E3

デオービット用膜面展開機構の開発

Development of Membran Deployment mechanism for Deorbiting

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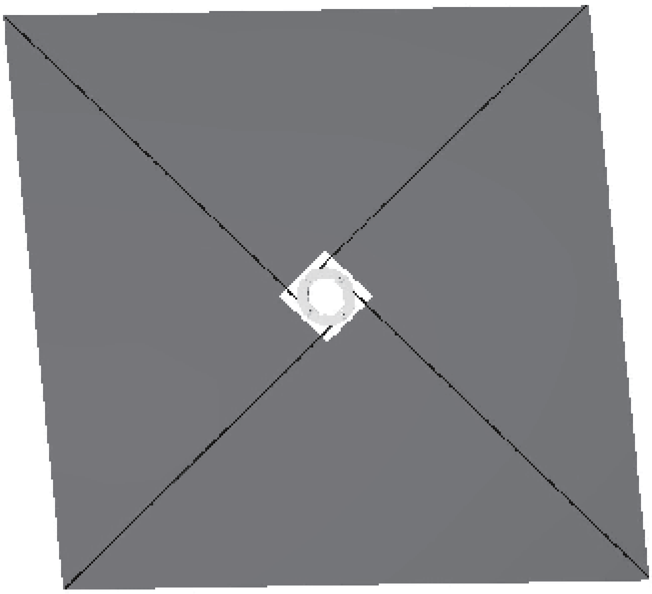
近年、世界的に 50～100kg もしくはそれ以下のサイズの超小型衛星の開発が積極的に進められており, 短期開発及び低コストであることから今後とも数が増加していくことが予想される. 一方で大多数の超小型衛星は非常にリソースが小さいことから推進系を持ち合わせておらず、軌道高度によってはスペースデブリと化してしまう恐れがある。軌道上離脱手段としては、アクチュエータを動作するだけの手軽さから膜面展開による大気抵抗を用いた手段が有力視されている。本発表では JAXA が開発している軌道上離脱用膜面展開機構のコンセプトと開発状況について紹介する。



6th Space Debris Workshop

Development of Membrane Deployment Mechanism for De-orbiting

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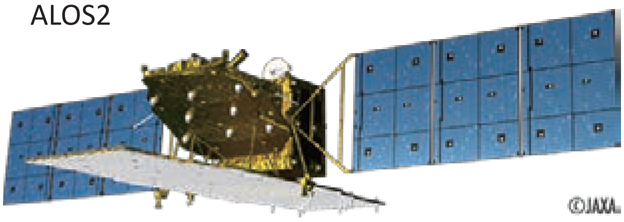
Small Satellite

Development of small-sat is growing in the world

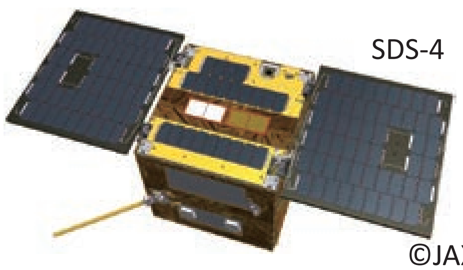
ALOS2



- Small Satellite
  - Low cost(hundreds of million yen)
    - piggy-back payload(low launch cost)
  - Light weight(1～100kg)
  - Small(10～100cm order)
  - Short life(2～3 years)

- Large Satellite
  - High cost(multibillion yen)
    - Main Satellite(High launch cost)
  - Heavy weight(several tons)
  - Large scale(1～10m order)
  - Long life(5～10 years)

SDS-4



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Rapildy increasing of small-sat by satellite constellation

- Planet labs:3U CubeSat constellation consists of 131 sat
  - creates a daily photo mosaic of most of Earth
- Skybox Imaging:100kg class sat constellation consists of 24 sat
  - offers customers timely access to high-resolution satellite imagery, video and data
- Axel Space:80kg class Remote sensing constellation consists of 60 sat
  - provides low-cost and high readiness Remote-sensing images

25 Year Rule

- IADC Space debris Mitigation Guidelines require that spacecraft or orbital stages passing through LEO region should be maneuvered to reduce their orbital lifetime 25 years or relocated if they cause interference with highly utilized orbit regions.
- JAXA Space Debris Mitigation Standard also requires that space systems after mission should be reduced the orbital lifetime within 25years or sent as far away from the useful orbital region as possible.

