Concept Design of 50-kg Class Satellite 'INSPIRE' : On-Orbit Demonstration of Orbit Control and Formation Flight by Atmospheric Drag Using Variable Shape Function

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WASEDA University 早稲田大学

GRAPHIUM MeV gamma-ray survey & formation flight

Project Website | Lab Website

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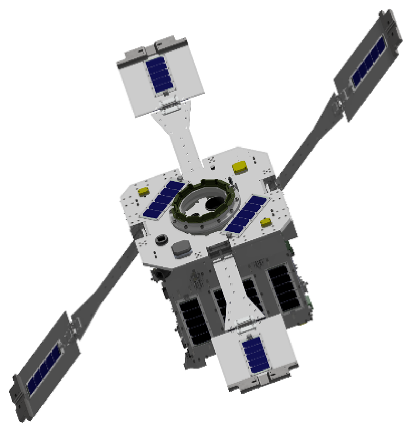
Tokyo Institute of Technology and Waseda University are developing a 50-kg class satellite, tentatively named INSPIRE and now officially named GRAPHIUM. The scientific mission of this satellite is to observe gamma rays from the galactic plane, solar flares, lightning, and auroras using the Compton Camera. On the other hand, the satellite aims to accomplish advanced engineering missions. It is to demonstrate orbit control and formation flight by atmospheric drag force using the variable shape function.

Variable Shape Satellite

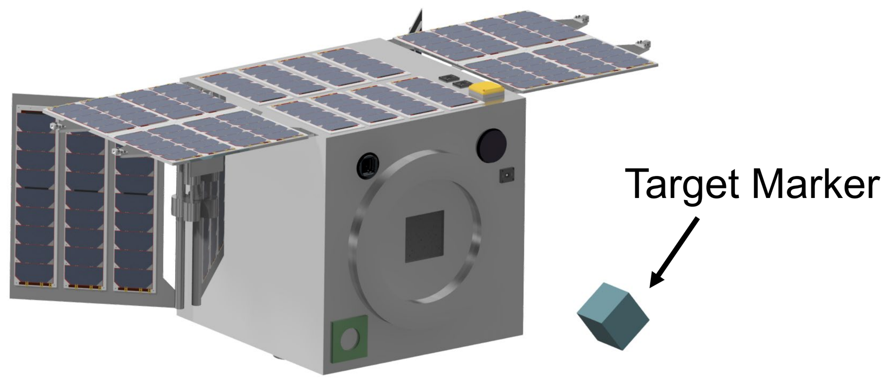
The variable shape function is an active shape change method to enable attitude control using changes in mass property and attitude/orbit control using external forces such as atmospheric drag. Attitude control was demonstrated on orbit by HIBARI, and we will demonstrate orbit control next.

Attitude Control Demonstration [1][2]



HIBARI (Launched in 2021 and under operation)

Orbit Control and Formation Flight Demonstration



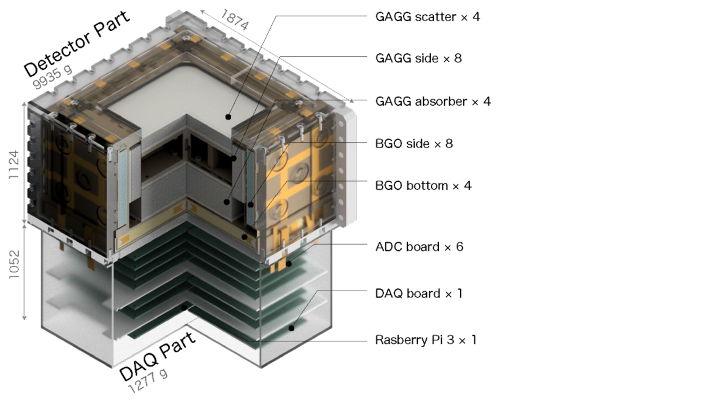
GRAPHIUM (To be launched in FY2026)

Size	550 × 550 × 550 mm³ (Paddle Stowed)
Mass	75kg • Bus 45kg • Science Mission 15kg • Engineering Mission 10kg
Power Generation	Sun pointing 192Wh LVLH 105Wh
Battery	9600mAh
Comm	S-band Uplink 1Kbps S-band Downlink 10K~100Kbps X-band Downlink 20Mbps
Orbit	SSO 550km, LST 10:00~10:30

Main Science Mission

MeV Gamma Astronomy

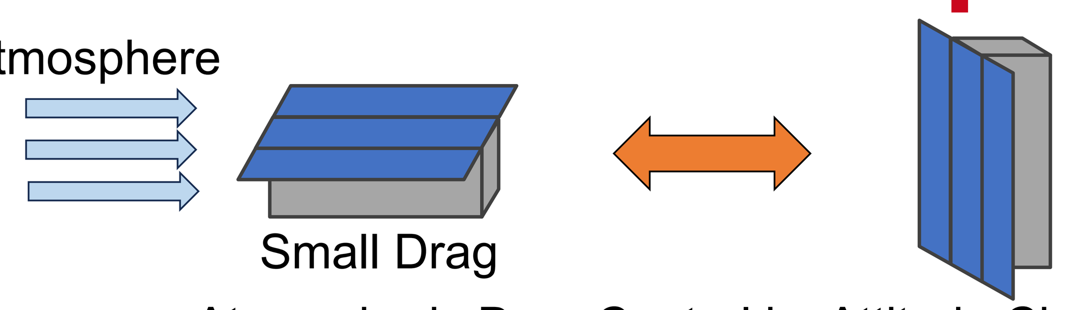
- Deep exploration of galactic plane and monitoring transient events such as solar flares using Compton Camera



