National Aeronautics and Space Administration

Lightweight Inflatable Solar Array:
Providing a flexible, efficient solution to space power systems for small spacecraft

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MSFC Advanced Concepts

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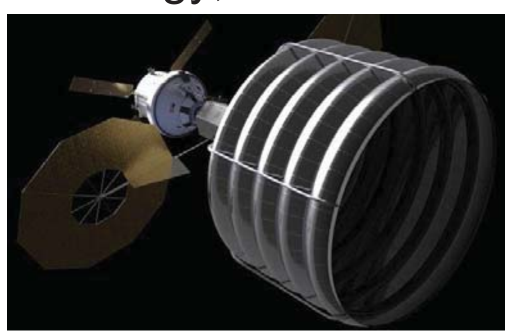
Marshall Space Flight Center

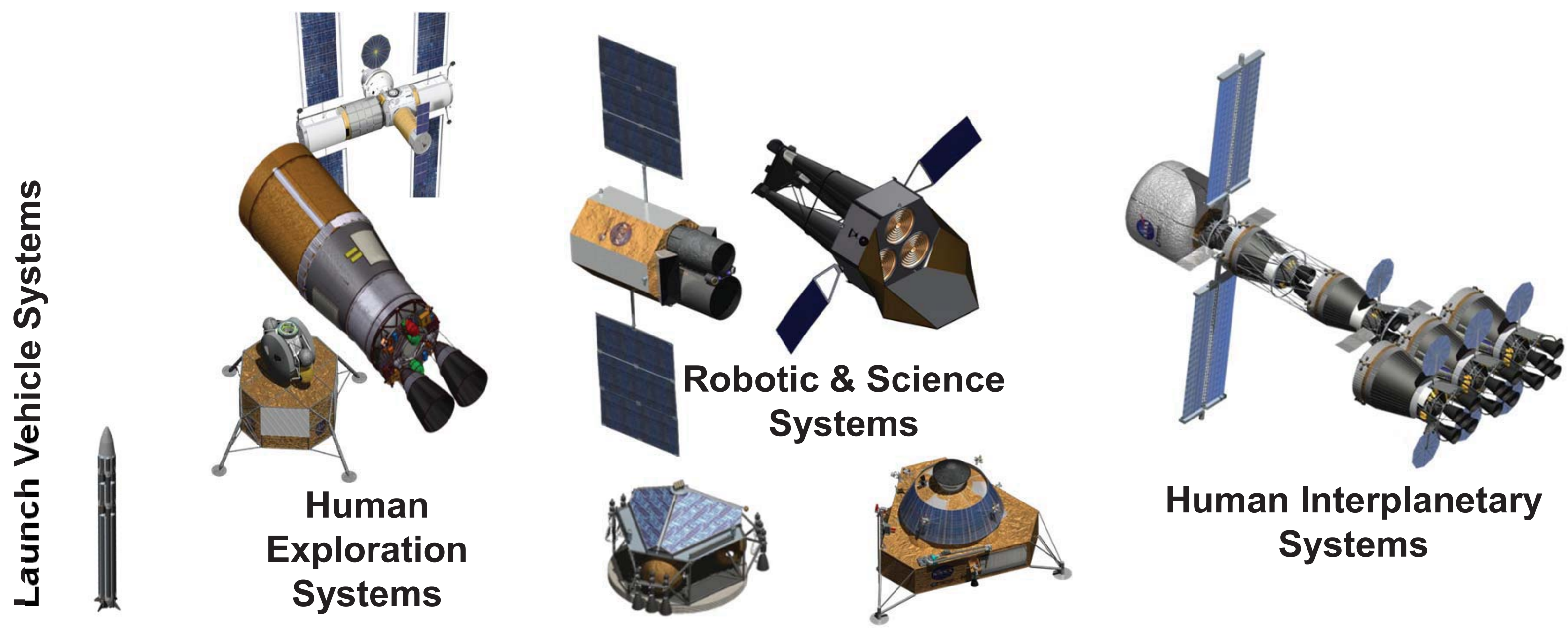
- Marshall Space Flight Center's technical capabilities and engineering expertise are essential to the nation's space exploration goal of sending humans beyond Earth and into deep space.
  - Our core capability is in space transportation and propulsion systems with unique expertise in large-scale complex space systems development.
  - We advance space technologies, spark economic development, expand our knowledge, and inspire a new generation of explorers.
  - Marshall supports three of NASA's Mission Areas: Human Exploration and Operations, Space Technology, and Science.



