DEPLOYTECH:
Deployment Technology Survey

How to Use This Index

The information in this survey provides a sample of details on deployable structures that have been proposed, tested, and flown from the 1960s to today.

- Study Description
- General Mission Assumptions
- Launch Vehicle
- TMI Stage Characteristics

In addition, several slides have been added to the end of each spacecraft summary describing other key information (referred to as Supplemental Information) including detailed spacecraft layouts, mission operations diagrams and trade study results.

You can navigate the index by clicking on the buttons in the index navigation table. Through this index you have access to individual study summaries, specific subject area slides for each summary and the study reference documentation (i.e. NASA TM's and study reports). The guide below describes how to use the index navigation table. You can always return to the navigation table by clicking the "INDEX" button at the bottom of the page.

When viewing the study summary documents, simply scroll through them as you would a normal PowerPoint Presentation. Click the "INDEX" button to return to the navigation table.

To end your session simply return to the index navigation table and click on the "QUIT" button.

Click the "INDEX" button to begin navigating the spacecraft summaries when you are ready.

Release Date	Study	Study Overview	General Mission Assumptions	Launch Vehicle	TMI Stage	Surface Access System	TEI Stage	Habitats & Crew Support	Other Notable Equipment	Supplemental Information
Jul - 1967	Alternative Mission Modes Study									

Click on the Study Name to View the Entire Study Summary Document

Click on the Buttons in the body of the table to view a specific subject for a specific study

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Survey Directions

The contents of this survey detail four demonstrated deployable technology groups:

1. **Centrifugal**
2. **Coilable Structures**
3. **Stiff Technologies**
4. **Inflatable Technologies**

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Transhab										
Vega 1&2 Balloon										
SAR										
ISIS										
Genesis 1										
Genesis 2										

Znamya 2

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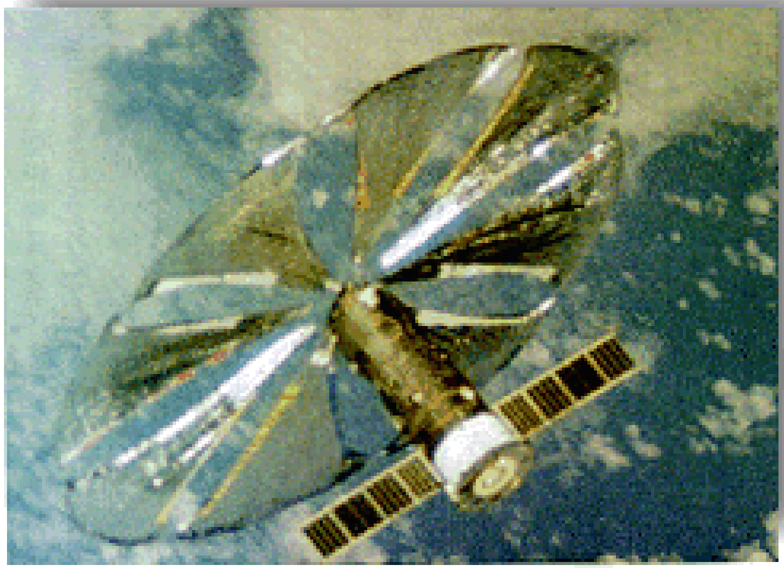
Znamya 2

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Znamya 2	9	n/a	20 diameter	n/a	1993



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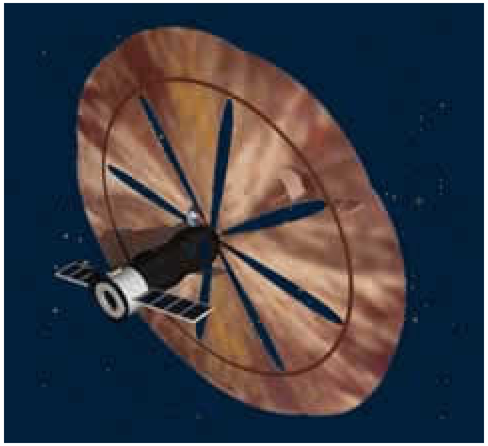
Znamya 2

Material Type

- Aluminized Mylar Reflector



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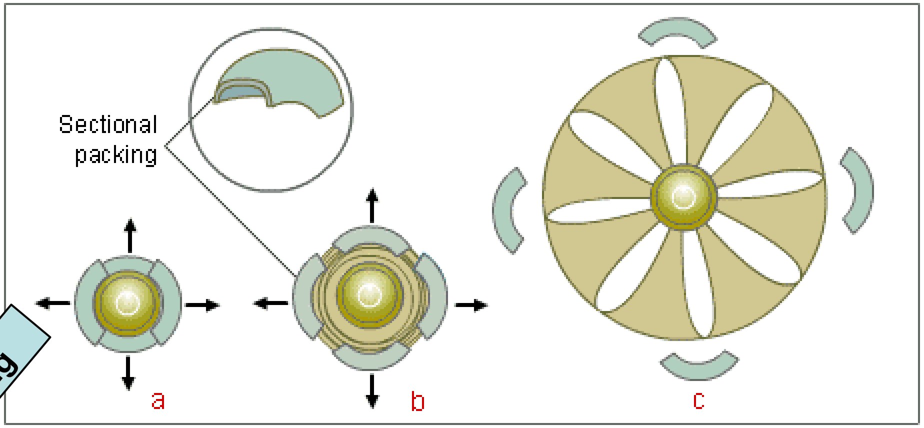
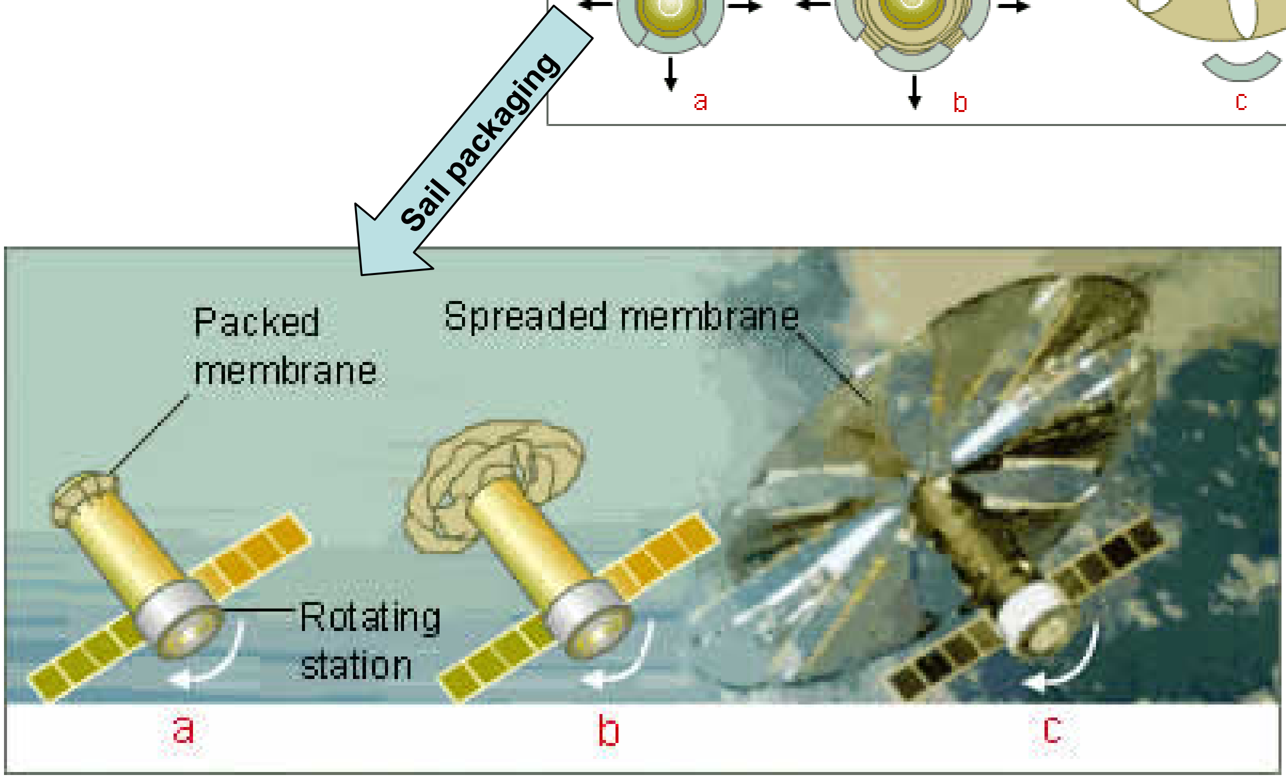
Znamya 2

Deployment Method

- Centrifugal Force





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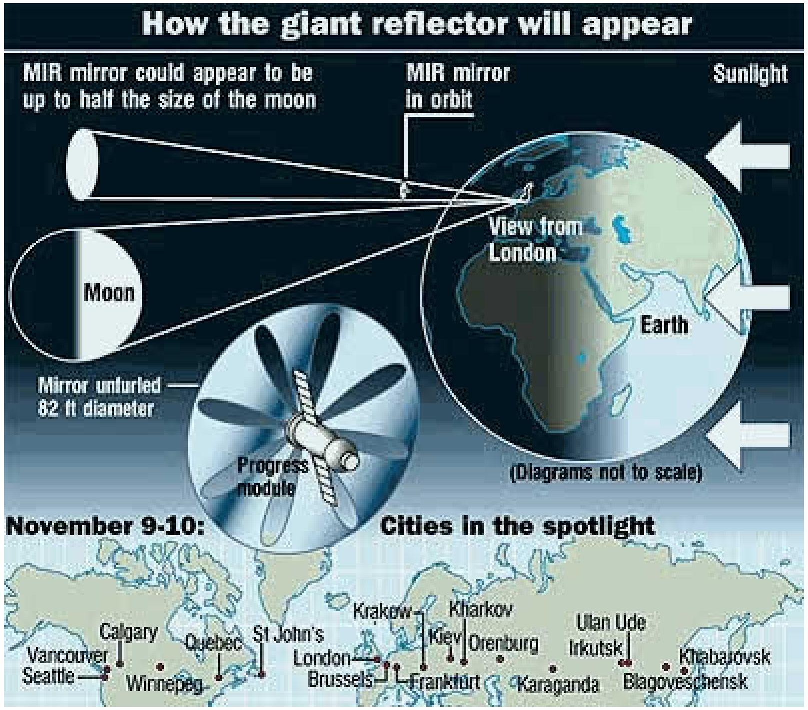
Znamya 2

Issues & Comments

- Znamya 2 was a successful in space demonstration of a solar reflector or “space mirror” technology concept to provide continual light to remote areas



Proposed concept illustration

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Znamya 2

References

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Znamya 2.5

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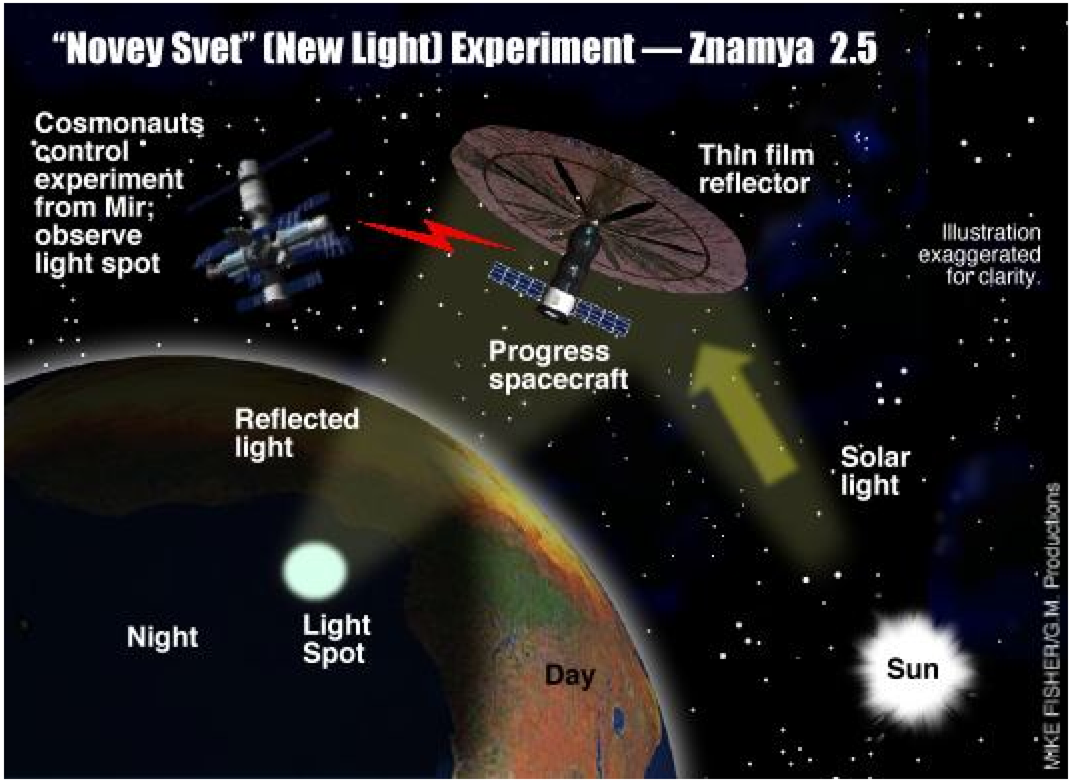
Znamya 2.5

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent demo
Znamya 2.5	9	n/a	20 diameter	n/a	1999



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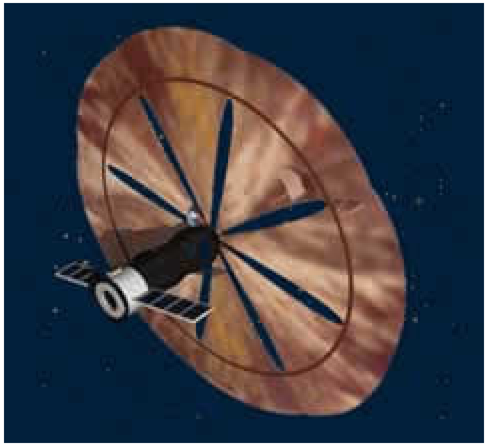
Znamya 2.5

Material Type

- Aluminized Mylar Reflector



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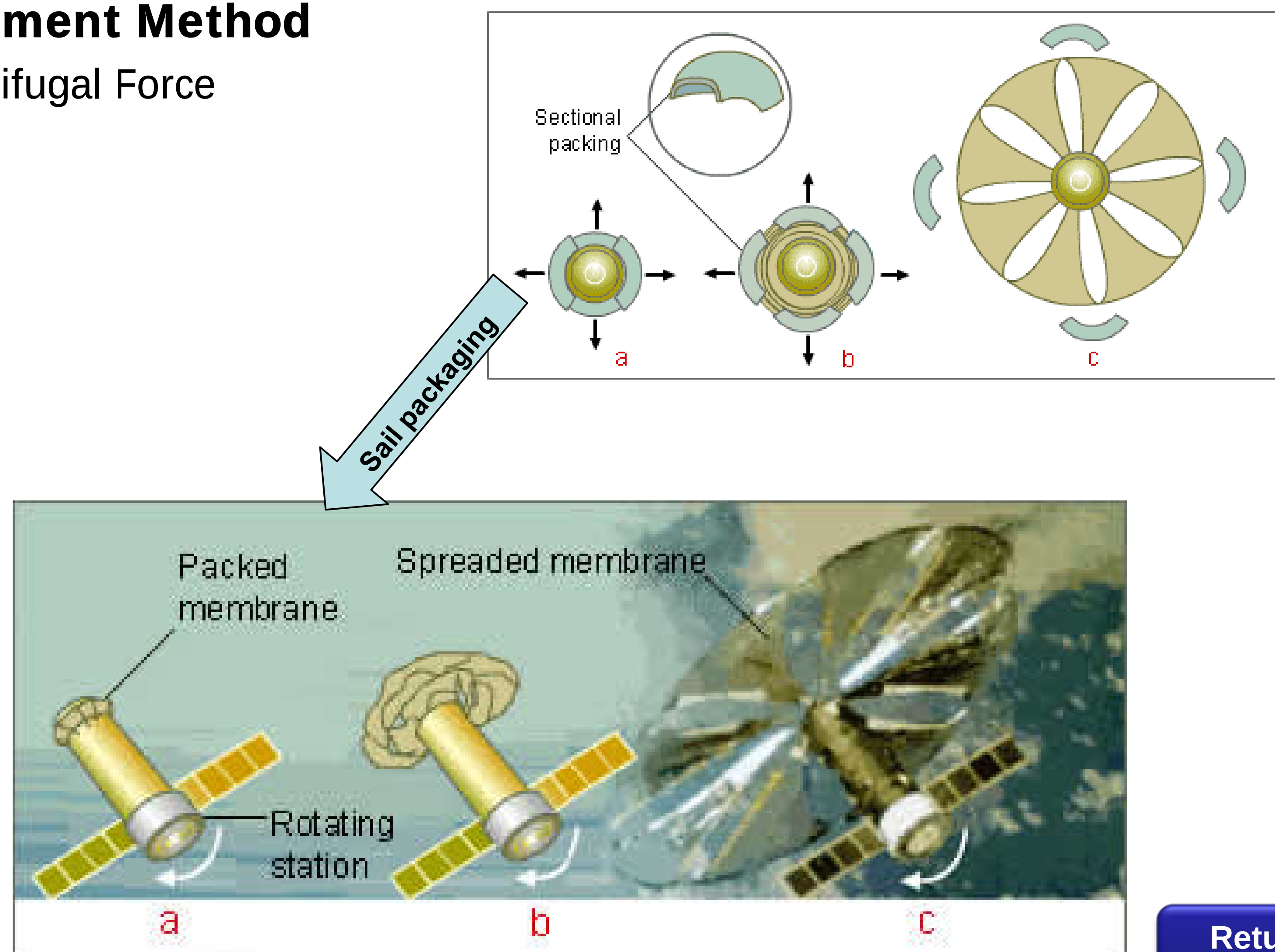
Znamya 2.5

