2023-2024 Performance Report of Tohoku University Students' Projects
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TOHOKU UNIVERSITY

HIGH-altitude Propeller Evaluation Research (HIGHPER)

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Background

Research and Development of Mars Airplane

- New exploration system enabling wide-area surveys near the Martian surface
- Mars Airplane Balloon Experiment（MABE）
  - Planning and conducting flight tests of a glider

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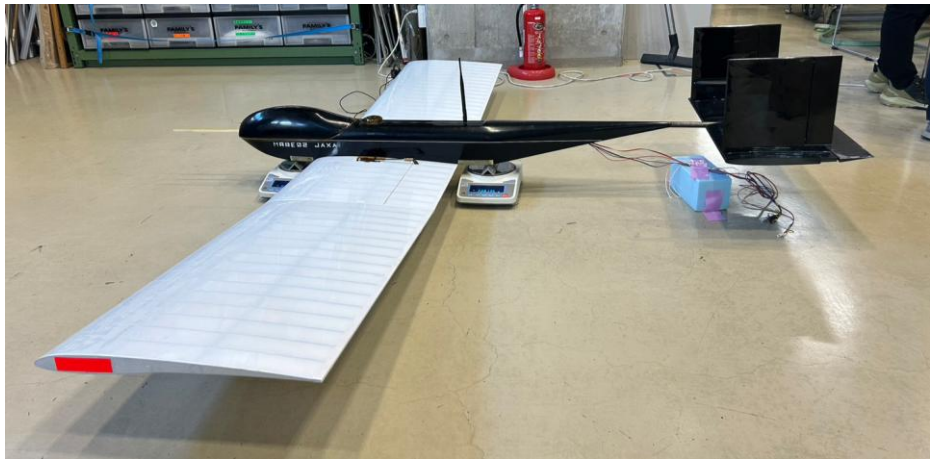
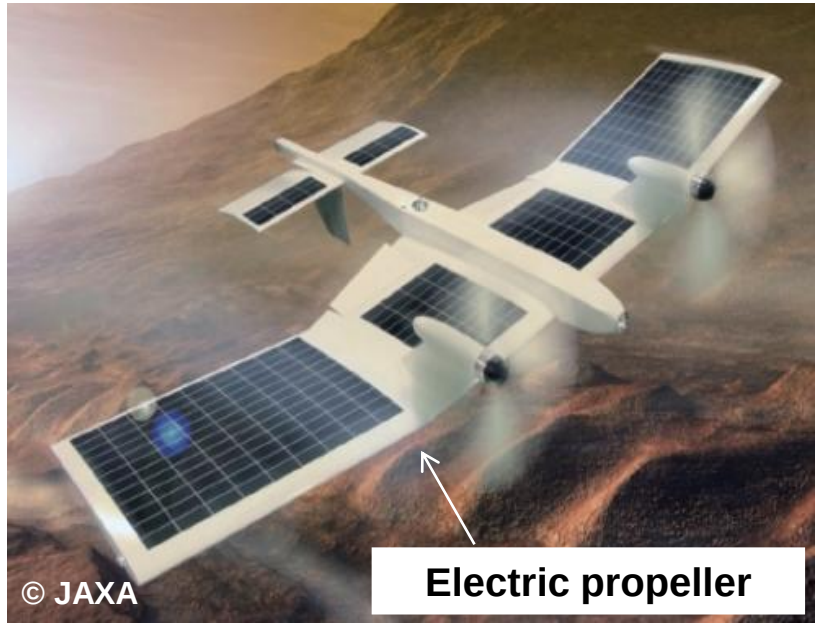
  - Future goal: Equipping propulsion systems for more extensive and flexible long-range exploration



High-altitude Test Airplane after Assembly（MABE2）

Electric Propeller

- The Martian atmosphere is thin and cold
  - High-performance propeller optimized for low Reynolds number and high Mach number conditions
  - Development and demonstration of a propeller-driven system operable in the Martian environment



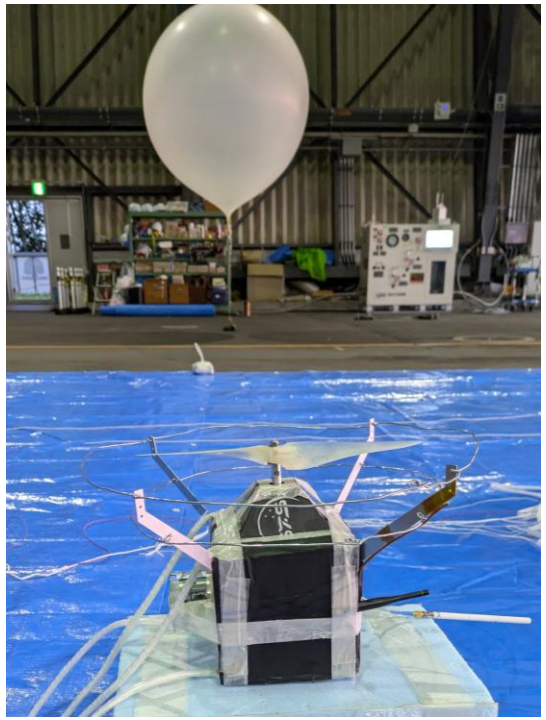
Conceptual Diagram of the Mars Exploration Aircraft

