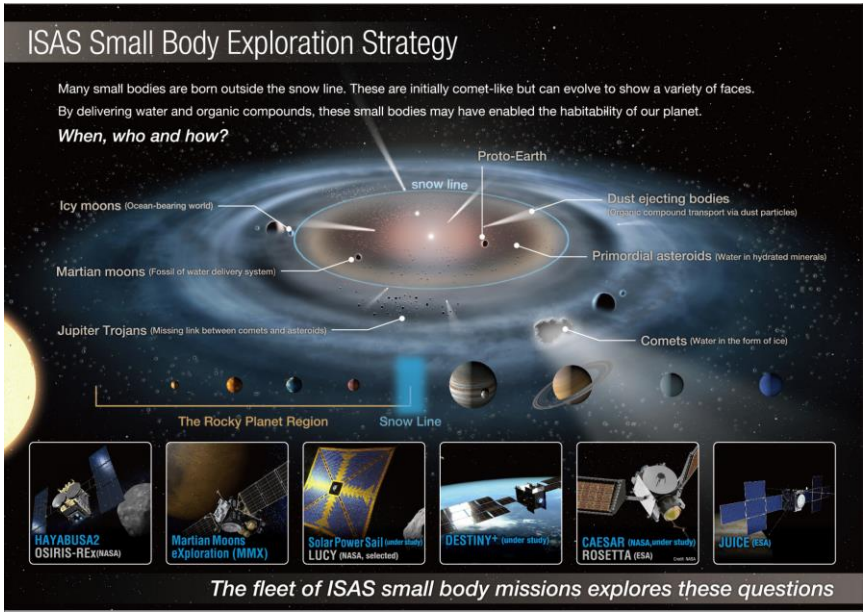
HOKKAIDO UNIVERSITY

RERA:
Rubber balloon Experiment for Reentry capsule with thin Aeroshell

ゴム気球を利用した新型大気圏突入カプセルの低速領域の自由飛行試験

○Hideto Takasawa, Takashi Miyashita, Kaito Wakabayashi, Yusuke Takahashi (Hokkaido Univ.),
Yoichi Suenaga (Univ. of Tokyo),
Koshiro Hirata (Tokyo Univ. of Agriculture and Tech.),
Yasunori Nagata, Kazuhiko Yamada (JAXA)

Background



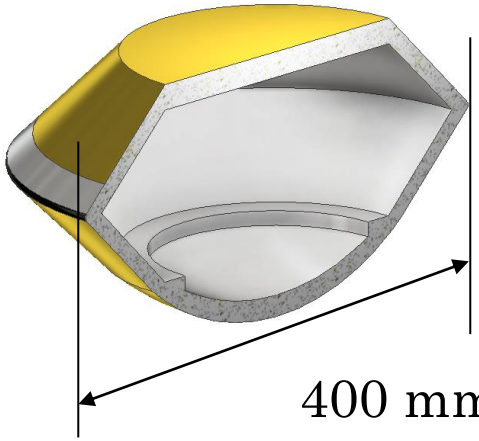
The sample return mission is a central part of “Small Body Exploration Strategy" and "Deep Space Fleet" to realize it.

The mission aims to explore to celestial objects beyond the snow line in order to obtain information on the origin of the solar system.

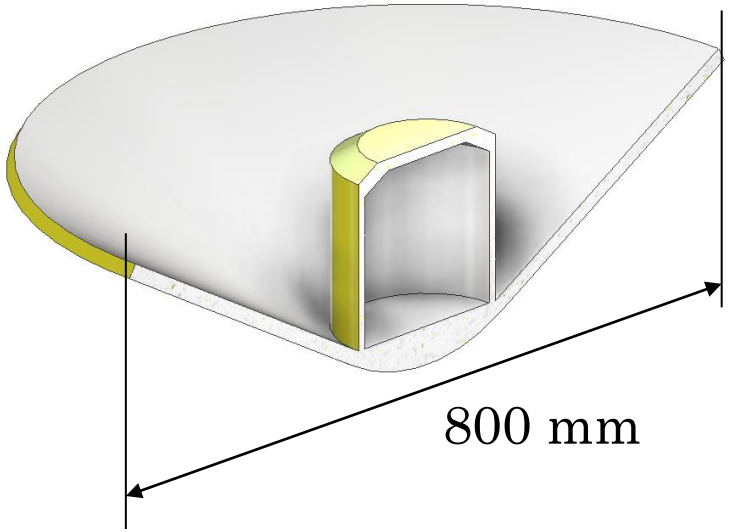
The significance and value of the sample return mission in the planetary exploration has already become a common global value by the success of HAYABUSA.

“THE CAESAR MISSION TO COLLECT A SAMPLE FROM A COMET”, ISAS/JAXA, https://cosmos.isas.jaxa.jp/the-caesar-mission-to-collect-a-sample-from-a-comet/, 24 Jul 2022.

