

National Aeronautics and Space Administration



NASA Perspectives on Deployable Gossamer Space Structures

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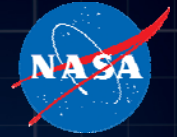
NASA Langley Research Center

Hampton Virginia, USA



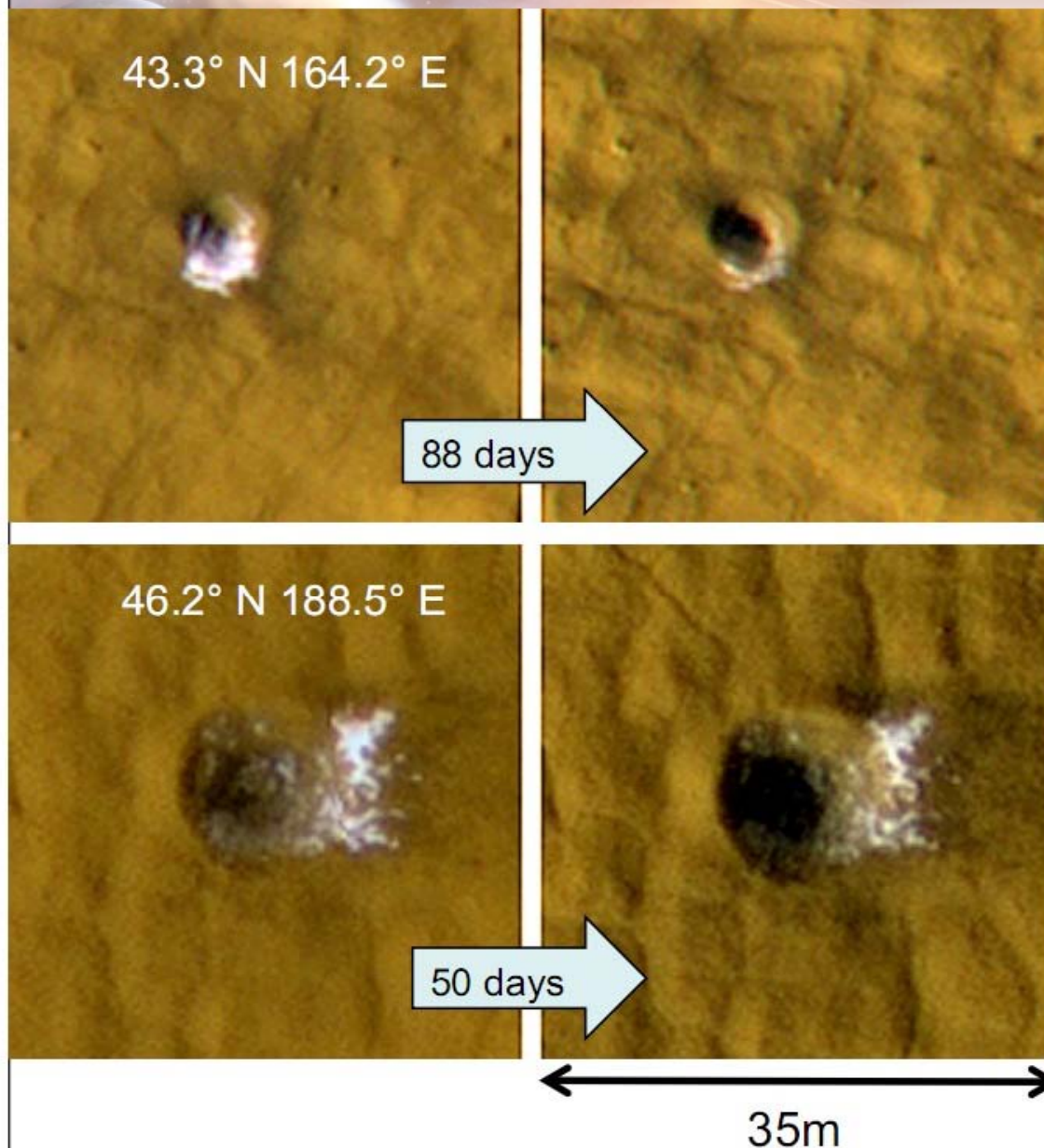
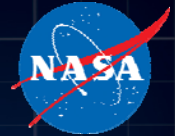
DLR Braunschweig Germany

Outline



- NASA Exploration Strategy for Technology Development
- Expandable Space Systems
 - Challenges
 - Need for Innovation
- Expandable Habitat Structures
- Solar Electric Propulsion
- Solar Sails and Damage Tolerance
- Summary

Mars Discovery – Water Ice



- Fresh, small impact craters show:
 - Ice layer ~0.5-1 m below surface
 - Sublimates over several weeks
- Spectral analysis shows 99% pure water
- Implication is extensive water ice available at mid-latitudes on Mars
- May change entire resource utilization strategy including which engines are chosen for Mars Return Vehicle

