Boom-Membrane Integrated Deployable Structures for De-orbiting Satellites and Future Applications

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Small Satellites

Development of small-satellite is growing in the world.

- Small Satellites:
  - –Low cost (hundreds of million JPY)
    - •Piggy-back payload (low launch cost)
  - –Light weight (1 – 100kg)
  - –Small size (10 – 100cm order)
  - –Short term (2 - 3 years)

- Large Satellites:
  - –High cost (multibillion JPY)
    - •Main Satellite (High launch cost)
  - –Heavy weight (several tons)
  - –Large Size (1 - 10m order)
  - –Long term (5 - 10years)

Small Satellites by Satellite Constellation

- Planet Labs:
  - –3U CubeSat Constellation consists of 131 satellites
    - Create a daily photo mosaic of most of Earth
      * 1U = 10cmx10cmx10cm
- Skybox Imaging:
  - –100kg class satellite constellation consists of 24 satellites
    - Timely access to high-resolution satellite imagery, video and data
- Axel Space:
  - –80kg class remote sensing constellation consists of 60 satellites
    - Provides low-cost and high readiness remote-sensing images

25 Years Rule

- IADC(Inter-Agency Space Debris Coordination Committee) Space Debris Mitigation Guidelines:
  - Spacecraft, Launch Vehicles, and orbital stages passing through LEO region should be maneuvered to reduce their orbital lifetime 25 years or relocated if their cause interference with highly utilized orbit regions.

De-orbiting of Small Satellites

- Small size and light weight:
  - Limited resource to install extra component for de-orbiting satellite
- Piggy-back launch:
  - Strict constraint to avoid impact on main satellite
  - Difficult to mount propulsion system

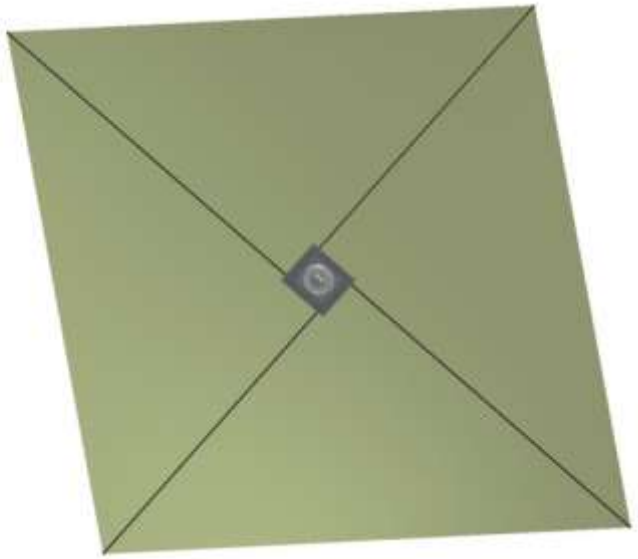
Requirements to develop light weight de-orbiting system for small satellites

De-orbiting Systems

- Electric Propulsion Systems
  - –Active systems
  - –Acceleration of charged ions
  - –Require high total impulse
- Chemical Propulsion Systems
  - –Active systems
  - –Combustion and expansion of chemical propellants
  - –Require high total impulse
- Atmospheric Drag-based Devices
  - –Passive systems
  - –Exploitation of natural atmospheric drag effect
  - –Altitude-limited
- Electrodynamic Tether Systems
  - –Electrodynamics interaction of tether rapidly mobing within eath's magnetic field
  - –Long tether length, deployment complexity

Deployable Membrane Systems

- Method:
  - –Change orbit due to atmospheric drag by large membrane
- Advantages:
  - –Passive control without power and attitude
  - –No Pressurized Gas
  - –Deploy membrane using stored strain energy by deployable booms
  - –Simple mechanism
- Disadvantages:
  - –Low altitude
  - –Long term operation in space environment