De-orbiting of Small Satellites

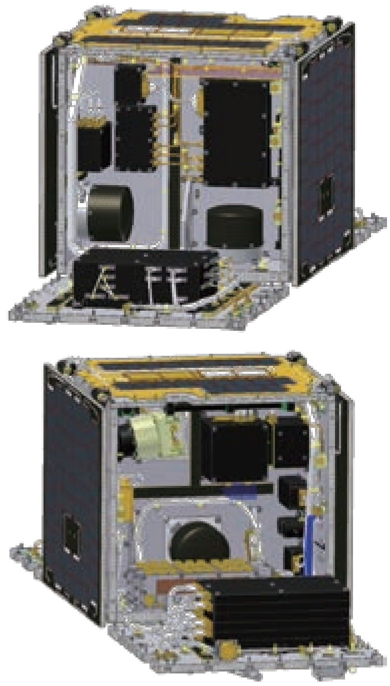
- Small Size and Light Weight
  - constraint of Size,Mass and Power.

  →no resource to mount extra components.

- Piggy-back launch
  - strict constraint not to have impact on main satellite

  →difficult to mount propulsion system

We must design the component that don't effect satellite system as possible.



Component Configuration of SDS-4

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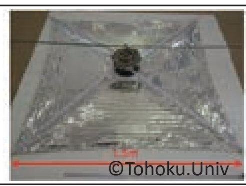
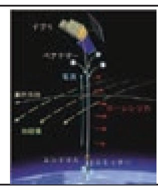
Deorbiting Device Options

	Electric Propulsion Systems	Chemical Propulsion Systems	Atmospheric Drag-based Devices	Electrodynamic Tether
Active / Passive	Active	Active	Passive	Passive
Method	The acceleration of charged ions	The combustion and the expansion of chemical propellants	The exploitation of the natural atmospheric drag effect	The electrodynamic interaction of the tether rapidly moving within Earth's magnetic field
Consideration	･Requires high total impulse	･Requires high total impulse	･Altitude-limited ･susceptible to MMOD degradation	･Large characteristic dimension ･Deployment complexity
Picture				

※The 4S Symposium 2012 – P. Pergola, A. Ruggiero, C. Finocchietti, M.Andrenucci .

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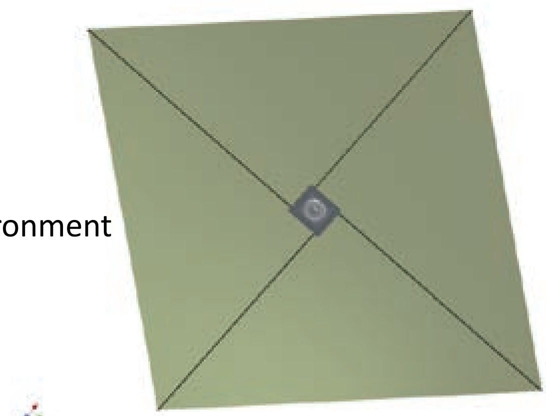
Membrane Deployment Mechanism

- Method
  - chaneges orbit due to atomosperic drag by using membrane
- Advantage
  - No Active Control (attitude, power)
  - No Pressurized Gas
  - Using only their own stored mechanical Energy
  - Simple mechanism
- Disadvantage
  - Only low altitude
  - susceptible to MMOD
  - Long duration against for space environment