Common Capabilities

Technology Building Blocks



“Breakthrough” Technologies

Aerocapture

Cryo Fluid

Robust/Efficient

Lightweight

Radiation Research

Zero/Low-g Research

Regenerable Life

Advanced Lightweight EVA

Hypersonic Inflatable Aerocell

Regenerative

Revolutionary ETO Pockets

Innovative Mission Concepts

Consistent Set of Exploration Capability Investments

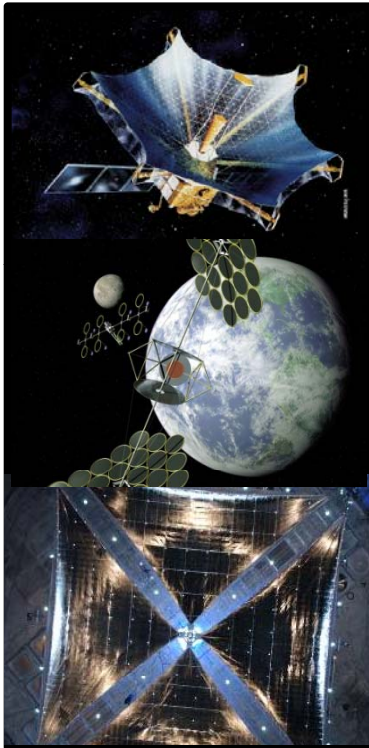


	1969	1986	1987	1988	1989	1990	1991	1997	2004	2009
	Post-Apollo Space Program (NASA STG)	Pioneering the Space Frontier (Paine)	America's Future in Space (Ride)	Beyond Earth's Boundaries (NASA)	90-Day Study (NASA)	Future of U.S Space Program (Augustine)	America at the Threshold, SEI (Stafford)	Human Exploration of Mars DRM (NASA)	President's Commission on U.S. Space Exploration Policy (Aldridge)	Report of U.S. Spaceflight Committee (Augustine)
Advanced/Closed Loop Life Support		X	X	X	X	X	X	X	X	X
Advanced Power Generation & Storage (in-space and surface, Solar and nuclear)	X	X	X	X	X	X	X	X	X	X
Advanced In-Space Propulsion (chemical, solar electric, nuclear thermal, nuclear electric)	X	X	X	X	X	X	X	X	X	X
In-Space Cryo/Propellant Transfer and Storage		X	X	X	X		X	X	X	X
Heavy Lift Launch Vehicle			X	X	X	X	X	X	X	
Autonomous/Expert Systems		X	X			X		X	X	X
Robotics (tele-robotic & autonomous operation)		X	X		X	X	X	X	X	X
EDL (includes aerocapture, aerobraking, aeroentry)		X	X	X	X	X	X	X	X	X
Human Health and Performance (Radiation, gravity, psychological effects and mitigation, medical technologies)	X	X	X		X	X	X	X	X	X
Autonomous Rendezvous and Docking				X	X		X		X	X
In-Situ Resource Utilization (Lunar, NEO, and Mars based)		X	X	X	X	X	X	X	X	X
Lightweight Structures and Materials		X					X	X	X	X
Advanced In-Space Engine					X	X	X		X	X
Advanced EVA Systems		X		X	X	X	X	X	X	
Communication Technology	X				X	X	X		X	
Reliable Efficient Low Cost Advanced Access to Space	X		X							X
Reusable In-Space Transfer	X	X	X		X	X				
Surface Rovers				X			X	X		5

Classes of Expandable Structures

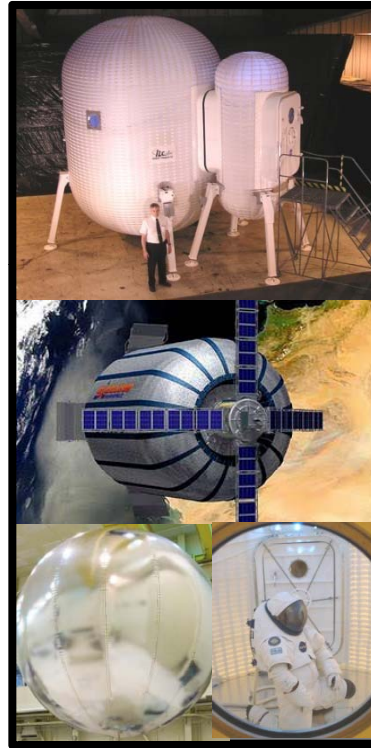


Large In-Space Systems



Antennas
Microwave Reflectors
Radiators
Solar Arrays
Solar Sails
Space Solar Power
Solar Shades

Pressurized Systems



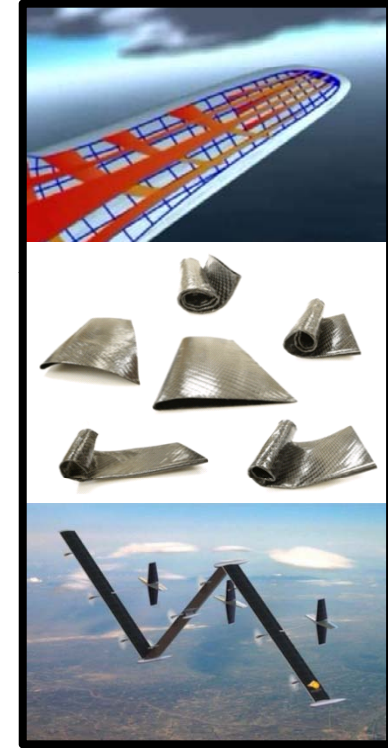
Space Stations
Radiation Barriers
Repair Hangars
Surveillance "Aircraft"
Inflatable Habitats
Expandable airlocks
Propellant Depots

Entry, Descent and Landing Systems



Aeroshells
Reentry Systems
Paragliders
Parachutes
Ballutes
Landing Bags
Aerocapture

Morphing Systems



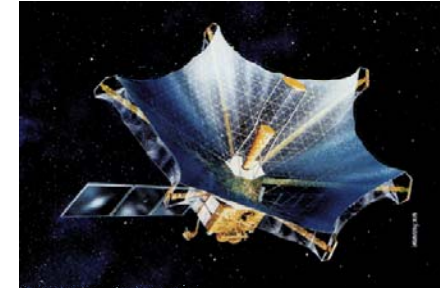
Morphing Aircraft / UAS
Microwave Reflectors
Inflatable Reentry Vehicles
Construction Vehicles
Planetary Flyers
Aerodynamic Surfaces

The Need for Expandable Systems Exists Now!