Lightweight Inflatable Solar Array

Advanced Concepts Office Overview

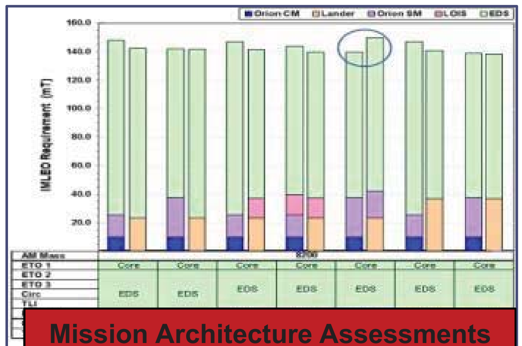
- Staff Office to Marshall's Engineering Directorate
- Specializes in Pre-Phase A and Phase A Concept Definition for Space Exploration Elements
  - Performed over 30 Design studies and 700 Launch vehicle analyses in the last year



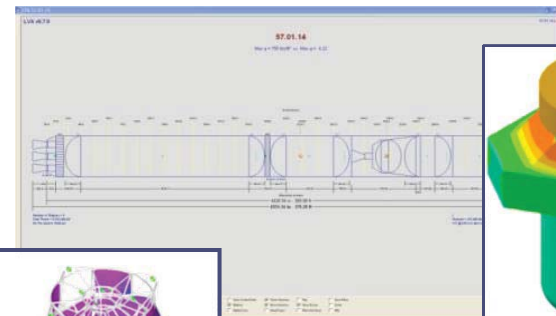
Advanced Concepts Office Overview (continued)

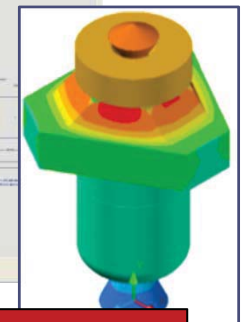
- We use multi-disciplined teams to provide fully integrated assessments of missions and their elements