Deployment Method

- Centrifugal Force



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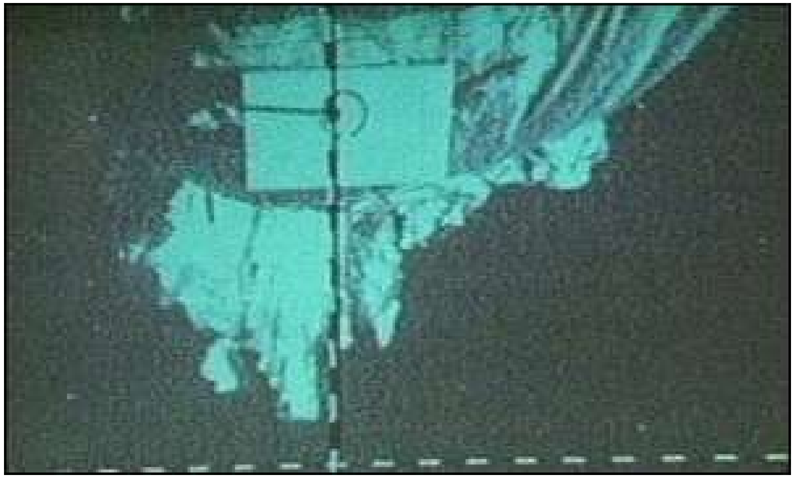
Znamya 2.5

Issues & Comments

- Soon after deployment, the mirror caught on MIR and ripped
- The failure of Znamya 2.5 caused the cancellation of Znamya 3 with a proposed size of 60-70m



Ripped sail during in-space flight demonstration

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Znamya 2.5

References

Shpakovsky, N., "Space Mirror," **http://www.triz-journal.com/archives/2002/06/e/index.htm**, 1997-2005.

BBC News online: **http://news.bbc.co.uk/2/hi/science/nature/272103.stm**

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Interplanetary Kite-Craft Accelerated by Radiation of the Sun

(IKAROS)

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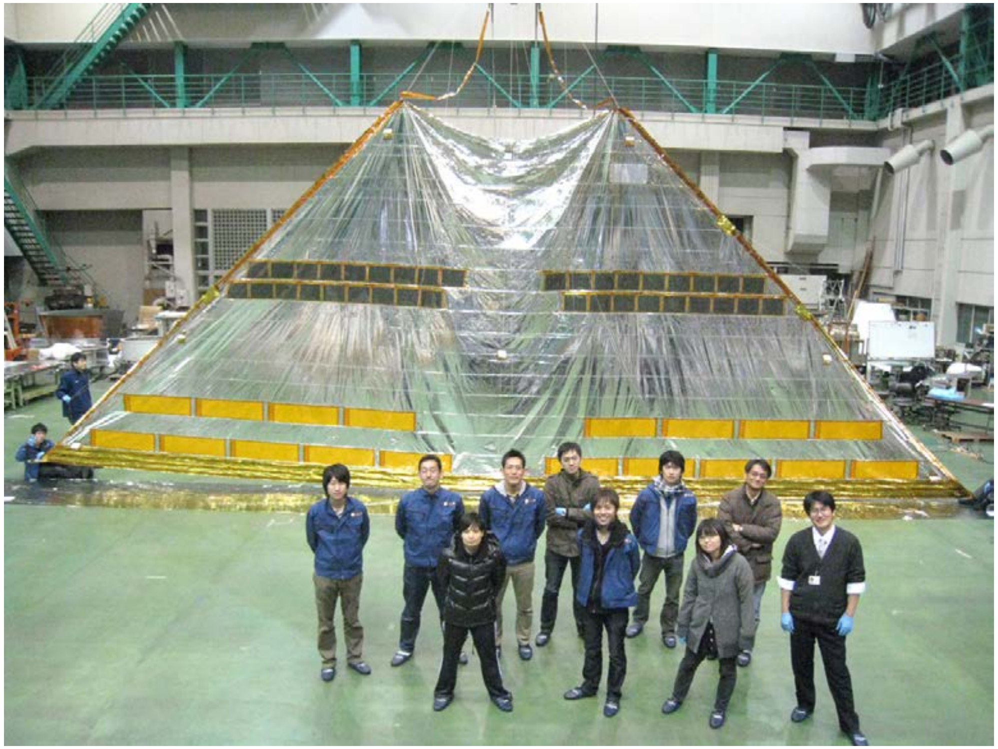
IKAROS

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Date of most recent demo
IKAROS	9	310 kg	20 diagonal	n/a	2010



[Source: JAXA]

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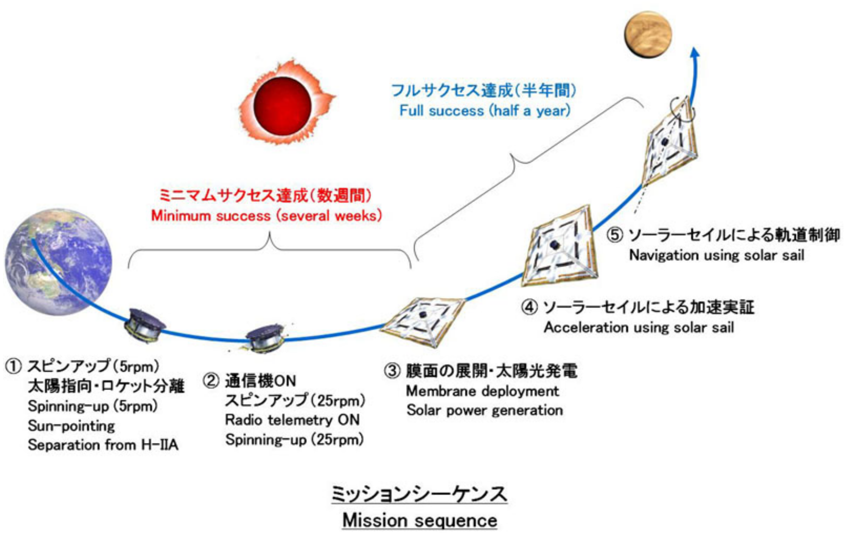
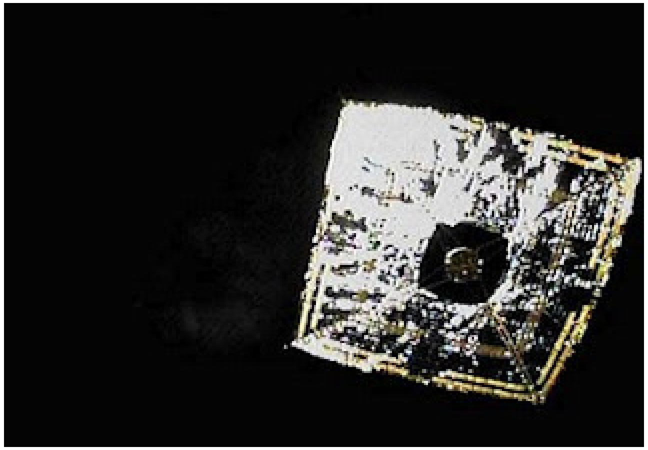
IKAROS

Material Type

- 7.5 micron thin film, polyimide
- Four trapezoid pedals configured into a box sail



[Source: JAXA]



[Source: JAXA]

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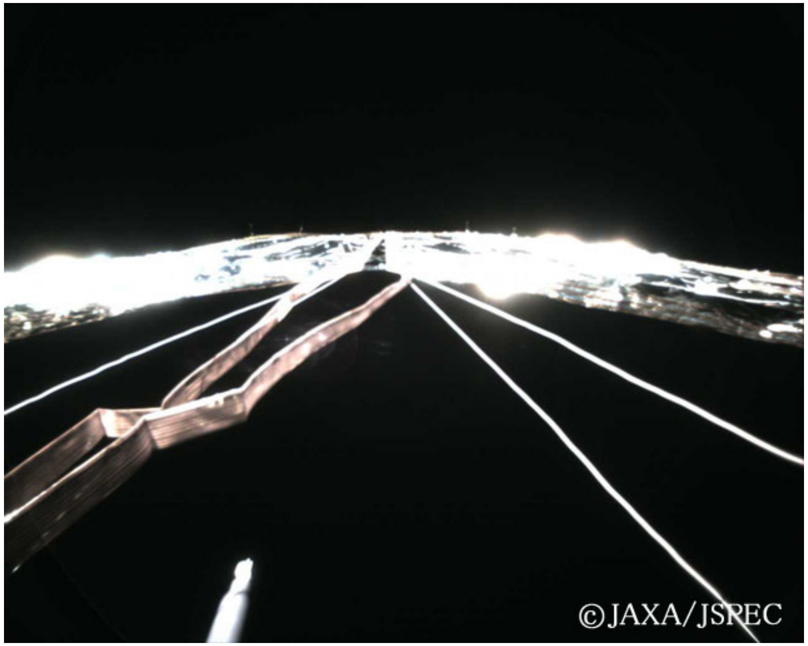
IKAROS

Deployment Method

- Centrifugal force from spinning spacecraft
  - Two stage process: Static and dynamic



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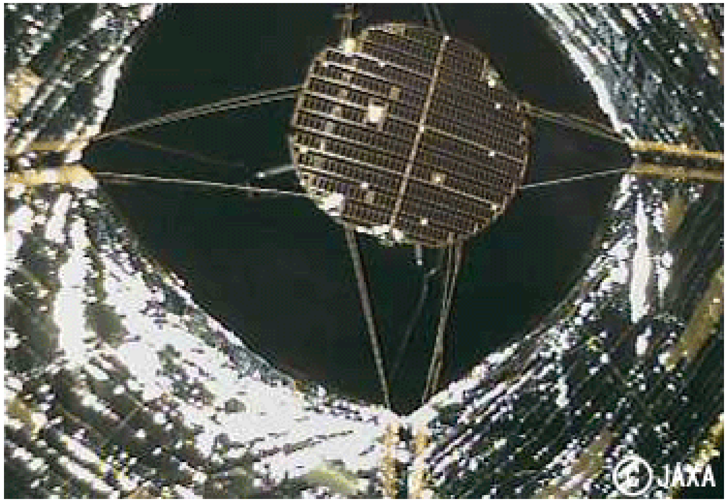

[Source: JAXA]

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IKAROS

Issues & Comments

- IKAROS was successfully deployed in June of 2010
- Venus fly by in December 2010
- All planned experiments and missions were completed in December 2010
- IKAROS is currently sailing through interplanetary space, allowing scientists to practice steering of the solar sail
- Due to the current angle of the sun, IKAROS is in a hibernation mode until the spring

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References

Furuya, Hiroshi, et al, “Manufacturing and Folding of Solar Sail “IKAROS””, 52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference AIAA-2011-1907, April 4-7, 2011, Denver, Colorado.

JAXA websites:

http://www.jaxa.jp/projects/sat/ikaros/index_e.html

http://www.jspec.jaxa.jp/e/activity/ikaros.html

http://www.jaxa.jp/article/special/explore/mori01_e.html

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COILABLE BOOM Ⅰ

Various Operations

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Coilable Boom I - Various

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Coilable Boom I – Various	9	0.24	1.6 to 44.5	44.5	2010

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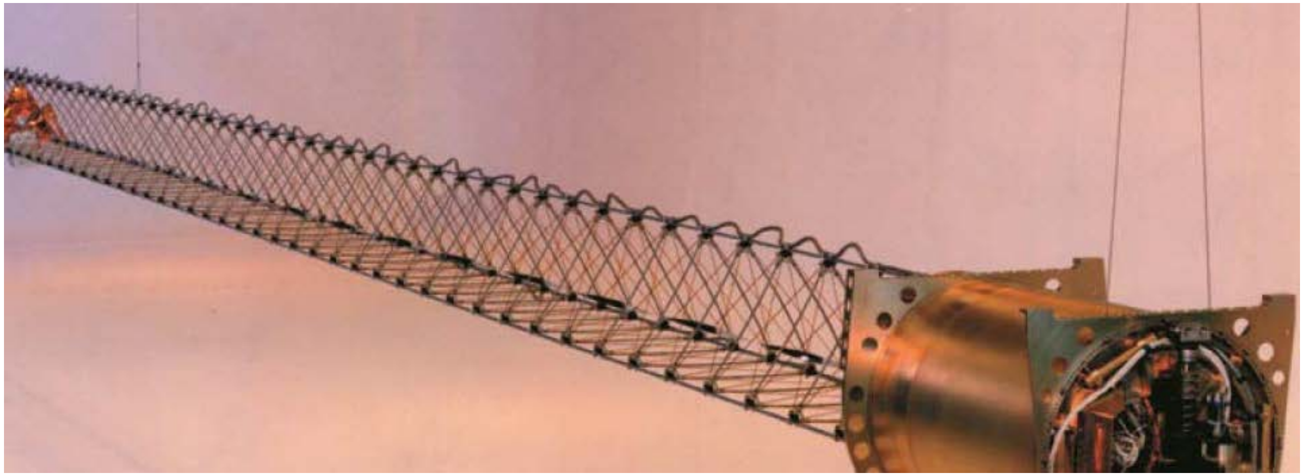
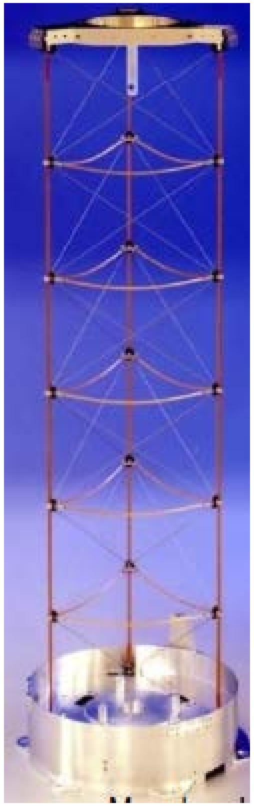
Coilable Boom I - Various

Material Type

- Carbon composite
- Aluminum
- Fiberglass
- Special coating required for spaceflight





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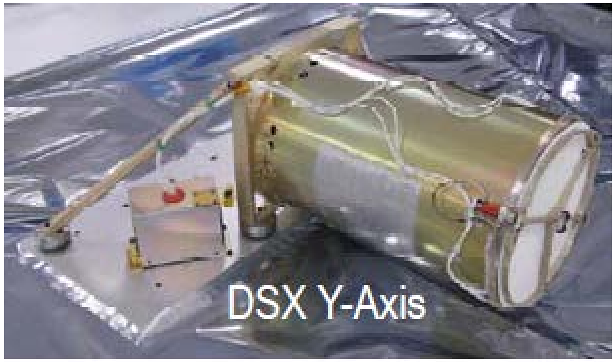
Coilable Boom I - Various

Deployment Method

TYPICAL DEPLOYMENT SEQUENCE

1. Power is applied to the tip/payload release actuator(s).
2. Boom self-deploys under internal strain energy. Deploy rate (typically ~1-3 in/sec) is regulated by lanyard to boom tip paid off a spool on canister-mounted rotary damper. Full stiffness is developed from root mounting as longerons rotate to their deployed angle. Boom uncoils from stack at tip end.
3. Boom is fully deployed. Boom may be retracted manually by re-coiling, or on-orbit by a lanyard-operated bridle mechanism and a motor drive.