Project Objectives

HIGH-altitude Propeller Evaluation Research: HIGHPER

Objectives

- Development and demonstration of a propeller drive & performance measurement system operates in the Martian environment
- Elemental development and preliminary experiments for Mars airplane development
  - Planning experiments using small rubber balloons, which provide frequent flight opportunities
  - Accumulation and transfer of expertise in balloon experiments



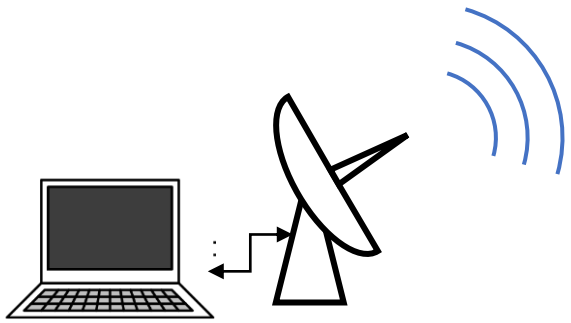
HIGHPER Gondola Just Before Launch (Launched on Aug. 21, 2024, 5:00 AM)

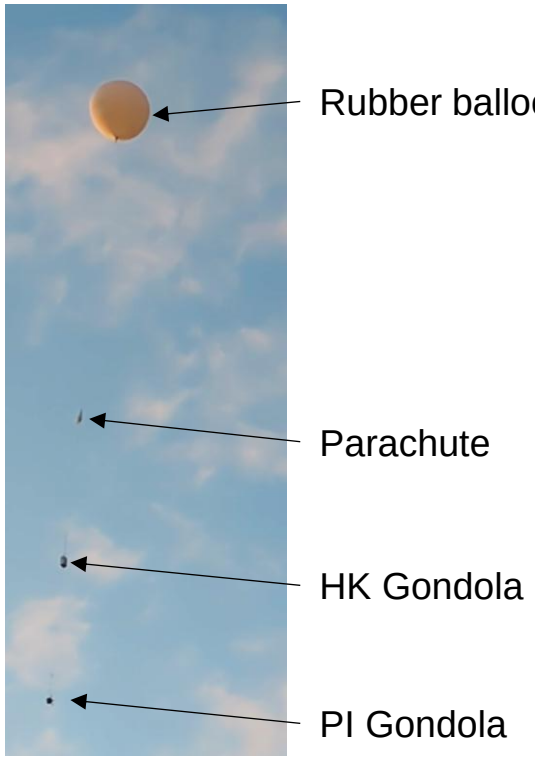
Success Criteria

- Minimum : The gondola operates at high altitude, and telemetry data is logged until the experiment ends
- Full : The propeller operates under one condition at high altitude, and the results are logged for analysis
- Extra : The propeller operates under multiple conditions at high altitude, and the results are logged for analysis

Overview of Balloon Experiments

Experimental System

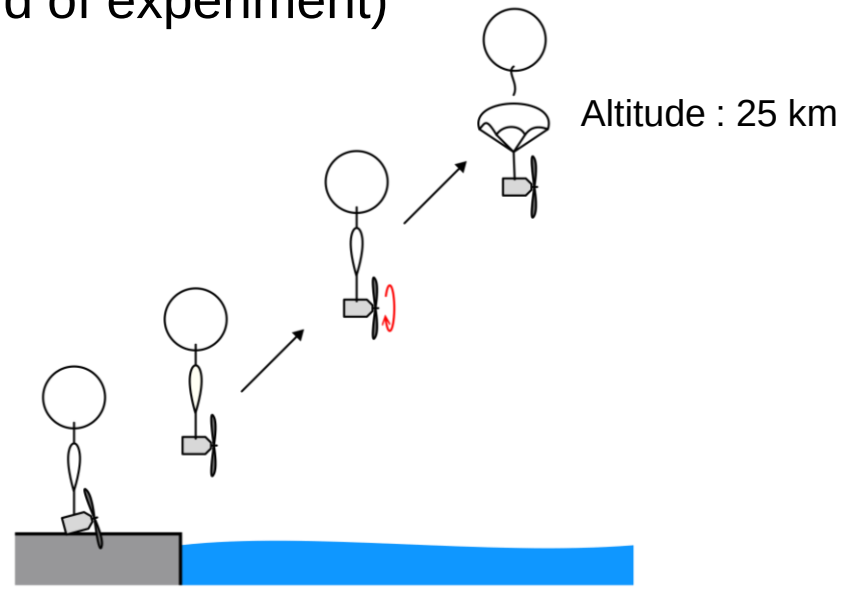




- Balloon
  - Two-gondola configuration based on previous example[1]
- Ground Station
  - Telemetry monitoring and command transmission

