Membrane Deployment De-orbit Device Composed of Self-Deployable Structure

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Requirements for De-orbit Device

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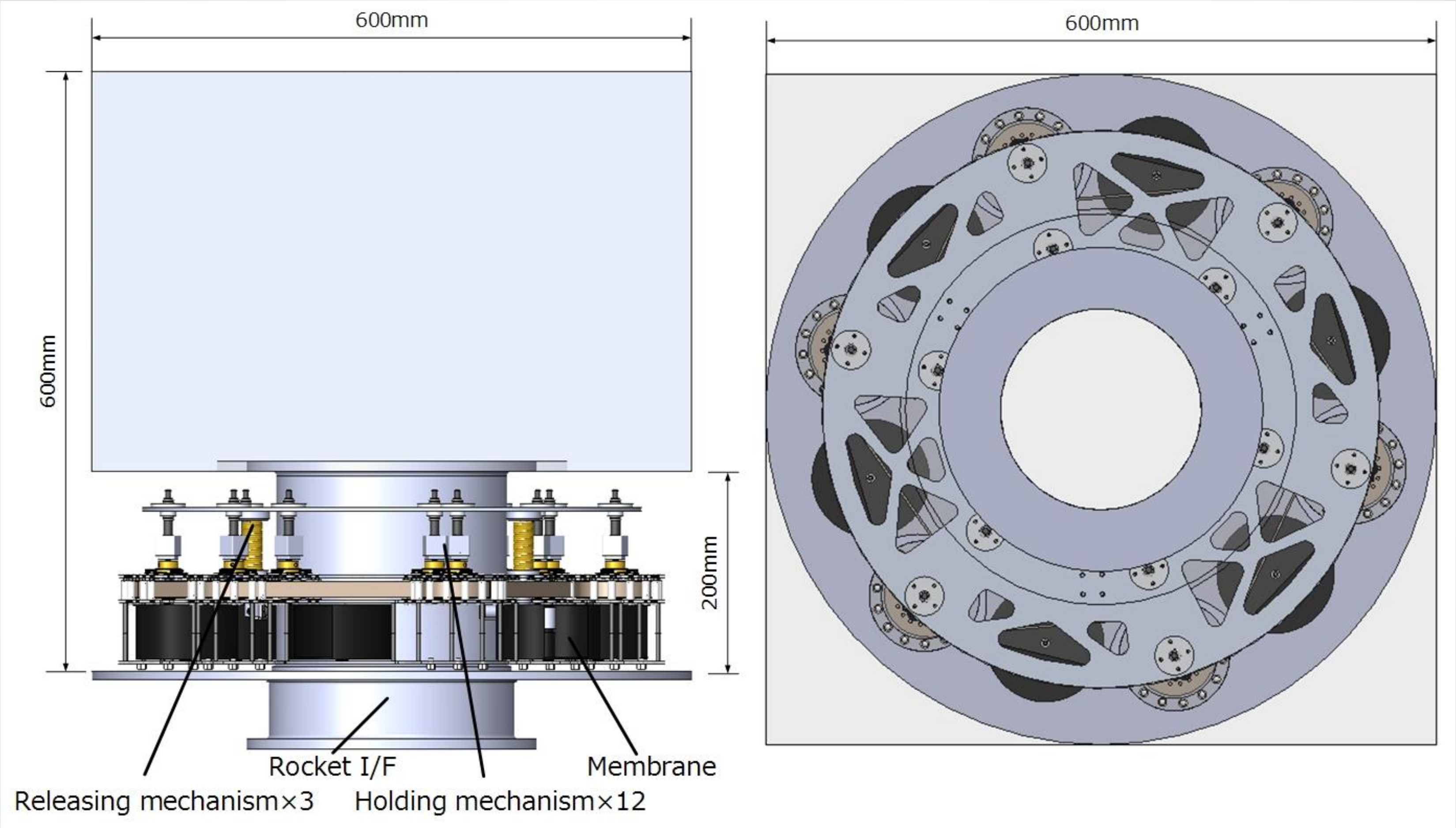
Basic Design