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Coilable Boom I - Various

Issues & Comments

- Higher mass
- At least 18 have flown operationally of various sizes

Program	Customer	Launch Date	Length each (m)	Diameter (in)	EI (lb*in^2)
SAFE	Lockheed/ NASA	3-Feb-84	32	14.4	1.79E+06
Galileo	JPL	18-Oct-89	3.5	12.5	1.34E+07
Galileo	Univ. of Iowa/JPL	18-Oct-89	6.45	12.5	1.34E+07
LACE	Naval Research Laboratory	14-Feb-90	44.5	10	4.97E+06
UARS	GE Astro	15-Sep-91	4.9	12.5	1.41E+07
EUVE	Fairchild Space	7-Jun-92	1.6	17.64	5.01E+07
GGS WIND	Martin Marietta	1-Nov-94	12.4	12.5	1.34E+07
GGS POLAR	Martin Marietta	24-Feb-96	6.2	12.5	1.34E+07
Mars Pathfinder	JPL	4-Dec-96	0.8	7.2	1.79E+06
Cassini	JPL	15-Oct-97	4.8	12.5	1.75E+07
Lunar Prospector	Lockheed Martin	7-Jan-98	2.6	8	2.20E+06
EOS-AM (Terra)	Lockheed Martin	18-Dec-99	9	13.75	
MIDEX IMAGE	U. Mass Lowell	25-Mar-00	9.9	7.2	9.00E+05
GOES N	Boeing	24-May-06	8.4	10	6.39E+06
Classified	Lockheed Martin	1-Jun-03			
GOES O	Boeing	26-Jun-09	8.4	10	6.39E+06
GOES P	Boeing	4-Mar-10	8.4	10	6.39E+06
GOES R	Lockheed Martin	In Work	8.5	12.5	1.34E+07
DSX Z-Axis	AFRL	delivered	8	10	4.97E+06
DSX Y-Axis	JPL/ AFRL	delivered	40	9.5	2.40E+06
LADD	Northrop Grumman/NASA/SIDO	Delivered	8	16.67	4.45E+07
Triana	Orbital	Delivered	3.5	10	4.97E+06
Mars Polar Lander	NASA JPL	21-Jun-05	0.8	7.2	1.80E+06
ST8 SAILMAST	JPL	delivered	40	9.5	2.80E+06
MMS	LASP	delivered	12	10.24	4.56E+06

See following website:

http://www.atk.com/Products/documents/Coilable%202011.pdf

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Coilable Boom I - Various

References

ATK/ABLE 2011 COILABLE Brochure

http://www.atk.com/Products/documents/Coilable%202011.pdf

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Coilable Boom II

In Space

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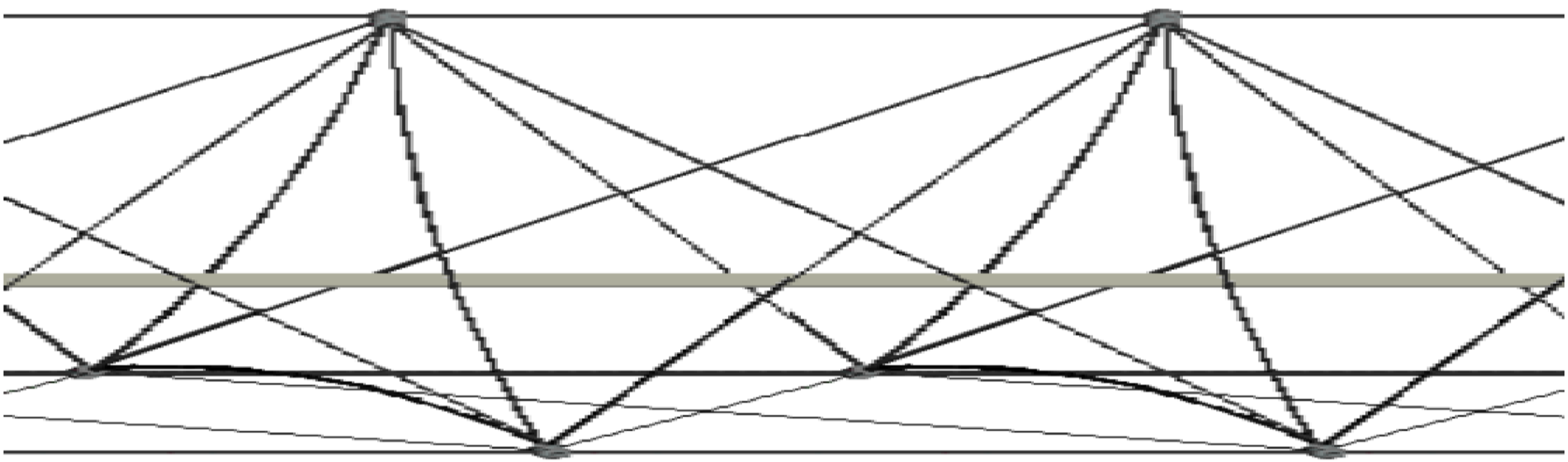
Coilable Boom II – In Space

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Coilable Boom II – In Space boom	6	0.070	20	80	2005



[Source: ATK]

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Coilable Boom II – In Space

Material Type

- Composite

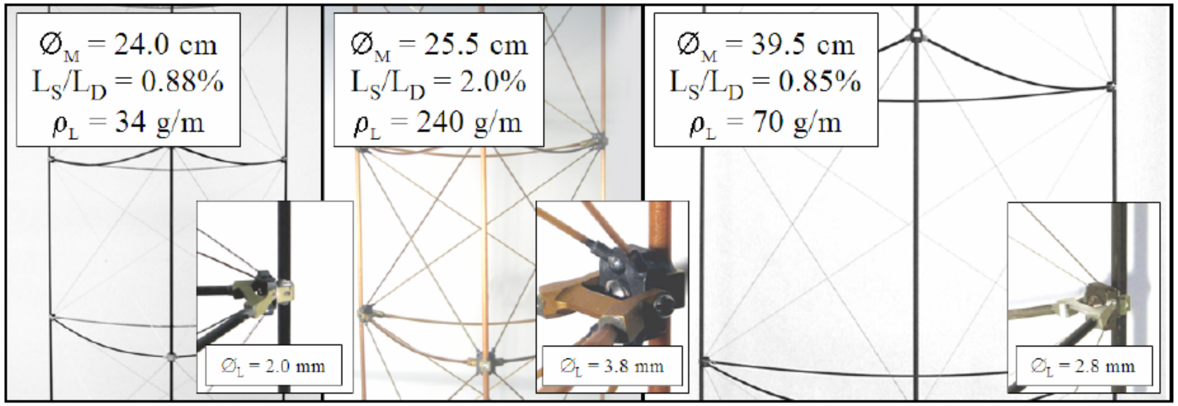

Figure 6. Comparison of a Heritage S2 Glass Boom to Gossamer Sail Masts (ST8-L, ISP-R)

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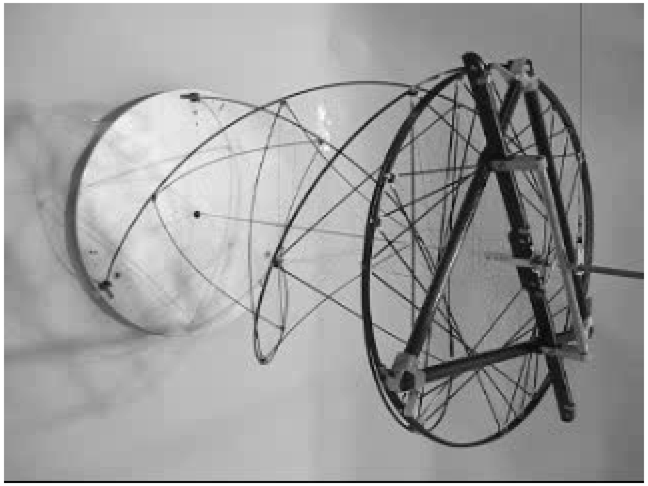
Coilable Boom II – In Space

Deployment Method

- Lanyard spring system



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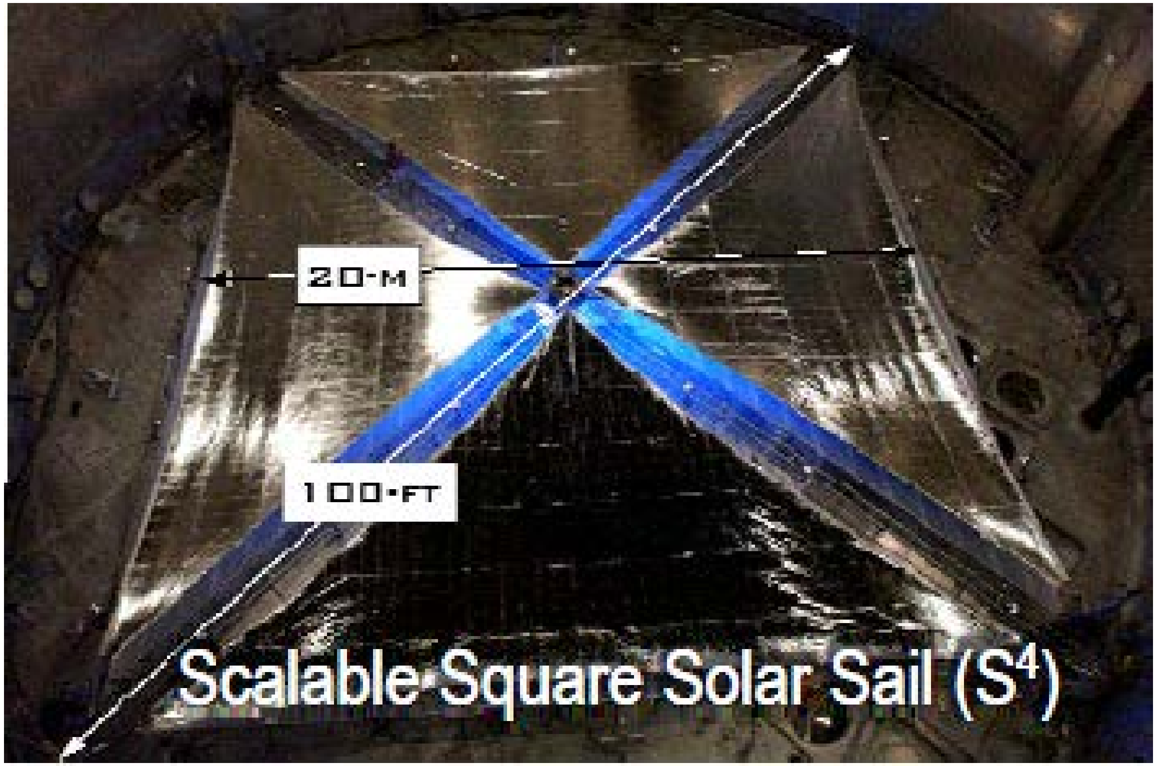
Coilable Boom II – In Space

Issues & Comments

- Lower TRL
- Designed for 80 meters and cut short



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Coilable Boom II – In Space

References

Murphy, David, McEachen, Michael, Macy, Brian, Gaspar, James, “Demonstration of a 20-m Solar Sail System”, 46t AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference AIAA-2005-2126, April 18-21, Austin, Texas.

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Coilable Boom III

ST8 SAILMAST

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Coilable Boom III- ST8 SAILMAST

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Coilable Boom III – ST8 SAILMAST	6	0.035	40	40	2008

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Coilable Boom III- ST8 SAILMAST

Material Type

- Fiberglass

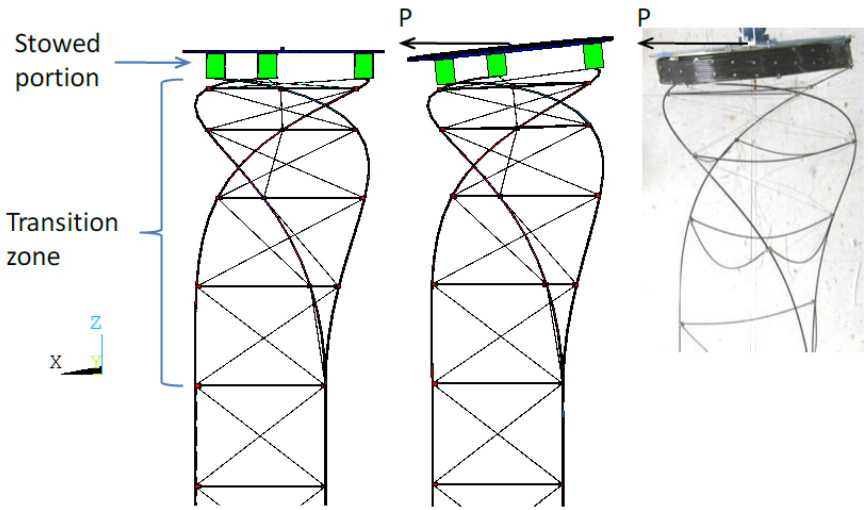

Figure 16. FEM and Test of Partially Deployed Boom

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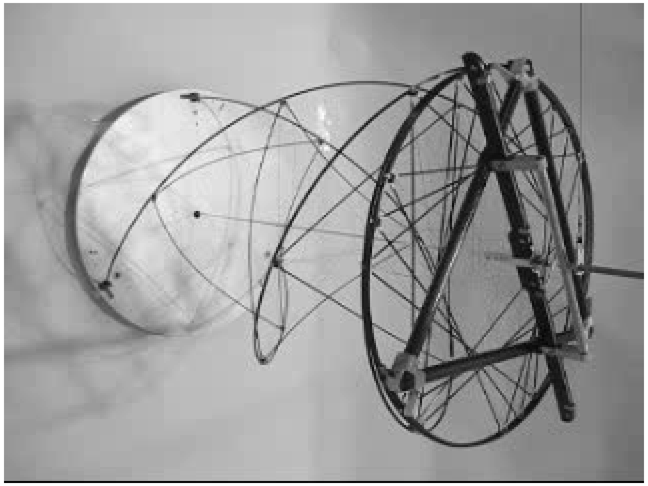
Coilable Boom III- ST8 SAILMAST

Deployment Method

- Lanyard spring system



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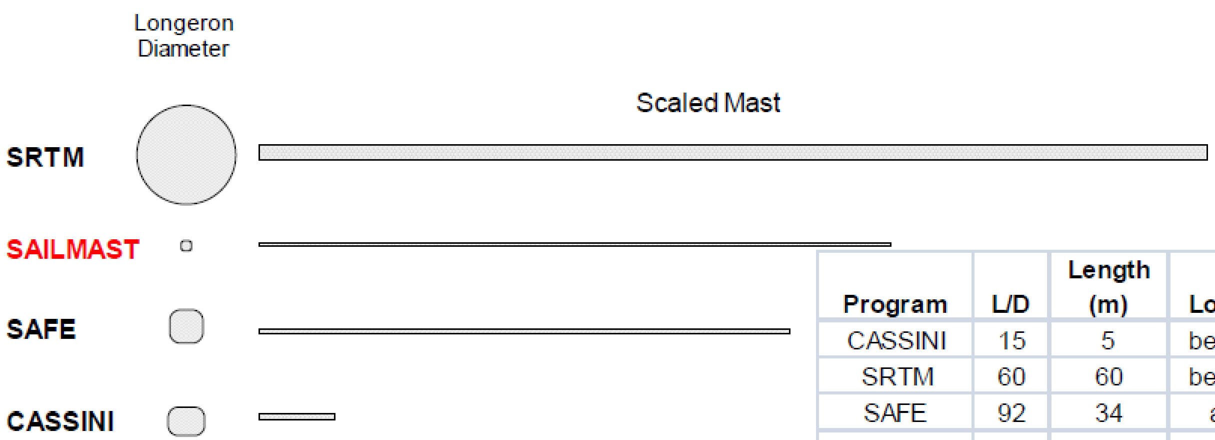
Coilable Boom III- ST8 SAILMAST

Issues & Comments

- Lower TRL

  SRTM – 1994 Shuttle Radar Topography Mission
  SAFE – 1984 NASA Science Mission
  Cassini – NASA Saturn Science Mission



Program	L/D	Length (m)	Loading
CASSINI	15	5	bending
SRTM	60	60	bending
SAFE	92	34	axial
SAILMAST	171	40	axial

Figure 1. Mast Slenderness Comparison

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References

McEachen, Michael E., "Validation of SAILMAST Technology and Modeling by Ground Testing of a Full-Scale Flight Article" AIAA 2010-1491, *48th AIAA Aerospace Sciences Meeting, January 4-7, 2010, Orlando, FL.*

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Superstring

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Superstring

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Date of most recent demo
Superstring	3	0.02 – 0.08	TBD	100	TBD