Thin Shell Type Reentry Capsule



Hayabusa type
(reentry velocity of 12 km/s)



Thin shell type
(reentry velocity of 15 km/s)

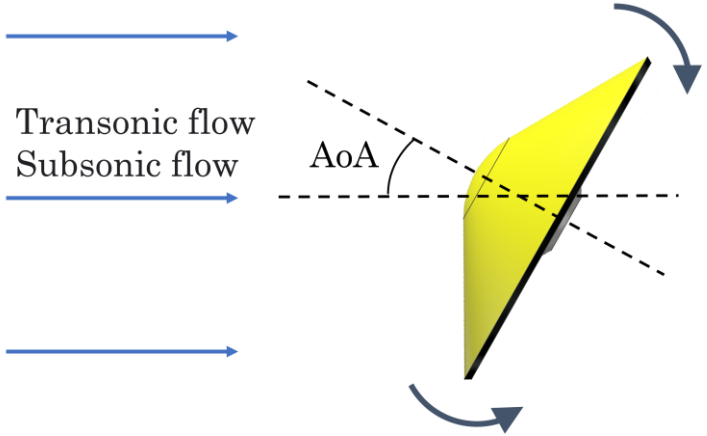
Design concept

Light weight and large area for deceleration at high altitude to avoid aerodynamic heating

山田和彦, 将来の深宇宙惑星探査に向けたサンプルリターンカプセルの研究開発, 2019年度衝撃波シンポジウム, 2C2-3, 201.

Aerodynamic Instability

It is a phenomenon of oscillation caused by aerodynamic force during flight, and tends to occur in the subsonic to transonic range



Aerodynamic Instability

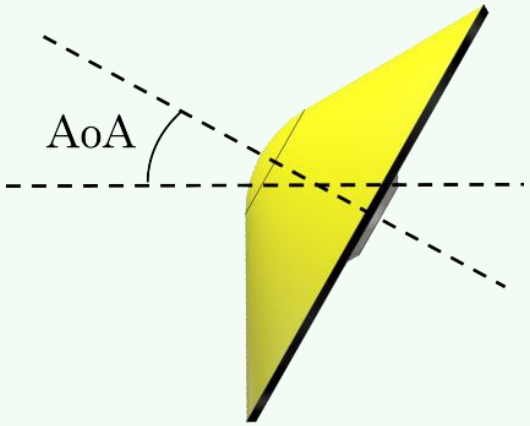
Disadvantages of instability

- Inability to perform proper aerodynamic deceleration
- Deviation from predicted landing point
- Inability to properly deploy the parachute

Y. Nagata, K. Yamada, T. Abe, K. Suzuki, Attitude Dynamics for Flare-type Membrane Aeroshell Capsule in Reentry Flight Experiment, in: AIAA Aerodynamic Decelerator Systems (ADS) Conference, American Institute of Aeronautics and Astronautics, Reston, Virginia, 2013. doi:10.2514/6.2013-1285.
K. Hiraki, Experimental Study on Dynamic Instability of Capsuleshaped Body, ISAS Rep. 103 (1999) 1–55.

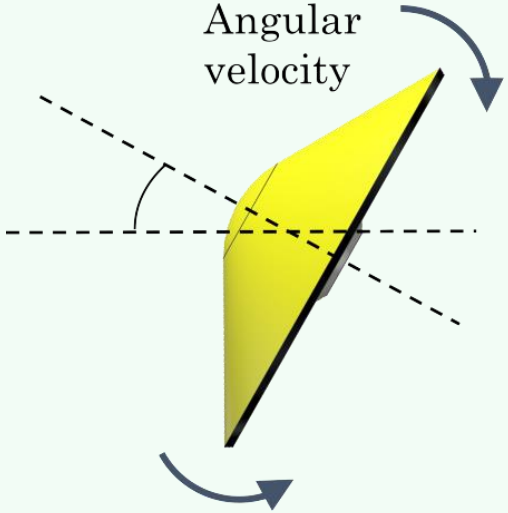
Aerodynamic stability

Static stability



The capsule is stationary at an angle of attack (AOA) to the flow.

Dynamic stability



There is angular velocity around the center of gravity.

K. Hiraki, Experimental Study on Dynamic Instability of Capsuleshaped Body, ISAS Rep. 103 (1999) 1–55.

Purpose of study

Static stability

- **Experiment**

The thin shell type capsule was statically stable at all speed

- **Numerical analysis**

The statically stability was due to the difference of pressure between the top and bottom of the front surface

Dynamic stability

- **Balloon experiment**

To evaluate the dynamic stability of the capsule at low-speed

- **1 DoF Wind tunnel test**

To evaluate the dynamic stability of the capsule for transonic and supersonic flow

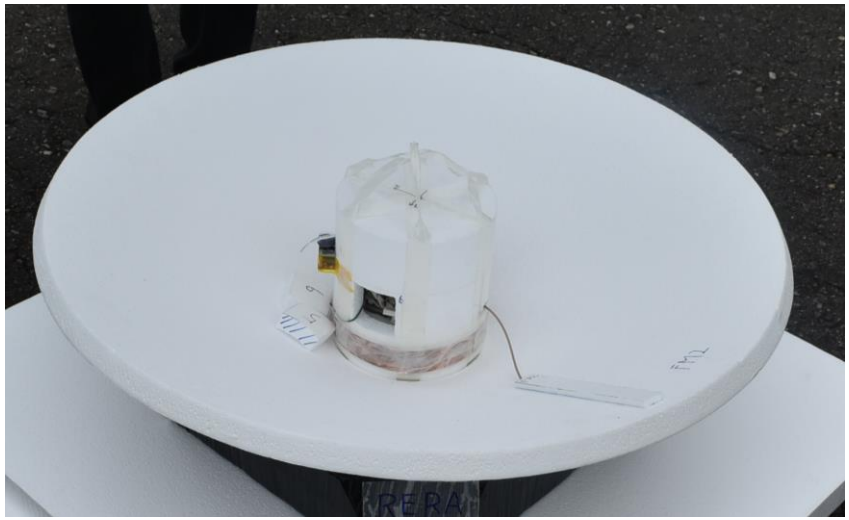
Hideto Takasawa, et.al, “Experimental and Numerical Study on Aerodynamic Instability of Thin Shell Type Reentry Capsule at Subsonic Speed", 33rd International Symposium on Space Technology and Science, 10th Nano-Satellite Symposium & 14th IAA Low-Cost Planetary Missions Conference, japan, 2022.
藤井智也, 他4名, 遷音速および超音速域における薄殻エアロシェル型再突入カプセルの空力安定性研究,,令和 3 年度宇宙航行の力学シンポジウム, 2021