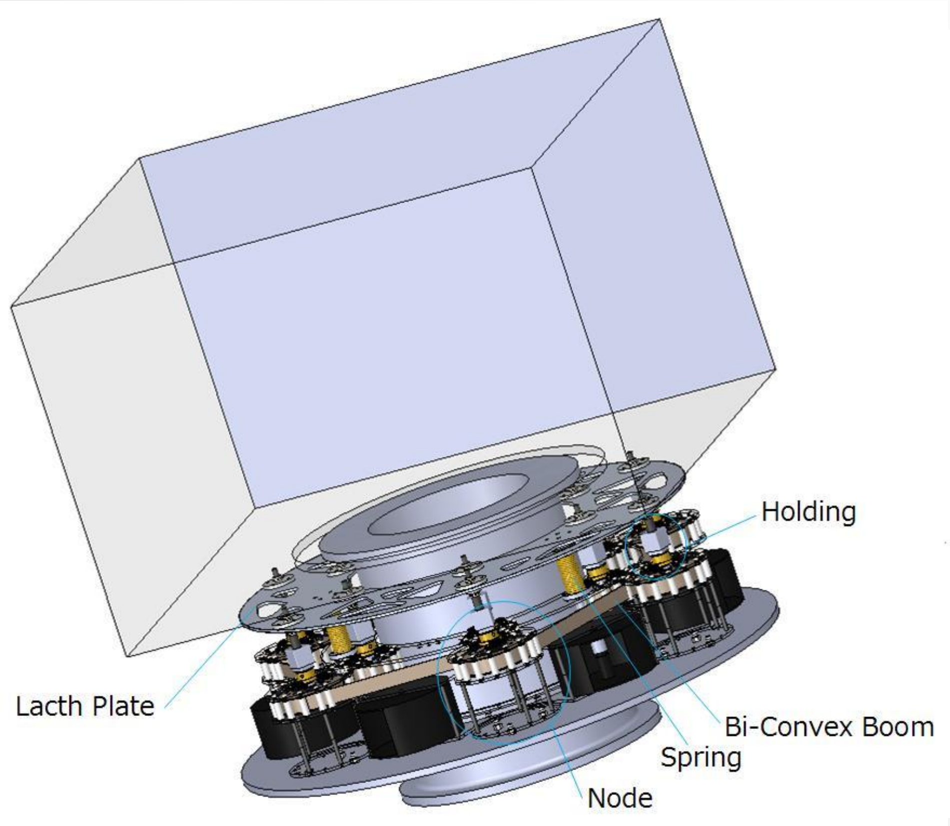
Basic Design

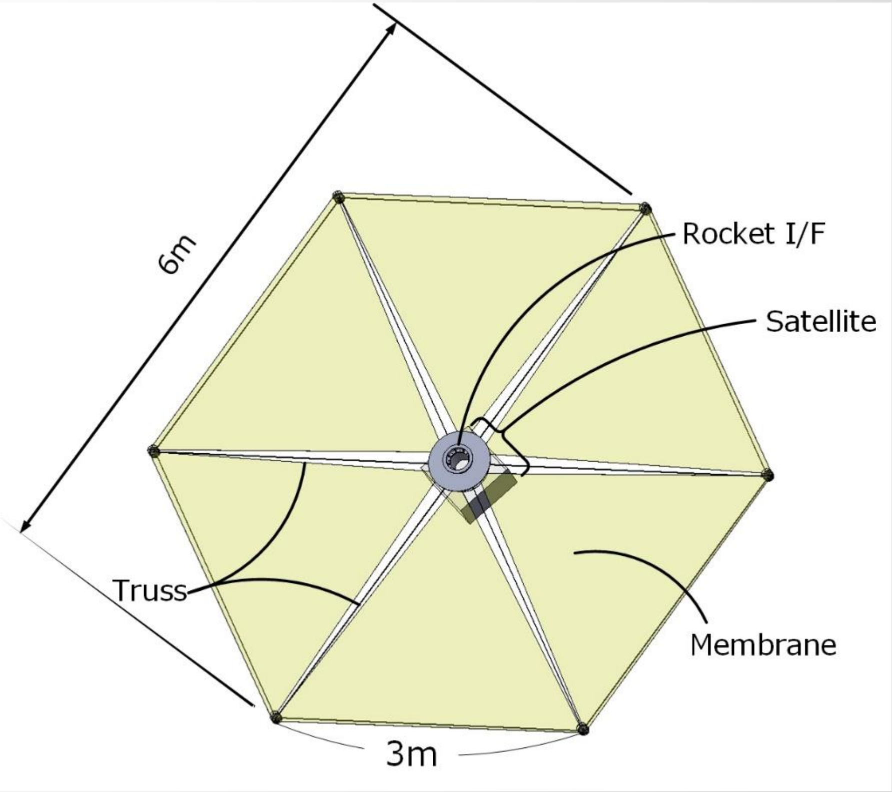
Conceptual model



Basic Design

Conceptual model

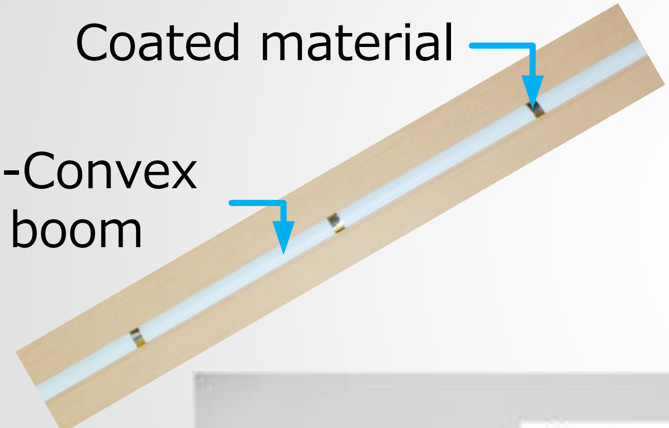


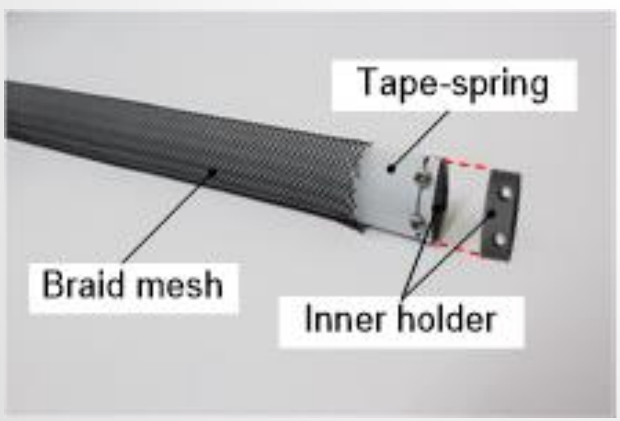


Basic Design

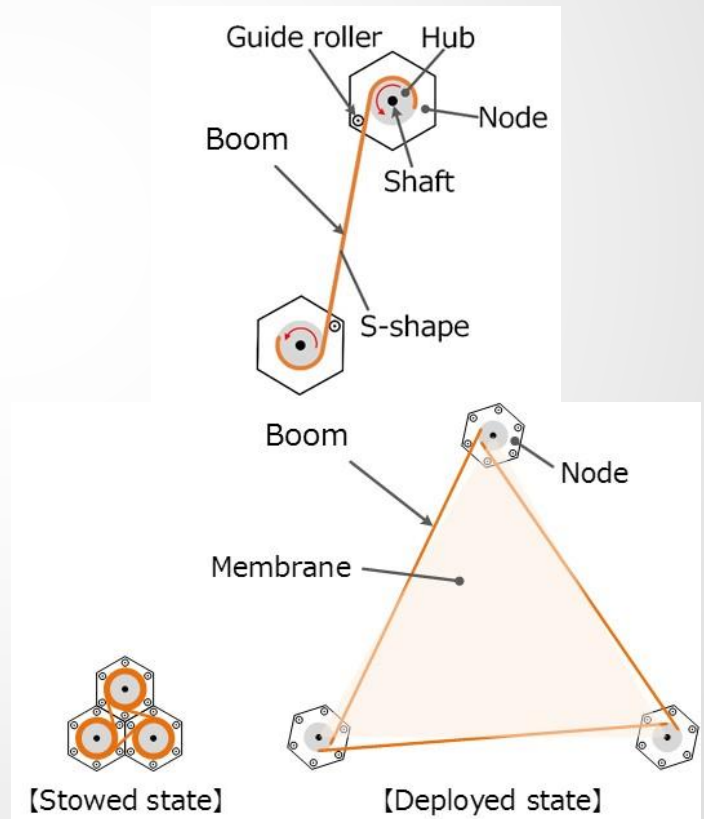
Principle of self-deployable structure

- The boom wrapped around the hub develops by releasing its strain energy.
- The extension direction is indicated by a guide roller.





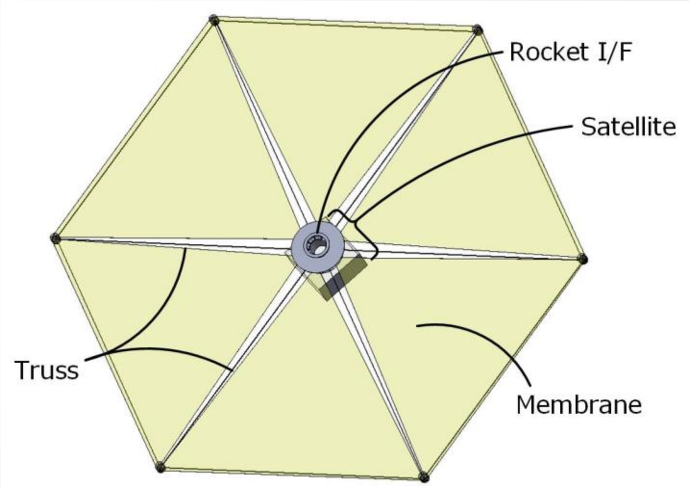