Deployable membrane de-orbiting system

Deployable Membrane Space Structures

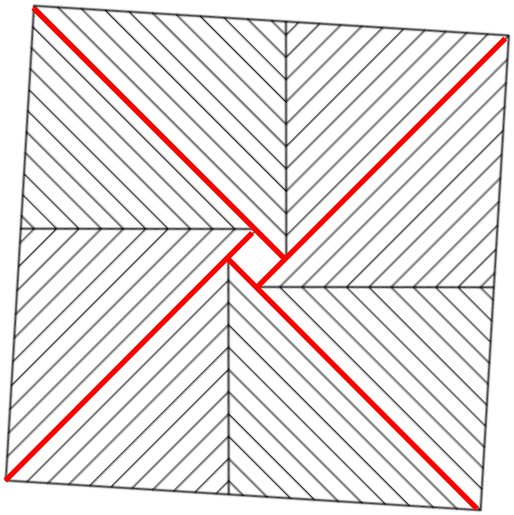
- Applications of deployable membrane for satellites
  - De-orbiting systems, Solar sail
    - Low precision
  - Solar array
    - Medium precision
  - Antenna systems
    - High precision

Deployment Mechanisms

- Centrifugal force
  - IKAROS (JAXA, 2010)
- Inflatable boom
  - Cosmos 1(Planetary Society, 2005)
- Deployable boom
  - NanoSail-D(NASA, 2010),
  - NanoSail-D2(NASA, 2011)

Boom-Membrane Integrated Deployable Structures

- Applicable for small-satellite missions
  - Integrated structure for boom-membrane deployable structures
    - Simplified holding and release mechanisms for membrane with deployable booms
  - Simple deployment mechanisms
    - Self-deployable booms
    - High specific stiffness with CFRP
- Small number of fold lines for higher accuracy membrane structures – ORIGAMI technique
  - Wrapping fold with skew/spiral fold
- Ground testing for gravity compensations
  - Sealing, air pad, hovercraft, ice-skating, water pool



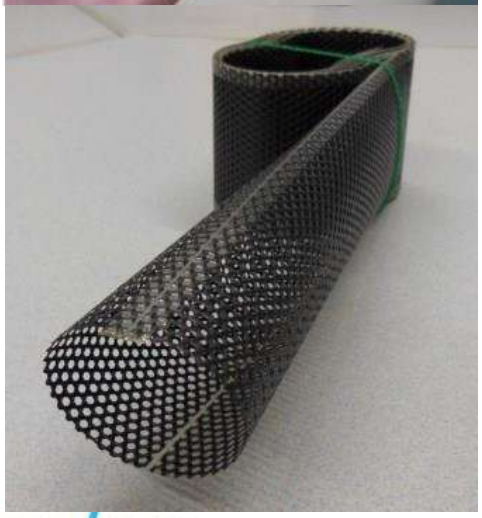
Boom-membrane integrated system

Configuration of Boom-Membrane Integrated Systems

- Boom
  - Tri-axis cylindrical CFRP deployable boom
    - Wrapping foldable
    - Self deployable
    - Low mass density, high specific stiffness
- Folding of membrane
  - Skew fold (Furuya, 2004), Spiral fold(Natori, 2007)
    - Smaller number of fold lines by wrapping fold
    - High packaging density