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Superstring

Material Type

- Fiberglass

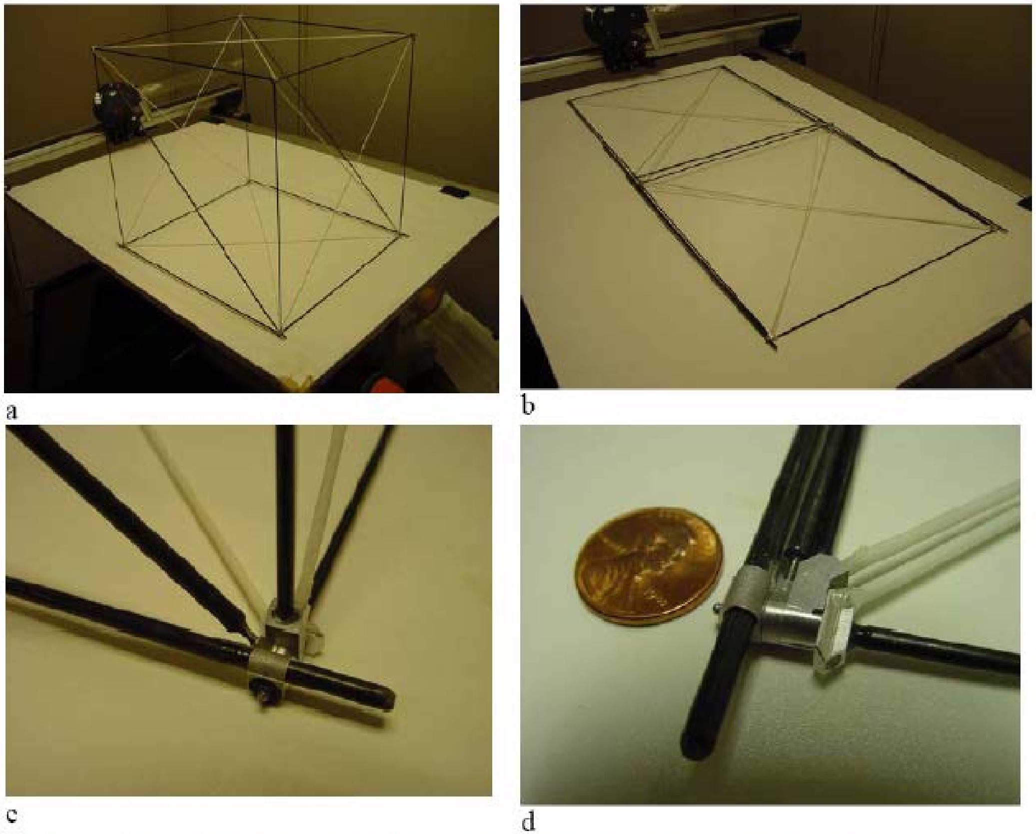

Figure 6. Photographs of Truss Boom Nodes and Assembly

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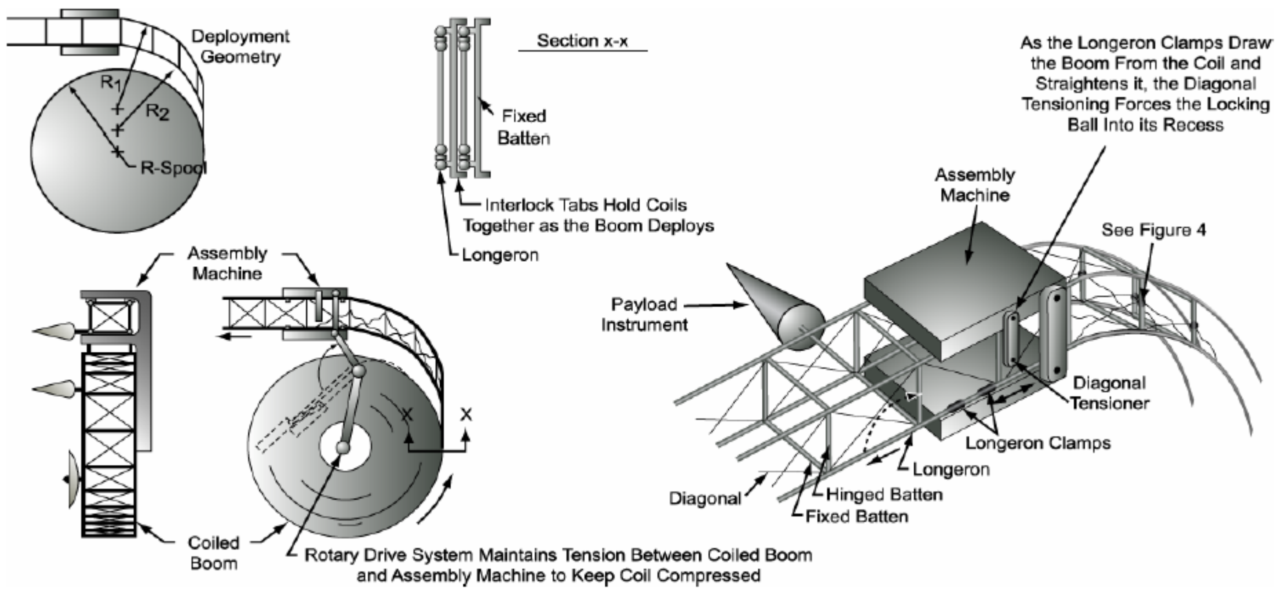
Superstring

Deployment Method

- Rotary Drive with Longeron Clamps



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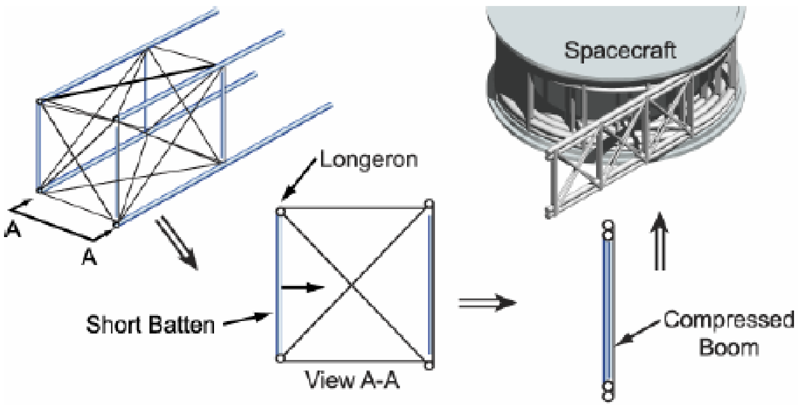
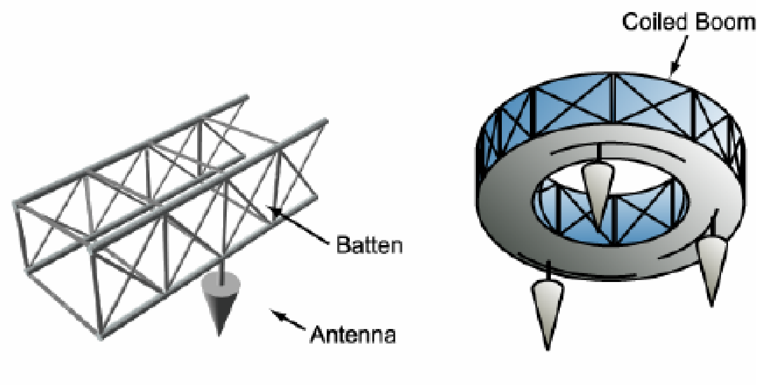
Superstring

Issues & Comments

- Low TRL
- Analytic with some preliminary testing
- Novelty is in the packaging



Superstring Stows By Wrapping Around a Drum or Spacecraft. It First Compresses Laterally So All Four Longerons Lie in Same Plane. Boom May Then Be Wrapped Around Drum Without Strain Between Longerons



Superstring Forms a Rigid Structure to Which All Kinds of Hardware Can Be Attached and Stowed for Launch

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References

Brown, M., Tasker, F., Kirby, G., “A Deployable Truss Beam for Long or Lightly Loaded Space Applications, 10th Gossamer Forum, 2009.

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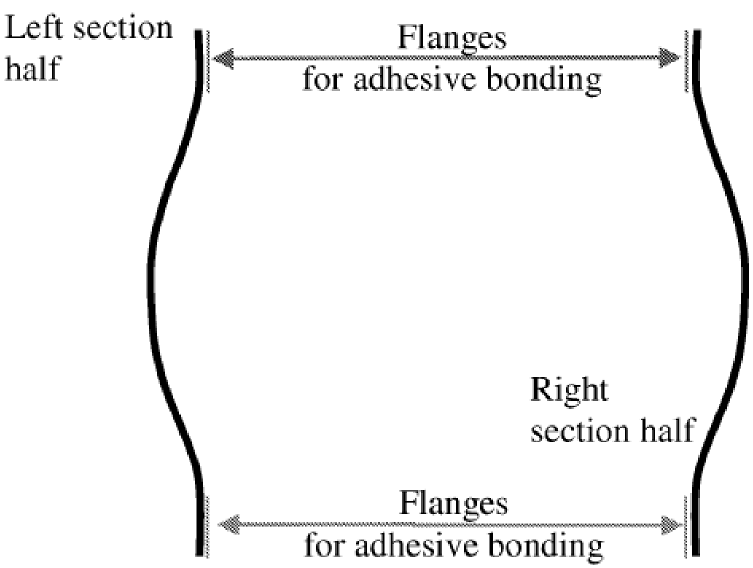
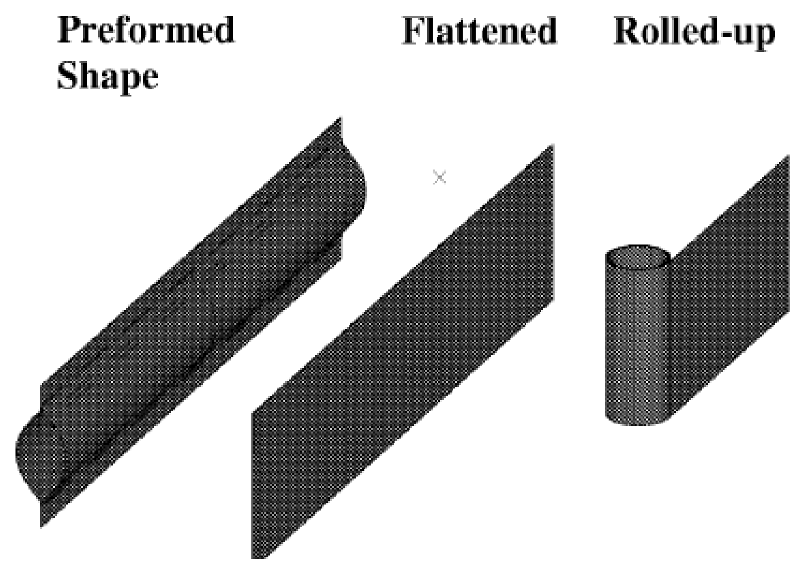
Bonded Boom

Bonded Boom

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Bonded Boom	5+	n/a	10	n/a	2005





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Bonded Boom

Material Type

- Carbon Fiber Reinforced Plastic (CFRP)
- Bonded during deploy

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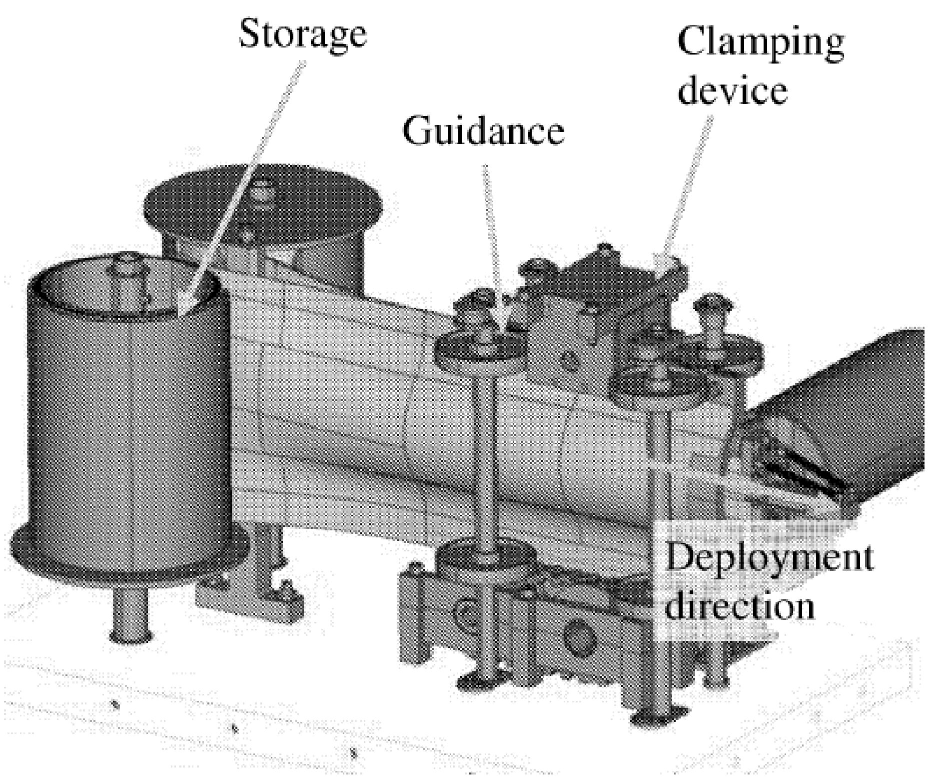
Bonded Boom

Deployment Method

- Bonded in space



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Bonded Boom

Issues & Comments

- Complexity of deployment methods

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Bonded Boom

References

Title: Deployable structure for flexible solar generators

Authors: Seifart, K., Göhler, W., Schmidt, T., John, R., & Langlois, S.

Journal: Proceedings of the European Conference on Spacecraft Structures, Materials and Mechanical Testing 2005 (ESA SP-581). 10-12 May 2005, Noordwijk, The Netherlands.

Websites:

http://adsabs.harvard.edu/full/2005ESASP.581E.104S

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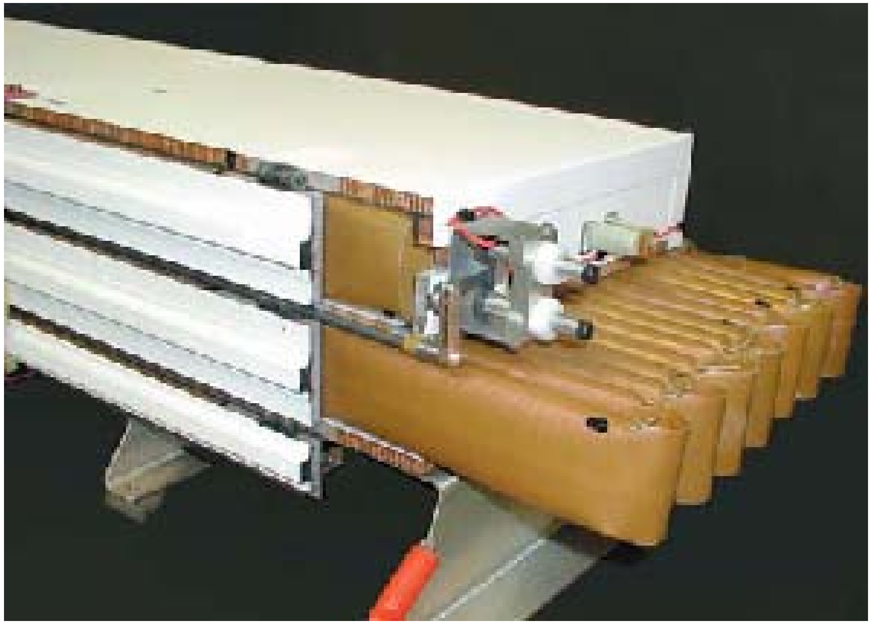
FlatFolded Tube

FlatFolded Tube

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
FlatFoldedTube	9	0.1875	40	Unlimited	Mars Express Satellite



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FlatFolded Tube

Material Type

- Fiberglass or composite

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FlatFolded Tube

Deployment Method

- Unfolding

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FlatFolded Tube

Issues & Comments

- Packaging for unfolding
- Clearance for unfolding sections

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FlatFolded Tube

References

Websites: Northrop Grumman (Astro Aerospace)

http://www.as.northropgrumman.com/products/aa_fftube/assets/DS-412-FlatFoldTube.pdf

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RolaTube

RolaTube

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
RolaTube	5	n/a	n/a	n/a	In Production

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RolaTube

Material Type

- Composite

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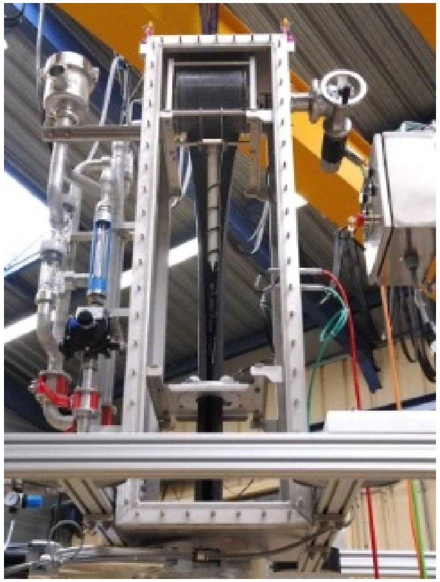
RolaTube

Deployment Method

- Reeled out



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RolaTube

Issues & Comments

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RolaTube

References

Title: Deployable structure for flexible solar generators

Authors: Seifart, K., Göhler, W., Schmidt, T., John, R., & Langlois, S.