BCON Boom®



Basic Design

Originality

- In the past similar device.
  - On the mounting surface of the de-orbit device, other devices can't be mounted.
  - There were restrictions on the mission.
- This device has a cylinder at its center.
  - Rocket I/F
  - Mission equipment mounting space etc.

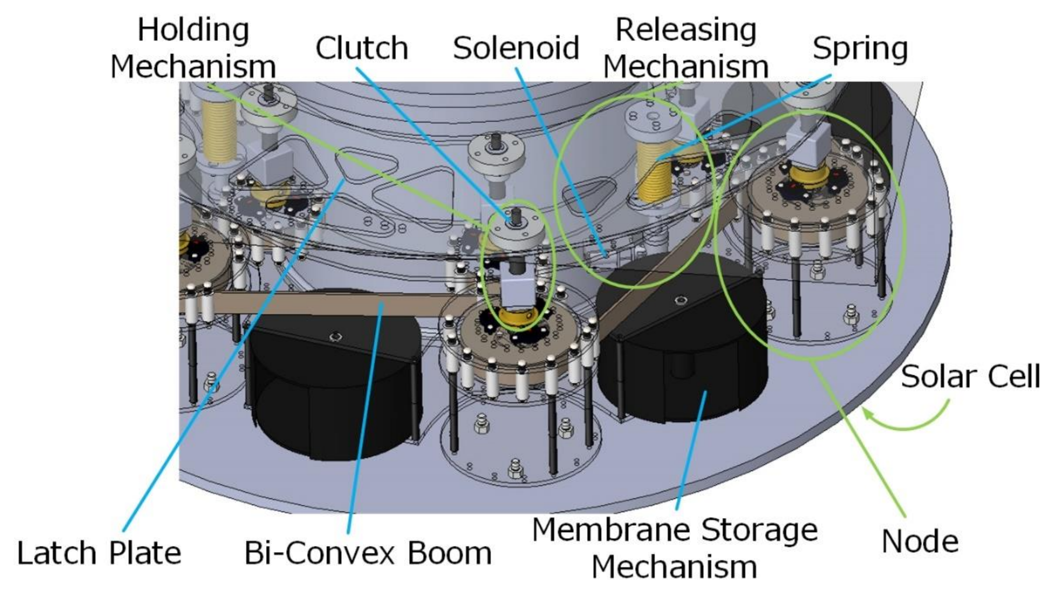


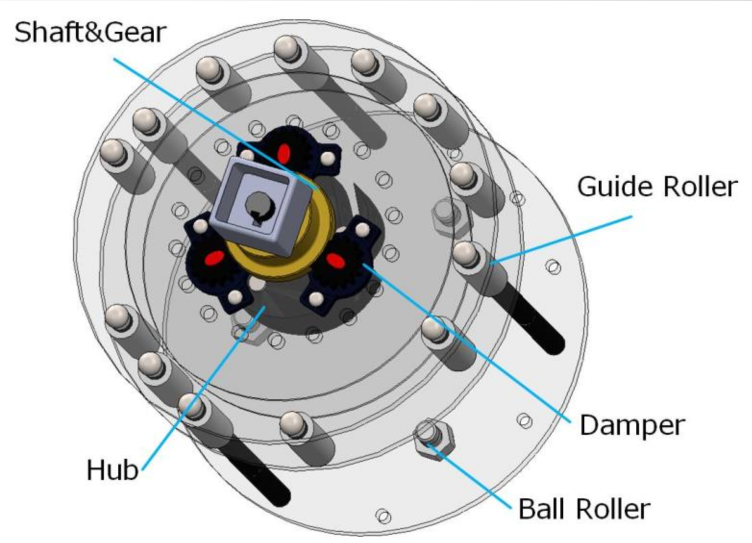
If space can be secured within the regulation, it can be mounted on any satellite, and the constraint on the mission can be minimized.