- Flight Sequence

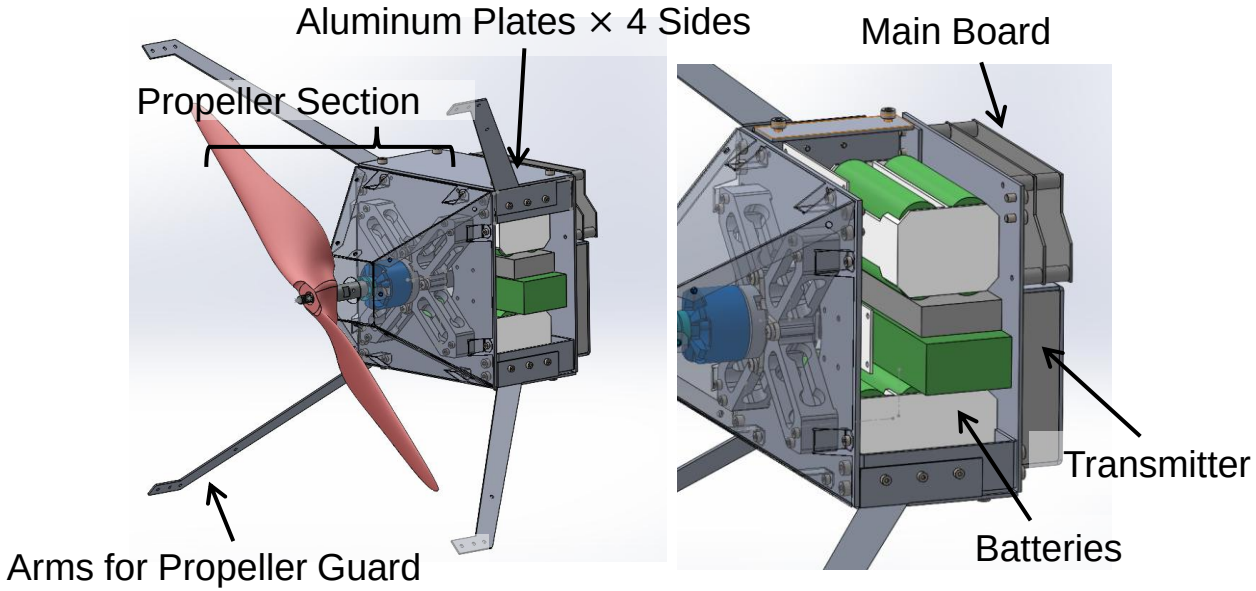
1. Launch
2. After reaching offshore, the propeller automatically starts rotating at predetermined altitudes
3. Upon reaching the target altitude, the gondola separates from the balloon (end of experiment)



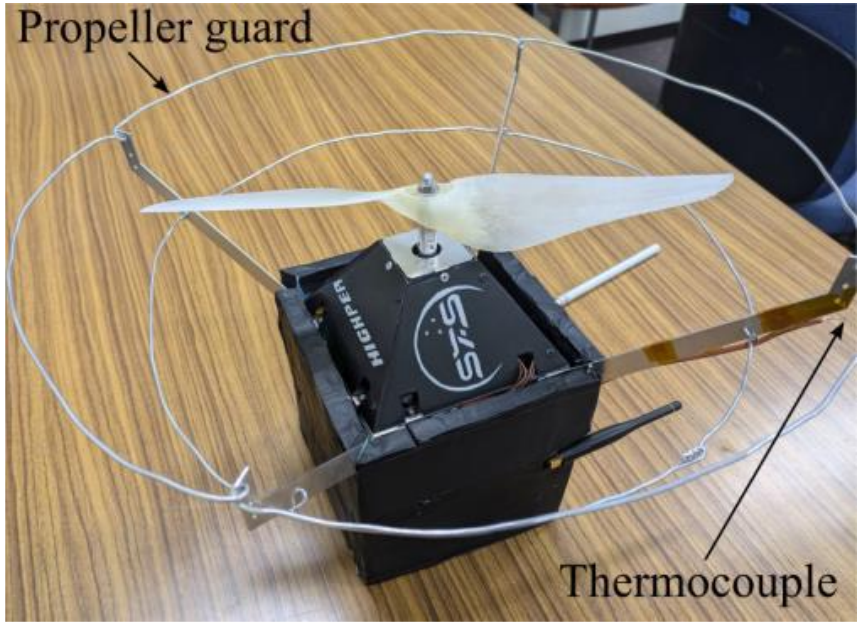
[1] H. Fuke, *et al.*, *J. Evol. Space Act.*, vol. 1, (2016), No. 22.