Tri-axis CFRP Boom

- Tri-axis cylindrical CFRP deployable boom



Reinforced by convex tape

→improving deployment force avoiding lateral buckling

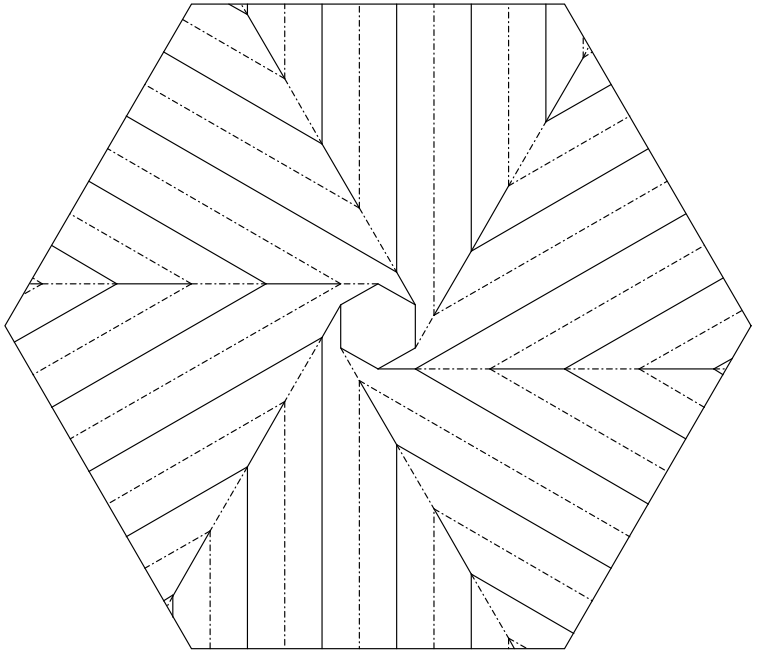
Reinforced by UD composite

Skew fold

- Skewed z-fold and wrap fold
- Double corrugation fold. Perfect fold if thickness=0

  – Hiroshi Furuya and Tadashi Masuoka: Concept of Rotationally Skew Fold Membrane For Spinning Solar Sail, CD-ROM Proc. 55th International Astronautical Congress, IAC-04-I.1.05 , Vancouver, pp.1-5, Oct.4-8, 2004.

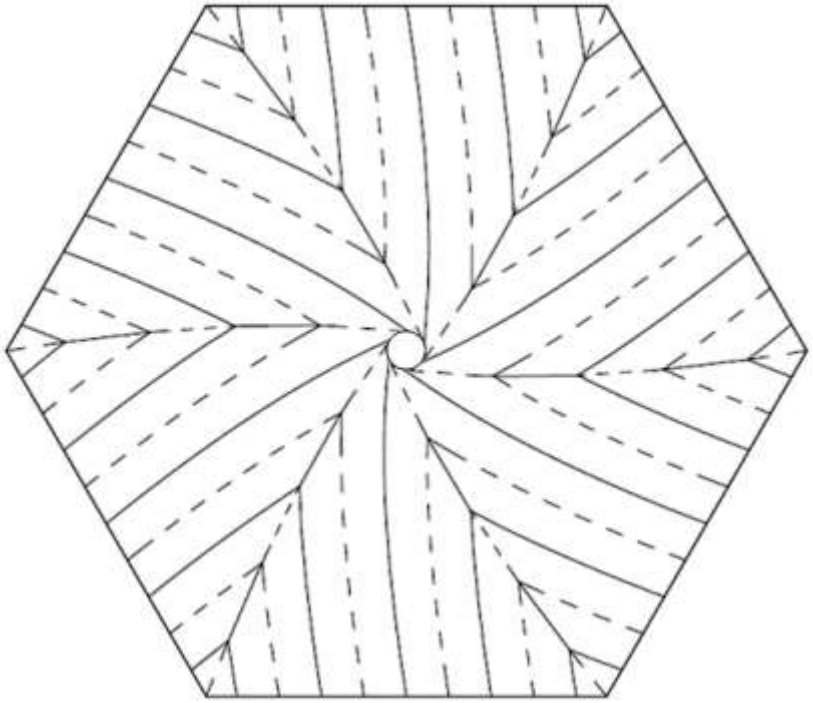
  – Hiroshi Furuya, Yosuke Inoue, and Tadashi Masuoka: Deployment Characteristics of Rotationally Skew Fold Membrane for Spinning Solar Sail, AIAA-2005-2045, 46th Structures, Structural Dynamics and Material Conference, Austin, pp.1-10, April 17-21, 2005.]