Journal: Proceedings of the European Conference on Spacecraft Structures, Materials and Mechanical Testing 2005 (ESA SP-581). 10-12 May 2005, Noordwijk, The Netherlands.

Websites:

http://www.rolatube.com/

http://www.rolatube.com/sites/default/files/Rolatube_Web_Site_Pres.pp

Video Demonstration:

http://www.youtube.com/watch?v=BNfxvdRWTkQ

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STEM

STEM

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
STEM	9	0.143	6.7	unlimited	In Production

Return to Index

STEM

Material Type

- Stainless steel

Return to Index

STEM

Deployment Method

- Reeled out

Return to Index

STEM

Issues & Comments

- Mass efficiency

Return to Index

References

Northrop Grumman (Astro Aerospace)

Websites:

http://www.as.northropgrumman.com/products/aa_stem/index.html
http://www.as.northropgrumman.com/products/aa_stem/assets/DS-415-150lbBI-STEM.pdf
http://www.as.northropgrumman.com/products/aa_stem/assets/DS-414-40lbBI-STEM.pdf
http://www.as.northropgrumman.com/products/aa_stem/assets/DS-101-BiStemActuator.pdf

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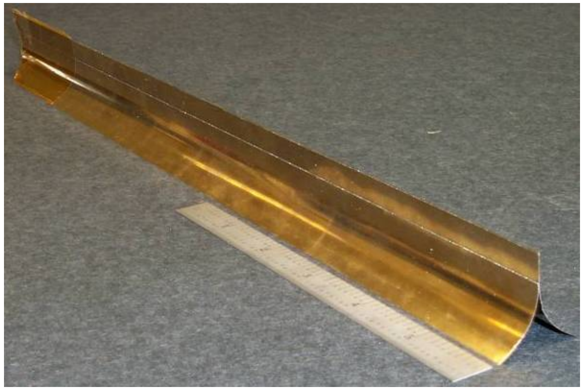
Triangular Rollable And Collapsible

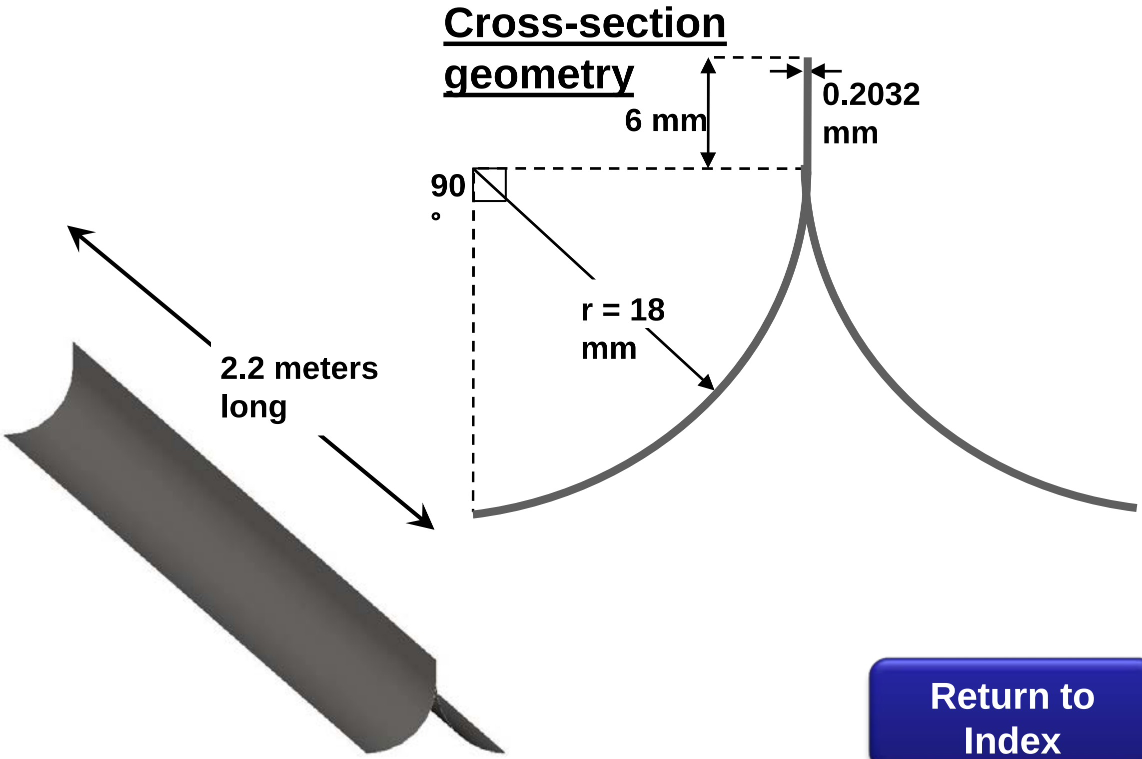
(TRAC)

Air Force Research Laboratory (AFRL)
NeXolve, Division of Mantech Inc. (Licensee)

TRAC

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
TRAC	8	n/a	2.2	n/a	2010





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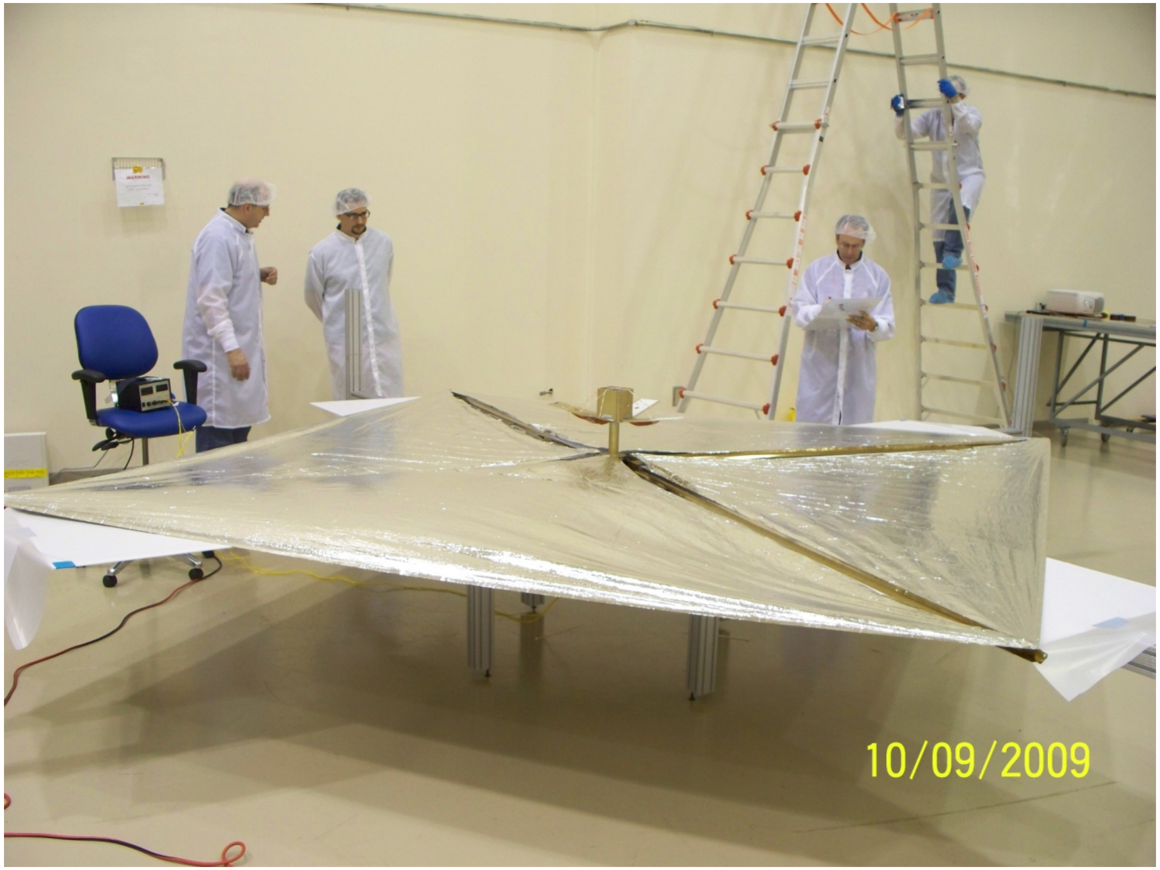
TRAC

Material Type

- Elgiloy (stainless steel)
- Composite (NeXolve)



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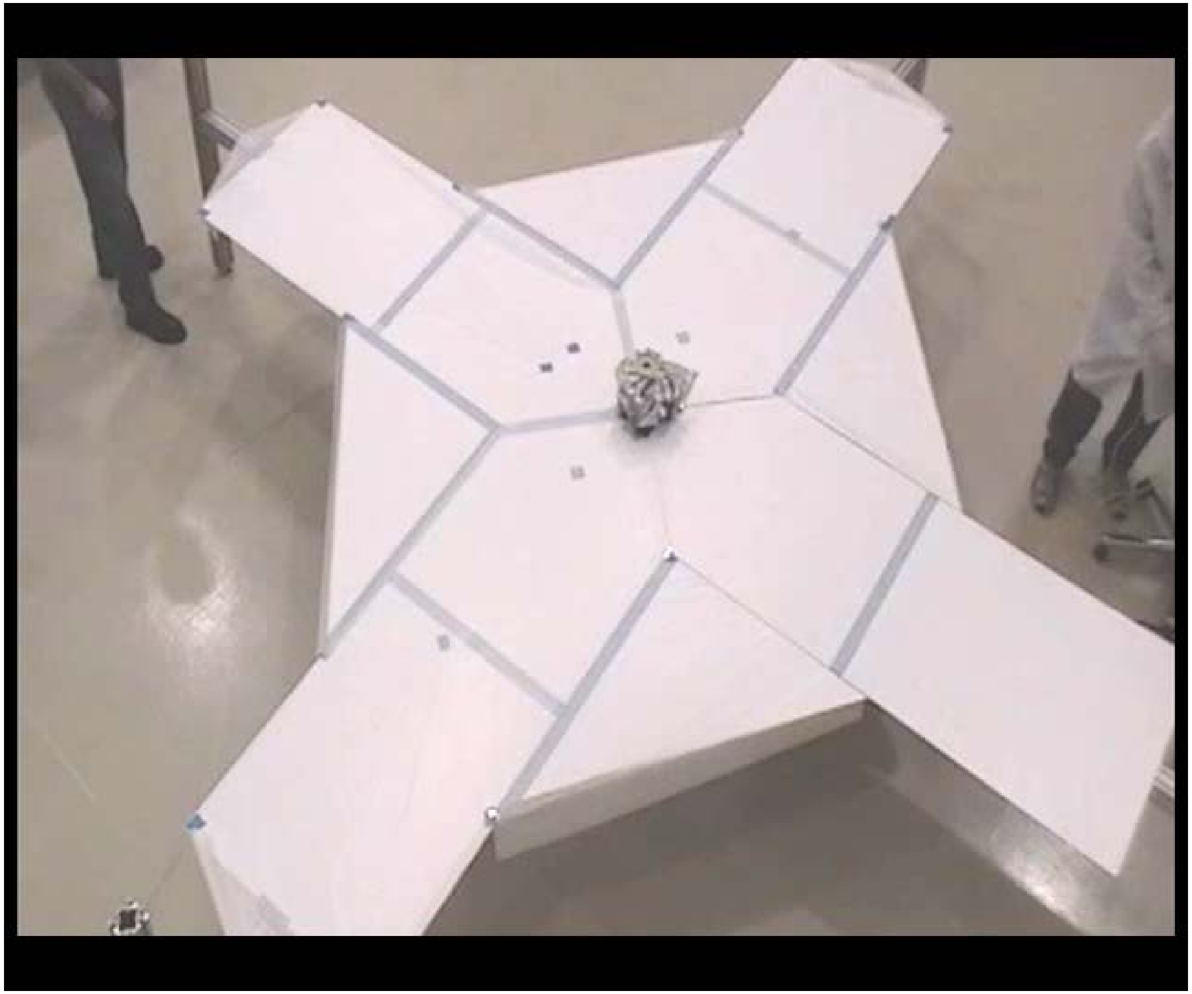
Deployment Method

- Self deploy (strain energy)



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TRAC

Issues & Comments

- Mass efficiency

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References

AFRL-Jeremy Banik

Alhorn, D., et al, "NanoSail-D: The Small Satellite that Could!", 25th Annual Small Satellite Conference, August 8-11, 2011, Logan, Utah.

Grant, Thomas, M., "Prototype Development and Dynamic Characterization of Deployable Cubesat Booms," Thesis, Department of the Air Force Air University, March 2010, Wright-Patterson Air Force Base, Ohio,

Websites:

http://www.nasa.gov/mission_pages/smallsats/nanosaild.html

http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA517408

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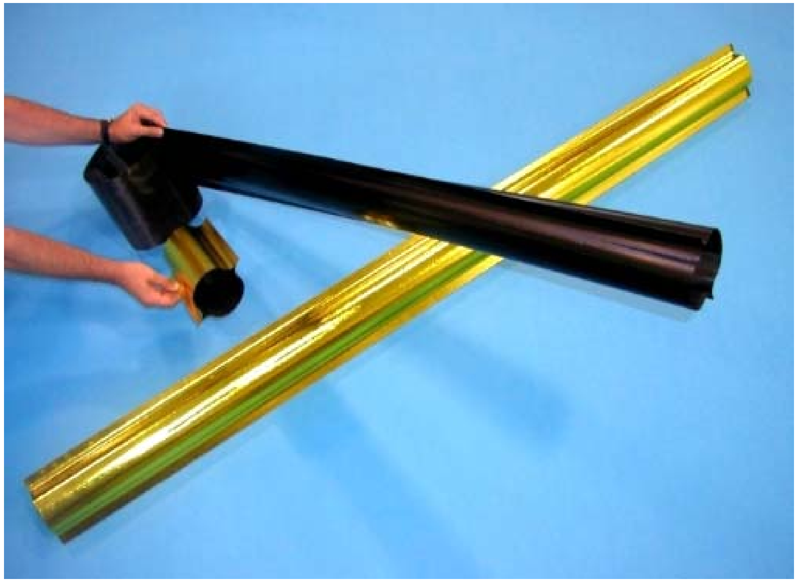
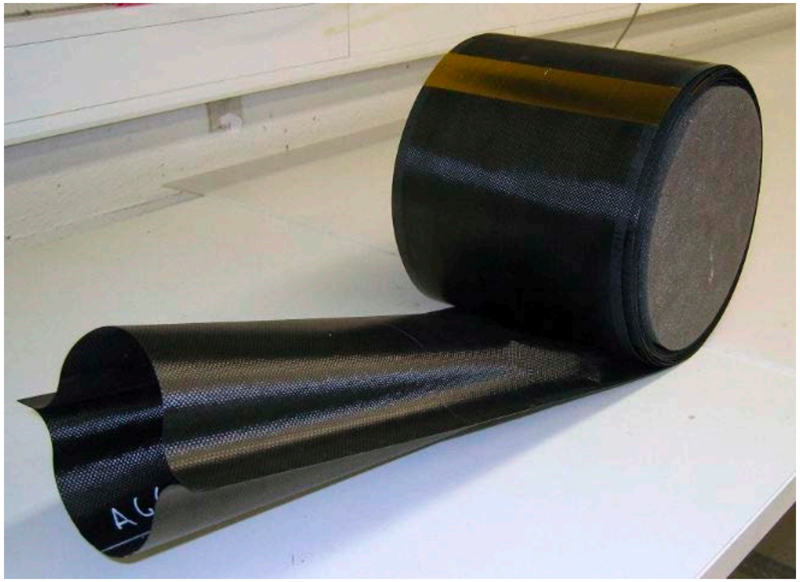
TubeMast

TubeMast

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
TubeMast	5	0.1	14.1	n/a	2000





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TubeMast

Material Type

- Carbon Fiber Reinforced Plastic (Composite)

Return to Index

TubeMast

Deployment Method

- Reeled out

TubeMast Deployed

Sail Fully Deployed

Sail Deployment Module
60cm x 60cm x 60cm – 35kg

Return to Index

TubeMast

Issues & Comments

Return to Index

TubeMast

References

Institute of Structural Mechanics, German Aerospace Center

Leipold, M. Runge, H., Sickinger, C., "Large SAR Membrane Antennas with Lightweight Deployable Booms," 28th ESA Antenna Workshop on Space Antenna Systems and Technologies, ESA/ESTEC, May 31-June 03, 2005

Sickinger, C,. Breitbach, E., "Ultra-Lightweight Deployable Space Structures," Thesis, Institute of Structural Mechanics, German Aerospace Center, 4th International Conference on Thin-Walled Structures, Loughborough, England, June 22-24, 2004.