Detail Design

Detail Design

De-orbit device overview





Node

De-orbit system specifications

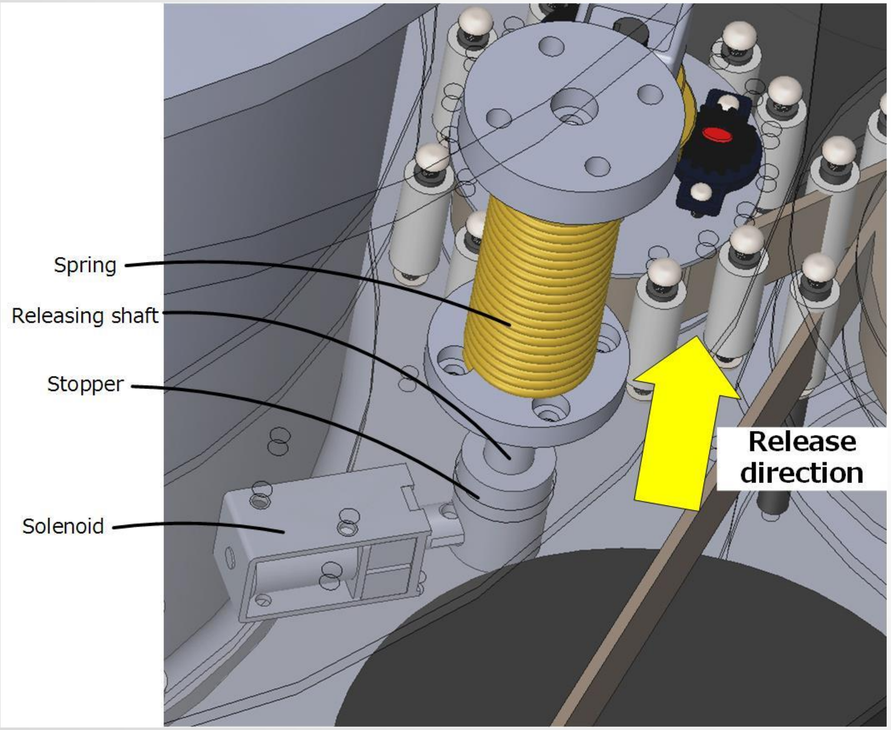
Width[m]	0.6	Surface area[m^2]	24.7
Depth[m]	0.6	Effective cross section[m^2]	6.18
Height[m]	0.2	Weight[kg]	3.7

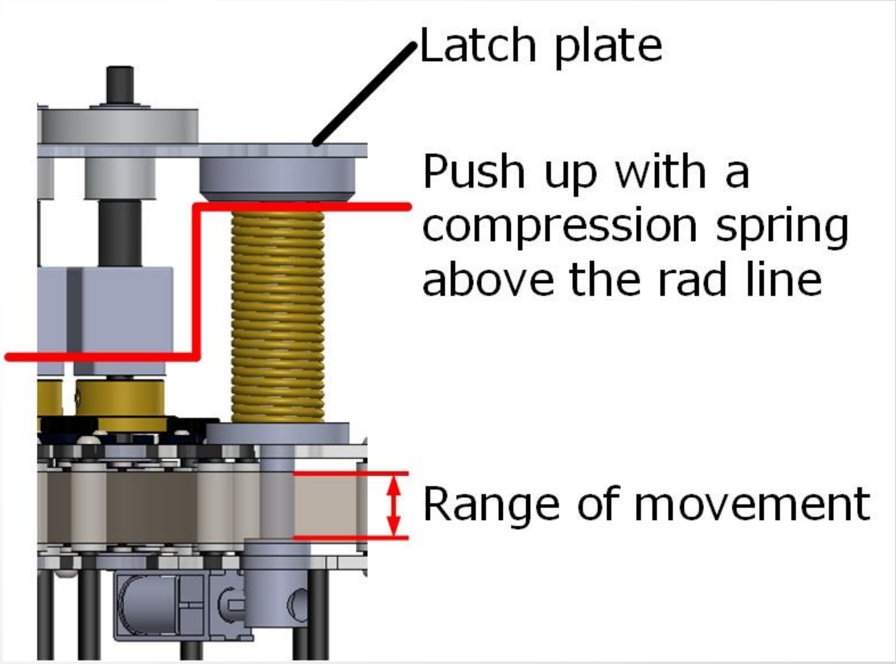
Detail Design

Technical feasibility - Mechanical design -

【Releasing mechanism】

As redundant, three are installed.