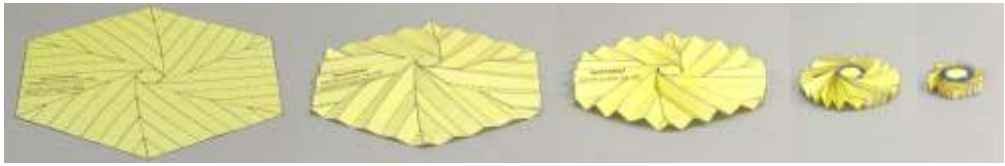


Spiral fold

- Perfect folding considering thickness of membrane
- Thickness = 0 → skew fold

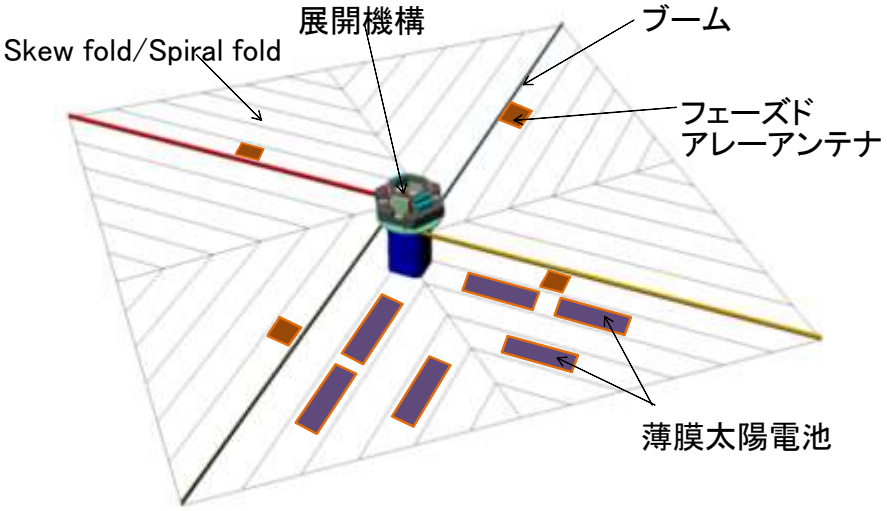
  - H. Watanabe, “Research on Folding Patterns of Circular Membranes Considering Their Thickness Effect,” Master Thesis, University of Tokyo (Dept. of Aeronautics and Astronautics), Feb. 2006.
  - M.C. Natori, H. Watanabe, N. Kishimoto, and K. Higuchi, Folding Patterns of Deployable Membrane Space Structures Considering Their Thickness Effects, 18th Int. Conf. on Adaptive Structures and Technologies, Ottawa, pp.1-9, Oct. 2007.

