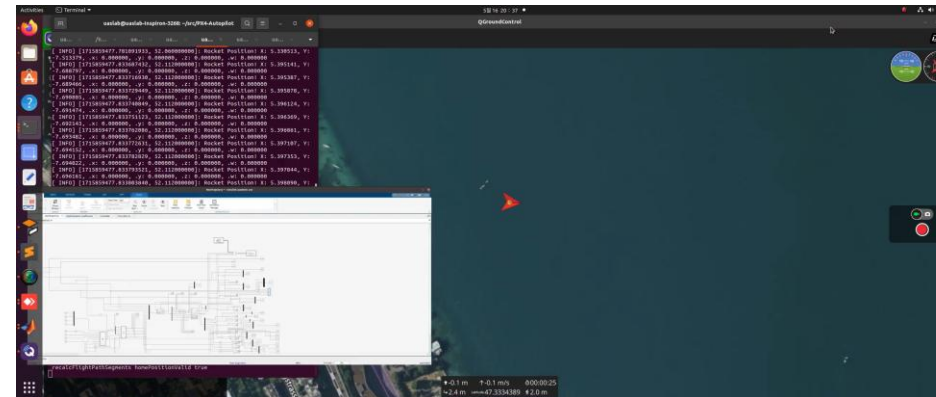
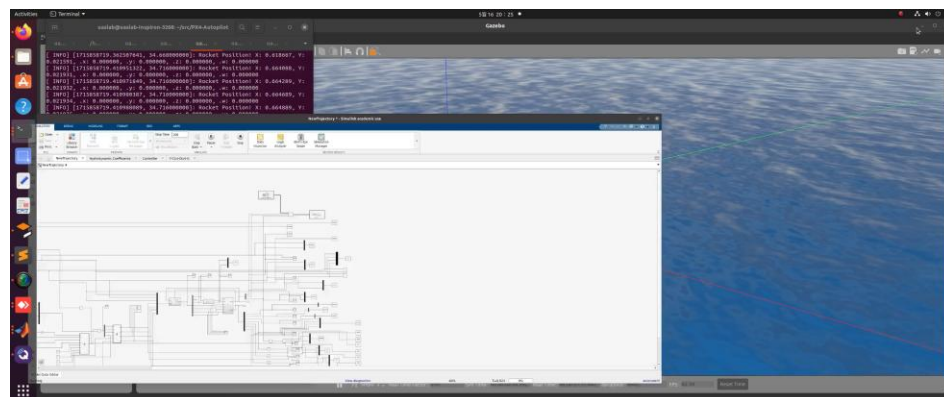
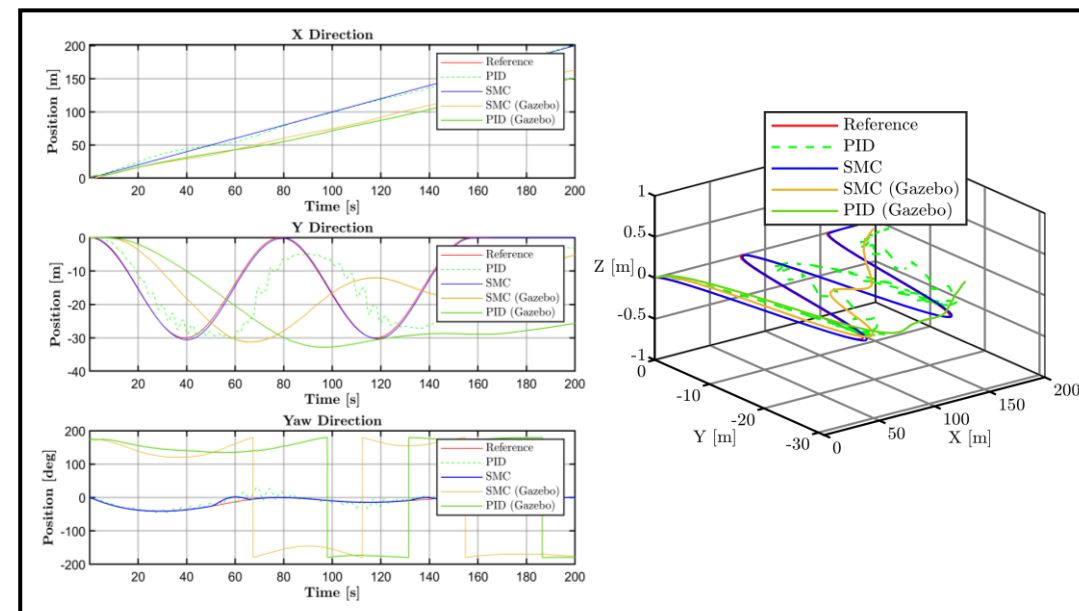
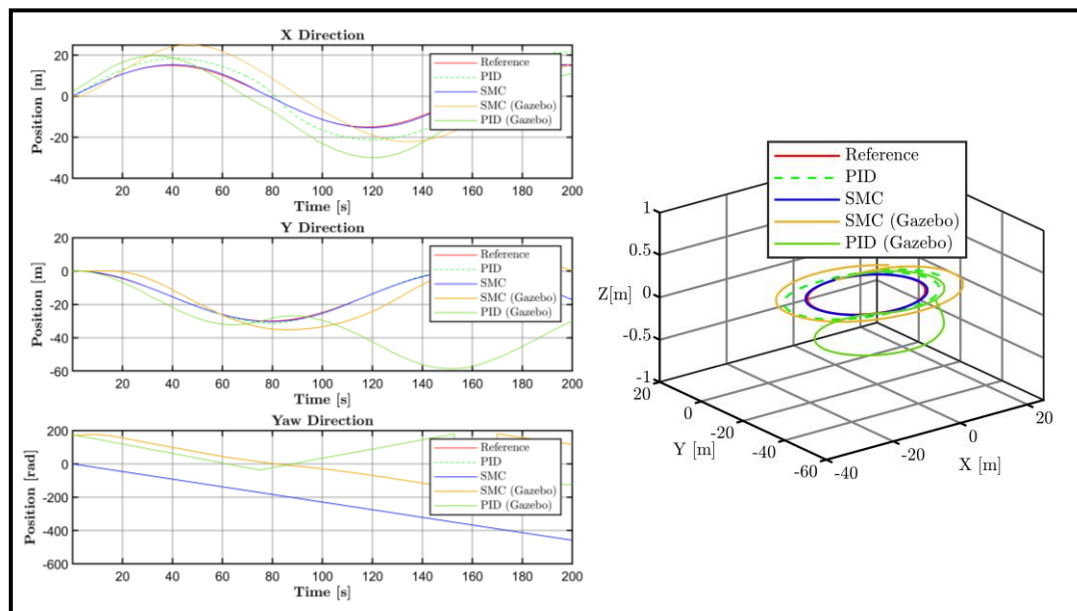


02



Evaluation of Controller Performance through Complex Path Tracking

Circular & Zigzag Trajectories Selected to Assess Controller Effectiveness





02

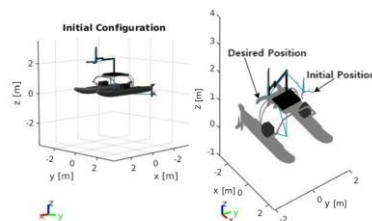
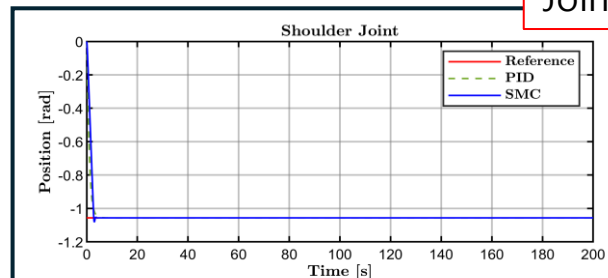


Evaluation of Robot Arm Dynamics Modeling

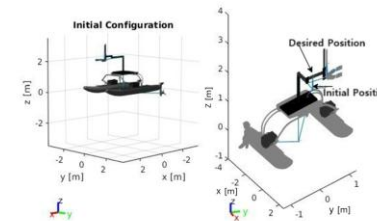
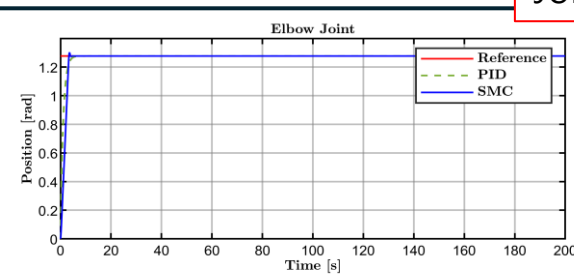