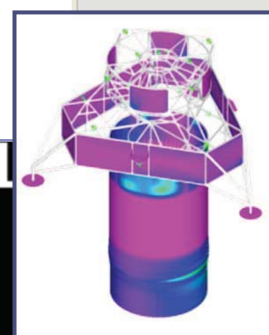
Integrated Systems Analysis Capability



Mission Architecture Assessments

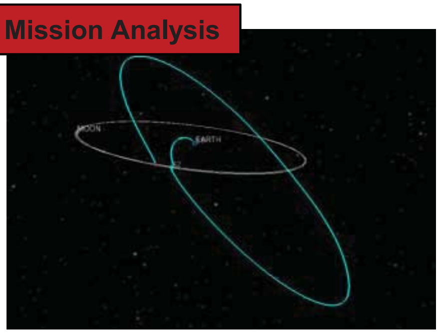


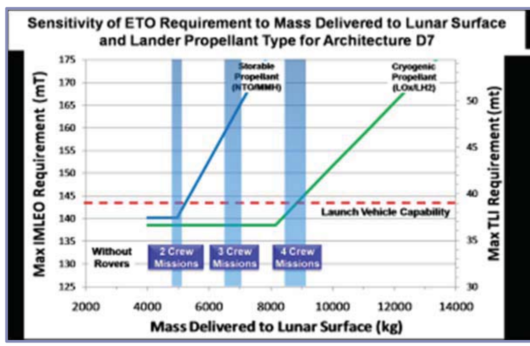




Subsystem Design & Analysis

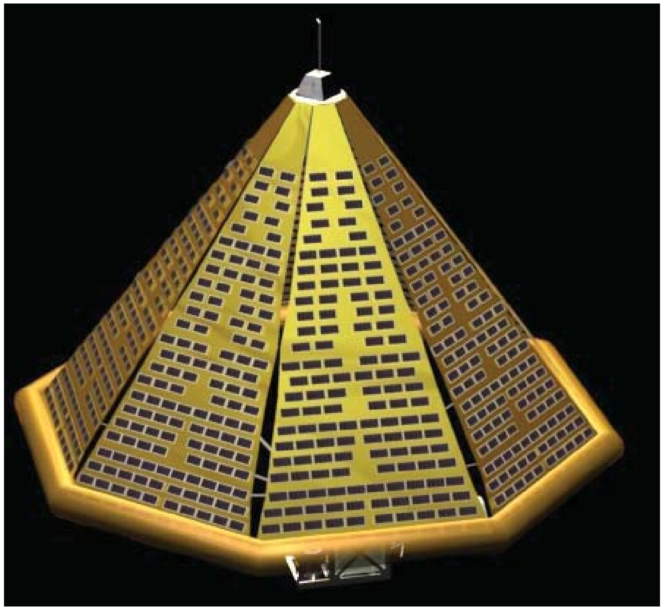
Mission Analysis





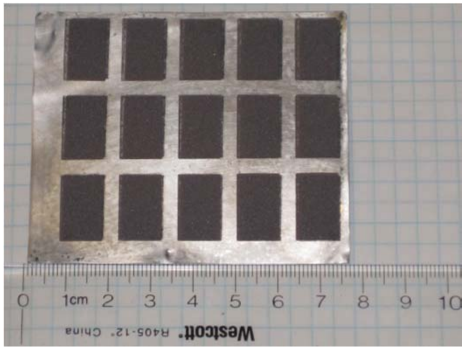
Lightweight Inflatable Solar Array (LISA) Background

- Increased emphasis on small satellites and spacecraft creates need for lighter weight and more efficient power systems
- Thin film and printable solar arrays paired with inflatable structures could revolutionize space (and terrestrial) power systems by making systems that are easily packaged in small volumes, lightweight, efficient, and relatively inexpensive
- In order to determine project feasibility, ACO teamed with Marshall's Space Systems Department to propose a conceptual design study and prototype development through the Technology Investment Program