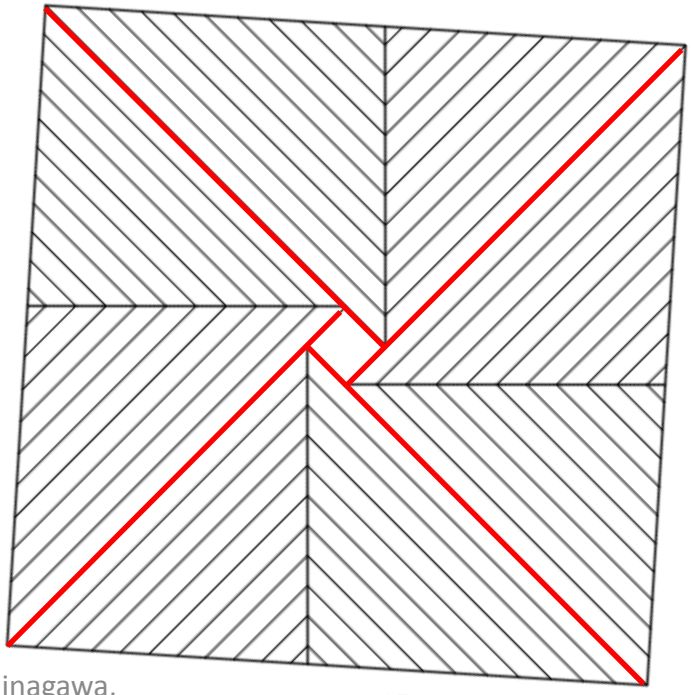




Design of Skew Folding Patterns

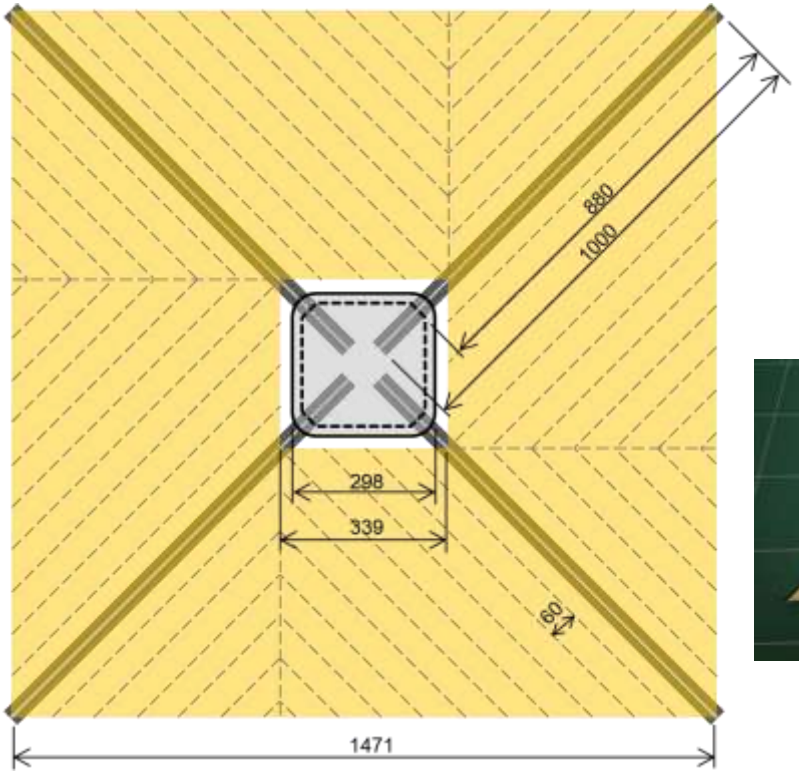
- Deployment direction of booms
  - Conventional skew fold → tangential direction
  - Symmetric design?