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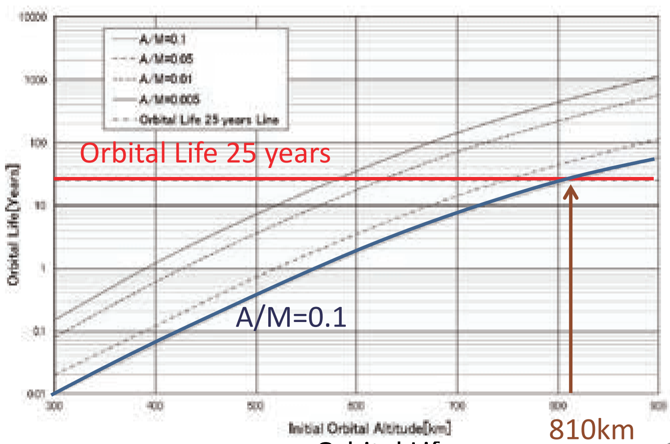
Orbit Life Calculation

- A/M=0.1:De-orbiting within 25 years from altitude 810km

$$A = \frac{100(Mass) \times 4(Tumbling)}{2} \div 0.1 = 20m^2$$

- Need 20m^2 as a membrane area.
  - Boom length 3m
  - membrane width 4.5m



Orbital Life

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Requirement Specifications

- De-orbiting Capability
  - 100kg class microsat deorbits within 25 years from altitude 810km

  →mounted 3m deployment boom and attached membrane.
- Size
  - 50kg microsat envelope

  →mounted in "dead space" to minimize impact for satellite system
- Design
  - Low cost and compatible to JAXA Safety Requirement
  - guarantee environmental resistant(Radiation,Ultoraviolet and Atomic oxygen) in misson and deorbiting term.

  →use AO-resistant Polyimide "BSF-30" and qualify mechanical property after exposing to Ultraviolet and Radiation

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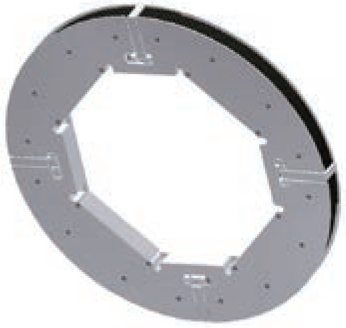
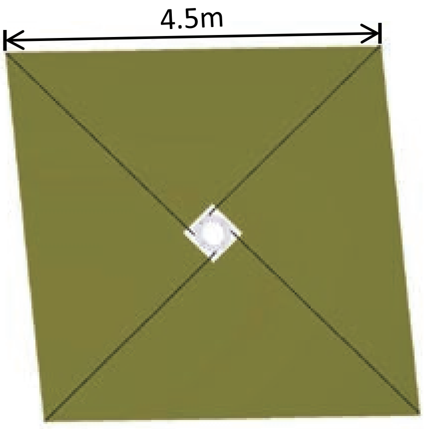
Membrane Deployment Mechanism Concepts

- Small satellite makers and Universities are able to conduct satellite development without regard for 25 years Rule.
  - Design the component that don't effect satellite system as possible.
    - Use "dead space"
    - "Thin" deployment mechanism by the wrapping stowage of the booms and the membrane together on the same hub.
    - Adjust mechanical interface to PAF239M.