Simulation Results of Robot Arm Dynamics Based on Lagrange–Euler and DH Methods

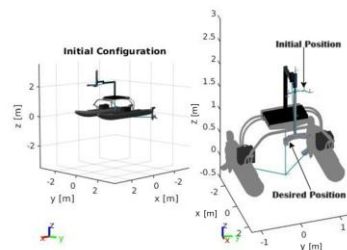
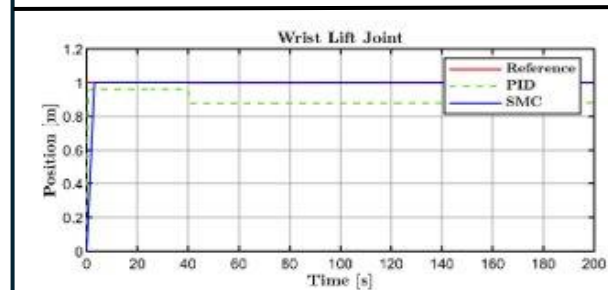
Joint 1



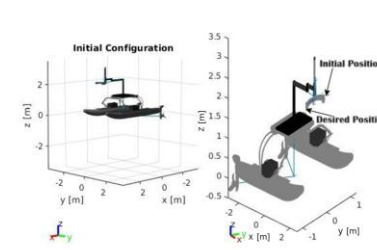
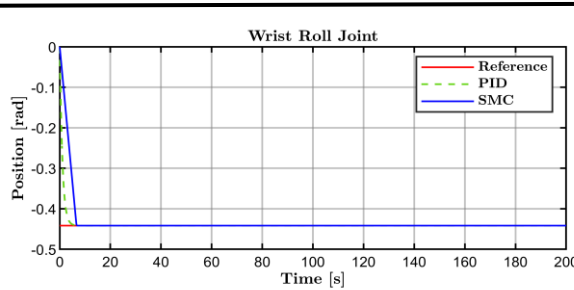
Joint 2



Joint 3



Joint 4



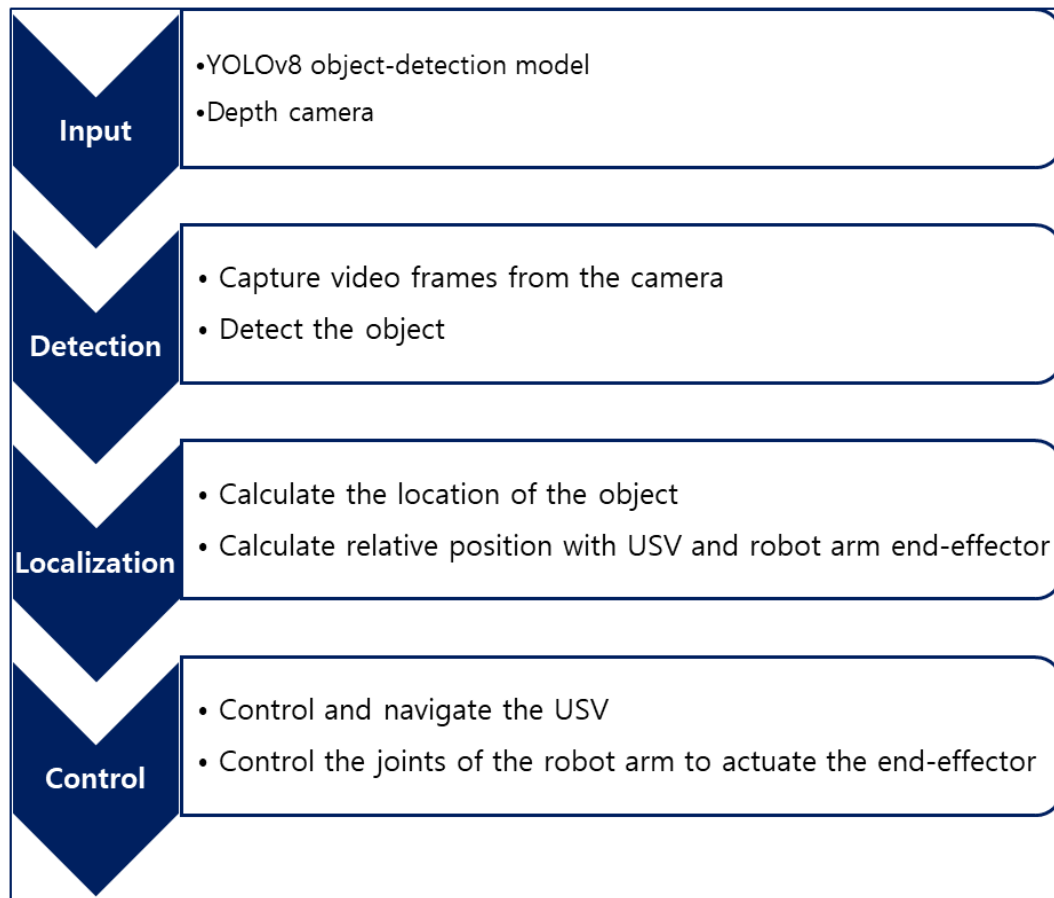
Parameter	Joint 1	Joint 2	Joint 3	Joint 4
Mass	5 [Kg]	3 [Kg]	3 [Kg]	1 [Kg]
Joint type	Revolute [rad]	Revolute [rad]	Prismatic [m]	Revolute [rad]



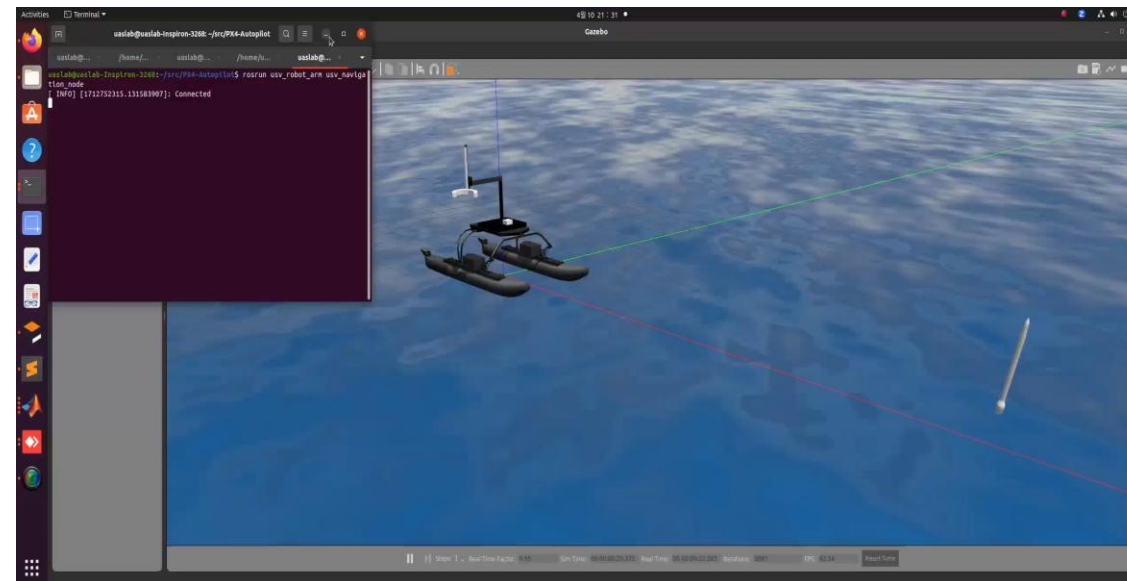
Rocket and UAV Recovery Simulation



Recovering Hovering RLV and UAV Using a Robotic Arm



Simulation Result



In this project...

- Robot operating system (ROS), Open-source PX4 framework and Gazebo simulation platform are used.