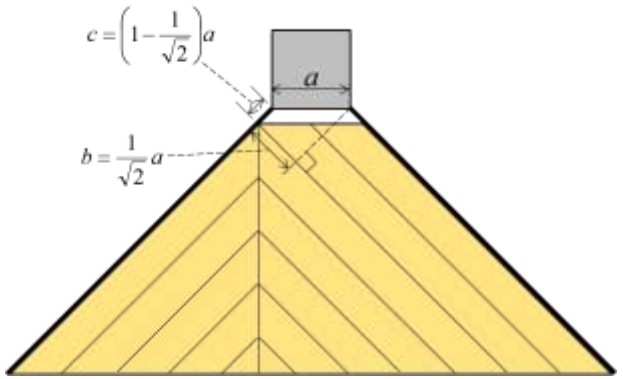


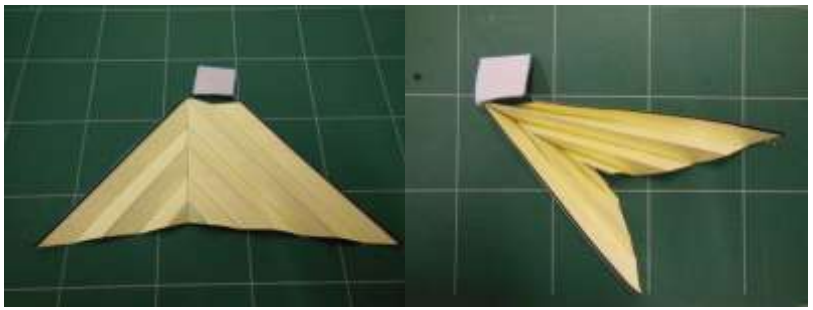


Symmetric Configuration of Boom-Membrane Structures

- 1.5mx1.5m model

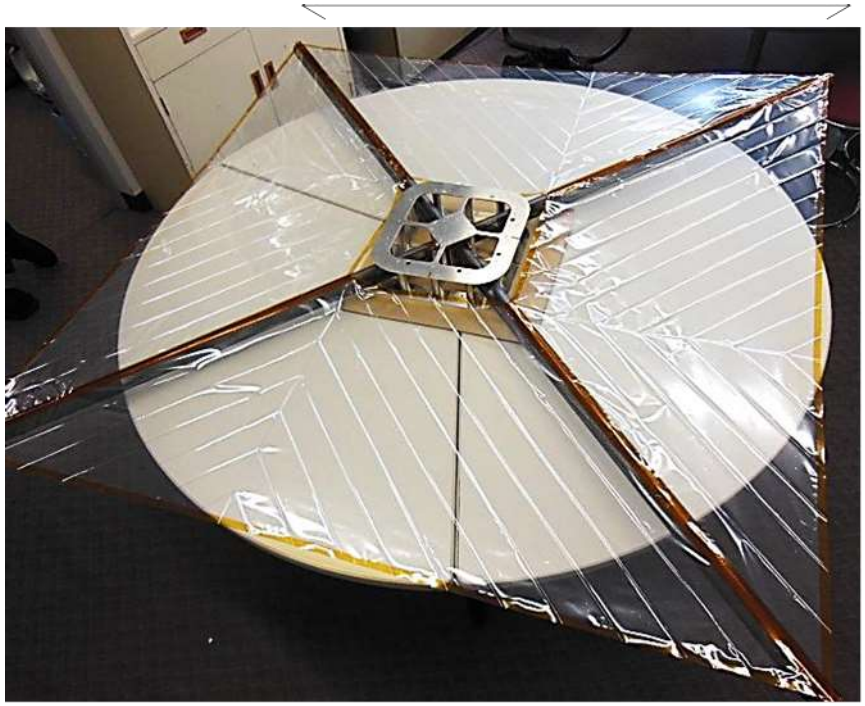