Game Changing Capabilities Require Very Large Area/Volume Space Systems

- Telescope and Antenna Apertures
- Space Solar Power Collectors and Concentrators
- Solar Sail Reflectors
- Long Duration Habitats
- Entry and Descent Aerodynamic Decelerators



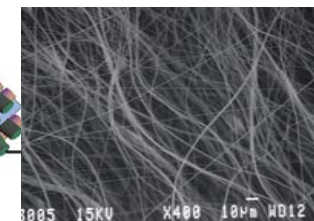
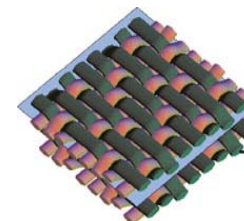
Expandable Systems Overcome Critical Constraints For Large Space Systems

- Launch Volume
- Launch Cost (related to mass)
- Space Operations
- System Mass/Area (areal density)



•There is a Coalescence of Expandable and Other Emerging Technologies

- Space System Fractionalization and Formation Flying
- On-Orbit Automated Rendezvous, Docking and Berthing
- Nanobased Flexible Structural Materials
- Flexible/Distributed Electronics
- In-Space Robotic Operations

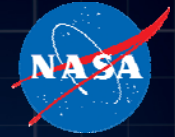


Opportunities and Challenges



Metric	Opportunity	Challenge/Risk
Cost	Much Lower Launch Costs	Mission durability
Mass	Lower to Much Lower	Low mass deployment mechanisms
Performance	Mission Enabling in Size	Shape and attitude control Long life and damage tolerance requirements
Power	Large Aperture for Power	
Produced/Used	Power use reduced with integrated electronics	
Launch/Transit Volume	Order of Magnitude smaller Use existing launch fairings.	Packaging of integrated systems Deployment/expansion reliability
Safety		Design standards inadequate. Need analytical predictability and fault tolerance
Reliability		Durability, Deployment, Complexity, Reliability, and Precision.

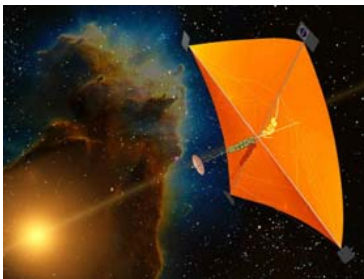
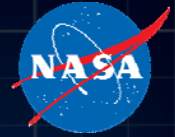
Technical Challenges For Expandable Space Systems



- **Expandable Systems Challenge: Meeting Mission Requirements**
 - Long life durability and damage tolerance – Environmentally Compatible
 - Achieving precision requirements – Fabrication/Deployment/Thermal Control
 - Deployment/Expansion Reliability – Reduce complexity and mass
 - Safety (Design/Diagnostics/Certification) – Testing and Analysis Confidence
- **Innovate Expandable Technologies**
 - The technology of expandable structures is cross-cutting with high pay-offs. (There is a convergence of promising technologies that make this a fortuitous time for development.)
 - Aerospace application of expandable structures poses a high risk unless innovations are realized in critical areas.
 - We want the technology in the commercial sector, but currently the risk and challenges are too great for industry R&D / venture capital investment.
- **Expandable Systems Benefit a Broad Array of Stakeholders**

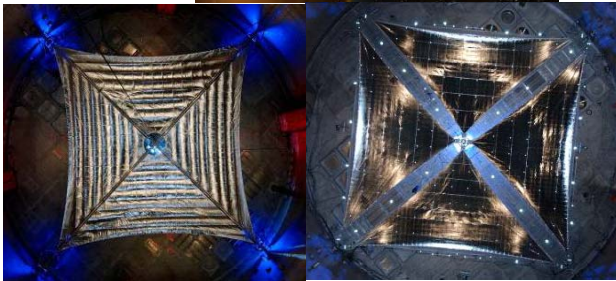
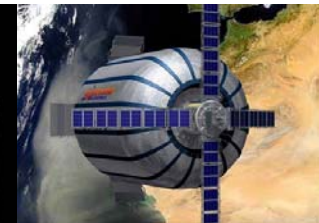
<u>Expandable Class</u>	<u>NASA Stakeholder</u>
Large In-Space Systems	Science, Exploration, US and International
Pressurized Habitats	Exploration, Science (Telescope Assembly)
EDL Systems	Exploration, Science, Aero
Morphing Systems	Science, Aero, Exploration

Current State-of-the-Art



Habitats:

*JSC, LaRC,
Bigelow, ILC Dover*



Solar Sails:

*LaRC, MSFC, JPL, AFRL,
ESA, DLR, JAXA, ILC
Dover, ManTech SRS
L'Garde*



EDL:

*LaRC, JPL, GA Tech.
ILC Dover,
Airborne Systems*

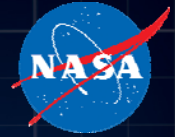


Antennas/Collectors:

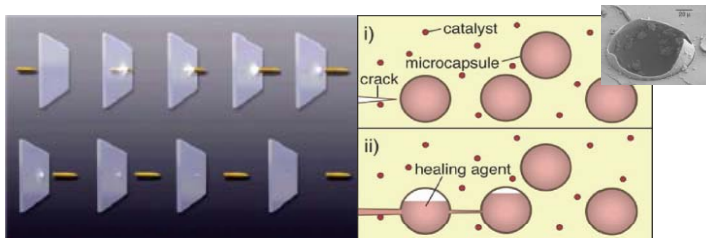
*ManTech SRS,
ILC Dover, LaRC, GRC,
AFRL, APL, JPL*



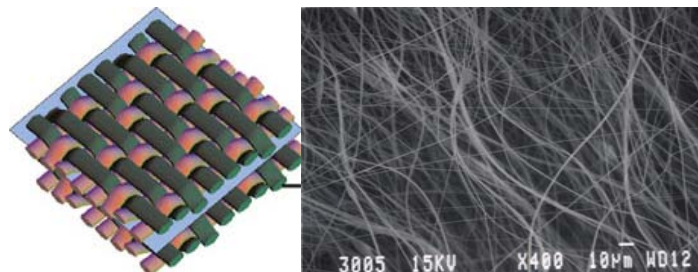
Innovation Area Engineered Materials



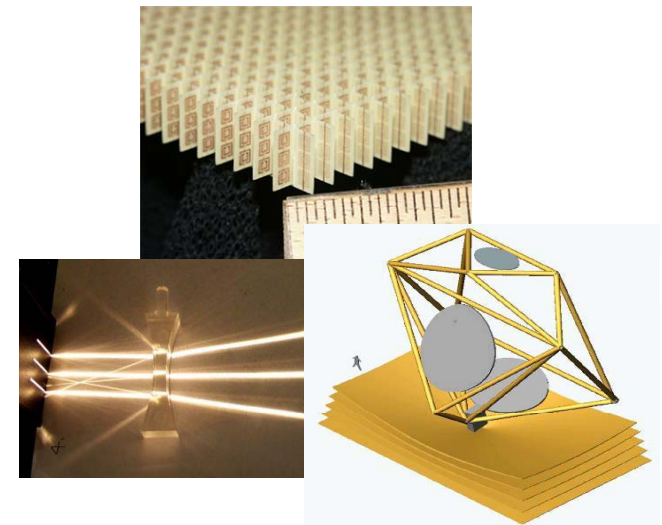
- Engineered designer materials integrate the synthesis, computational molecular modeling and characterization of materials to achieve precision on an atomic scale.
- Design and preparation of materials with specific combinations of chemical, physical, electrical, thermal, mechanical, optical, electromagnetic, and electro-active properties.
- For Example, increase durability and functionality of expandable structures.