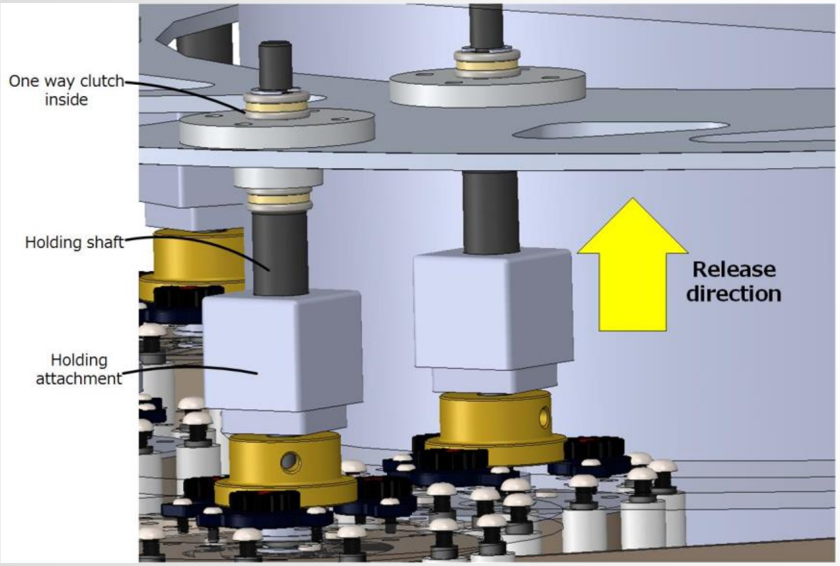




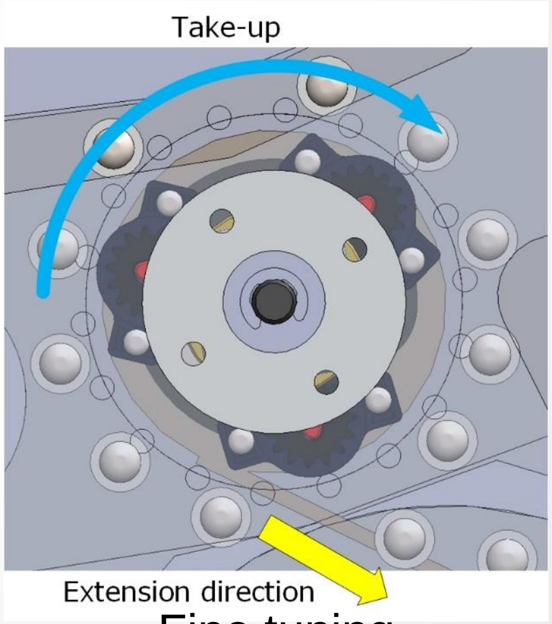
Detail Design

Technical feasibility - Mechanical design -

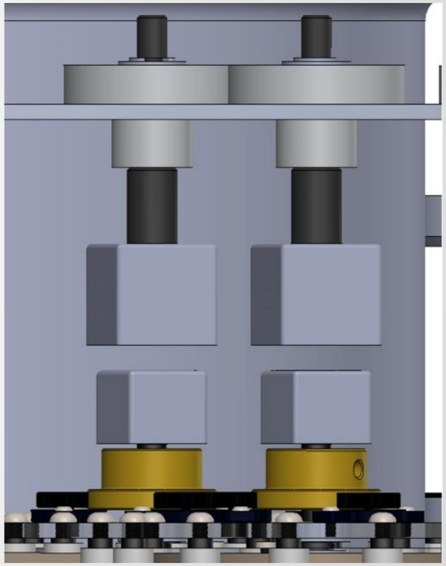
【Holding mechanism】



Capture



Fine tuning



Release

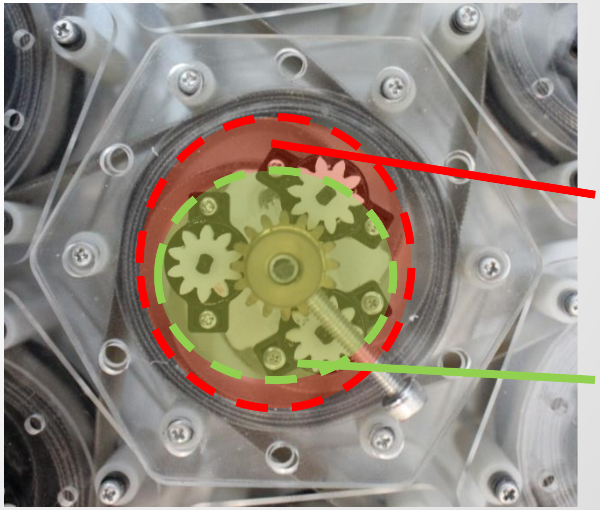
Detail Design

Technical feasibility - Mechanical design -

【Improve deployability】

- Fatal phenomenon…Detachment
  - ➢ This is the boom leaving the hub.
  - ➢ There is a high possibility that deployment will fail.

- Design that does not cause peeling
  1. Guide roller arrangement
  2. Mechanically metastable state



Detail Design

Technical feasibility - Mechanical design -

【Improve deployability】

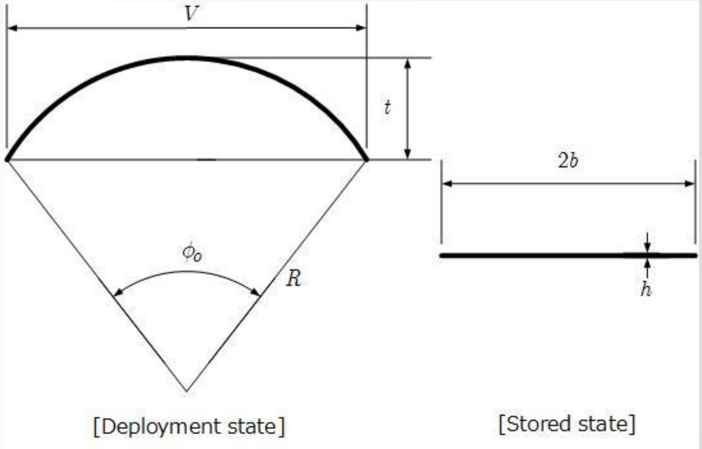
1. Guide roller arrangement
   - ➢ The interval between the guide rollers is made narrower than the width at the time of bending the boom.
2. Mechanically metastable state
   - ➢ First assume that the diameter of the hub is twice the radius of curvature of the boom.
   - ➢ It is decided within the range that satisfies this formula.