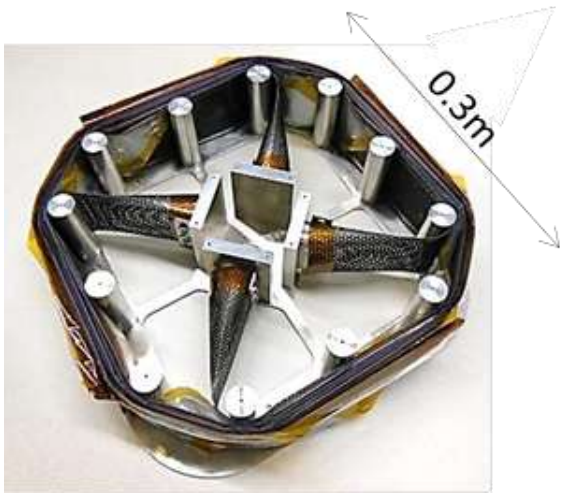


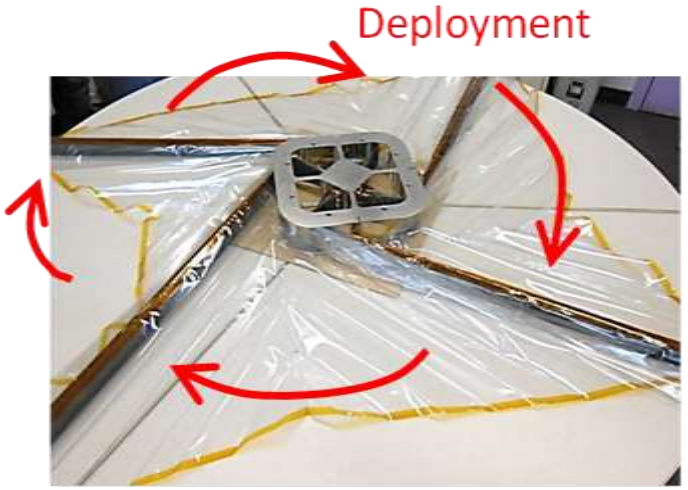


folding process

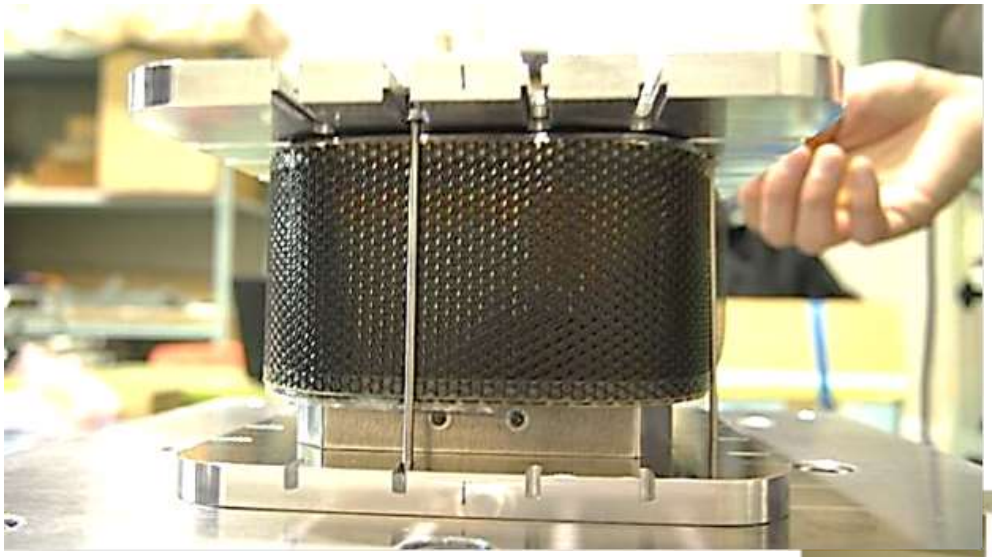
1.5mx1.5m Boom-Membrane Integrated Model