Balloon experiment

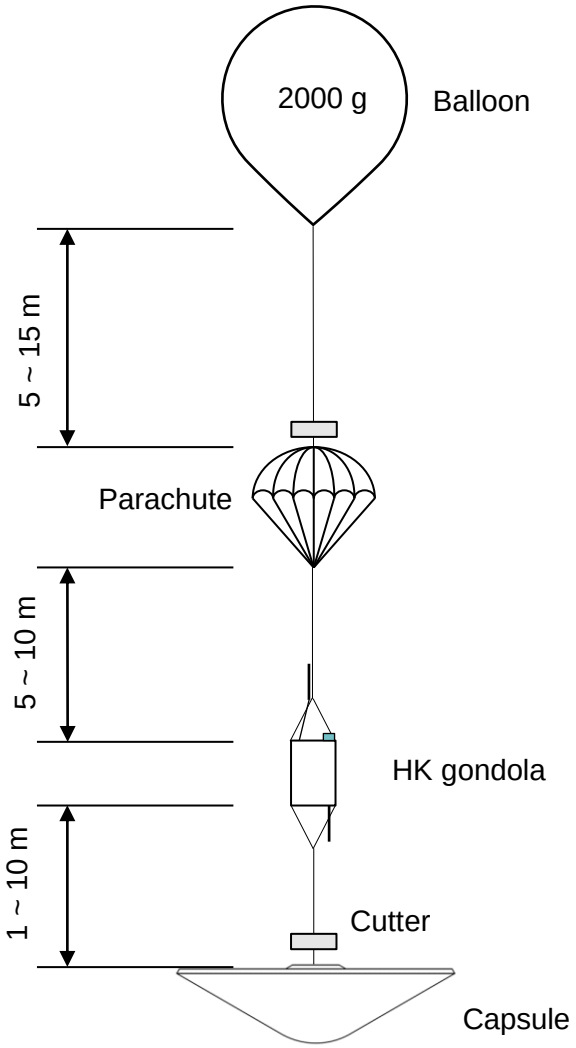
Purpose of rubber balloon experiment

- To evaluate the dynamic stability of the capsule at low-speed
- To build the platform for balloon experiments

Altitude	25 km
Mass	1.5 kg
Size	φ 800 mm× 240 mm
Material	Styrofoam
Moment of inertia	X : 1.99e7 g · mm^2 Y : 1.99e7 g · mm^2 Z : 3.29e7 g · mm^2



Experimental sequence



＜Experimental sequence＞

① Turning on the power

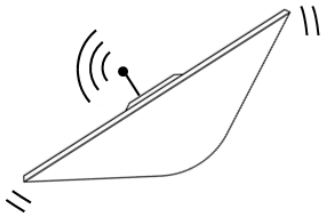
② Confirming system operation

③ Launch of balloon

④ Ascent to an altitude of 25 km

⑤ Cutting the rope by command

⑥ Flight

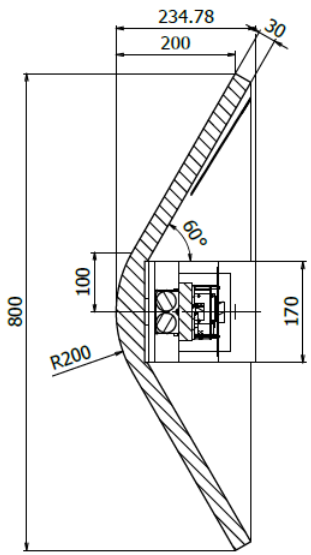


⑦ Landing on the sea

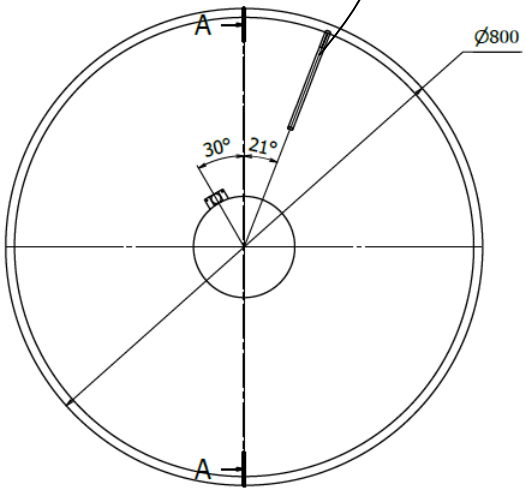
Capsule for balloon experiment

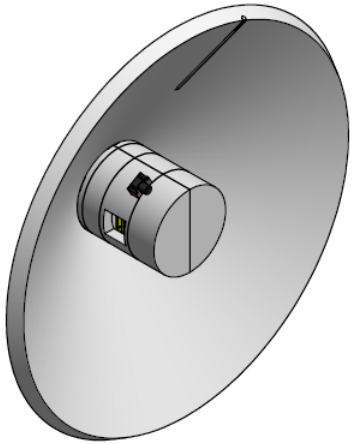
Total weight : 1.56 kg
(including 0.4 kg of styrofoam)