Websites:

http://www.dlr.de/fa/en/desktopdefault.aspx/tabid-1322/1831_read-3439/

http://www.dlr.de/fa/en/Portaldata/17/Resources/dokumente/publikationen/2005/11_leipold.pdf

http://www.dlr.de/fa/portaldata/17/resources/dokumente/publikationen/2004/25_sickinger.pdfhttp://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA517408

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ECHO 1 - Sphere

Inflatable Technology

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ECHO 1 - Sphere

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
ECHO 1 - sphere	9	n/a	n/a	30	1960

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ECHO 1 - Sphere

Material

- Mylar 12um thick, with 2000A of vapor-deposited aluminum

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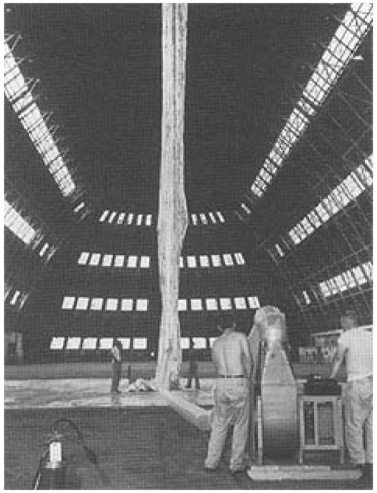
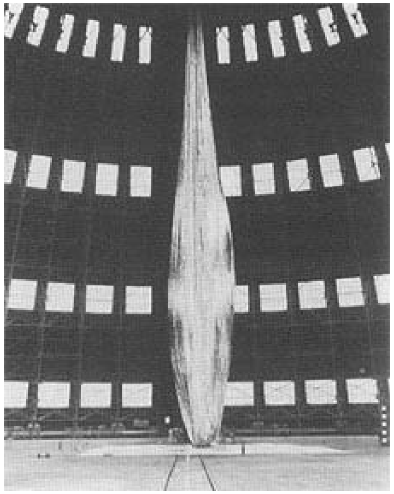
ECHO 1 - Sphere

Deployment Method

– Gas pressure





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ECHO 1 - Sphere

Issues & Comments

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ECHO 1 - Sphere

References

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ECHO 2 - Sphere

Inflatable Technology

ECHO 2 - Sphere

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
ECHO 2 - sphere	9		41.8		1964

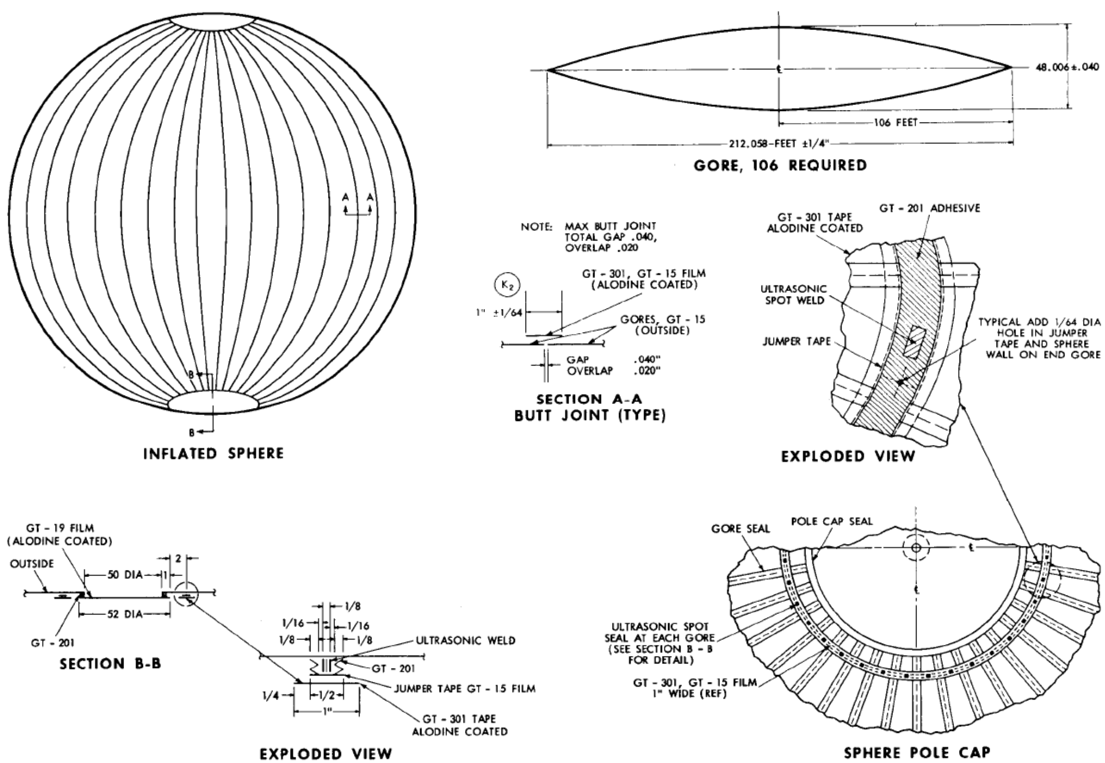

Figure 3-37. Electrical Continuity Jumper Strip and Pole Cap Installation

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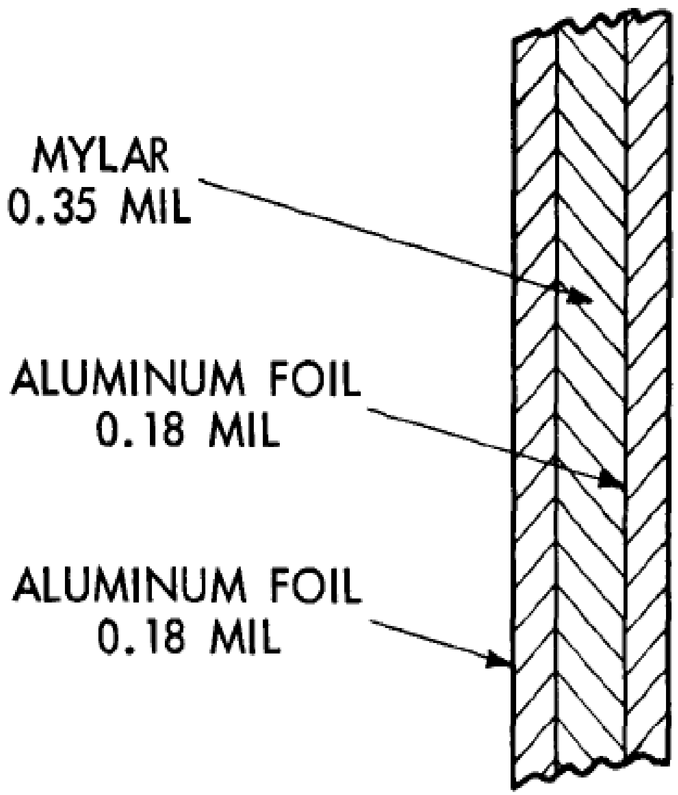
ECHO 2 - Sphere

- **Material**
  - Aluminum



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ECHO 2 - Sphere

- **Deployment Method**
  - Material stressed beyond yield

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ECHO 2 - Sphere

Issues & Comments

Return to Index

ECHO 2 - Sphere

References

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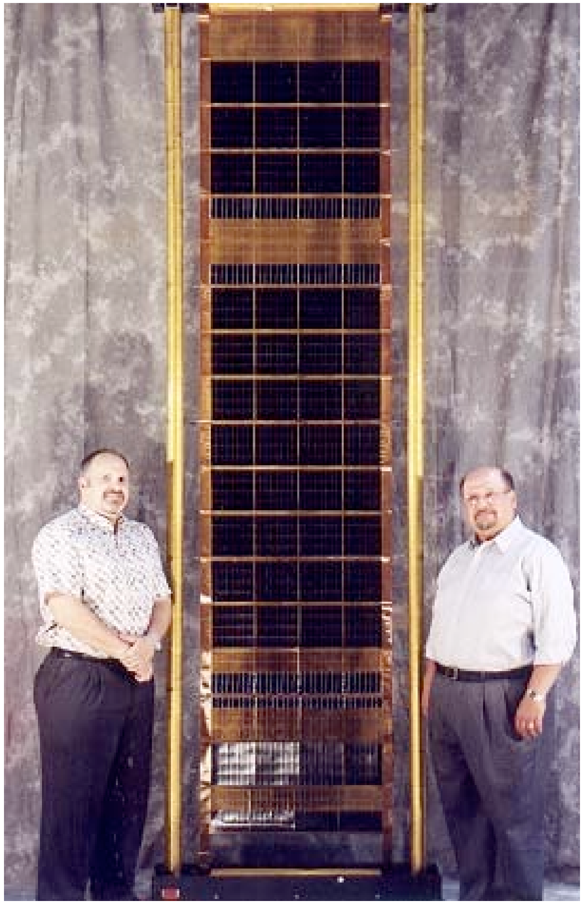
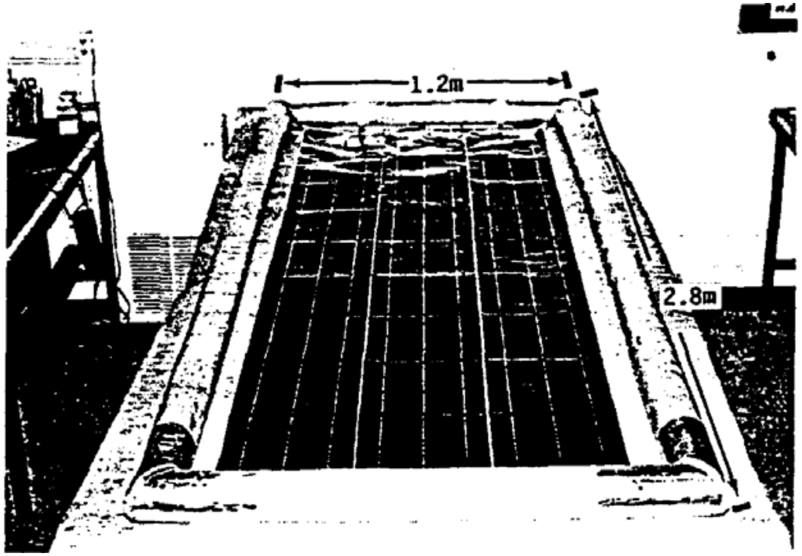
Inflatable Torus Solar Array Technology (ITSAT)

Inflatable Technology

ITSAT

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
ITSAT	5+		3.64 X 1.1		1993





Prototype unit

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Material

- The laminate is aluminum foil sandwiched between two layers of thin plastic. The plastic film is necessary to hold the pressure when inflating by increasing the tear resistance; otherwise the soft foldable aluminum would tear very easily, allowing large leak paths.

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Deployment Method

- Sub Tg rigidization

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ITSAT

Issues & Comments

- Phase I was a feasibility study of point designs for low Earth orbit (LEO), geosynchronous Earth orbit (GEO), and Molniya orbits with array sizes from 100 W to several thousand watts.' A prototype system was built and this phase was completed in October of 1991. Phase II revised the design of PhaseI , generated detailed drawings, and retested the components, producing a protoflight unit. This phase ended with a successful deployment at a temperature of -9O'Y in the Naval Research Laboratory's (NRL) 9 meter vacuum chamber, and subsequent dynamics testing and thermal cycling in the deployed state. Phase II was completed in January of 1994.

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ITSAT

References

- Lightweight Inflatable Solar Array, Patrick K. Malone and Geoffrey T. Williams, JOURNAL OF PROPULSION AND POWER, Vol. 12. No. 5, September-October 1996
- Inflatable Torus Solar Array Technology Program - Phase 1 Final Report, Gordon Veal, LTR-91-GV-022, L'Garde, Inc., December 1991

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Pathfinder Impact Attenuation System

Mars Pathfinder

Mars Pathfinder

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Years of Most Recent Demo
Pathfinder Impact Attenuation System - Mars Pathfinder	9		Six 1.8 m diameter		1997

Spherical lobes in a "billiard rack" arrangement

Airbag Subsystem and Lander

Return to Index

Mars Pathfinder

Material

- The airbag bladder material selected was a silicone coated Vectran fabric. A coating of Dow LT50 low temperature silicone rubber was selected from several candidates. The Pathfinder abrasion layers were an uncoated Vectran fabric. The Bladder Layer Components weighed 41 kg and the Abrasion Layer Components weighed 38 kg

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Mars Pathfinder

Deployment Method

- Gas pressure
- The 3.25 kg gas generator assembly is housed in a double-cone shaped titanium shell. The unit burned its propellant in two stages: the main grain burned for 1.85s at a high rate for airbag inflation, and the sustain grain burned for 20s at a lower rate for gas make-up during the landing. The gas passed through a coolant chamber before discharge, where pellets of a proprietary propellant endothermally evolve additional cooler gas.

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Mars Pathfinder

Issues & Comments

Return to Index

Mars Pathfinder

References

- DEVELOPMENT AND EVALUATION OF THE MARS PATHFINDER INFLATABLE AIRBAG LANDING SYSTEM, D. Cadogan, C. Sandy, M. Grahne, IAF-98-I.6.02

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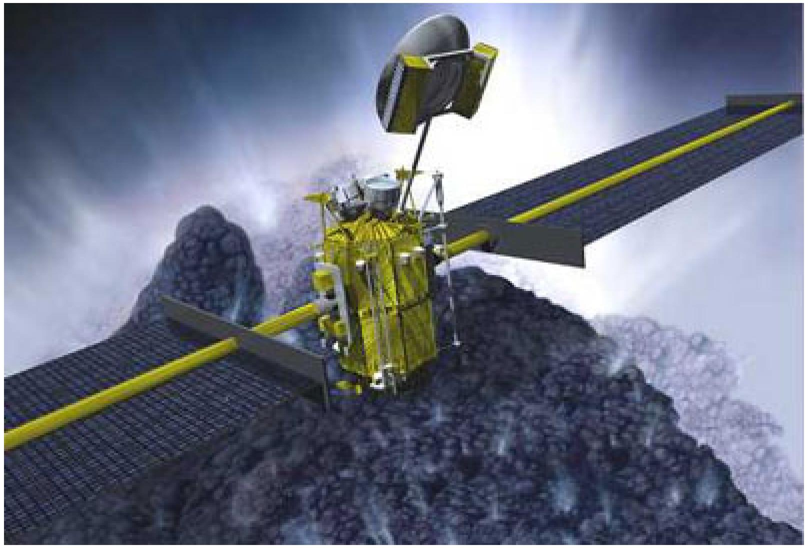
Champollion Solar Array

New Millinium Program ST-4

Champollion Solar Array

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Champollion Solar Array	5		14.65 X 3		1999



Champollion [NASA]

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Champollion Solar Array

Material

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Champollion Solar Array

Deployment Method

- The thermal heating method will be utilized for the flight experiment. The purpose of the inflatable beam is to provide a deployment mechanism and support structure for the solar array.
- A compressed gas system is currently baselined for the ST4 inflatable solar array inflation system.

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Champollion Solar Array

Issues & Comments

- Lightweight, low-volume flexible blanket array
- Developed in support of New Millennium Program ST4 comet rendezvous mission
- Inflatable Solar Array Experiment (ISAE) planned for technology demonstration on Shuttle
- ILC Dover / AEC-ABLE / L'Garde / JPL / USAF Team
- 5 kW flexible blanket array
- Inflatable, rigidizable beam provides structure
- Rigidization method is heated thermoset epoxy
- Controlled deployment (wire brake roll-up)
- Array size : 15m x 3m, split blanket configuration
- 102W/Kg with 15% mass margin

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Champollion Solar Array

References

Inflatable Solar Arrays: Revolutionary Technology?, Mark S. Grahne, David P. Cadogan, 1999-01-2551, Society of Automotive Engineers, Inc.