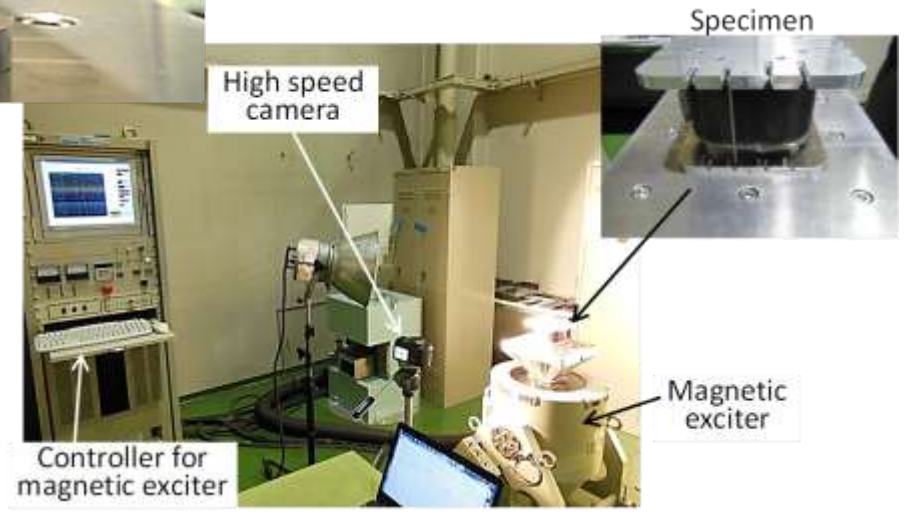




Hold and Release Mechanisms



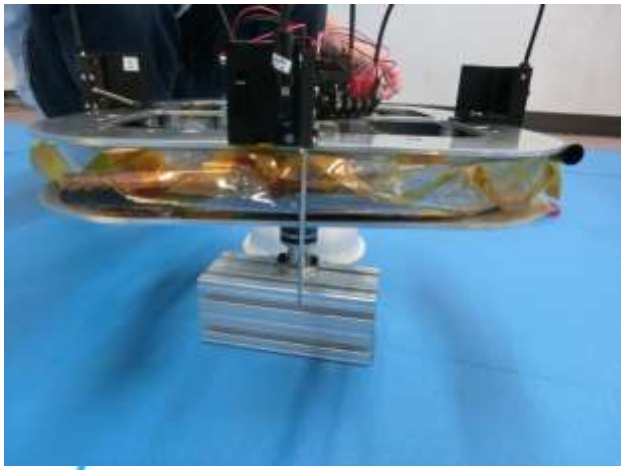
Integrated holding



Deployment of UD Reinforced Boom

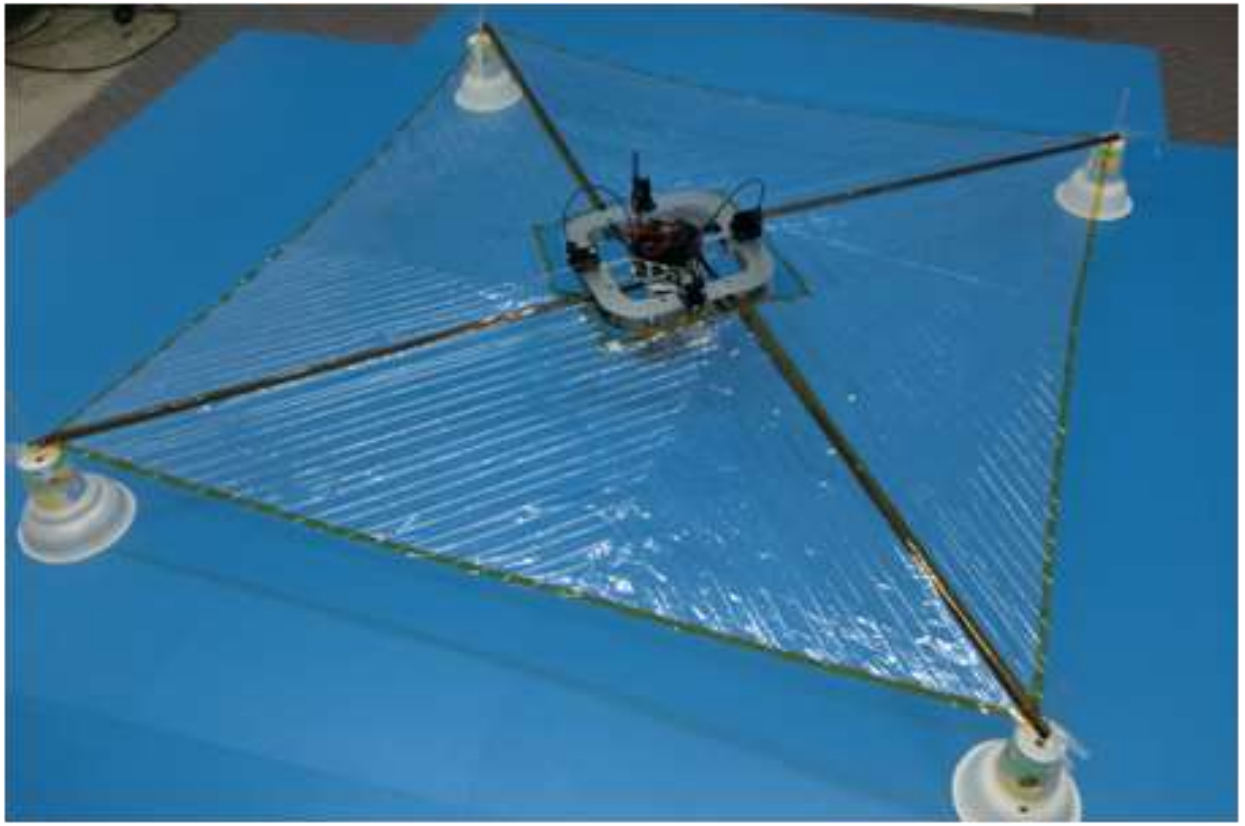
UD reinforced CFRP boom + membrane(240fps, 2013.11.18)

De-orbiting Model



- UD tri-axis CFRP boom
- L=1,000mmm, D=13mm
- Membrane : 1.5mx1.5m
- 12.5µm PET
- Fold pitch : 25mm
- Fold diameter : 30cm

Deployment of De-orbiting Model



UD reinforced CFRP boom(D=13mm,120fps, 2014.07.16)

Future works

- Develop engineering model (EM) and flight model (FM) of 3U small satellite
- Deployment experiment of deployable membrane in space environment in 2017-2018
- Large membrane solar cell array systems for satellites
- Deployable membrane array antenna systems for SAR