Equipment of PI Gondola

PI Gondola



Experimental Gondola Structure (Insulation Omitted))



Gondola after Assembly

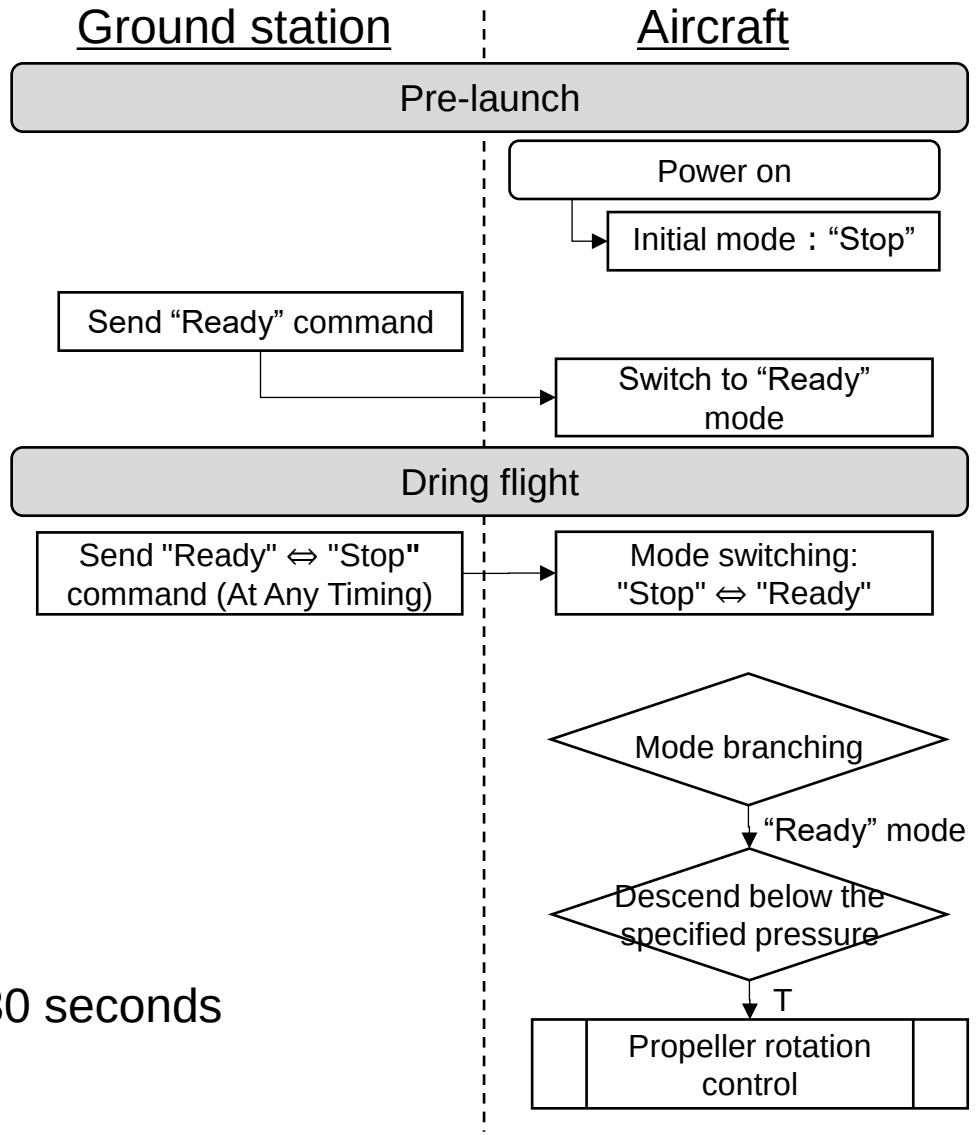
- Structure : 120 mm cubic rectangular shape (aluminum plate, foam insulation)
- Propeller : 300 mm diameter, with wind shield
- Total Weight : 1.96 kg

- Measurement Data (Downlink: 5 Hz)
  - Propeller RPM, thrust, and torque
  - Atmospheric temperature and pressure
  - 9-axis attitude

Rotation Conditions and Sequence

Pressure & Rotation Speed Conditions

#	Pressure Conditions	Target Rotation Speed
1	P < 240 hPa (11.0 km)	1800, 2400, 3000, 3600 rpm
2	P < 128 hPa (15.0 km)	2000, 4000, 5000, 6000 rpm
3	P < 58 hPa (20.0 km)	2000, 4000, 5000, 7000 rpm



- Rotation speed is controlled using proportional control
- Rotation sequence is based on atmospheric pressure
- Transition to the next rotation speed occurs when:
  - The target rotation speed is maintained within ±30% for 30 seconds or 120 seconds have elapsed since the start of rotation
- Mode switching takes priority, allowing manual stop at any time