Compton Camera

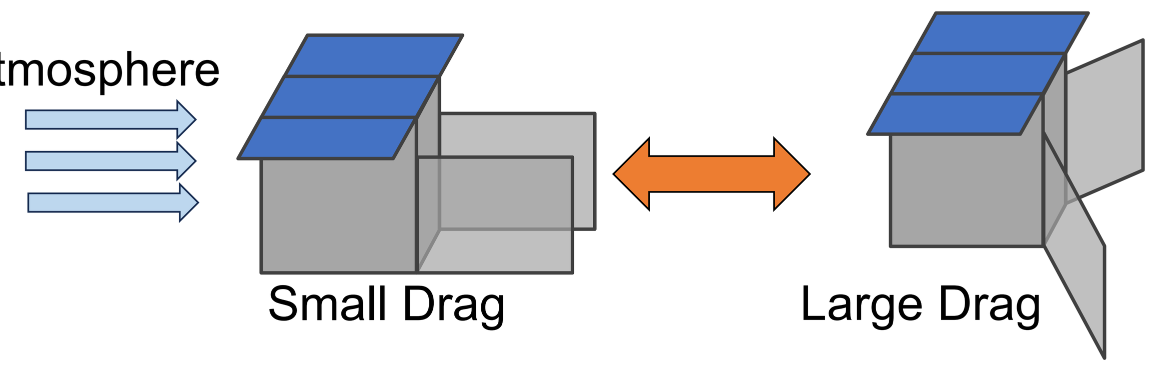
Weekend Session IV「MeV Gamma-Ray Detector on the 50-kg Class Satellite」

Differences from Atmospheric Drag Orbit Control in Previous Studies



Attitude is constrained.

Atmospheric Drag Control by Attitude Change



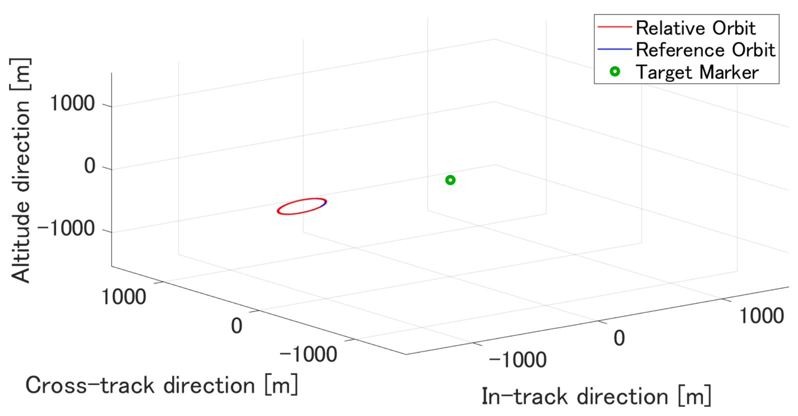
Attitude is free.
Observation, communication, power generation are not constrained for orbit control.

Atmospheric Drag Control by Shape Change

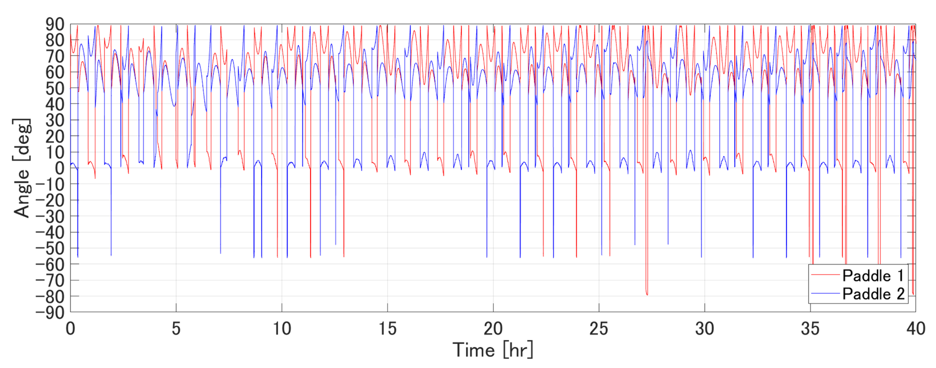
	Advantage	Disadvantage
Thruster	• High acceleration • Can generate thrust in out-of-plane direction • Can increase mechanical energy	• Requires large power and volume resources • Limited mission life • Coarse thrust resolution
Maneuver and Atmospheric Drag Control	• System is simple	• Attitude is constrained for orbit control • Changing the cross-sectional area causes atmospheric lift and torque in unwanted directions • Need to estimate atmospheric drag • Difficult to generate force in out-of-plane direction
Variable Shape Atmospheric Drag Control	• Free attitude → easier observation, communication and power generation • Easy to generate drag vectors in the desired direction (also in the direction of lift) • Can generate drag force without unwanted torque	• Need to estimate atmospheric drag • Difficult to generate force in out-of-plane direction • System is complex