$$Mk - P = 0.$$

M : bendingmoment

k : curvature radius

P : extension force



Thickness	h	1.51[mm]
Wide(Deployment)	V	15.2[mm]
Height	t	2.25[mm]
Wide(Storage)	2b	16.0[mm]
Angle	Φo	1.09[rad]
Young' s modulus	E	206[GPa]
Poisson' s ratio	n	0.3[-]
Radius of curvature	R	14.6mm]
Radius of hub	Rh	19.0[mm]

Conference

Momoko Fukunaga, Yasuyuki Miyazaki, Detachment Condition of a Tape-Spring Wrapped Around a Hub, SEC'16, 1B5, 2016

Detail Design

Technical feasibility - Mechanical design -

7N12B with membrane(under microgravity)→

24N42B(only truss)↑

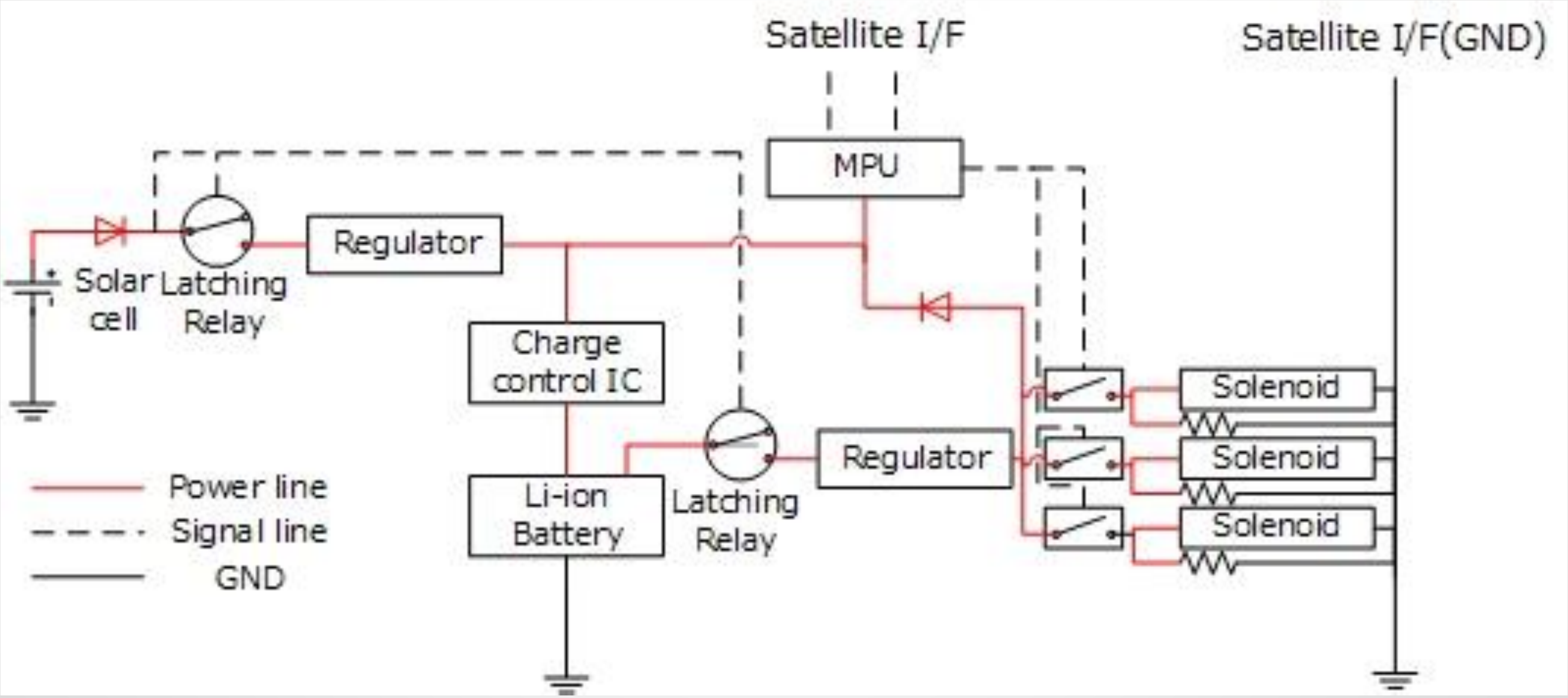
3N3B with membrane→

Debris Mitigation Competition

Detail Design

Technical feasibility - Electrical design -

【Circuit】



Detail Design

Reliability

From the above design, in summary

1. The basic design is over for the holding and releasing mechanism.
2. Based on the theoretical formula, we design the storage section.
3. To prevent unintentional release, there are three similar release mechanisms.
4. Successful deployment experiment of same shape 24N42B model.
5. From the deployment experiment under microgravity, it was confirmed that it developed without problem even with a membrane.
6. Successful deployment experiment of membrane with one side of 5 m with membrane.
7. Even without the signal from the satellite, it can operate with its own power supply.

From these facts, it can be said that the proposed debit device is sufficiently developed and reliability is high.

Detail Design

Impact on the satellite

1. Because it has a height of 200 mm, it occupies one third in terms of volume.
2. A hollow cylinder is secured as a rocket I/F.
3. Although nothing can be mounted in the direction of deployment of the device, mission equipment and the like can be mounted on the surface mounted by this cylinder.
4. It is electrically independent. The I/F with the satellite is a total of three lines including a communication line for judging whether release is possible and GND.
5. Mechanically, only the center node and cylinder are fastened using six M5 screws.

➡ From the above, it can be said that the influence / restriction on the satellite is the minimum.