System-Level Optimization & Validation

시스템 수준 최적화 및 검증 →

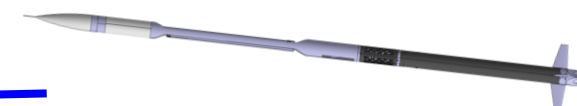
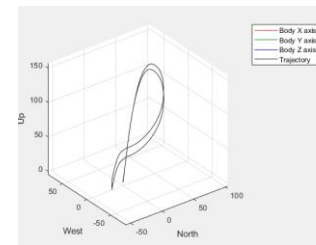
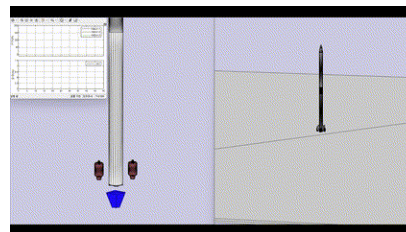
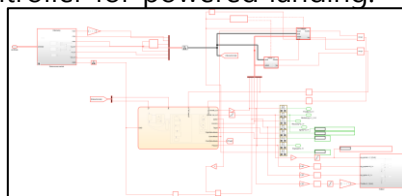
Rocket based foldable UAV Simulation



Simulation Development Results

Fuzzy Logic Based Controller Selection, UAV Separation Order

- Controller for Ascent.
- Controller for post-separation and return.
- Controller for powered landing.



Rocket Based Foldable UAV Dynamics

Aerodynamic Model

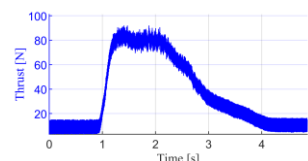
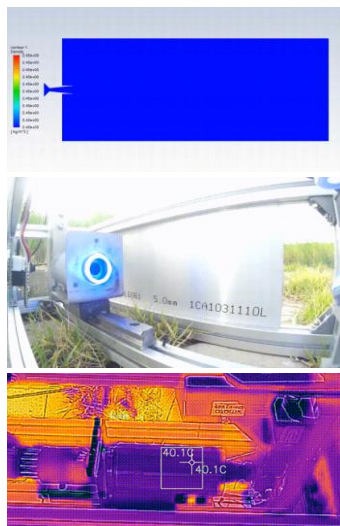
UAV(Dummy) Drag Fin Unit



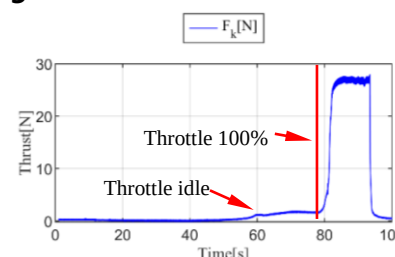
Control Wing

Turbojet Engine

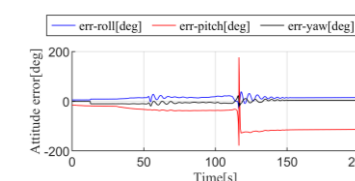
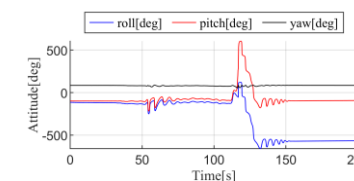
Solid Rocket Booster Model



Fuel consumption and performance characteristics according to turbojet engine environment/throttle



$$\text{Max thrust} = \max(F_k) + F_f = 26[\text{N}] + 6.2[\text{N}] = 32.2[\text{N}]$$



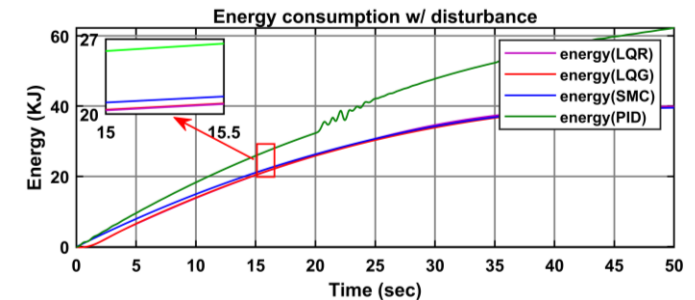
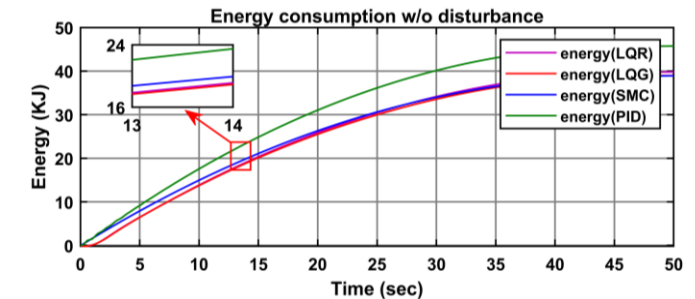
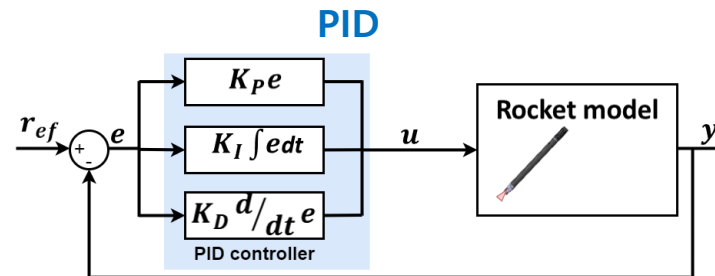
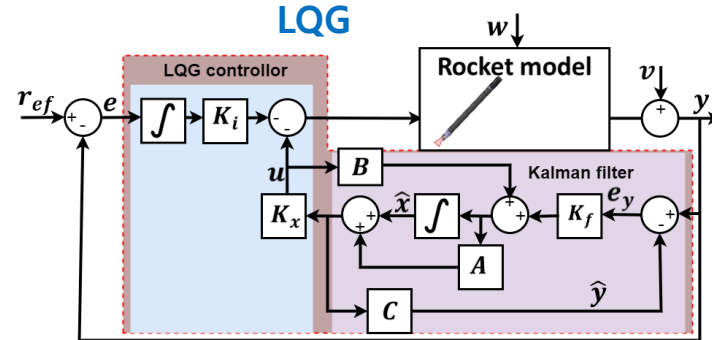
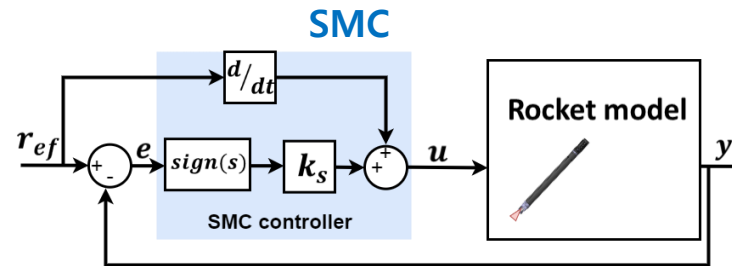
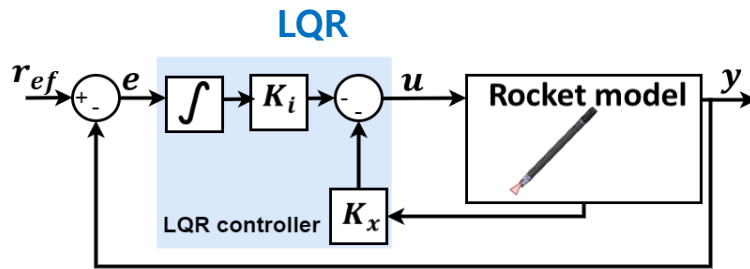
Study RLV Controller Based on Simulation



Comparative Analysis of Four RLV Controller Types

- Energy-Efficient Control:** Ensures stability and precision during ascent and descent.