A-A (1 : 5)



Groove for antenna
of transmitter



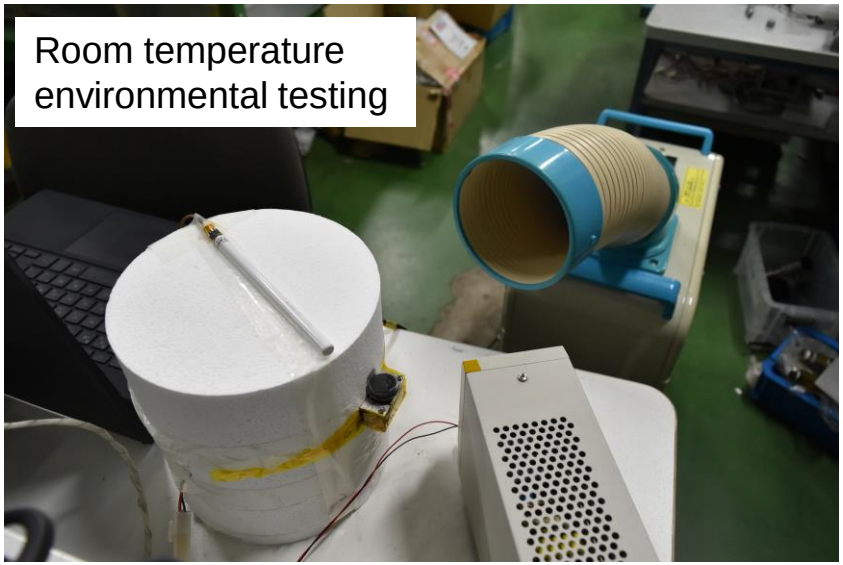


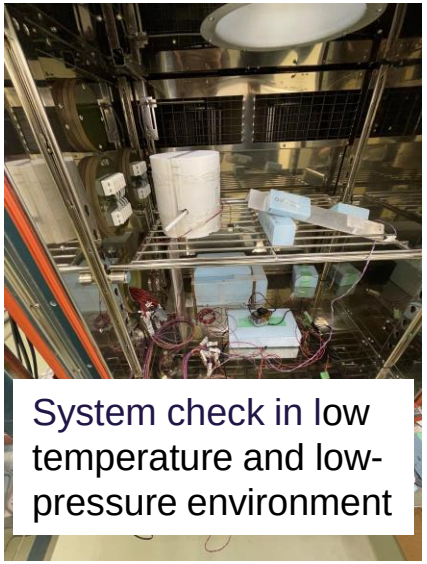
Assembly_RERA_v3

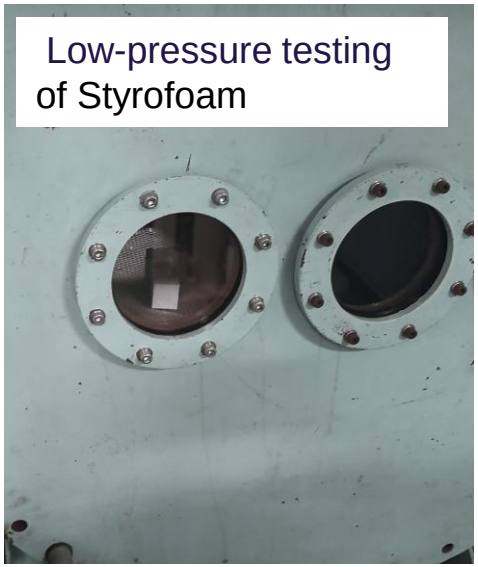
Development test for RERA

Various tests before flight

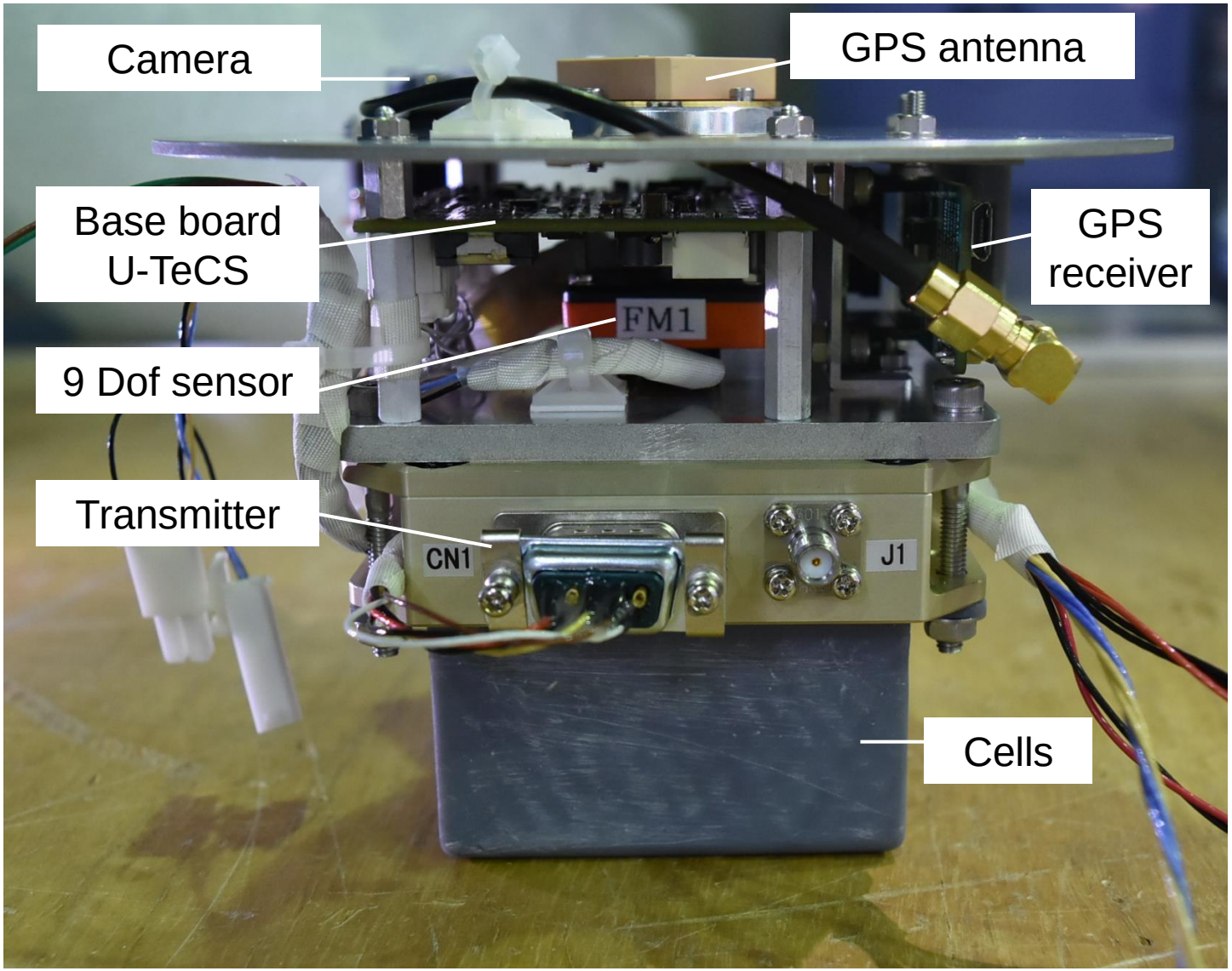
- Strength evaluation of adhesive
- Room temperature environmental testing
- System check in low temperature and low-pressure environment
- Low-pressure testing of Styrofoam