Detail Design

Cost

Approximate cost of de-orbit device(exchange rate : 1USD = 113.211819JPY)

Parts	Price[USD]	Parts	Price[USD]
Shaft	301.35	Roller	124.02
Clutch	46.74	Membrane	70.66
Aluminum Plate	264.99	Power supply unit	70.66
Attachment	264.99	Solenoid	44.78
Hub	17.67	Spring	14.84
Spacer	14.79	Screw	77.52
Snap ring	8.27	Nut	45.05
Bearing	152.53	Gear	109.71
Convex tape	28.85	Damper	133.55
Key	35.49	Margin	173.55
		Total	2000.00

Analysis

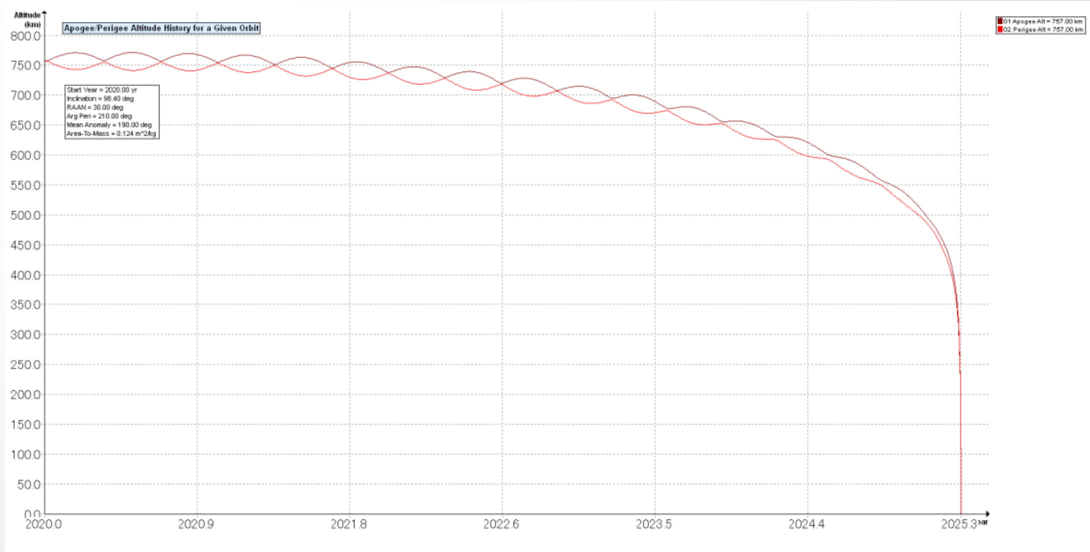
Analysis

Effectiveness

- The orbital life time after operating the de-orbit device was calculated.
  - Orbit calculation software DAS was used.
- As a result, it was found that it reenters the atmosphere in about **5.262 years**.

Analysis parameter

Semi-major axis	7128[km]
Orbital inclination	98.4[deg.]
Eccentricity	0.001[-]
R.A.A.N	30[deg.]
Argument of Perigee	210[deg.]
Mean Anomaly	190[deg.]
Perigee Altitude	756.996[km]
Apogee Altitude	757.000[km]
Effective cross section	6.18[m^2]
Area-To-Mass Ratio	0.1235[m^2/kg]



Analysis

Debris risk

- Before de-orbit device deployment
  - ➢ Calculate the orbital life by setting Area-To-Mass Ratio to 0.011.
    → Over 90 years
  - ➢ The initial orbital altitude does not change almost.
    → Analyze for **6 years from 2020** at orbital altitude **750km**.

- After de-orbit device deployment
  - ➢ The orbital life is 5.262 years.
  - ➢ The orbital altitude changes in a short time.
    → **700~800km**…**2.6 years from 2020**
    → **600km**………**1.8 years from 2022.6**
    → **200~500km**…**1 years from 2024.4**

Analysis

Debris risk

Impact rate 10^(value)[time/year]

Size of debris/meteoroid 10^(value)[cm]			-1.0	-0.8	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.8	1.0	1.20	1.40
Device	Altitude	Years													
ON	800	2.6	0.28	-1.46	-1.20	-1.88	-2.52	-3.06	-3.48	-3.78	-4.00	-4.16	-4.26	-4.36	-4.46
	700	2.6	0.22	-1.66	-1.36	-2.12	-2.84	-3.42	-3.86	-4.14	-4.32	-4.44	-4.52	-4.60	-4.70
	600	1.8	0.20	-0.78	-1.60	-2.38	-3.12	-3.68	-4.10	-4.38	-4.54	-4.60	-4.64	-4.70	-4.76
	500	1	-0.14	-0.86	-1.70	-2.46	-3.22	-3.80	-4.28	-4.64	-4.84	-4.98	-5.06	-5.14	-5.20
	400	1	-0.34	-1.12	-1.96	-2.72	-3.50	-4.20	-4.66	-5.04	-5.26	-5.38	-5.46	-5.54	-5.60
	300	1	-0.62	-1.46	-2.40	-3.10	-3.80	-4.58	-5.20	-5.64	-5.86	-5.94	-5.98	-6.02	-5.98
	200	1	-0.80	-1.60	-2.50	-3.14	-3.82	-4.58	-5.18	-5.60	-5.78	-5.86	-5.88	-5.92	-6.06
OFF	750	6	-0.80	-1.58	-2.34	-3.08	-3.78	-4.36	-4.76	-5.04	-5.22	-5.32	-5.40	-5.46	-5.52

- Excerpt and compare collision rates of size $10^{-1.0}$ cm, 10^{0} cm, $10^{1.0}$ cm.
- Device ON vs OFF