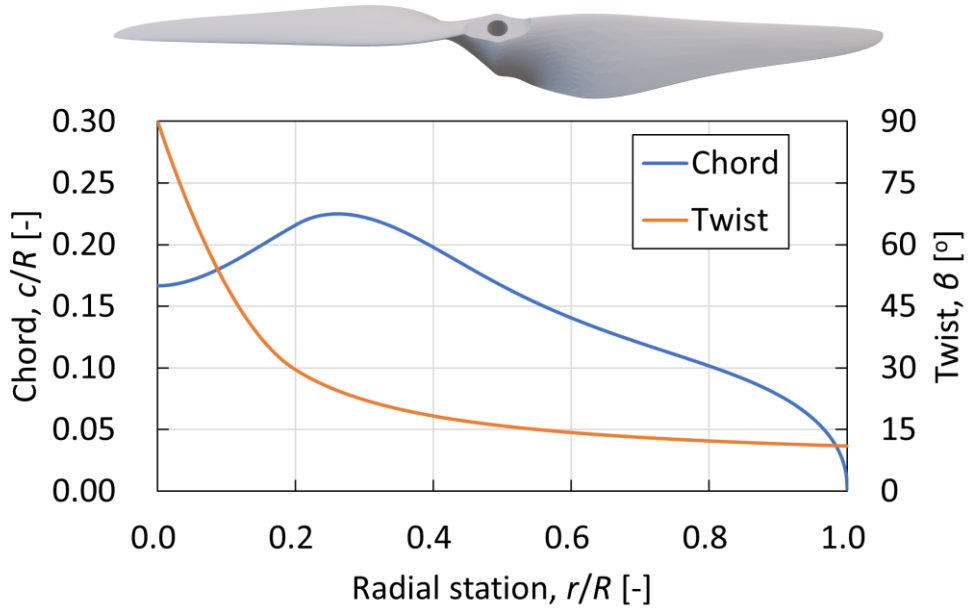
Design and Performance of the Installed Propeller

Design Conditions & Method

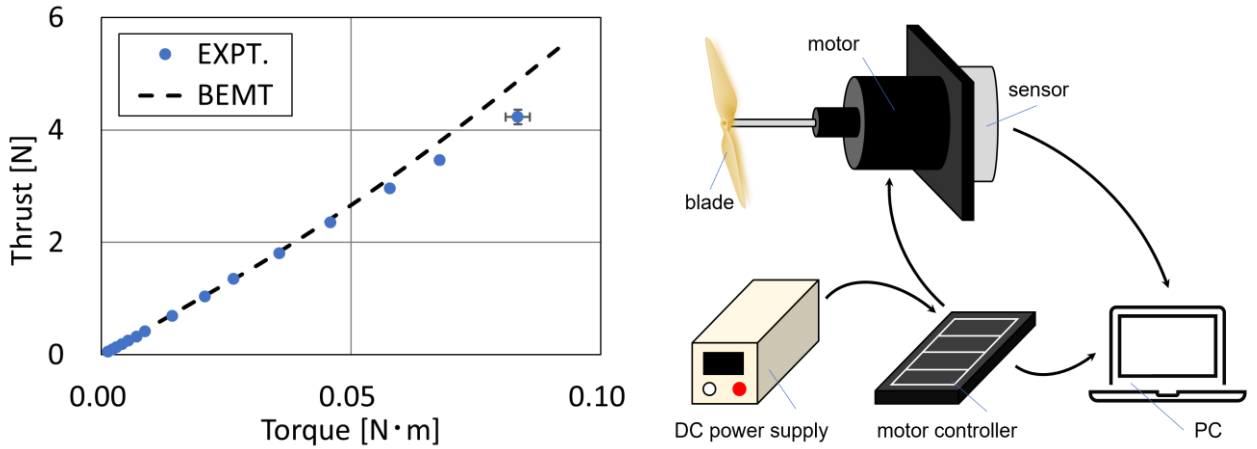
- Designed using Blade Element Momentum Theory (BEMT) [2, 3]
- Atmospheric Conditions: High altitude of 20 km
- Blades: 2 blades, Diameter 300 mm
- Torque Constraint: 20 mN·m

Hovering Performance (Calculated by BEMT)

- Thrust, T: 0.98 N @ 20 mN·m
- Power, P: 14.7 W
- Figure of Merit: 0.588
- Ground tests and BEMT calculations show good agreement