Energy consumption performance with different controllers:



TVC-based rocket with 4 different controller configurations

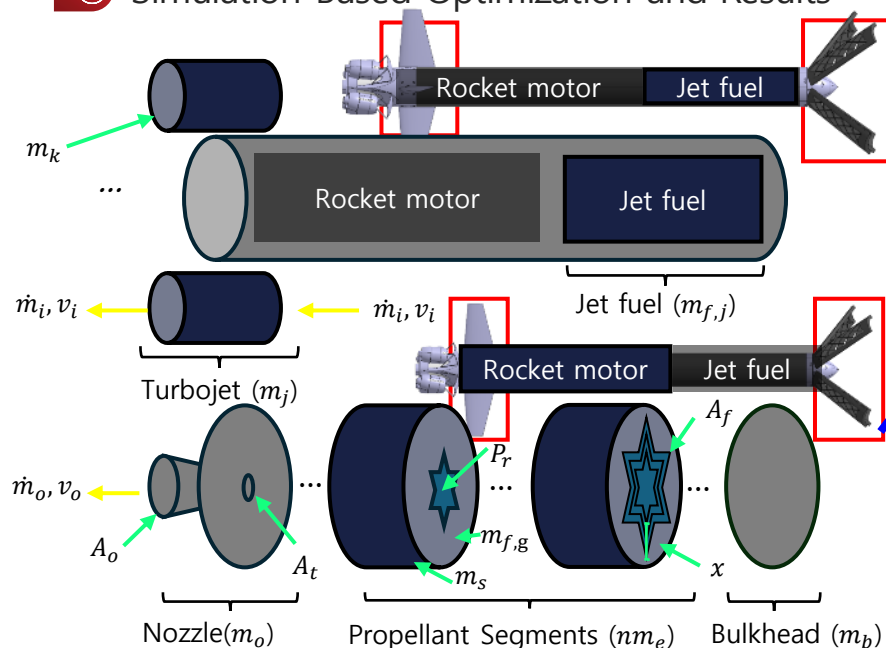
- LQG's** Kalman filter estimation allows it to anticipate system behavior more accurately, **optimizing fuel usage**.
- Overall, **advanced controllers** show less energy consumption, making them optimal for **reusable rocket landings**.

Total energy usage over time

Controller	Tot. energy (w/o disturbance)	Tot. energy (w/ disturbance)
LQR	1330.65 kJ	1338.68 kJ
LQG	1308.85 kJ	1326.36 kJ
SMC	1341.01 kJ	1351.24 kJ
PID	1579.43 kJ	1886.61 kJ

Simulation-Based Optimization

Simulation-Based Optimization and Results

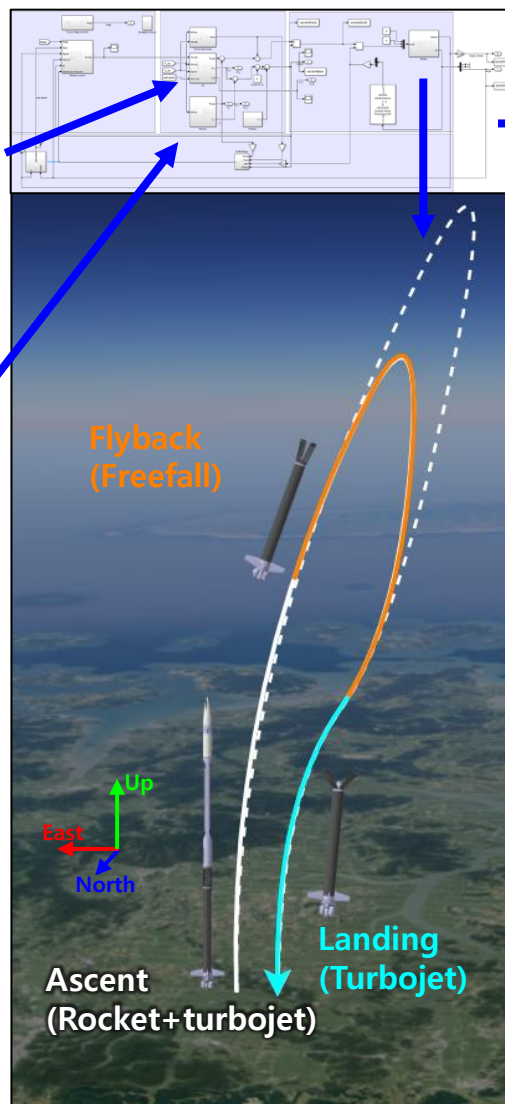


Turbojets Thrust
 $F_j = l \times F_k$

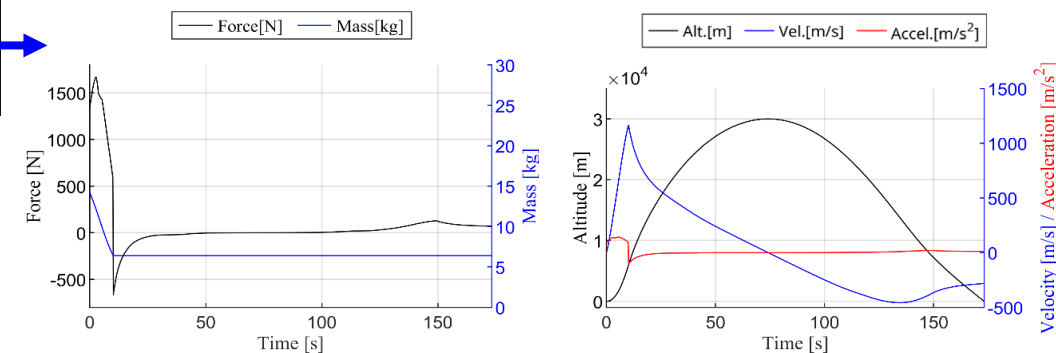
Rocket Thrust
 $F_r = n \times m_f v_o$

Optimization parameters

Parameter	Description.
l [-]	Number of turbojets
n [-]	Propellant segment factor (number)
$m_{f,j}$ [kg]	Jet fuel mass
$m(0)$ [kg]	Initial vehicle mass (cost)

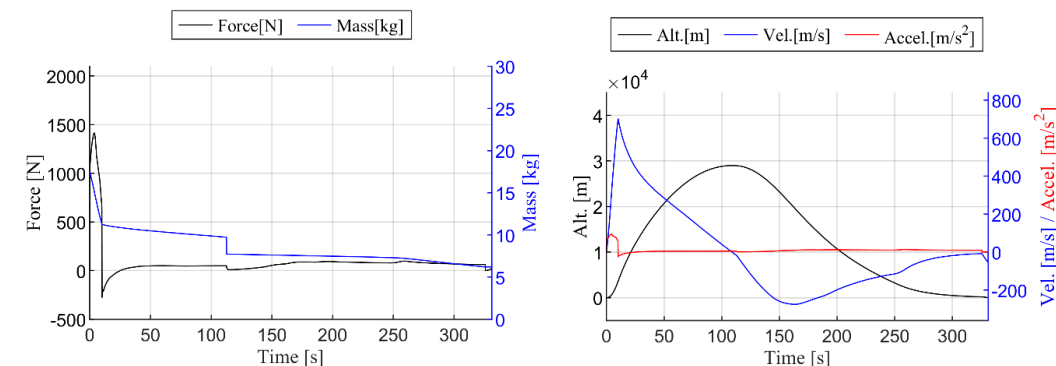


Ascent Optimization Results



Altitude Achievement Control: Mission objective met at 30km altitude.

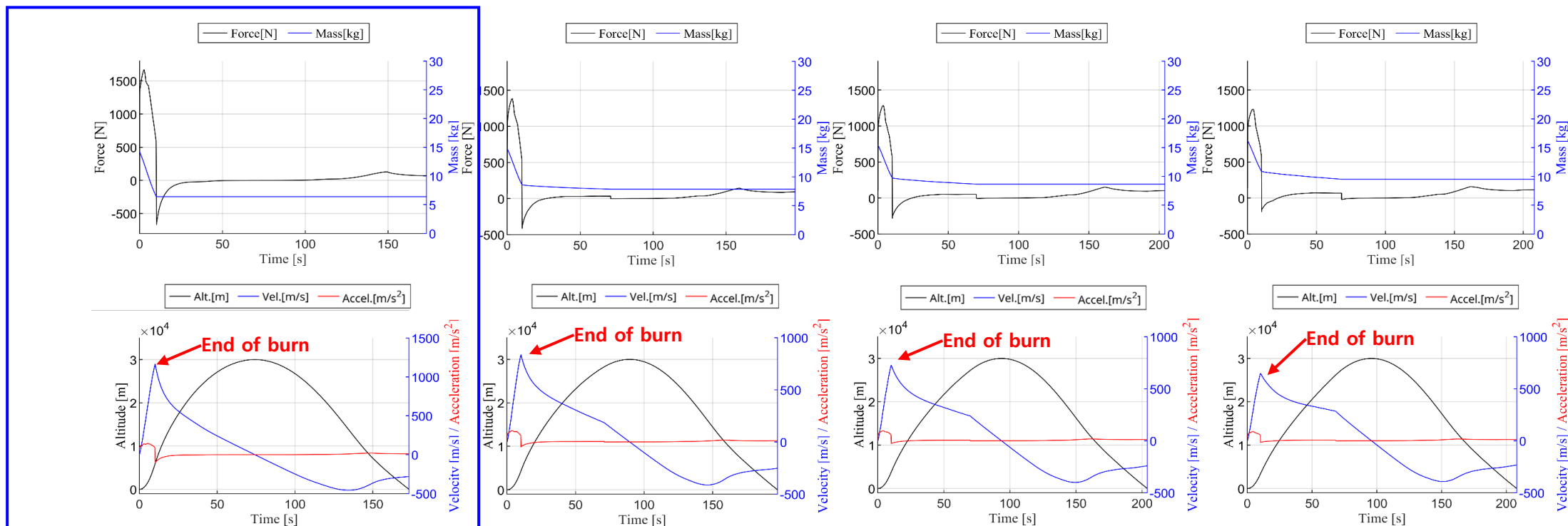
Ascent+Flyback+Landing Optimization Results