Self-healing and rigidizable materials



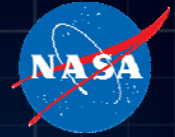
**Carbon Nanotube (CNT) and
Boron Nitride Nanotube (BNNT)**
(Structural Fabrics)



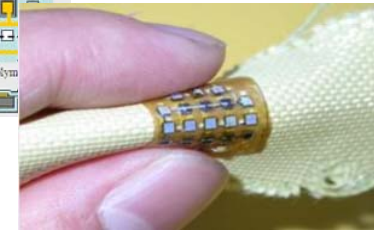
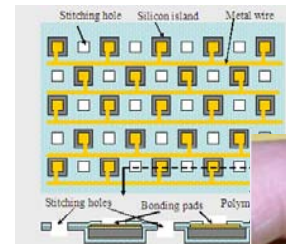
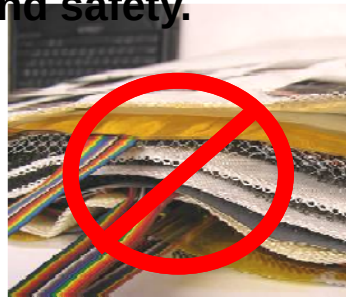
Metamaterials
(unique electromagnetic
properties)

Innovation Area

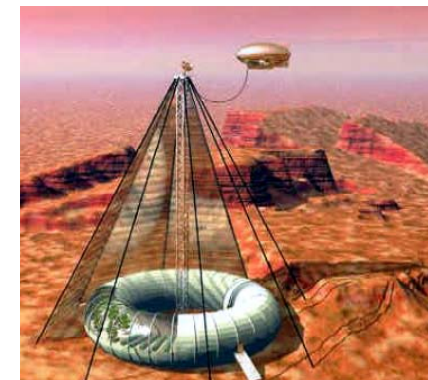
Fault-tolerant, pressurized fabric systems



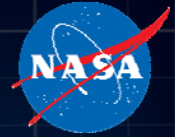
- Integrated health monitoring techniques, nano-sensors, wireless micro-sensors, and space-based instrumentation to aid in initial certification and long-term verification.
- Improves safety and reliability for mission assurance.
- Expandable structures with integrated health monitoring and in-situ test and diagnostic capabilities can meet the requirements for long-term reliability and safety.



***Integrated IVHM, Communication,
Power, Thermal Control, Repair***

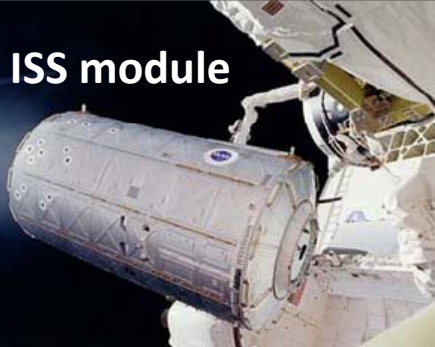
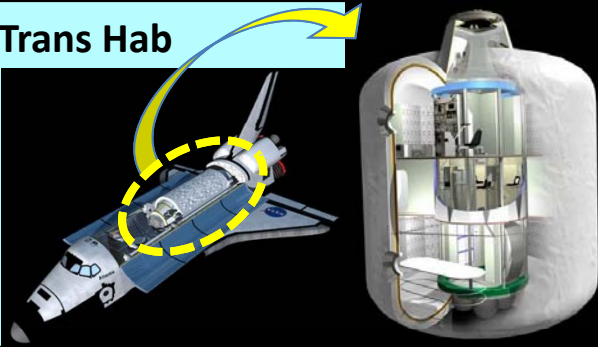