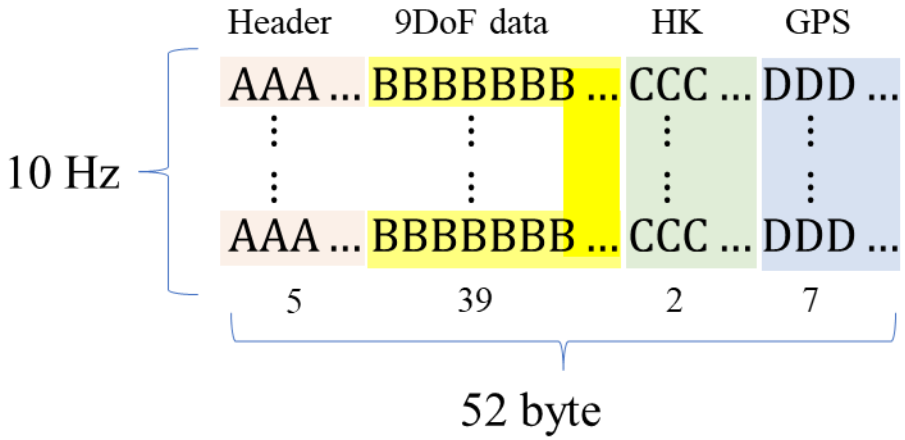


Capsule for balloon experiment



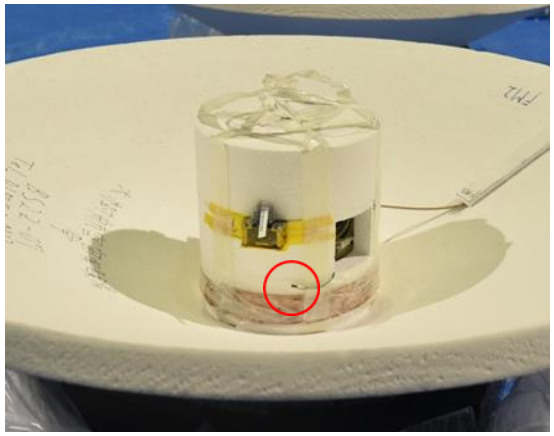
Measurement items

Measurement Items	
	Frequency
Acceleration, m/s^2	100 Hz
Angular velocity, rad/s	100 Hz
Magnetic field	100 Hz
Quaternion	10 Hz
HK data (Temperature, Pressure, Voltage…)	10 Hz
GPS (Altitude, longitude…)	10 Hz
Picture	0.1 Hz



Measuring position

- Temperature
  - Motion sensor
  - Base board
  - Cells
  - Transmitter
  - Outside
- Pressure
  - around equipment