Vertical Landing Control: Mission objective met with touchdown velocity < 0.5 m/s at 0m altitude after the Altitude Achievement.



30km Ascent Optimization Results



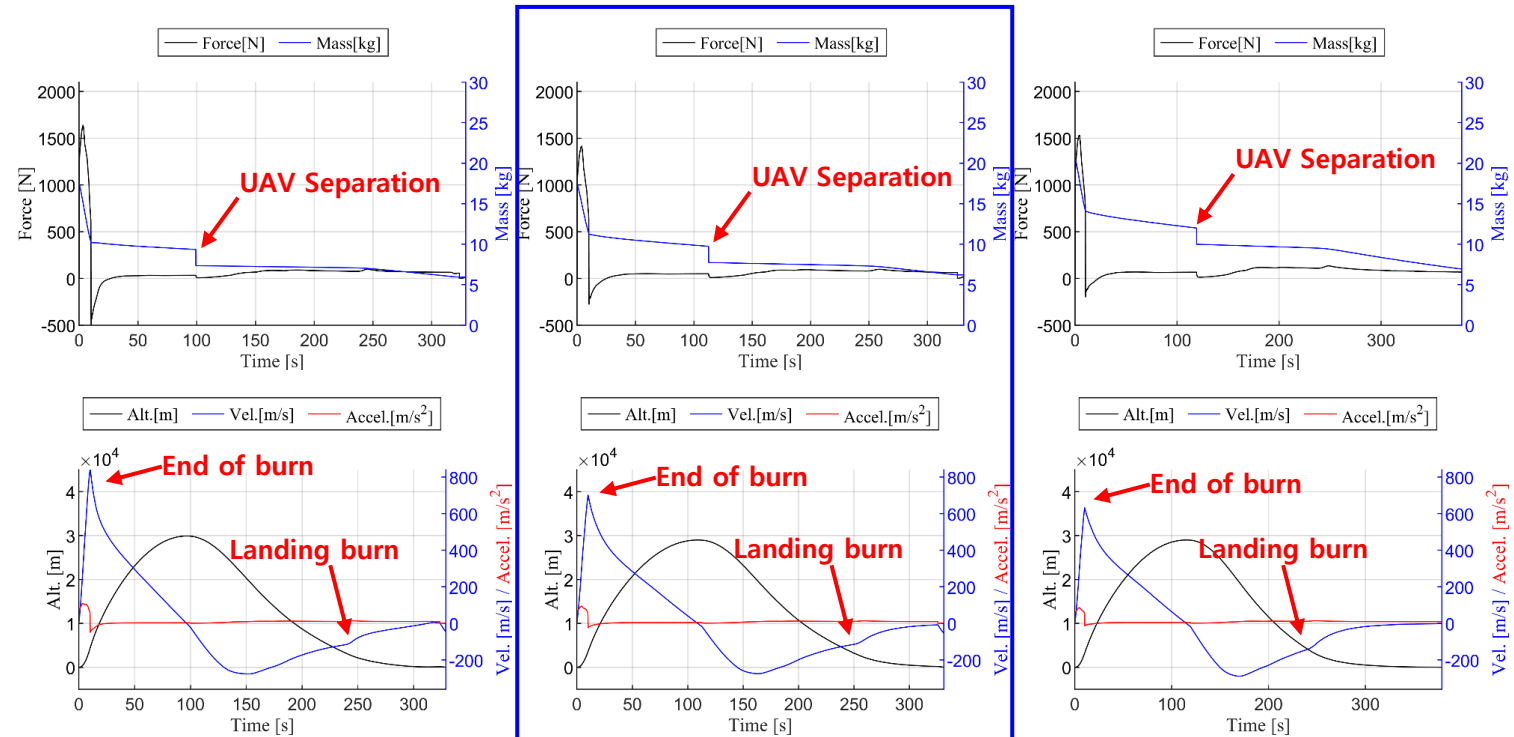
Case	I (0 Jet)	II (2 Jet)	III (3 Jet)	IV (4 Jet)
F_j [N] (Net)	0.00	64.00	96.00	128.00
F_r [N] (Max)	1830.60	1400.20	1251.40	1157.70
m_j [kg]	0.00	1.90	2.85	3.80
m_r [kg]	2.40	2.00	1.80	1.70
m_f [kg] (Rocket fuel)	7.80	6.00	5.40	5.00
m_f [kg] (Jet fuel)	0	0.96	1.35	1.71
m_y [kg] (Final-with payload)	6.40	7.90	7.70	7.60
m_y [kg] (Initial-with payload)	14.20	14.80	15.40	16.20
Fuel/Structure Weight Ratio	1.22	0.88	0.89	0.88

Entire Flight (30km Ascent, Flyback, and Landing) Optimization Results

Optimization Results for the Entire Flight Process: Ascent+Flyback+Landing.

Case III was identified as providing the optimal take-off weight.

- Therefore, the future 30km target rocket will be designed and developed based on three jet engines, total providing 96N of thrust.
- Additionally, this optimization method can also be applied to the 150m experimental RLV. (For the 150 m target with scaled RLV, case II showed optimal results)



Case	I (0 Jet)	II (2 Jet)	III (3 Jet)	IV (4 Jet)
F_j [N] (Net)	-	64.00	96.00	128.00
F_r [N] (Max)	-	1664.00	1381.00	1456.00
m_j [kg]	-	1.90	2.85	3.80
m_r [kg]	-	1.14	1.71	2.36
m_f [kg] (Rocket fuel)	-	7.17	5.96	6.30
m_f [kg] (Jet fuel)	-	2.44	3.30	5.54
m_y [kg] (Final-without payload)	-	3.93	4.20	4.94
m_y [kg] (Initial-with payload)	-	17.53	17.47	20.69
Fuel/Structure Weight Ratio	-	1.62	1.49	1.71