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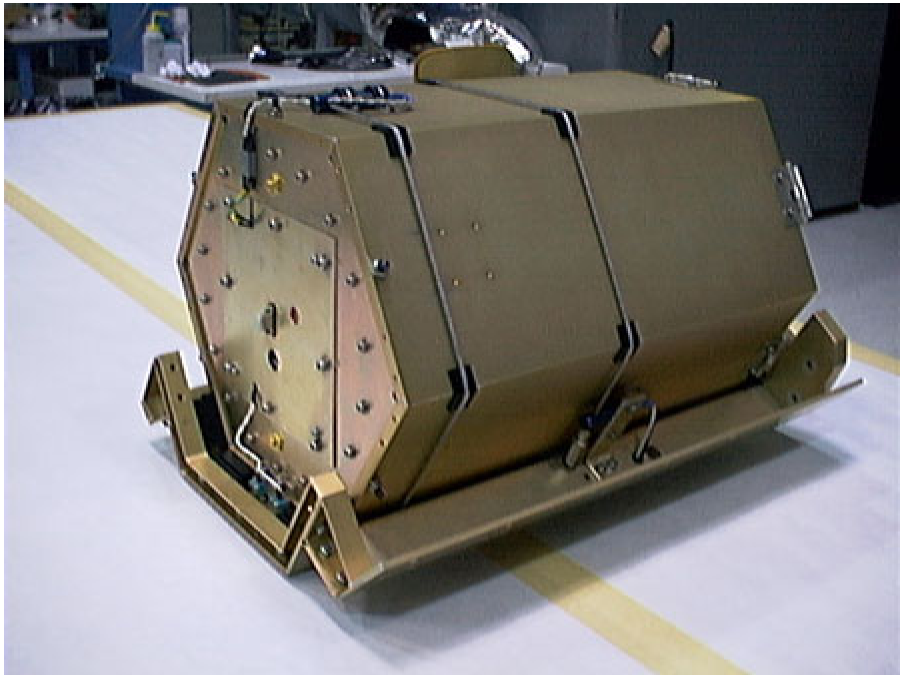
Optical Calibration Sphere

(OCS)

OCS

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
OCS	9		4	30	2000



The OCS and its ejection cradle.

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OCS

Material

- Kapton / aluminum balloon

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Deployment Method

Sphere slightly larger than OCS

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OCS

Issues & Comments

- OCSE (Optical Calibration Sphere Experiment) or IOSS (Inflatable Optical Sphere System), a 3.5m diameter inflatable sphere built by L'Garde Inc. for calibrating the lasers at the AFRL Starfire Optical Range.

- The 0.48m long 0.41m diameter OCSE canister was ejected from the JAWSAT stack; 42 seconds later, with the canister clear of the other payloads, the canister door opened and 10 seconds after that inflation of the sphere began. The canister remains attached to the inflated sphere. Once inflated, the sphere's material becomes rigidized.

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OCS

References

- http://www.astronautix.com/craft/ocse.htm

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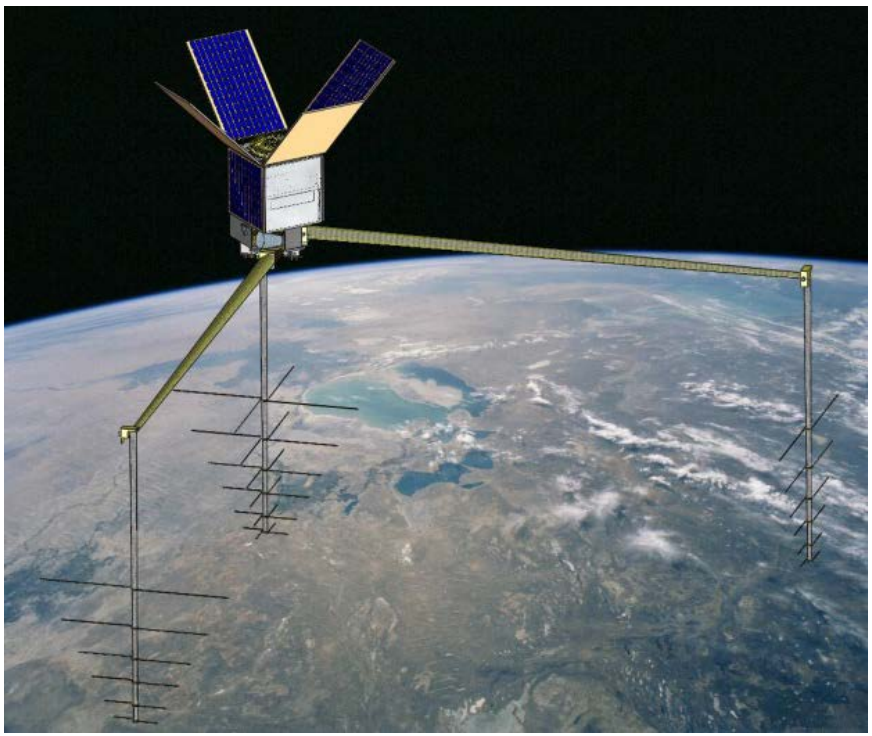
Cibola Experiment

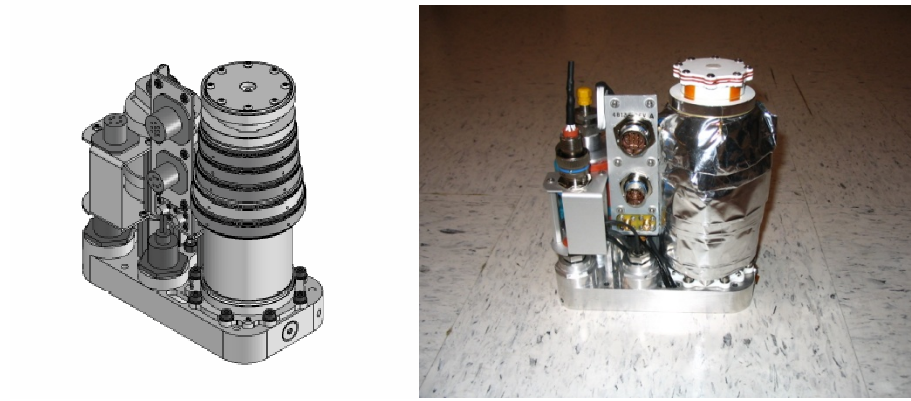
Inflatable Boom with Radio Antenna

Cibola Experiment

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Cibola Experiment	7	n/a	2.4	n/a	2007



The Cibola Flight Experiment Satellite



CAD model (l) and hardware (r)

Weighs 1.8 Kg, with a packaged volume of 0.002 m^3 (0.09 ft^3)

Each antenna (3) deploys to a final length of 2.2 m (7.3 ft.)

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Cibola Experiment

Material

- Kevlar fabric with sub-Tg resin impregnated fibers.

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Cibola Experiment

Deployment Method

- Cooling below glass transition
- Utilizes conical, inflation-deployed mast.
- Deployed successfully in vacuum after proto-flight environmental tests, and three previous deployments in ambient and thermal/vacuum environments

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Cibola Experiment

Issue & Comments

- The antenna mast design was based upon the same inflatable mast structure that L'Garde designed and demonstrated on the ground for a NASA solar sail demonstration. Each antenna mast is comprised of a Kevlar fabric impregnated with a temperature sensitive, rigidizable resin that is deployed by inflation. Each antenna assembly weighed 2.1 kg and was approximately 16 x 16 x 6 cm in dimension when stowed. Inflated, each antenna was to be 2.4m in length. Unfortunately, only one of the three antenna masts inflated correctly, potentially due to the RF cable bundle being too tightly constrained interior to the antenna masts. The other two masts inflated about half way before they stalled and vented, leaving the antenna elements in a non-optimal orientation

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Cibola Experiment

References

- The Cibola Flight Experiment, Michael Caffrey et. al., 23rd Annual Small Satellite Conference, Logan, UT, USA, 8/10/2009

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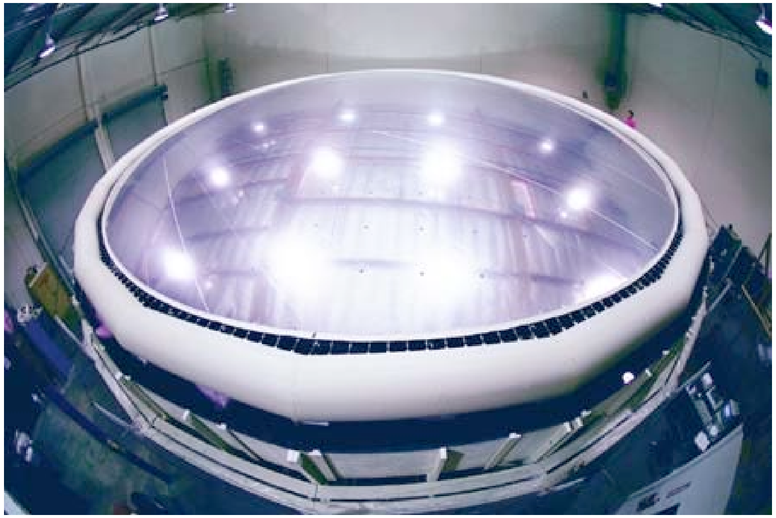
Inflatable Antenna Experiment

(IAE)

IAE

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
IAE	8		14x28		1996



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Material

- Canopy - one-quarter-mil clear mylar
- 14-meter-diameter reflector was based on using 62 individual one-quarter-mil aluminized mylar gores
- Torus - neoprene-coated kevlar
- Struts - same neoprene-coated kevlar material as used on the torus. The diameter and resulting bending stiffness are based on a requirement for a minimum natural frequency to accommodate the orbital stability needed for the experiment. The minimum diameter required was 35.6 cm.

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Deployment Method

- Gas pressure
- High-pressure nitrogen gas

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IAE

Issues & Comments

- The antenna configuration is an off-axis parabolic reflector structure consisting of (a) a 14-meter-diameter, multiple-gore reflector structure and a transparent canopy (which is a mirror shape of the reflector) to maintain gas pressure on orbit, (b) a torus structure that supports the reflector/canopy circumferentially, and (c) three 28 meter-long struts that interface the torus structure with the canister which is located at the center of curvature of the reflector to accommodate operation of the surface measurement system.

- The inflatable structure deployment sequence was not nominal due to an unexpected amount of residual air in the stowed structure and a significant amount of strain energy release from the torus structure. This resulted in early deployment of the reflector structure such that the ejector plate was not able to propel it away from the canister. Consequently, when the struts deployed, they were not fully extended resulting in more strut deflection than anticipated. This also caused sequential rather than simultaneous strut inflation. However, as they completed deployment, the reflector was pushed away from the canister and deployment was completed.

- The lenticular structure failed to completely deploy for unknown reasons at this time. Initially, it appears that the residual air in the stowed structure caused partial deployment, but subsequently that air escaped from the ascent vent holes and the lenticular structure went almost completely flat.

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References

- Preliminary Mission Report Spartan 207/Inflatable Antenna Experiment Flown on STS-77, Spartan Project Code 740.1, NASA Goddard Space Flight Center

- DEVELOPMENT OF FLIGHT HARDWARE FOR A LARGE, INFLATABLE-DEPLOYABLE ANTENNA EXPERIMENT, R. E. Freeland, G. D. Bilyeu, G. R. Veal, IAF-95-1 S.O. 1

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20 Meter L'Garde Ground System Demonstration

Solar Sail

L'Garde Solar Sail Demo

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
20 meter L'Garde Ground System Demonstration	5+		20 x 20	150 x 150	2006

Deployed 20m Sail System with Vane

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L'Garde Solar Sail Demo

Material

- Sail - 2 micron commercial mylar and kevlar ripstop
- Boom - kapton bladder with kevlar reinforcement and sub Tg impregnated resin
- Beam - boom plus graphite spreader bars and kevlar longerons and battens

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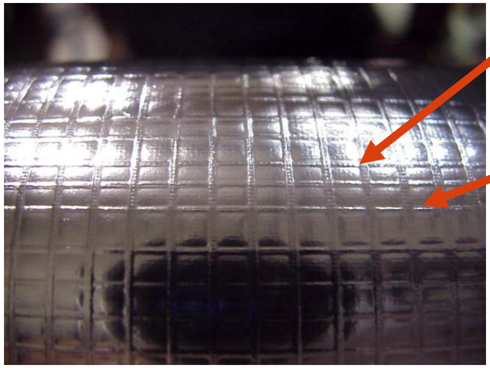
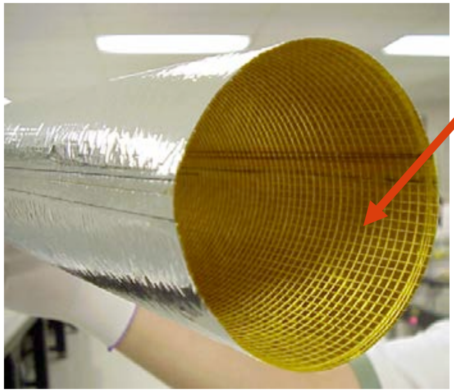
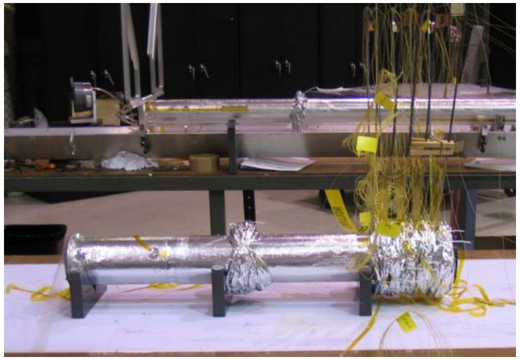
L'Garde Solar Sail Demo

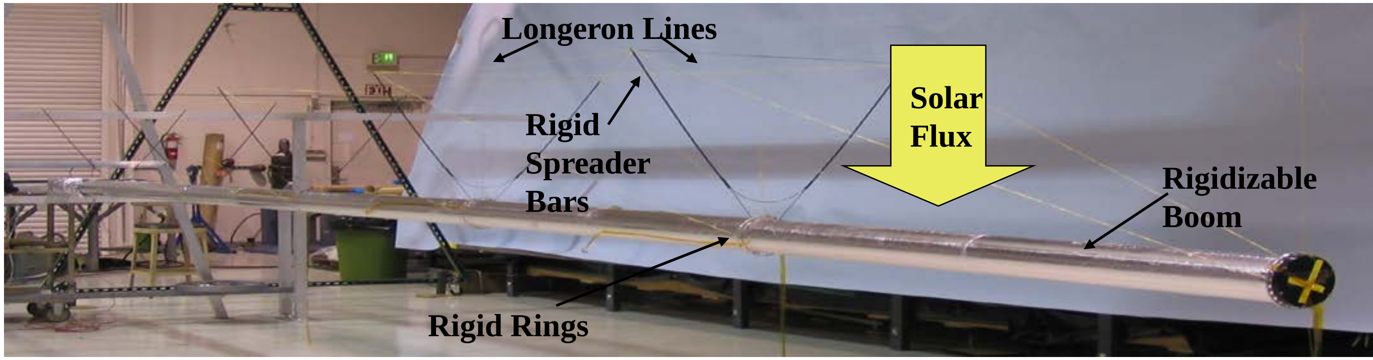




- Boom - Kapton bladder with Kevlar reinforcement and sub Tg impregnated resin
  - Load bearing longitudinal uni-directional fibers
    - Fibers impregnated with sub-Tg resin (rigid below -20º C)
    - 0.48 AU design requires greater fiber density to withstand loads from the increased solar flux
  - Spiral wrap
    - Stabilizes longitudinal fibers
    - Allows over-pressurization for deployment anomalies
  - Bonded Kapton bladder and Mylar
    - Encapsulation "skin" carries shear
    - Aircraft fuselage like structure
- Beam Structure - boom plus graphite spreader bars and kevlar longerons and battens
  - Sail structure is stressed for solar loading in one direction for mass efficiency
  - Truss system comprised of mostly tension elements, minimal rigid components
  - Highly mass efficient, ~36g/m linear density



Stowed 7 m beam (~.5 m)



Deployed 7 m beam

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L'Garde Solar Sail Demo

Deployment Method

- Sub – Tg rigidization
- Nitrogen gas until rigidization

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L'Garde Solar Sail Demo

Issues & Comments

- No deployment modeling or asymmetric deployment results have been presented.
- Asymmetric deployment issues during vacuum testing.
- Sail material - an issue with coated mylar in a VUV environment. Material loses strength in 3 years and disintegrates in a 6 years.
- No testing has been done on seams, booms, beams, targets, insulation, repairs or elements
- Process and procedures are not well documented.
- Reliability and repeatability of the manufacturing and assembly processes are an issue.
  - Deployed one boom 5 times and the system 2 times
- Process are highly labor intensive and personnel training is critical. (i.e..Beam assembly persons cannot reliably perform sail assembly functions)
  - Inspection of line management is critical but difficult and labor intensive. The risk probability of misrouting lines is great and the problem can cause damage to the sail, stripped net, insulation, cats' cradle and the tip. Greater than 500 inspection points for a 20m system
- Inflation system design and especially the leaking of the tip mandrels is a potential life issue.