$10^{-1.0}$ cm : 1.91 vs 0.16

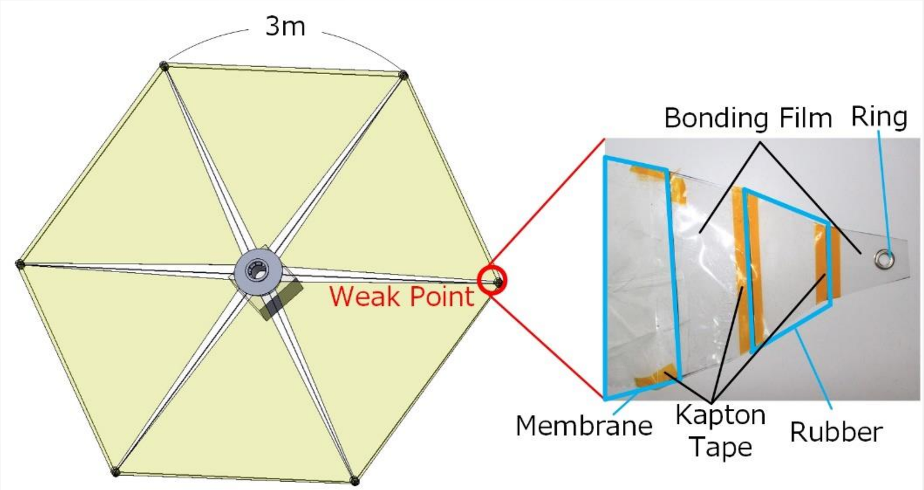
10^{0} cm : 0.000871 vs 0.0000437

$10^{1.0}$ cm : 0.0000550 vs 0.00000398

Analysis

Debris risk

- Weak point…membrane attachment parts
- In order to stretch the membrane, the device replaces each vertex of the membrane with rubber. Therefore, the most tension works, it tends to split.



Research reports that only debris collides will be gas.
Just in case, Consider that debris collides, consider only to make a hole in the membrane and not to split. For example, by attaching Kapton tape at regular intervals on the surface of the film, the range of avoidance is limited.

Conclusion

Conclusion

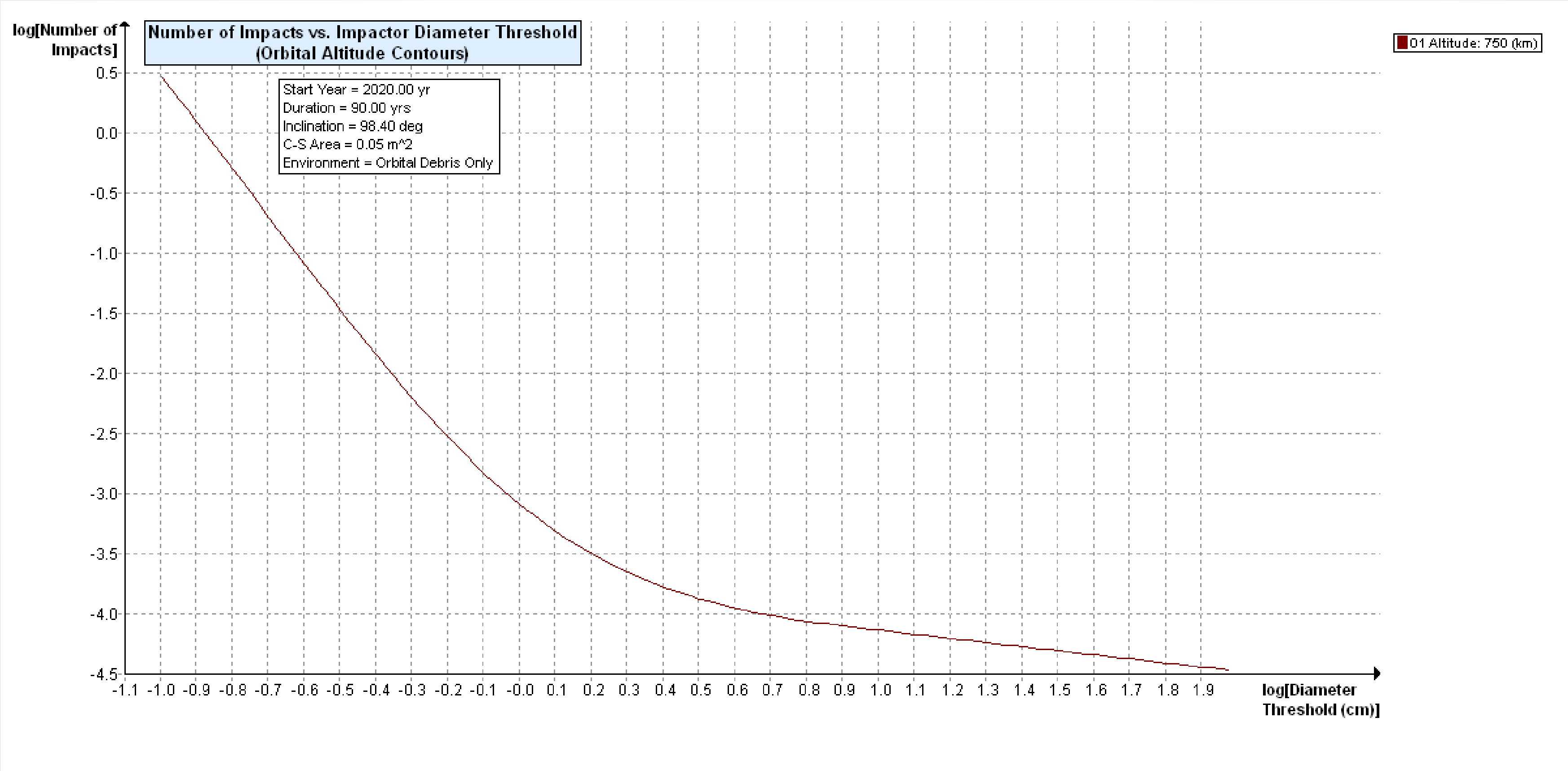
- It can be realized sufficiently from the reliability, the influence on the satellite, the cost, etc. It can be said that it is a de-orbit device suitable for 50kg satellite.

Since we are preparing a prototype, we will be providing it soon.

THANK YOU FOR YOUR ATTENTION!

Appendix

- 10^-1cm >>> 10^0.5=3.16



Debris Mitigation Competition