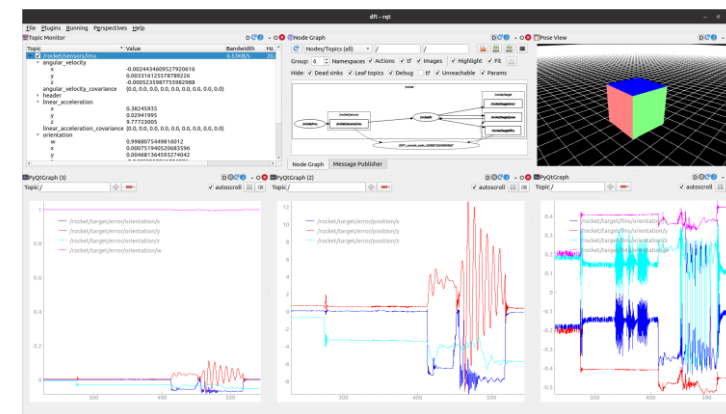
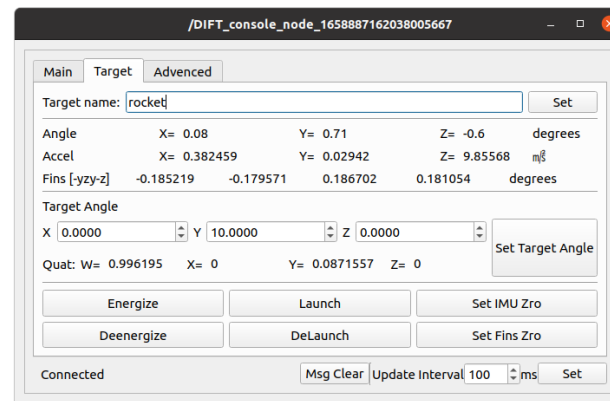
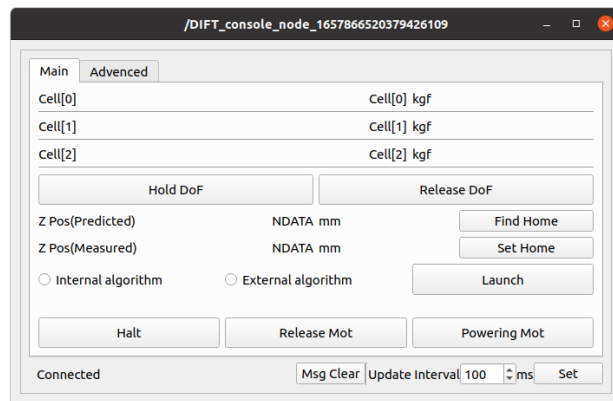
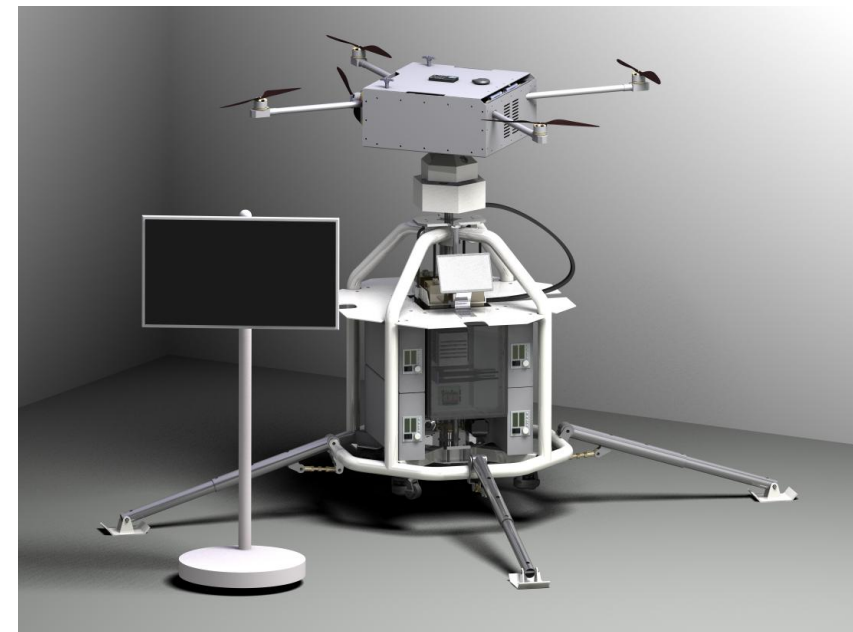
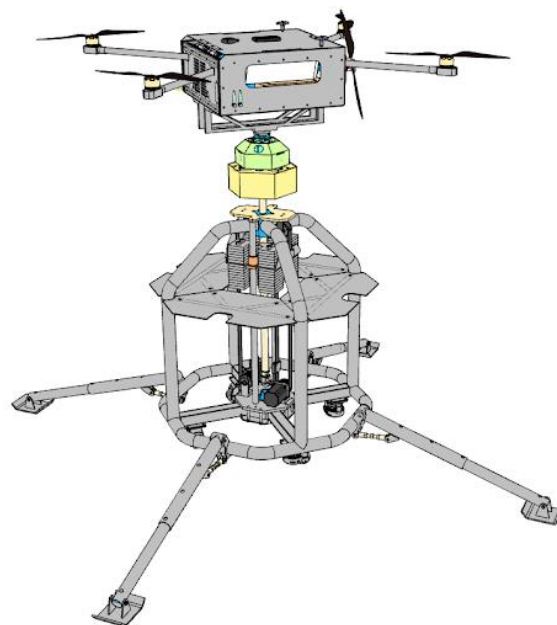
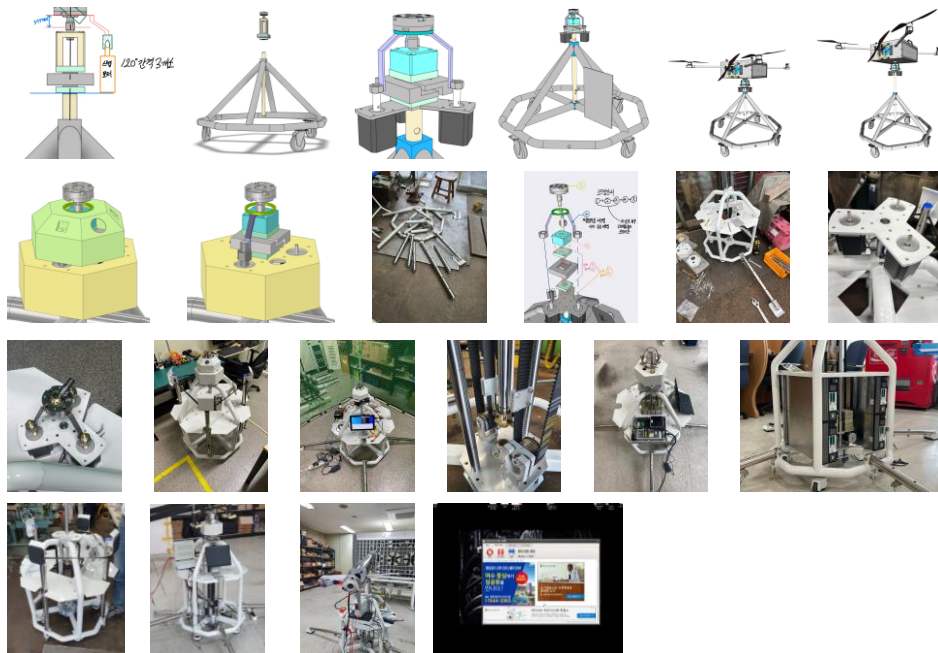
Test Equipment Development