Inflatable Habitat Structures



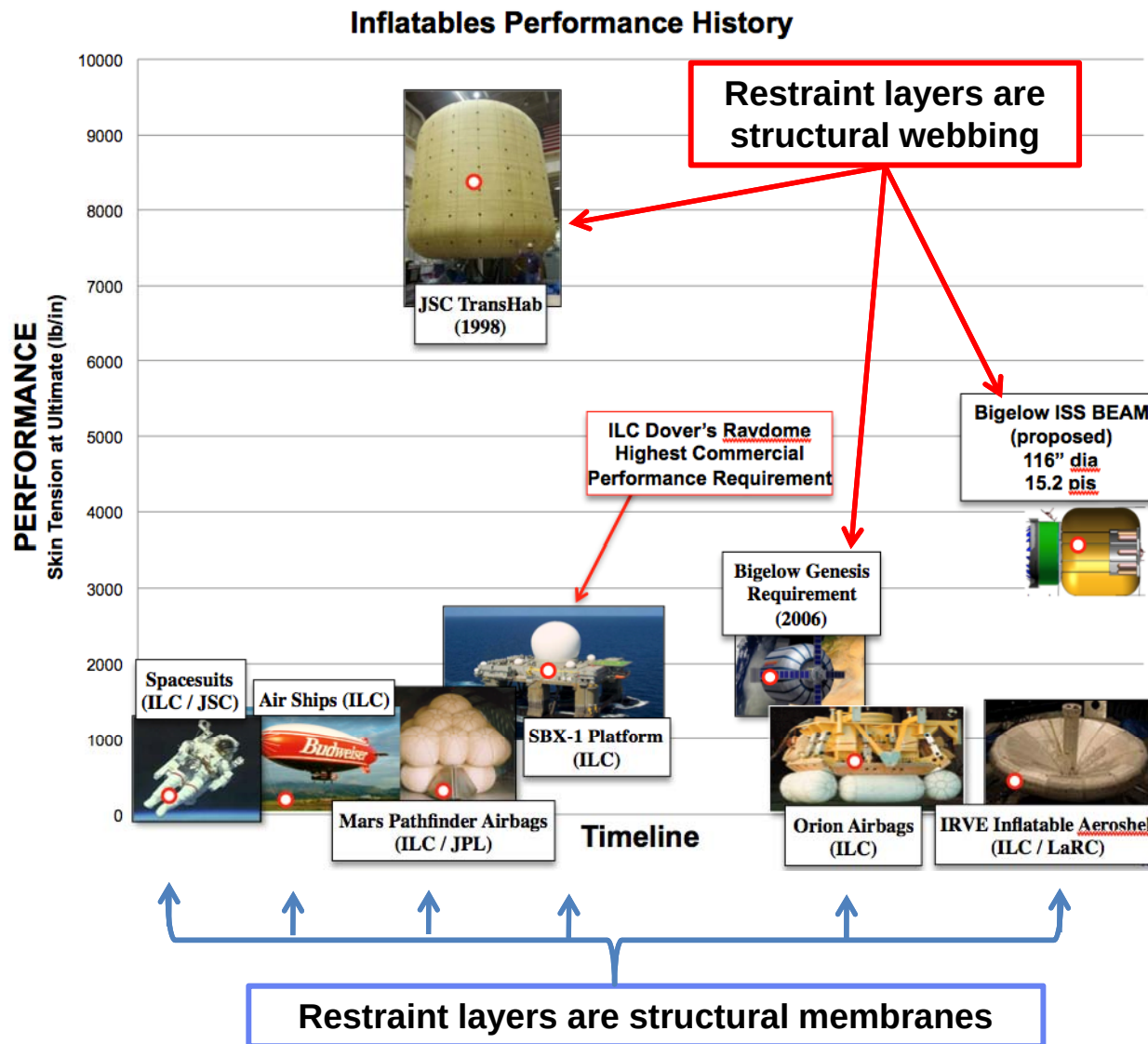
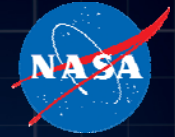
Long-Duration Human-Exploration Mission Capabilities:

- 2x load of ISS demo
- Long duration mission in space environment (Riskier for MMOD)
- Human certified

Metallic Structures	Composite Structures	Inflatable Structures
Constrained to launch vehicle diameter	Constrained to launch vehicle diameter	Diameter allowed to expand beyond launch vehicle diameter
 ISS module	 Composite Crew Module	 Trans Hab

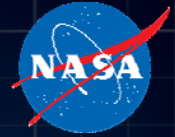
This project will help NASA leap from metallic habitats (Skylab, ISS) to inflated softgood structures for “beyond LEO” human exploration.

Inflatable Structures – Current Uses

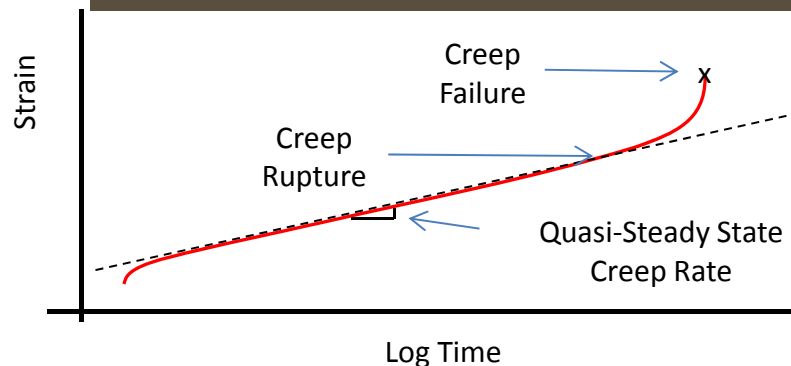
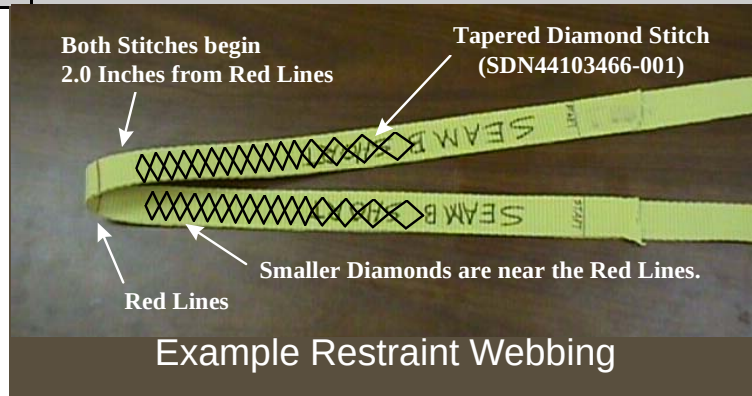


- **Human Space Exploration**
 - Trans Hab
 - Spacesuits
 - Landing Airbags
- **Non-habitable Space Exploration:**
 - Aeroshells/ballutes
 - Robotic Mission Landing Airbags
- **Non-space Applications**
 - Air Ships
 - Raydome
 - Air beam Shelters

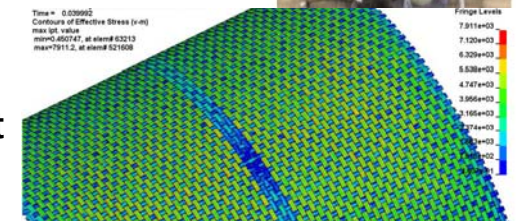
Current NASA Research and Development



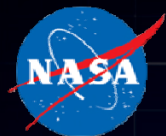
	Creep Behavior	Damage Tolerance
SOA	- Currently Inflatable structures are designed based on the restraint layer's short term properties - NASA and Industry use very conservative inflatable designs due to the lack of long term data on these materials - There have only been small scale creep tests on the fibers and limited correlation to accelerated creep data.	- Damage testing has been limited to: - Pass/fail MMOD testing, unloaded specimens - Burst testing of scaled structures - Strap component evaluation for pristine, folded, seam strength but no induced damage - Number of parameters that can be investigated are limited by the time, expense, and set-up for test of full modules - Factor of Safety of 4 used because uncertainties in materials and understanding of damage (FAA)