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L'Garde Solar Sail Demo

References

IN-SPACE PROPULSION SOLAR SAIL EXECUTIVE SUMMARY, L'Garde, Inc, NASA MSFC NAS8-03046

VACUUM DEPLOYMENTAND TESTING OFA 20M SOLAR SAIL SYSTEM, D. Lichodziejewski, B. Derbès, D. Sleight, T. Mann, AIAA 2006-1705, 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2006

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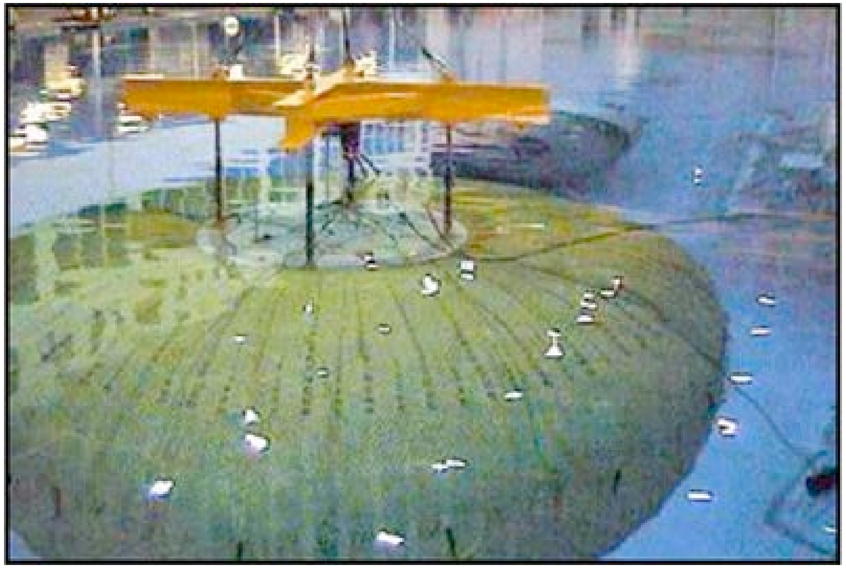
Transhab

Inflatable Habitation Module

Transhab

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Transhab	9*	n/a	23 ft tall x 27 ft diameter	n/a	1998



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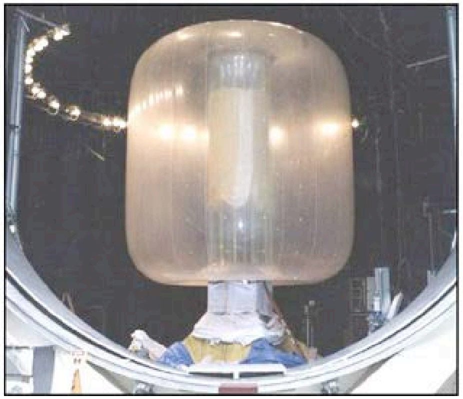
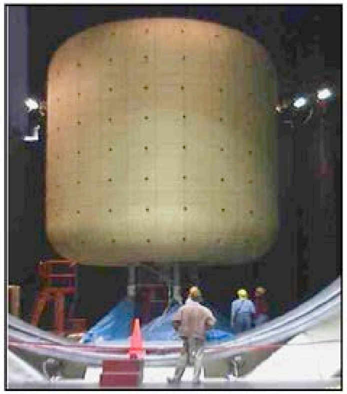
*design implemented by Bigelow Aerospace on orbit as Genesis 1 and 2

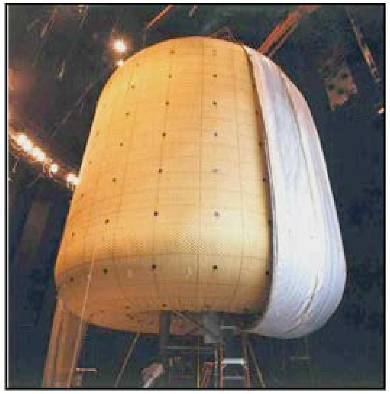
Transhab

Material

- Inflatable shell is 16 inches thick and is composed of over 60 layers arranged as five major subassemblies: (1) is the innermost layer and acts as a protective layer for the tripely redundant bladder layers (2). A woven restraint layer supports the bladder and is designed to withstand 4 atmospheres of internal pressure (3). The restraint and bladder layers are protected from micrometeoroid impacts by the debris protection system which consist of multiple layers of ceramic fabric separated by open cell foam and a Kevlar fabric debris catcher (4). The outer most layers consist of multilayer insulation (MU) and atomic oxygen (AO) protective layers (5)







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Transhab

Deployment Method

- Gas pressure

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Transhab

Issues & Comments

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Transhab

- **References**
- http://www.ilcdover.com/Transhab/
- Deployment Testing of an Expandable Lunar Habitat, Jon Hinkle and John K.H. Lin, Judith Watson
- TRANSHAB: NASA's LARGE-SCALE INFLATABLE SPACECRAFT
- Horacio de la Fuente, Jasen L. Raboin, Gary R. Spexarth, Gerard D. Valle, AIAA 2000-1822, 2000 AIAA Space Inflatables Forum; Structures, Structural Dynamics, and Materials Conference

Vega 1 & 2 Balloon Probe

Venus Balloon Probe

Vega 1 & 2

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Vega 1 & 2 Balloon – Venus Balloon Probe	9	n/a	3.54	n/a	1985

Weight: 12.5 kg for balloon

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Vega 1 & 2

Material

- Teflon cloth matrix coated with teflon film

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Vega 1 & 2

Deployment Method

- Gas pressure – inflated to 30 mbar over pressure
- 2 kg of helium

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Vega 1 & 2

Issues & Comments

Flew in the atmosphere of Venus for a prolonged period of time

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Vega 1 & 2

References

- Title: The Vega balloons - A tool for studying atmosphere dynamics on Venus
  - Authors: Kremnev, R. S., Selivanov, A. S., Linkin, V. M., Lipatov, A. N., Tarnoruder, I. I., Puchkov, V. I., ,
- Journal: (Pis'ma v Astronomicheskii Zhurnal, vol. 12, Jan. 1986, p. 19-24) Soviet Astronomy Letters (ISSN 0360-0327), vol. 12, Jan.-Feb. 1986, p. 7-9. Translation.

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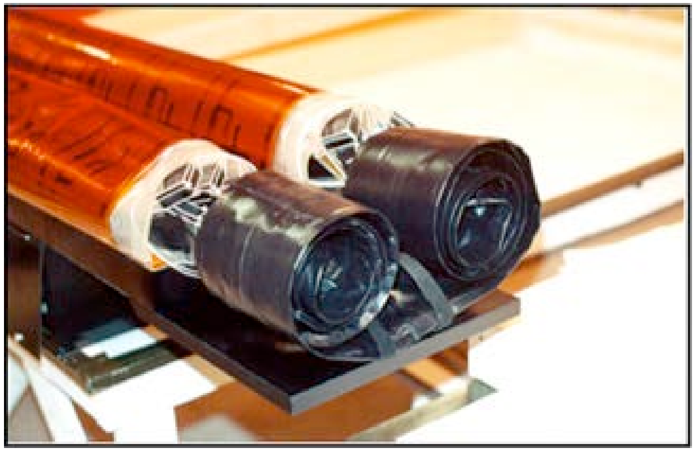
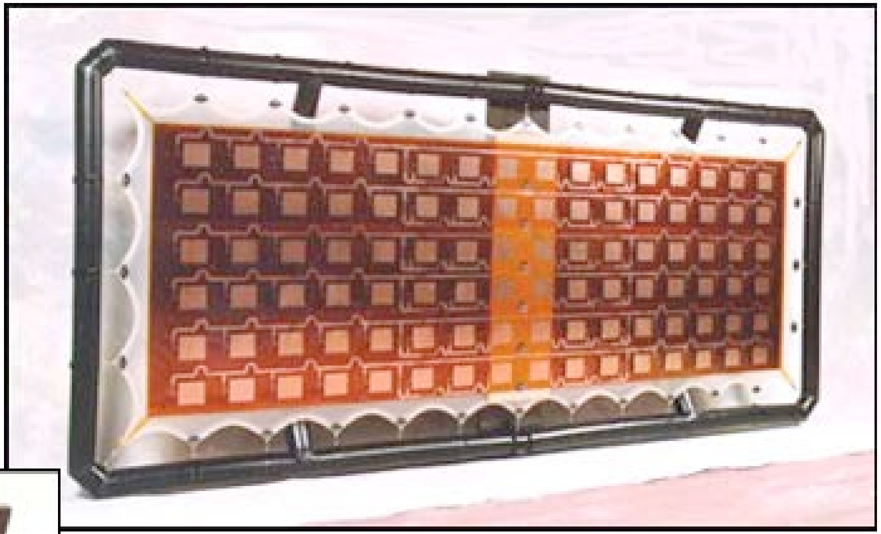
Synthetic Aperture Radar

(SAR)

SAR

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Synthetic Aperature Radar (SAR)	n/a	n/a	n/a	n/a	n/a





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Inflatable Technology

Material

- The inflated tube frame has a diameter of 13 cm and is made of 10-mil thick urethane coated Kevlar material

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Inflatable Technology

Deploymentutf Method

- The tube structure has imbedded steel coil spring to produce a smooth and controlled deployment. The inflatant bottle, made of lightweight composite material, is housed inside the central support box and has a regulator to inflate and maintain tube pressure at 5 psi

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Inflatable Technology

Issues & Comments

- ILC worked in conjunction with NASA JPL to develop the 1.25 GHz L-Band SAR technology demonstrator with dual linear polarization, 80 MHz Bandwidth and electronic beam scanning for space application. The goal of the program was to determine if a deployable large aperture SAR could be produced with an aerial density of <2Kg/M2. ILC designed a 1/3 scale deployable support structure, assembled the membrane layers and conducted system testing.

- The key to achieving the goals of the program was in creating a stable deployable support structure which properly spaced and tensioned the radiating patch, microstrip transmission line, and ground plane membrane layers with high accuracy. Deployment was controlled with embedded mechanisms in the inflatable structure to ensure protection of the membranes from the packed to deployed state.

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Inflatable Technology

References

- http://www.ilcdover.com/SAR/

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In Space Inflatable Sunshield Experiment

(ISIS)

ISIS

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
ISIS	5-6	n/a	4.5 x 10.4	n/a	n/a

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Material

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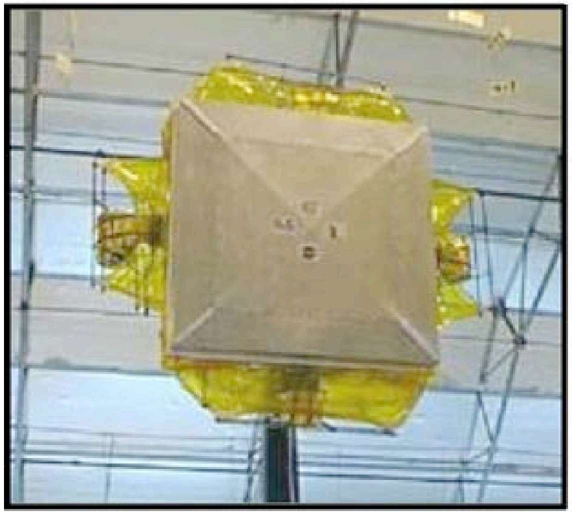
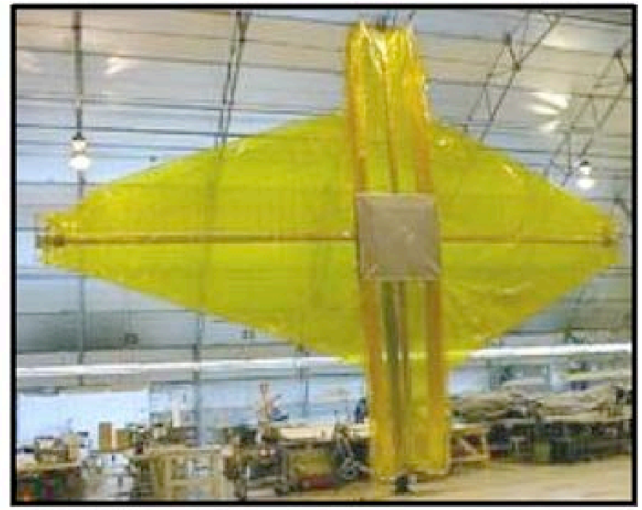
ISIS

Deployment Method





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Issues & Comments

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ISIS

References

- Next Generation Space Telescope Inflatable Sunshield Development, Charles R. Sandy, 2000 IEEE
- Sunshield Technology and Flight Experiment for the Next Generation Space Telescope, Linda Pacini, Michael Lou, John Johnston, Sebatien Lienard, SPIE 2000

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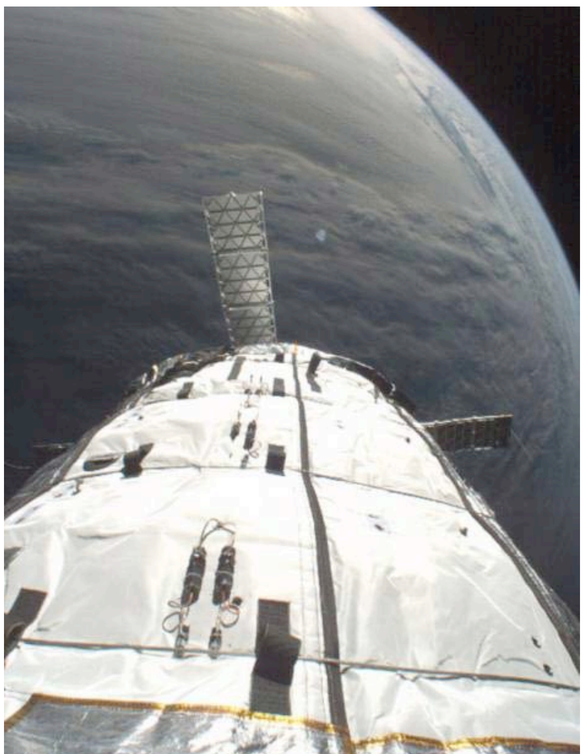
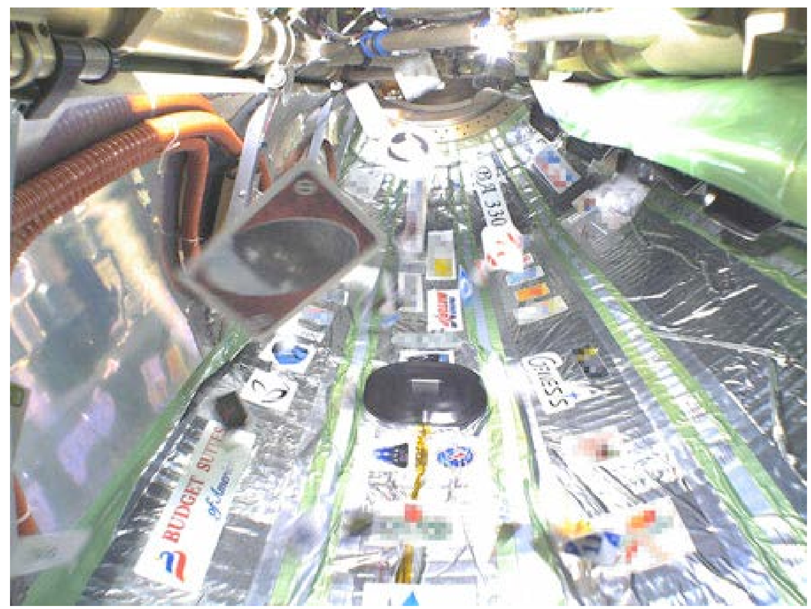
Genesis 1

Genesis 1

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Genesis 1	9		4.4 x 2.54 4.4 x 1.6 stowed		2006





Genesis 1 Exterior and Interior

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Genesis 1

Material

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Genesis 1

Deployment Method

- Gas pressure

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Genesis 1

Issues & Comments

- Bigelow originally licensed the multi-layer, expandable space module technology from NASA after Congress canceled the ISS TransHab project following delays and budget constraints in the late 1990s. Bigelow continued to develop the technology for a decade, redesigning the module fabric layers—including adding proprietary extensions of Vectran shield fabric, "a double-strength variant of Kevlar" -- and developing a family of uncrewed and crewed expandable spacecraft in a variety of sizes. Bigelow invested US$75 million in proprietary extensions to the NASA technology by mid-2006, and $180 million into the technology by 2010.

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Genesis 1

References

- Wikipedia

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Genesis 2

Genesis 2

Technology	TRL	Specific Mass (kg/m)	Size Demonstrated (m)	Size Limit (m)	Year of Most Recent Demo
Genesis 2	9		4.4 x 2.54 4.4 x 1.6 stowed		2007

Genesis 2 On Orbit and Mockup

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Genesis 2

Material

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Genesis 2

Deployment Method

- Gas pressure

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Genesis 2

Issues & Comments

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Genesis 2

References

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