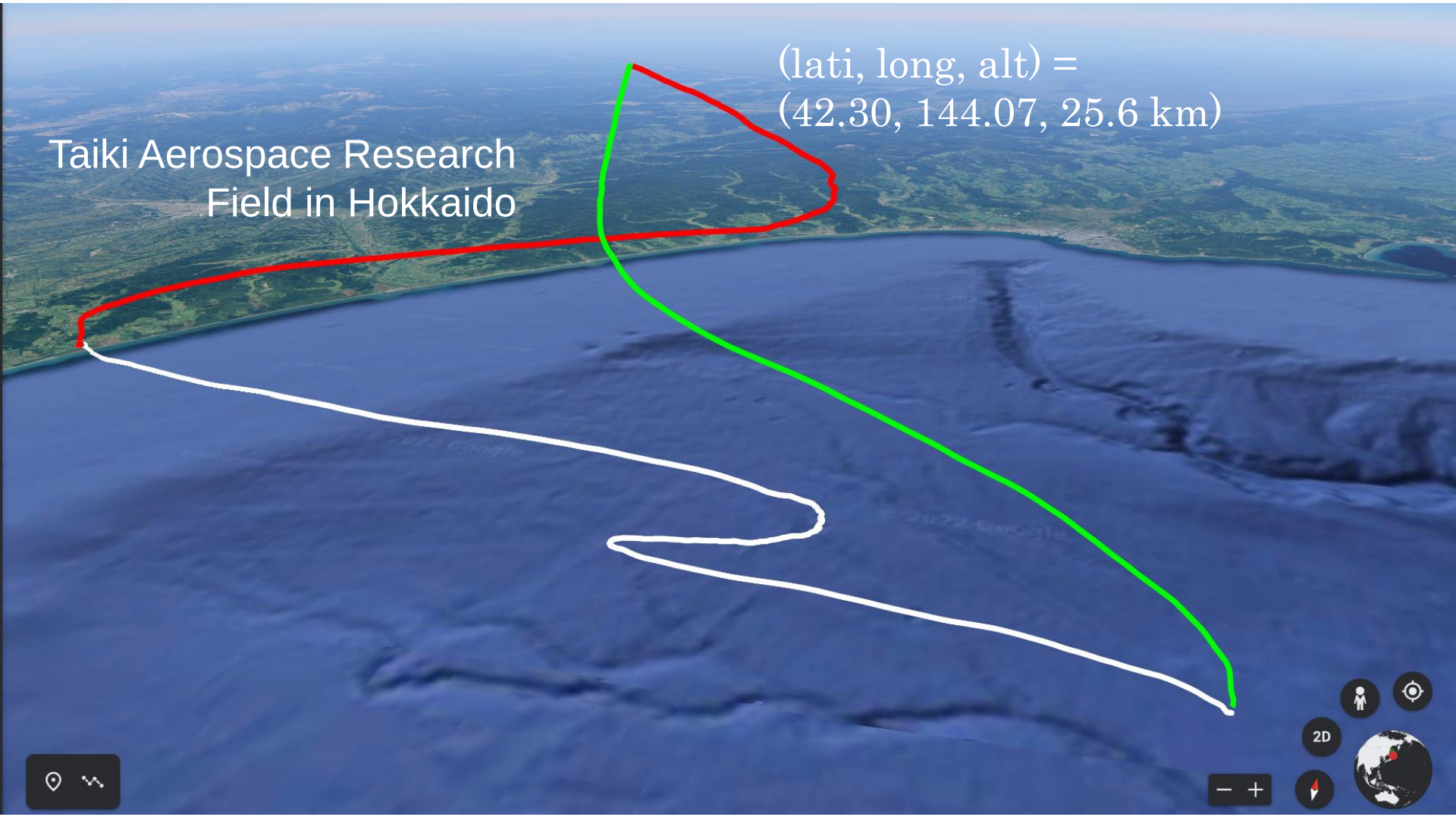


Trajectory analysis

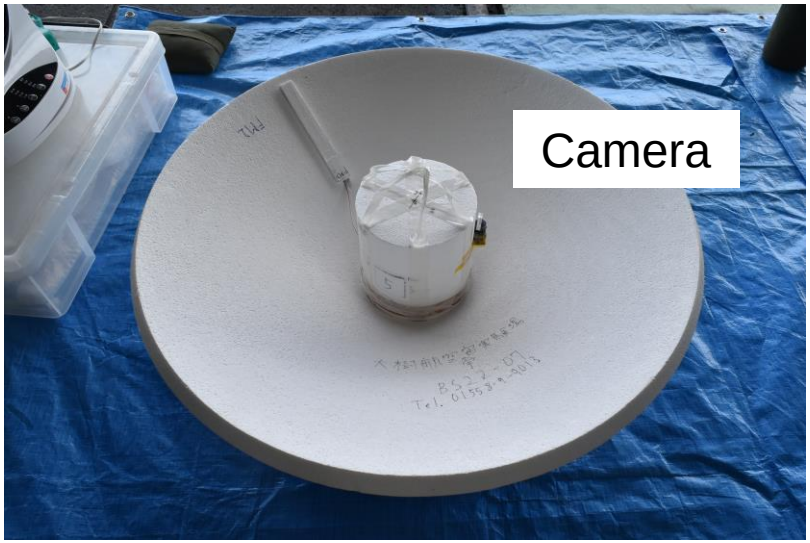
Trajectory analysis conditions		
	Reentry	Balloon test
Software	Tacode v1.12	
Atmosphere Model	NRLMSISE-00 Atmosphere Model	
Initial velocity, km/s	15	0
Initial altitude, km	200	25
Longitude, latitude	0, 0	144.08, 42.34
Flight-pathangle, deg	-11	0
Diameter, m	0.8	0.8
Mass, kg	10.0	1.5
Drag coefficient	1.0	1.0
Ballistic coefficient	19.9	3.0

Y. Takahashi, et, al., Trajectory reconstruction for nanosatellite in very low Earth orbit using machine learning, Acta astronautica, 194 (2022), p.301—308.