stowed configuration



deployment configuration

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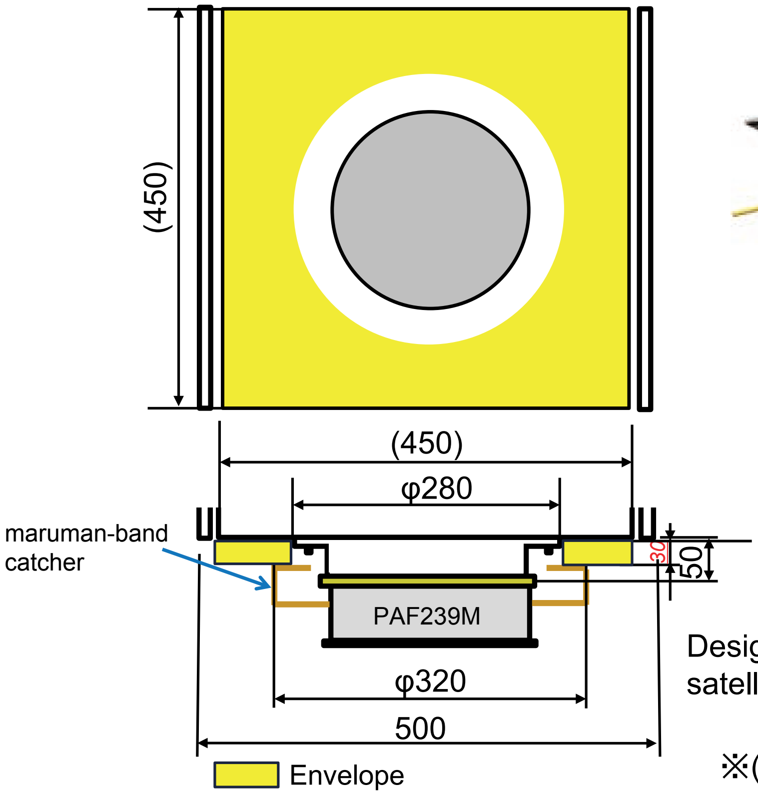
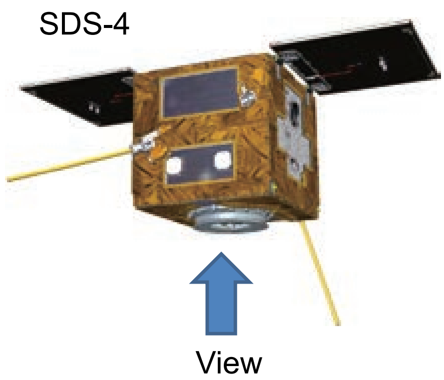
Envelope





Design the component that don't effect satellite system as possible.

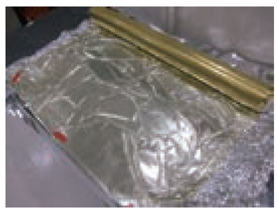
※():Referenceof SDS-4

Technology of Membrane Deployment Mechanisim

- Tri-axis CFRP deployable boom
  - Good formability and specific rigidity
- Membrane holding mechanism
  - Spiral folding where the membrane thickness is considered
- AO-resistant Polyimide 「BSF-30」
  - self-repairability against Atomic Oxygen

Deployable boom

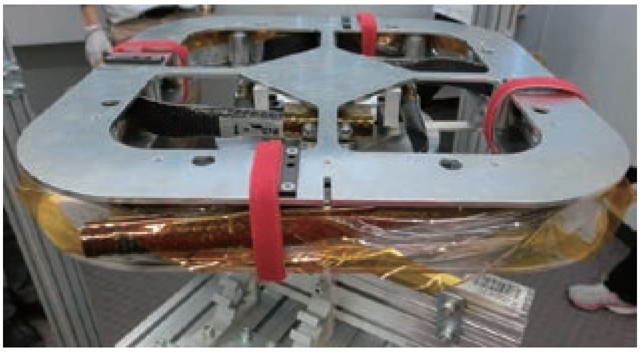
Folding Pattern



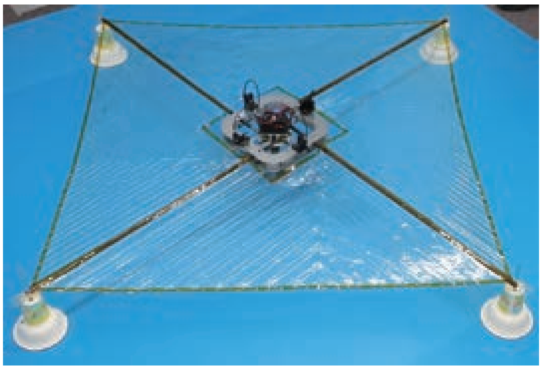
BSF-30

Membrane-Boom Wrapped Structure

- Basic Concept
  - The wrapping stowage of the booms and the membrane together on the same hub.
    - The deployment of the booms and the membrane can be synchronous.
    - Simple mechanism. when a hold mechanism for booms is released, the booms and the membrane automatically deploy together.