Formation Flight Using Atmospheric Drag

Relative orbit maintenance at 1km behind the target marker



Relative orbit



Paddle angle

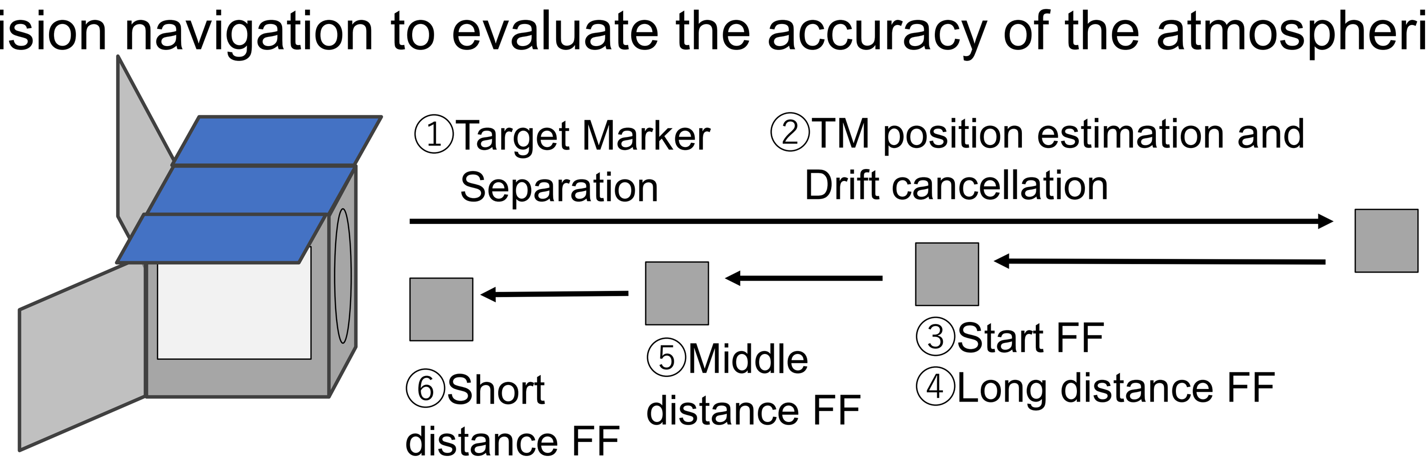
Accuracy 10m (only perturbation J2 is considered)

Success Criteria

	Orbit Control Using Atmospheric Drag	Thruster	Target Marker Separation	Navigation
Minimum	➢ Deploy and drive atmospheric drag control paddles ➢ Confirm orbit change by external force with driving paddles	➢ Check performance • Δv • Torque offset		
Full	➢ Orbit control • In-plane control < TBD m • Out-of-plane control < TBD m	➢ Thrust toward target direction • Δv error < TBD m/s	➢ Separation with speed error less than TBD m/s	➢ Demonstration of Offline VBS ➢ Confirm TM Separation
Extra	➢ Formation Flight with Target Marker • Maintain accuracy within TBD m for TBD days			➢ Demonstration of Angle Only Navigation ➢ Demonstration of Online VBS

Formation Flight Mission Sequence

Short distance FF requires high-precision orbit control to prevent collisions, so start with long distance coarse control. After confirming long distance FF, short distance FF is performed using high-precision navigation to evaluate the accuracy of the atmospheric drag orbit control.



#	Phase	Distance [km]	Period	Navigation	Control	Demonstration
1	TM Separation	0	1 pass	VBS （Offline Estimation）	Separation by spring	TM position estimation with VBS
2	Drift Cancel	>100	2, 3 days	TLE	Thruster	
3	Start FF	30	5 days	TLE	Drag and thruster assist	
4	Long Distance FF	30	2 days	TLE	Drag + Thruster	Confirm control performance with TLE accuracy
5	Middle Distance FF	1~10	2 days	TLE ＋VBS(Angle Only Navigation)	Thruster + Drag	Confirm control performance with Angle Only Navigation
6	Short Distance FF	< 1	2 days	Wide-angle Camera Coarse VBS →STT VBS (Model Based Navigation)	Thruster + Drag	Confirm control performance with VBS

Reference

[1] K.Watanabe, H.Kobayashi, Y.Amaki, T.Chujo, S.Matunaga, "Attitude control and on-orbit performance evaluation of spacecraft with variable shape function," Advances in Space Research, Volume 72, Issue 6, pp. 2313-2323, 2023
[2] K.Miyamoto, K.Watanabe, T.Chujo, S.Matunaga, "Attitude dynamics of satellites with variable shape mechanisms using atmospheric drag torque and gravity gradient torque," Acta Astronautica, Volume 202, pp. 625-636, 2022