Propeller Geometry



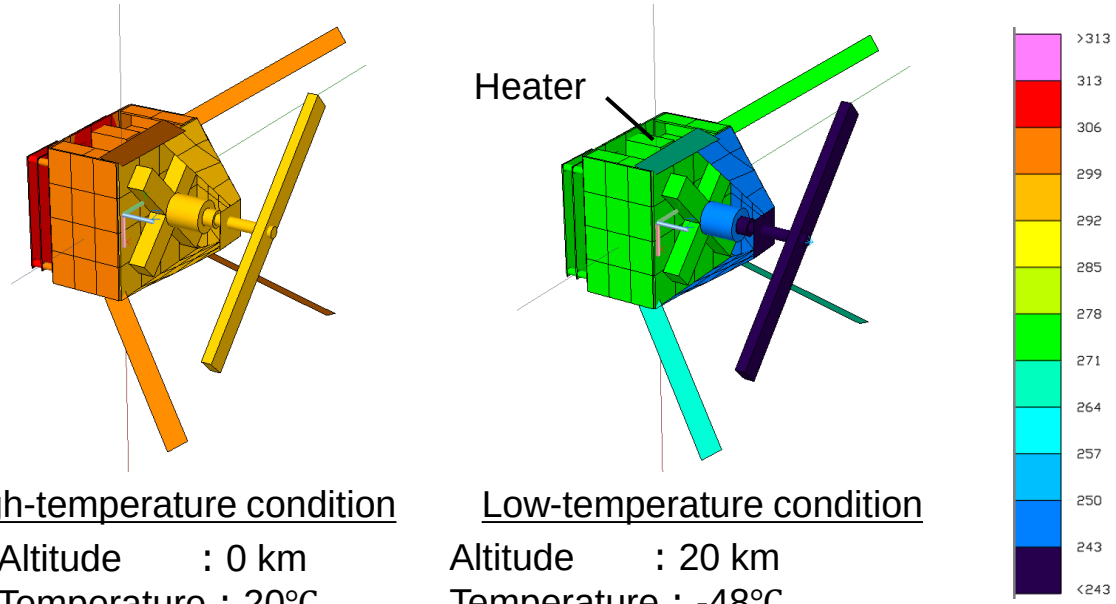
Ground Performance Test of the Propeller

[2] 三瀬ら,日本航空宇宙学会北部支部2024年講演会, 2024. [3] 三瀬ら, 第62回飛行機シンポジウム, 2024.

Thermal Design of the Gondola

Thermal Analysis Using Numerical Models Thermal Vacuum Test

- Thermal mathematical model built via Thermal Desktop and SINDA/FLUINT by C&R Technologies
- Heater power and surface optical properties determined from analysis



High-temperature condition

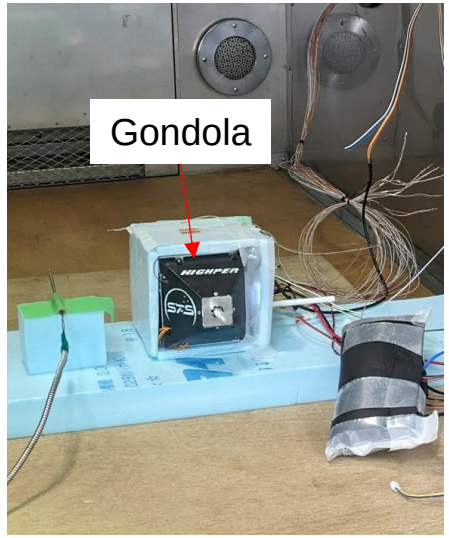
Altitude : 0 km
Temperature : 20℃
Heater : OFF

Low-temperature condition

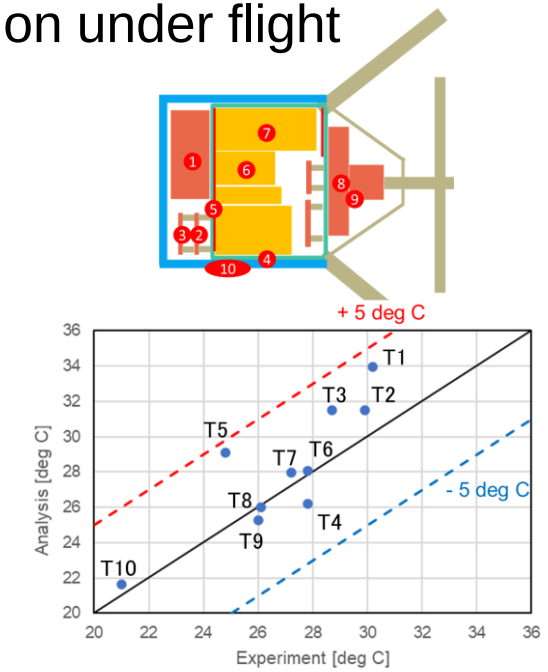
Altitude : 20 km
Temperature : -48℃
Heater : **10 W** @Battery

Steady-State Thermal Analysis Results

- Conducted in a thermal vacuum chamber of the JAXA/ISAS Balloon Experiment Group
- Correlation analysis between test results and the numerical model
- Verification of operation under flight conditions