Stowed Configuration



Deployment Configuration

※This study have conducted by Furuya Lab. supported by Solar Sail WG

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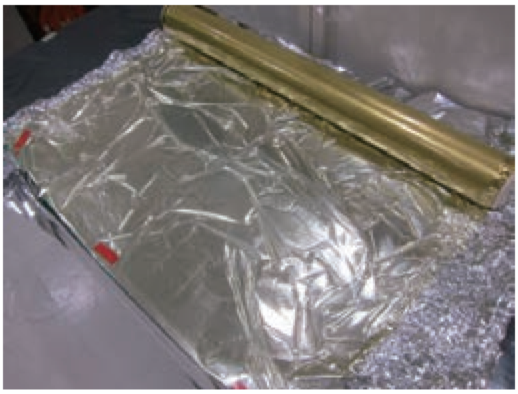
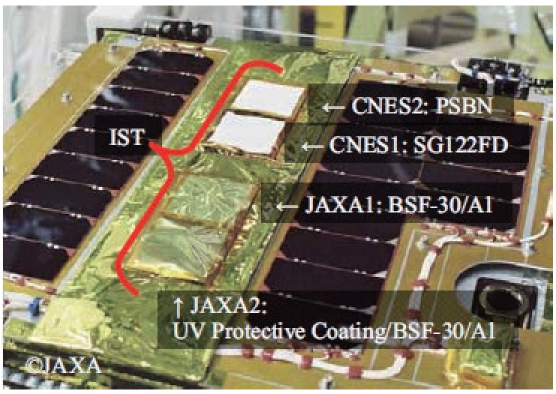
BSF-30

- Siloxane-modified polyimides
  - react to Atomic oxygen by add Si to polyimides and self-organize resistant coating of SiO_2 .
    - have self-repairability against Atomic Oxygen
  - In-orbit demonstraion:JEM/MPAC & SEED and SDS-4/THERME



BSF-30



SDS-4/THERME

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BSF-30 Environmental Testing

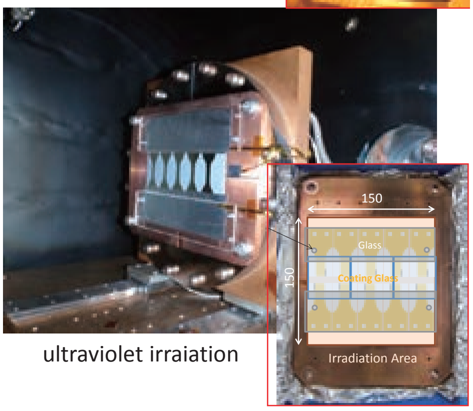
- Irradiates with made crease

→To confirm ability to deploy membrane when mission terminated.

  - Radiation irradiation test
    - Radiation total dose : 15,30,45Mrad
      - 7.8Mrad is radiation total dose in 3 years mission term.
      - Line type: Proton
    - Mechanical properties testing
      - maintain strength after radiation.

  - Ultraviolet irradiation test
    - Radiation dose : 50ESD
      - mission term:3 years
    - Mechanical properties testing

radiation irradiation



ultraviolet irraiation

Summary

- Introduce development status of JAXA's Membrane Deployment Mechanism for De-orbiting
  - Numbers of satellites can increase by expanding use of small satellite. Launched all small satellites have to observes 25 years rules.
  - As a de-orbiting method, membrane deployment using atomospheric drag is suitable for small sats.