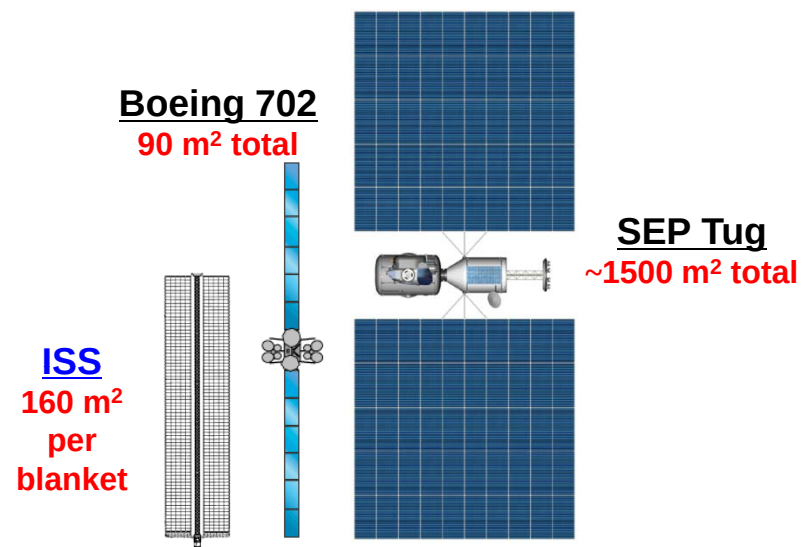
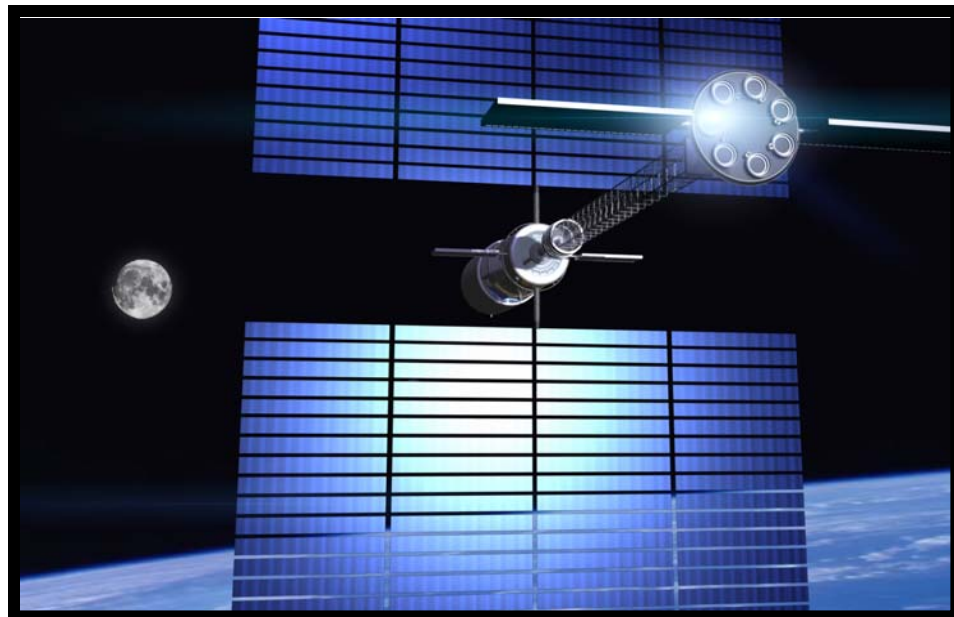
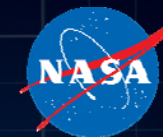
Hypervelocity Impact
on Protected Restraint
(TransHab)



Simulated Damage Test and
Analysis 15



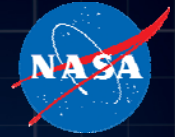
Solar Electric Propulsion – 300 kW Class



Solar electric propulsion (SEP) tugs for cost-effective, *reusable* transfer of cargo & crew beyond LEO.

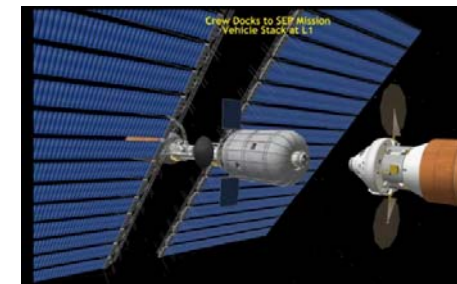
- SEP is ~10x more fuel-efficient than chemical.
- Deployable solar array structures ~10x larger than SOA

SEP- The Capability Need

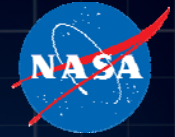


High-Power SEP Tugs Have Many Uses

- Human Exploration
 - Full Capability NEO
 - Martian Moon – Phobos / Deimos
 - Mars Landing
- Robotic Exploration
 - Asteroid / comet rendezvous (w/ much faster travel time than Dawn)
 - Cargo delivery to Lagrange Points, NEOs, Moon, Mars and its moons
- Reusable servicing / refueling capability beyond LEO
- Earth orbit transfers and High ΔV maneuvering

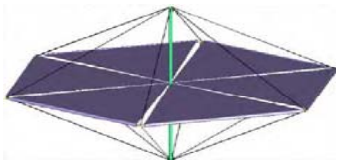


Current NASA Research and Development



Mature innovative deployable structures technology that maximize structural efficiency, deployment reliability and robustness for multi-mission use that enables cost-effective SEP systems.

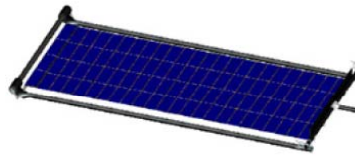
- Focus areas:
 - Innovative designs that maximize **structural efficiency, predictability, and robustness; deployment reliability; and reusability** between LEO and GEO, Earth-Moon L1, or beyond.
 - Ground deployment testing, which is a key to risk mitigation / qualification without flight test. Flight tests are expensive & offer limited range of qualification.