시험 장비 개발



Development of Anti-Gravity Test Bench for Flight Simulation

Anti-Gravity Test Bench



Development of a Horizontal Wind Tunnel Test Facility for Flight Simulation



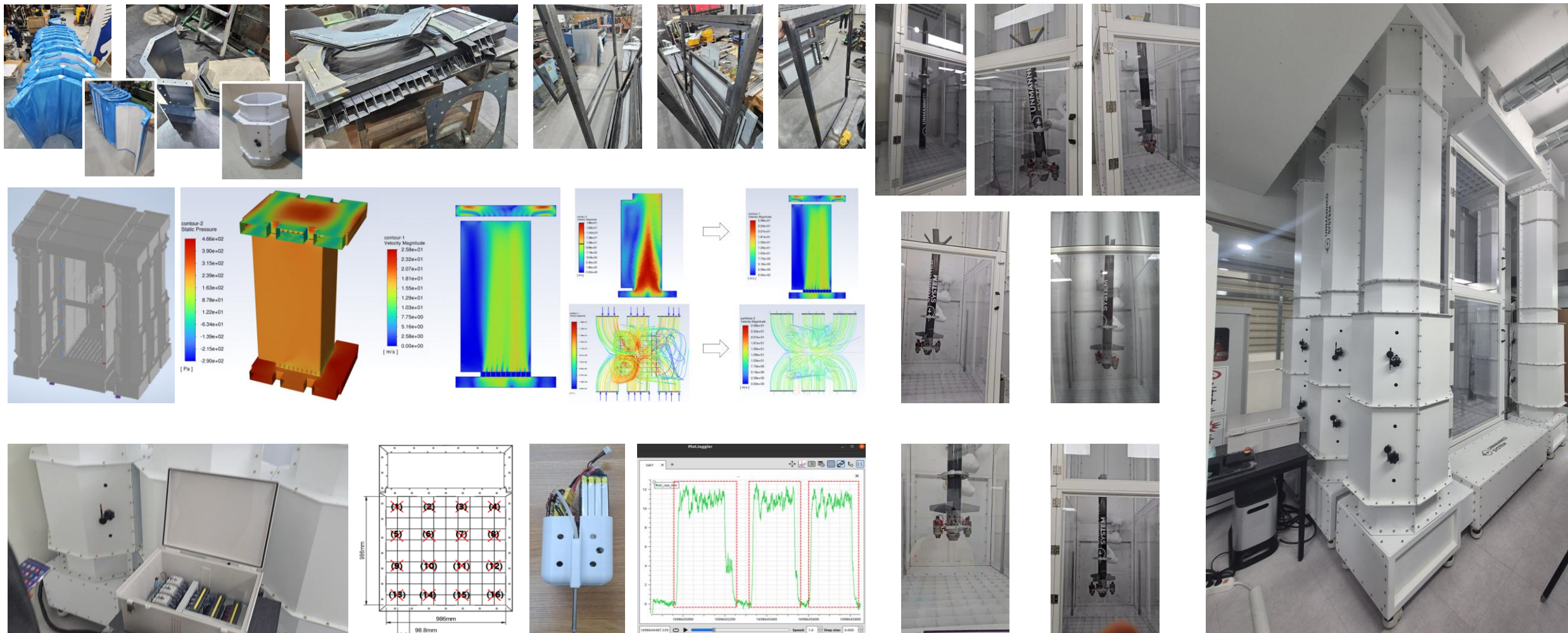
Horizontal Wind Tunnel



Development of a Vertical Wind Tunnel Test Facility for Rocket Landing Simulation



Vertical Wind Tunnel



Development of a Crane Test Facility for Outdoor Rocket Takeoff-Hover-Landing Experiments



Compact Crane



Development Completed & Currently Under Validation Test

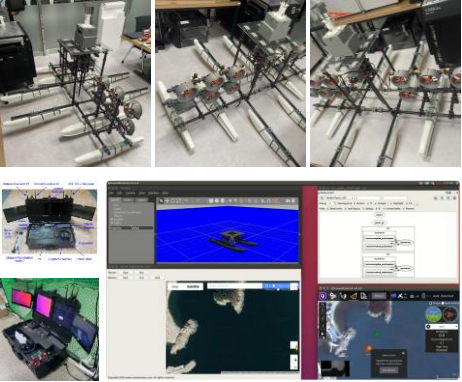
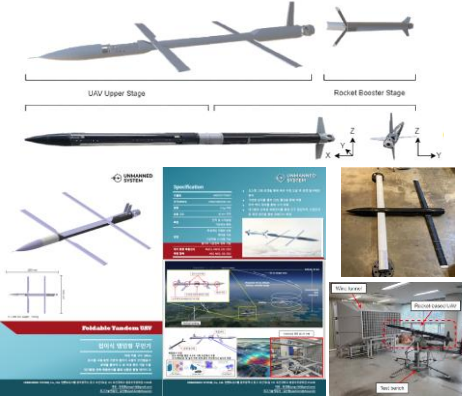
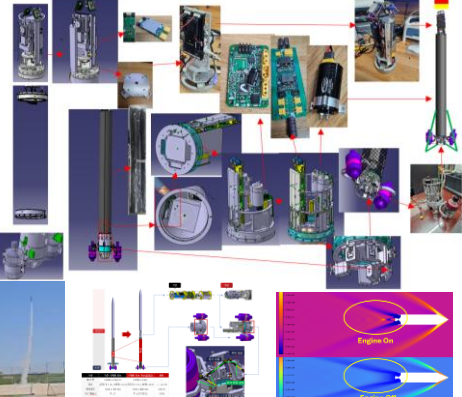


Future Works

향후 계획

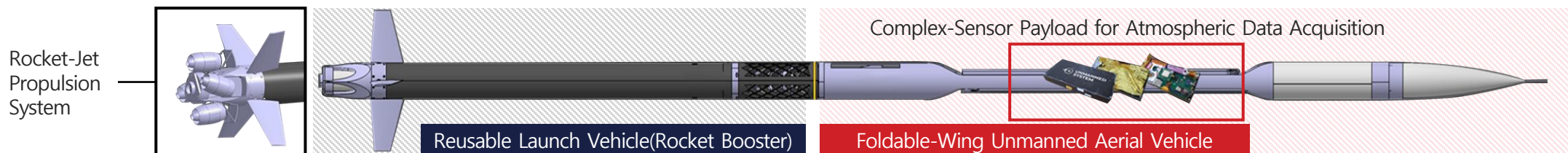
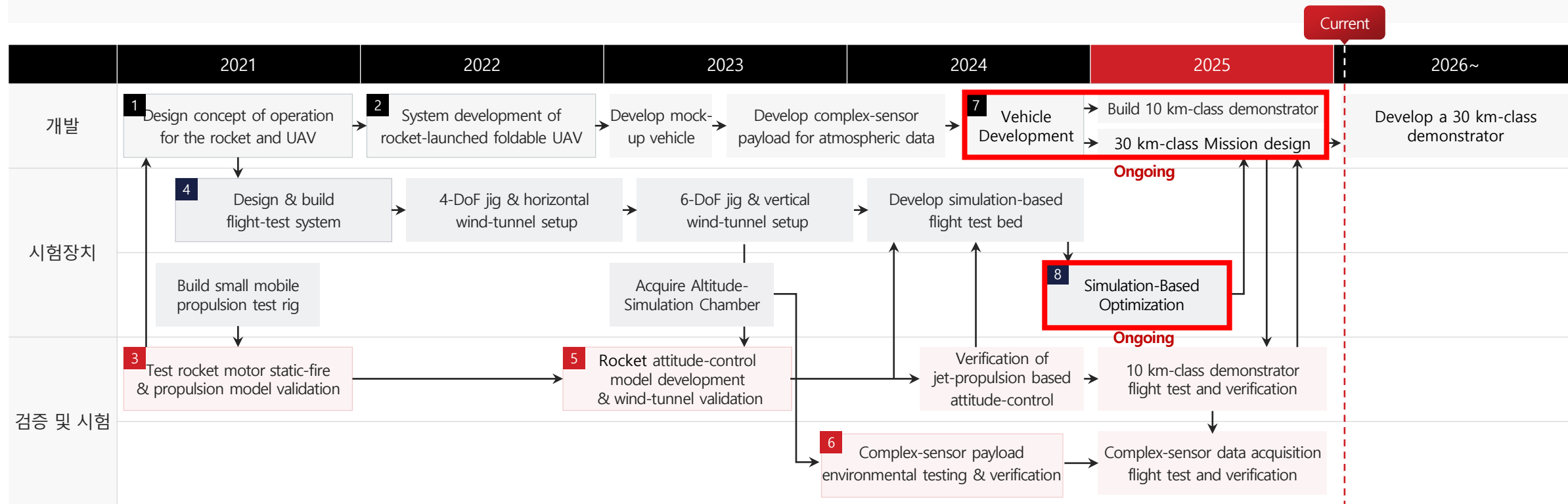