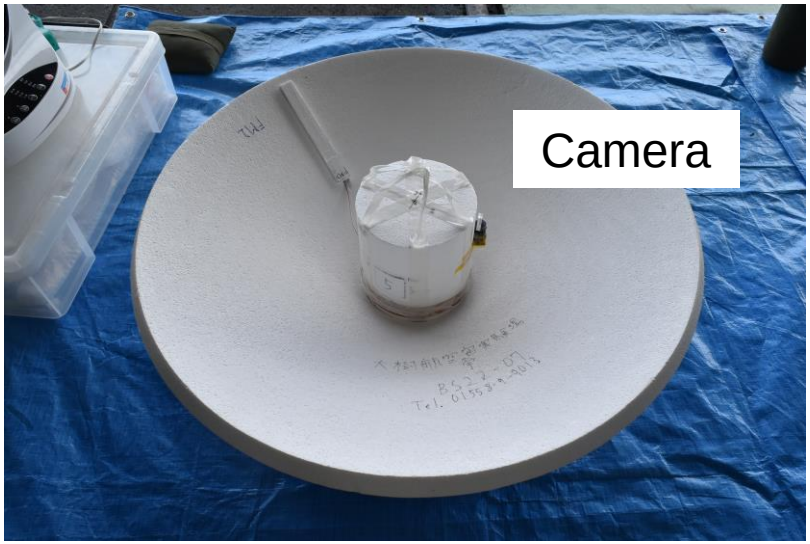
Time history



Pictures in flight

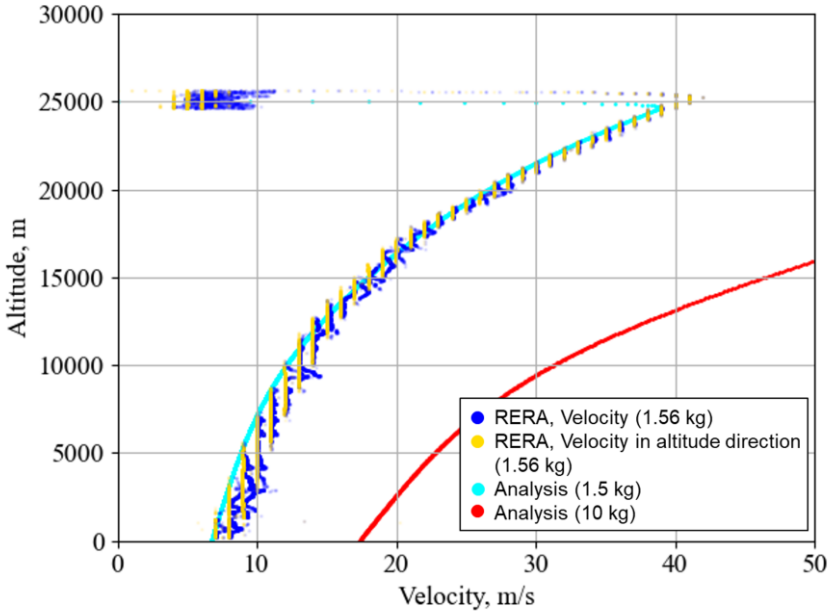


Pictures in flight

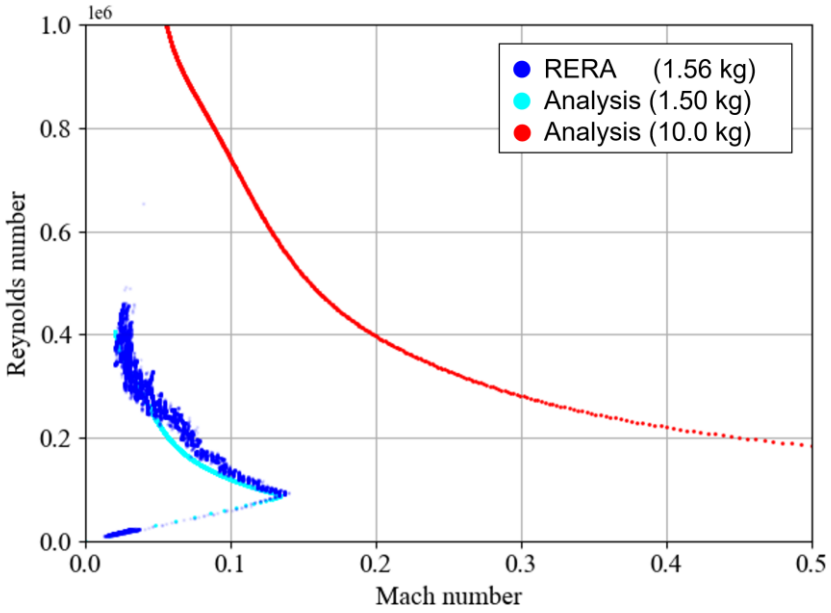


There was little roll rotation during flight.