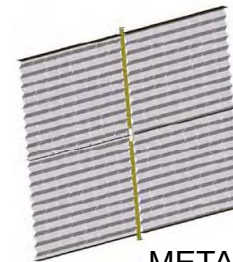
HexWheel



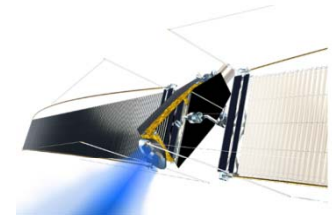
WrapFlex



ROSA

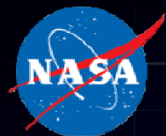


META Aurora

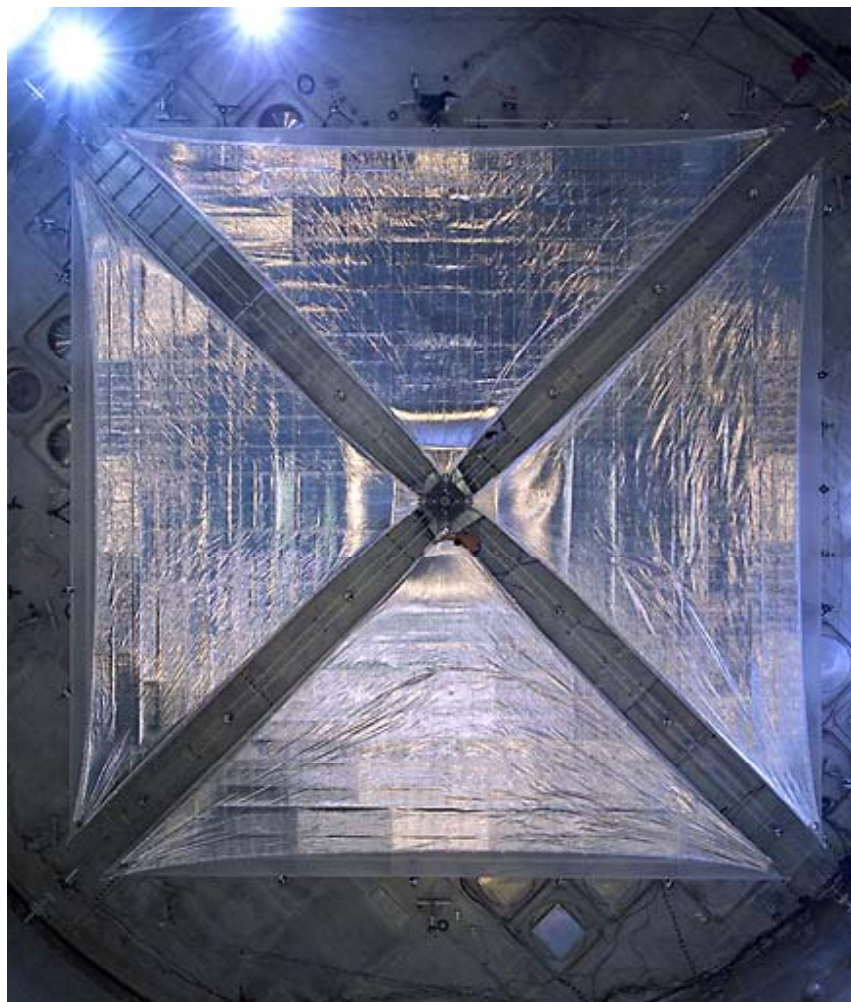
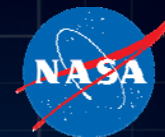


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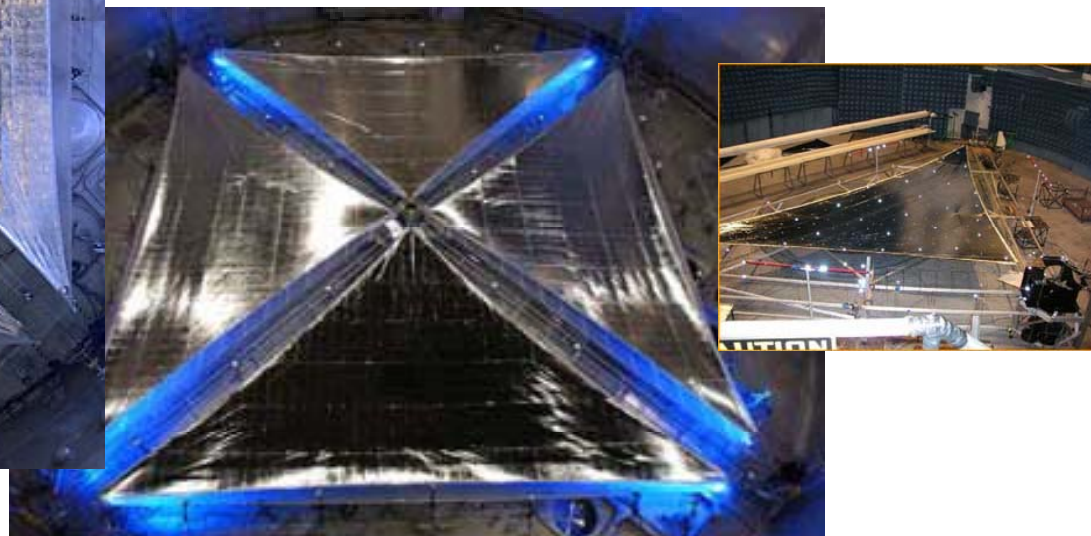
NOTE: Many Other Proposed Concepts for High-Power Solar Arrays Not Shown

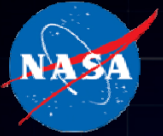


Catenary Solar Sail - 20m X20m

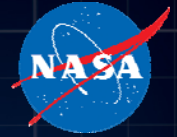


- Deployed in Vacuum
- Strain Energy Deployed Coilaile Booms
- Catenary Shaped Membrane