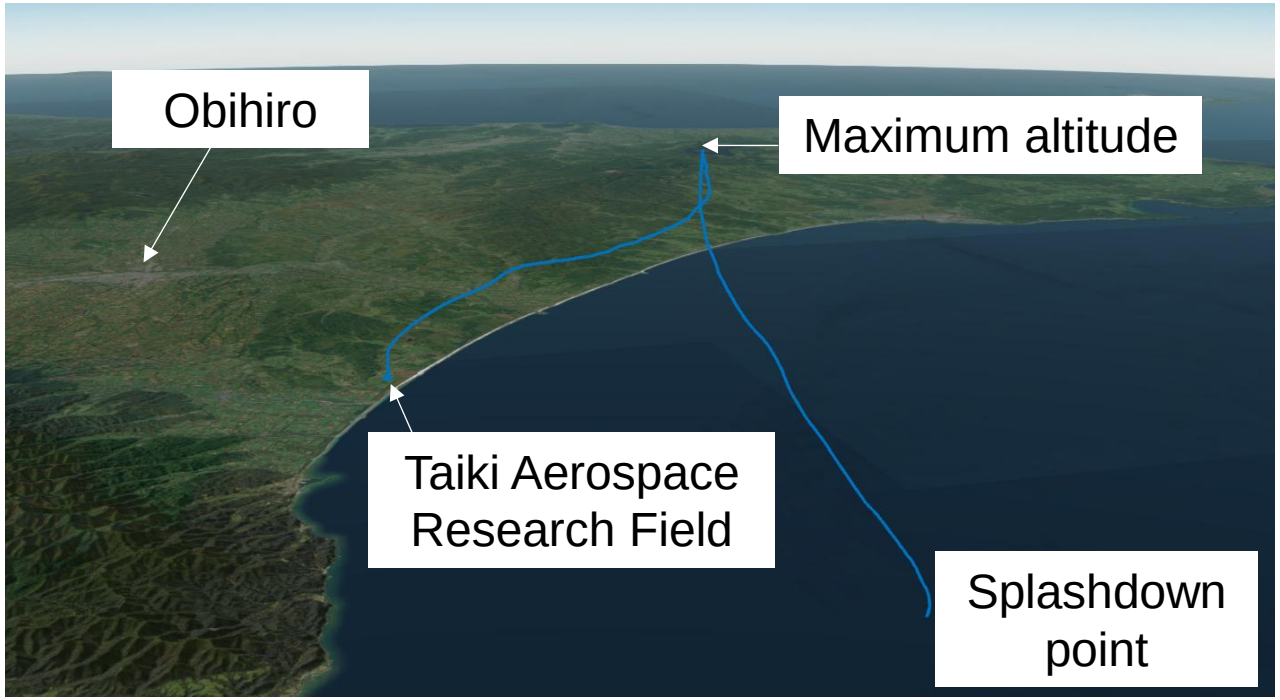
Gondola During Thermal Vacuum Test



Correlation Results (Steady-State & High-Temperature Condition)

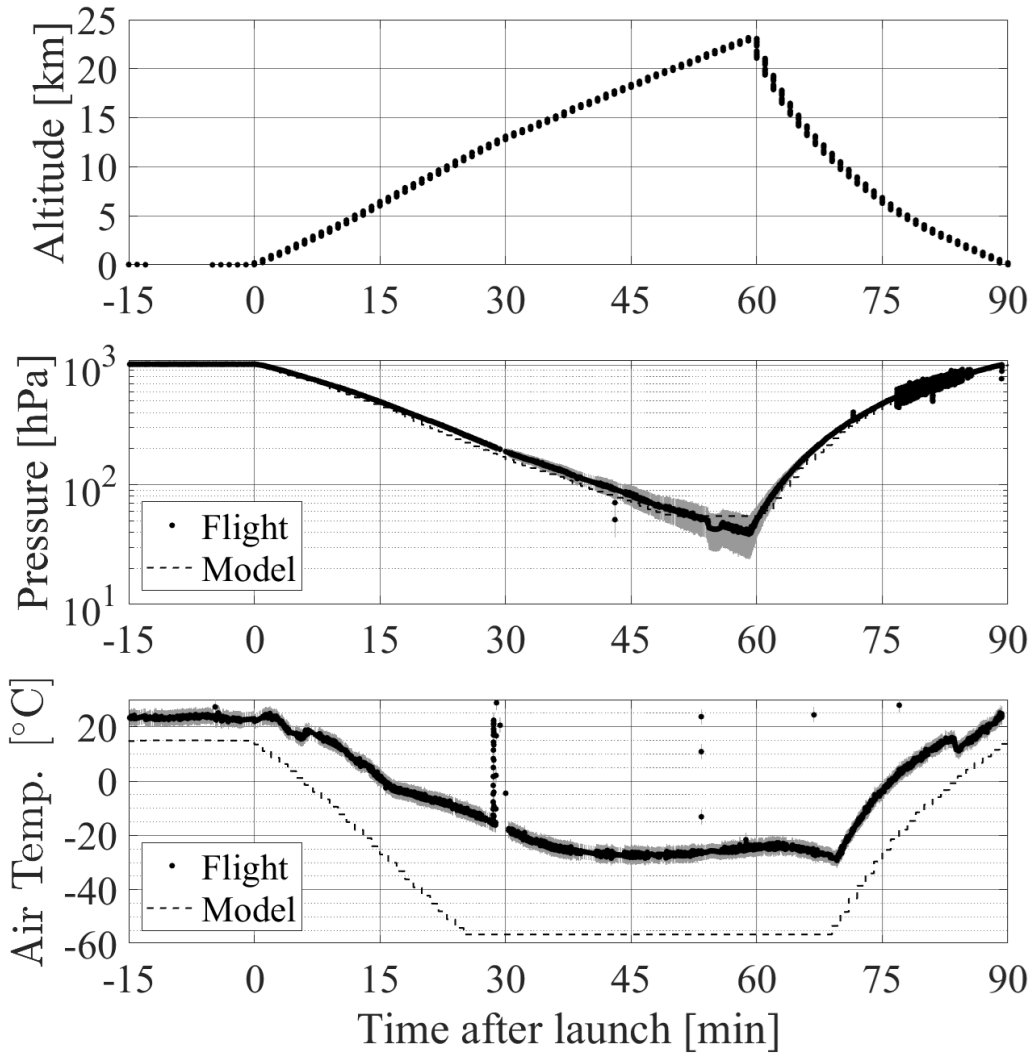
Preliminary Results of the Flight Experiment