Flow field



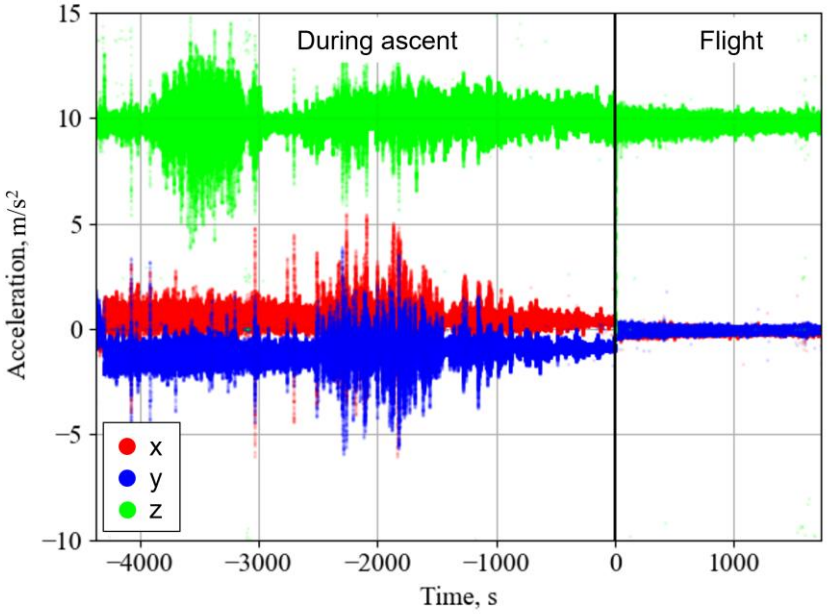
Altitude versus Velocity



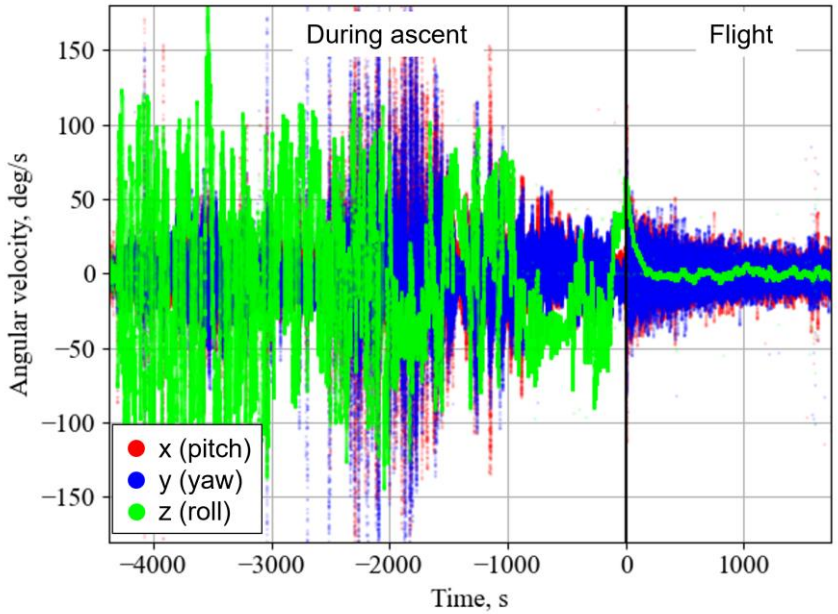
Reynolds number versus Mach number

The experimental results were in good agreement with the results of the trajectory analysis.
The Reynolds number was consistent between RERA and reentry at low-speed.
Terminal velocity was about 8 m/s.

Time history



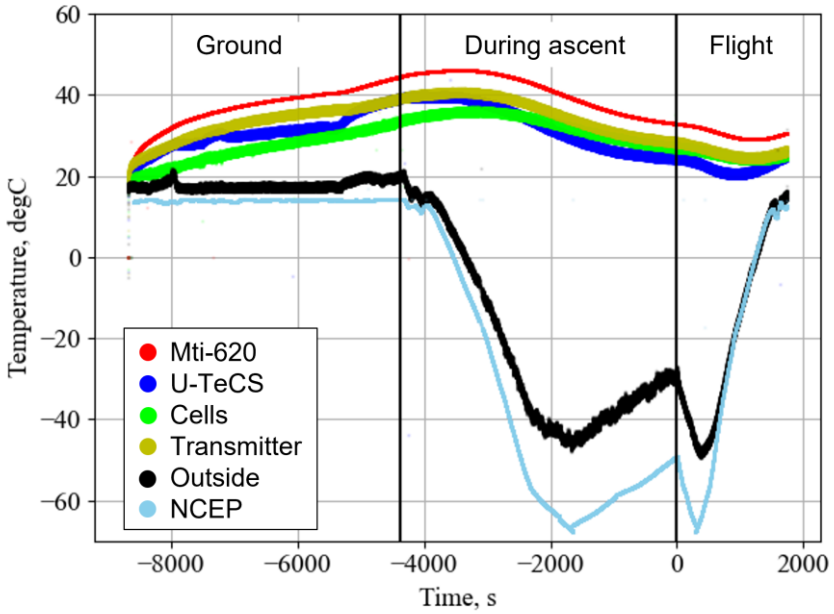
Acceleration



Angular velocity

The acceleration results indicated that the capsule did not tip over.
There was little roll rotation during flight.

Time history



Temperature

The temperature of the equipment was at least 20 degrees Celsius.
This temperature does not affect battery life.

Conclusion

Balloon experiment : RERA (Rubber balloon experiment for reentry capsule with thin-type aeroshell)

- RERA was successfully finished.
- We built the platform for rubber balloon experiments
- The capsule was in low oscillation in attitude without a vertical rotation.

Future

- Calculation of attitude from angular velocity and magnetic field
- Numerical analysis
- Wind tunnel test for transonic and supersonic