	USV for Rocket Launch Operations	Rocket-based UAV Prototype	Rocket-based UAV Verification System	Complex Sensor for Atmospheric Data Acquisition	Integrated Convex MPC-Based Control Framework
Project	2021 Regional Meteorological and Climate Industry Startup and Growth Support Program	2022 Youth Startup Academy (Startup Success Package Program), Ministry of SMEs and Startups	2023 Generation-Tailored Pre-entrepreneur Discovery and Incubation Program (POST Support Program), Gwangju Technopark	2024 Technology Development Program for Startup Growth (Didimdol - Stepping Stone), Ministry of SMEs and Startups	2025 Startup Leap Package (General Type), Ministry of SMEs and Startups
Objective	Enable autonomous coastal access and recovery for rocket-based UAV launch operations	Develop a compact rocket-based foldable-wing UAV for remote data acquisition	Establish an indoor experimental infrastructure for rocket-UAV control validation	Develop a lightweight multi-sensor system for real-time atmospheric observation	Enhance flight performance of a hybrid-propulsion rocket-assisted UAV using convex MPC
Features					
Key Achievements	- Developed a micro autonomous USV for rocket-UAV launch support - Implemented collision avoidance, object recognition, and autonomous docking/undocking	- Designed and manufactured a foldable-wing UAV platform - Completed solid rocket motor design and fabrication - Verified basic flight feasibility through indoor system-level testing	- Developed horizontal and vertical wind tunnel systems - Built an indoor GNC experimental environment for rocket and UAV systems - Completed takeoff and vertical flight modeling and validation (Simulink-based)	- Designed a compact satellite-LTE dual communication sensor system - Achieved stable operation under extreme atmospheric conditions	- Designed a convex MPC-based controller covering all flight phases - Integrated multi-sensor fusion for robust stratospheric operation - Verified control performance via simulations and hardware-based experiments
System Specs	[USV] - Size: 2.1(W) × 2.2(L) × 1.3(H) m - Mass: 23 kg [GCS] - Power: 11.1 V, 155 Ah Li-ion battery (1.72 kWh) - Output: DC & AC 220 V (≤ 1 kW), multi-port support	[Rocket] - Size: 0.3(W) × 1.5 (L) × 0.3(H) m - Mass(Dry): 3 kg - Mass(Wet): 4 kg (1 km) ~ 20 kg (30 km) [Foldable UAV] - Size(Folded): 1.4(W) × 0.9 (L) × 0.3(H) m - Size(Unfolded): 0.1(H) × 0.9 (L) × 0.1(H) m - Mass(Dry): 1.5 kg - Mass(Wet): 2 kg	[Horizontal Wind Tunnel] - Size: 3(W) × 5.5 (L) × 2.3(H) m - Size(Test Area): 2(W) × 3(L) × 1(H) m - Wind Speed(Max): 13 m/s [Vertical Wind Tunnel] - Size: 3.1(W) × 2(L) × 3.8(H) m - Size(Test Area): 1(W) × 1(L) × 3(H) m - Wind Speed(Max): 12.5 m/s	- Mass: 0.416 kg - Size: < 100 × 200 × 30 mm - Operating range: -60 ~ 60 °C, 10~98% RH, 0.01~1 atm - Thermal management: Intake, heat generation - Operation under high-altitude external environments	- Convex MPC for takeoff, transition, cruise, and landing - Indoor verification (MATLAB/Simulink, rocket test-stand) - Outdoor flight-test-based performance validation

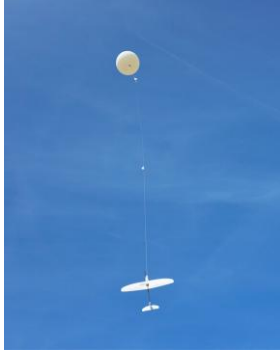
Roadmap to Stratospheric Environmental Data Acquisition

- UNMANNED SYSTEM has spent the last three years building a foldable fixed-wing UAV launched by a solid rocket to collect real-time atmospheric data at ~30 km altitude.
- An unmanned surface vehicle equipped with YOLO-based AI vision software detects, tracks, and **autonomously recovers both the rocket and the UAV**.

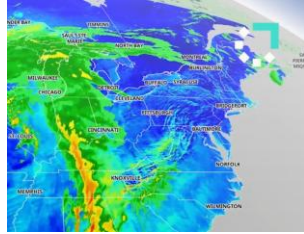


Under International Collaborations

☛ MeteoGlider

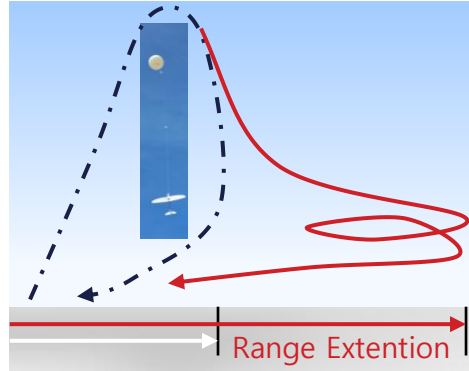


☛ Weather Model



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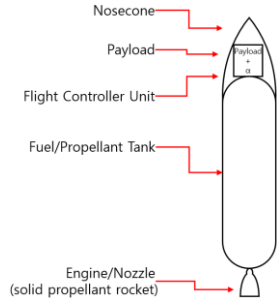
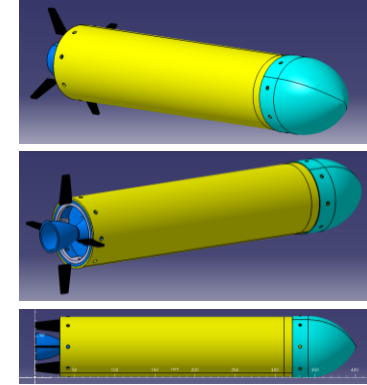
☛ MeteoRocket



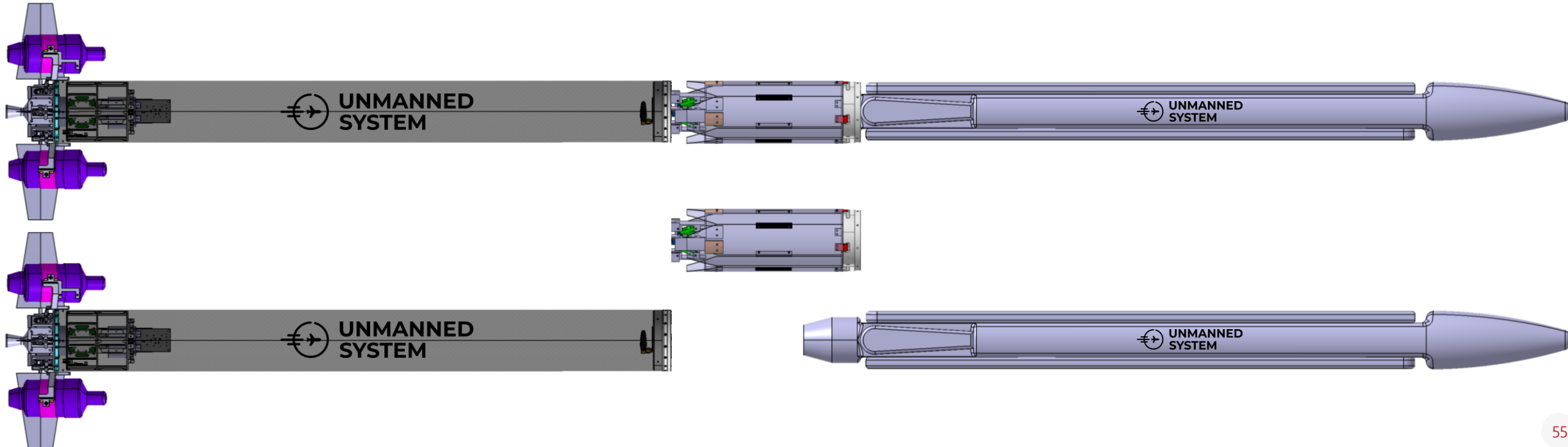
Powered Flight for Extended Reach

- **Optimized for Complex Missions:** The combination of powered flight and advanced guidance allows for more intricate flight paths and targeted observation strategies.
- **Strategic Energy Use:** Leveraging the BMS's precise monitoring and control, the energy-intensive propulsion system can be employed strategically, primarily when its use is critical or most impactful.

☛ MeteoRocket2

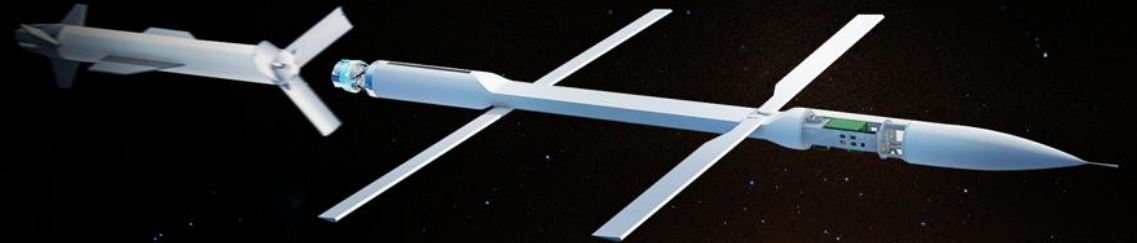


☛ Small RLV and UAV System





Thank you very much!



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