Flight History – Flight Path and Atmospheric Data



Bird's-Eye View of the Flight Path (Created from HK Gondola GPS Data)

- Launch Date & Time: August 21, 2024, at 5:00 AM
- Flight Duration: Approximately 1 hour of floating before descent over offshore Obihiro
- Maximum Altitude: 23.2 km (39.1 hPa, -25.1°C)
- Temperature: 20–30°C higher than the standard atmosphere model



Atmospheric Data During Flight
(Flight: Downlink Data, Model: U.S. 1976)

Conclusion

Preliminary Results of the HIGHPER Experiment

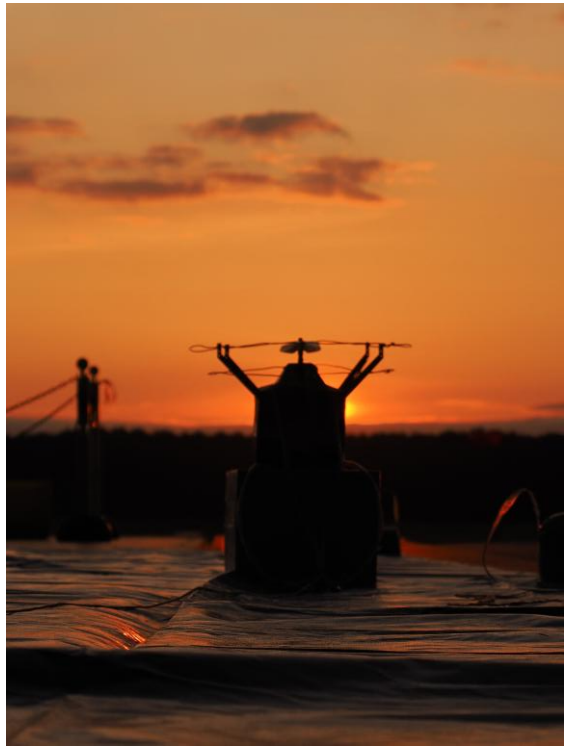
Success criteria		
Minimum	: Operation verification and data downlink at high altitude	○
Full	: Propeller operation under one condition with data downlink	△ (downlink was lost midway)
Extra	: Propeller operation under multiple conditions with data downlink	△ (downlink was lost midway)

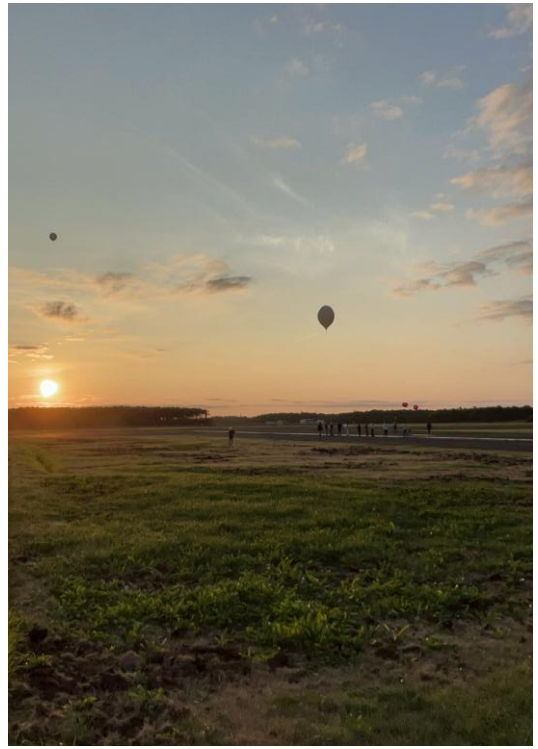
- Successful verification of the propeller drive system operation
- Further analysis required for propeller performance data
  - Correction of vehicle motion and attitude is necessary

Insights on Propeller Operation & Control at High Altitude

- RPM control tends to diverge under low-pressure conditions
  - Atmospheric pressure compensation is required
- With a gondola mass-to-thrust ratio of ~20:1, propeller rotation significantly affects vehicle attitude and cannot be ignored

Acknowledgment





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We sincerely appreciate the assistance. Thank you.