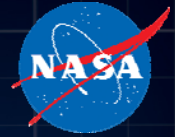
Striped Solar Sail - 20m X20m



- Deployed in Vacuum
- Inflation Deployed
- Rigidizable Booms
- Striped Membrane

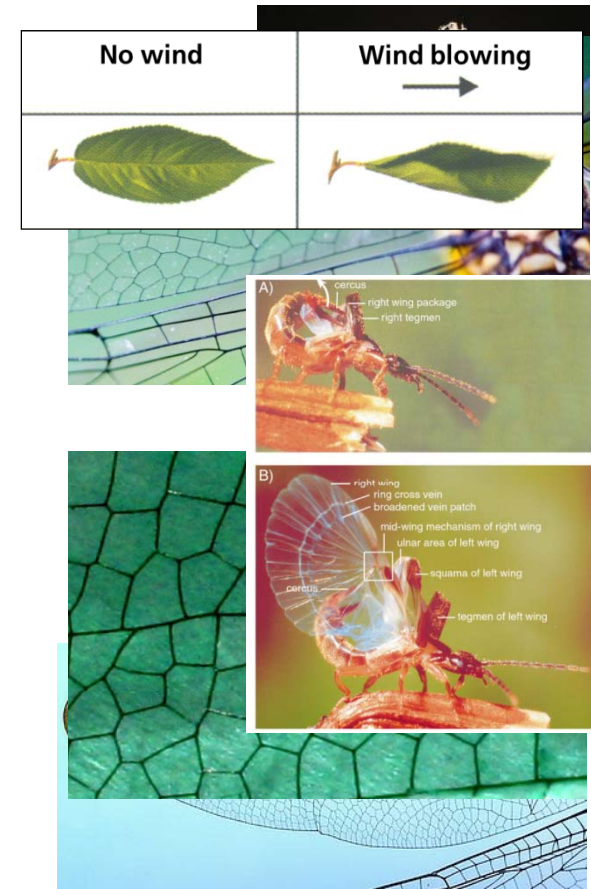


DLR/NASA Collaboration in Bio-Inspired Design

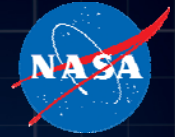


Nature's optimized membranes:

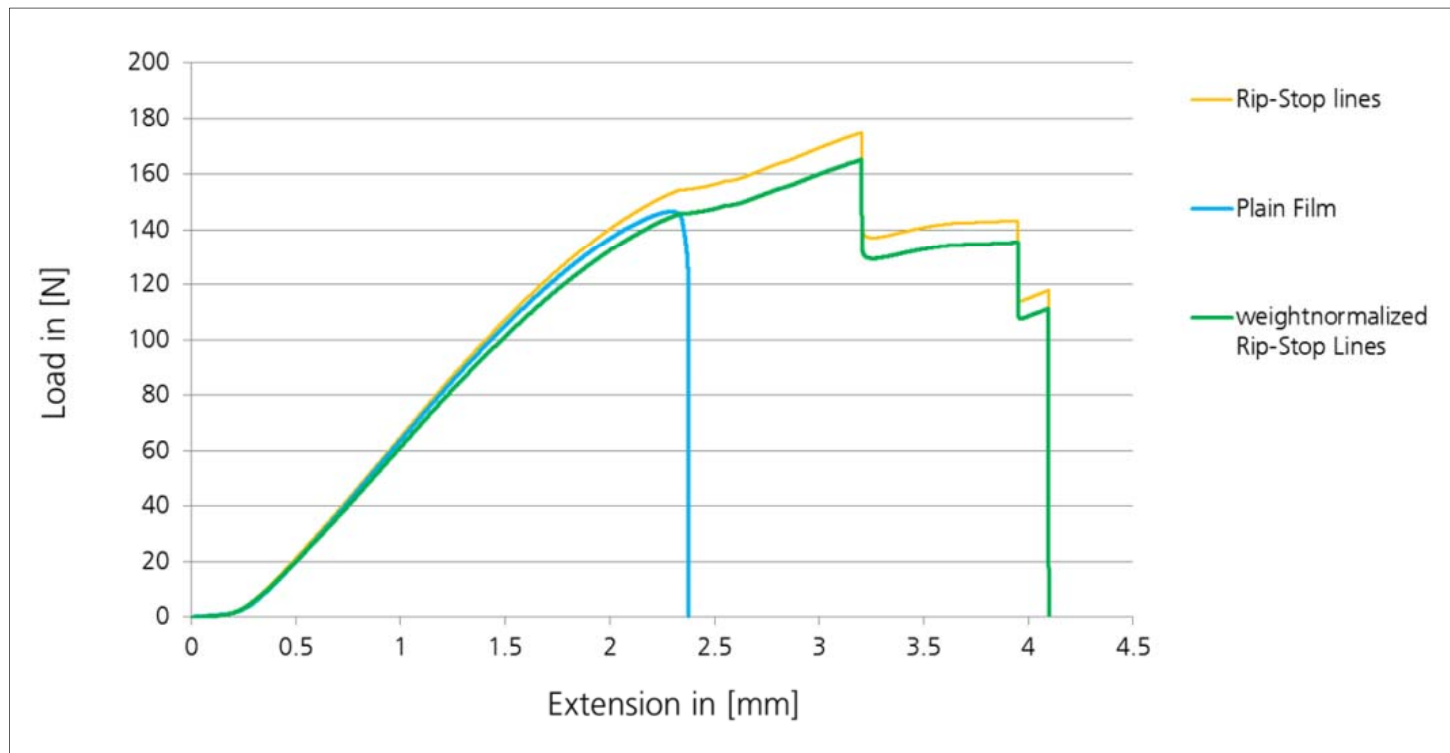
- **Ultra-light membrane areas**
 - Leaves, insect wings
- **Damage tolerance**
 - Insect wings
- **Self-Deployment**
 - Stored elastic energy (insect wings)



Additive Manufacturing - Experimental Results



Rip-Stop Test Results



- Additional weight of rip-stop structures was about 5% of the mass of the *Plain Film specimen*
- increase in maximum load was approx. 22% (15% for the weight-normalized value)
- Maximum extension almost doubled

Summary

- NASA's mission goals have not changed, but the approach to achieving them is open to new innovations.
- System and discipline level innovation in the areas of materials and structures are critical to many of the capabilities needed for space science and exploration
- Expandable structures hold significant promise and should be a focus of the structural space systems community.
- NASA and DLR collaborations in expandable structures technology development have been valuable.