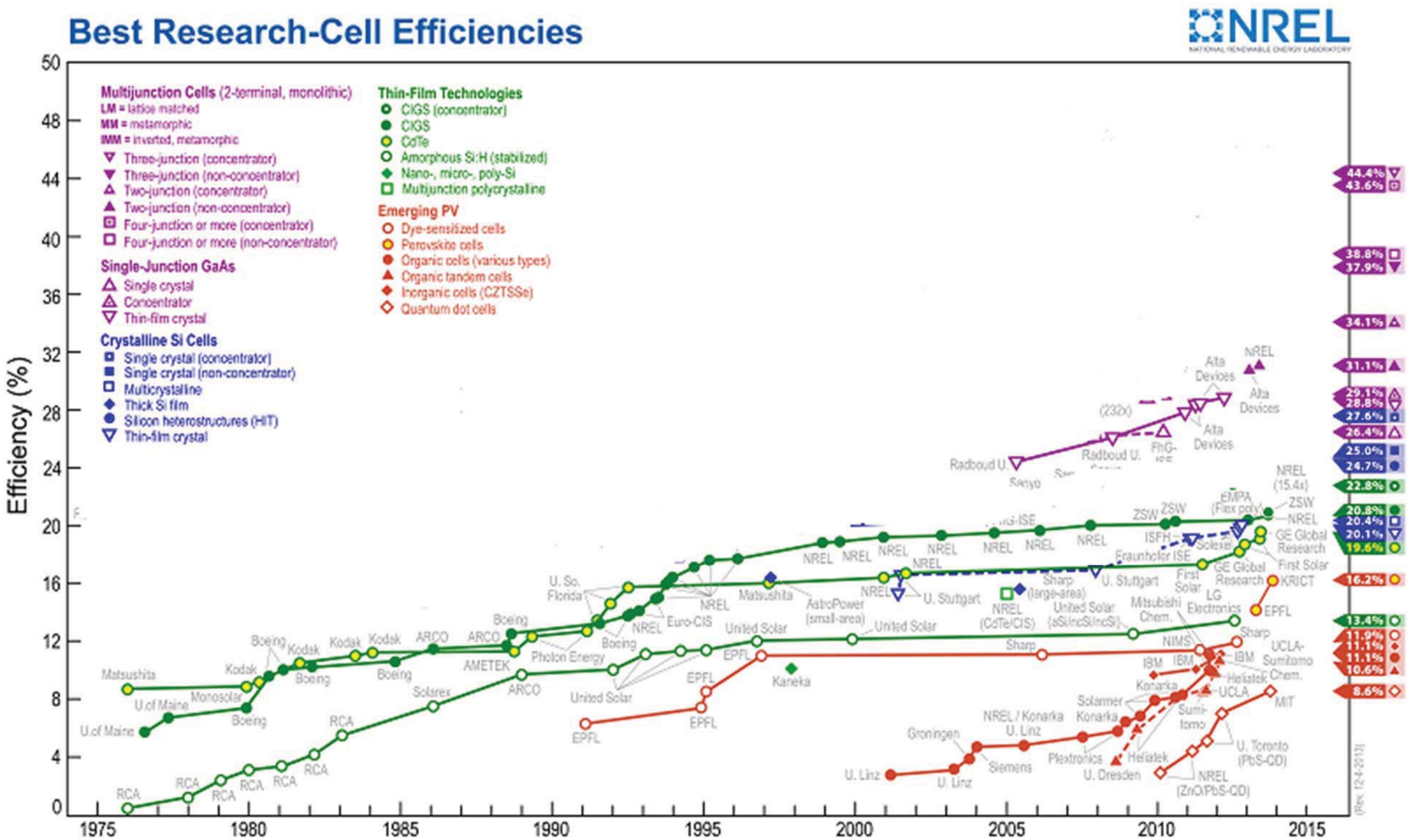


Advanced Thin-Film Evolution

- Thin-film cells have been available for > 30 years
  - Lower conversion efficiencies than conventional cells
  - Durability issues
- Recent advances have brought conversion efficiencies to > 20% and have reduced areal mass density to < 250g / m^2
- Costs have been reduced as well



Advanced Thin-Film Evolution

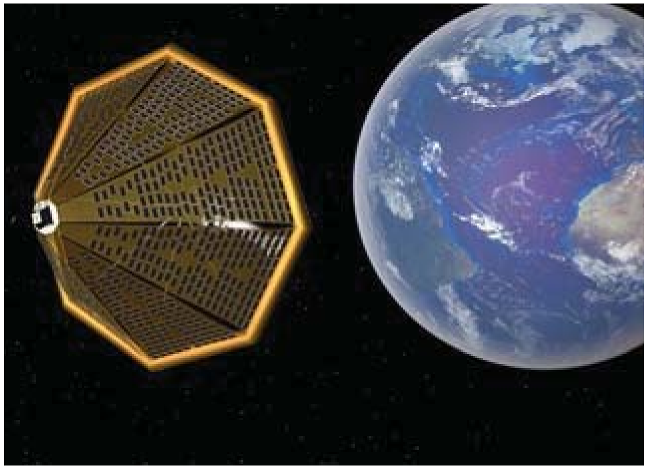


Thin-film Deployable Arrays

- Thin-film technology has advantages for use in deployable solar arrays
  - Flexibility of thin-film cells allows construction of foldable, rolled deployable arrays. Packaging efficiency is very high
  - Cells may be deposited or printed in exact shape to conform to existing deployable surface geometry
  - Deployable arrays have high mass-specific power (> 250W / kg)

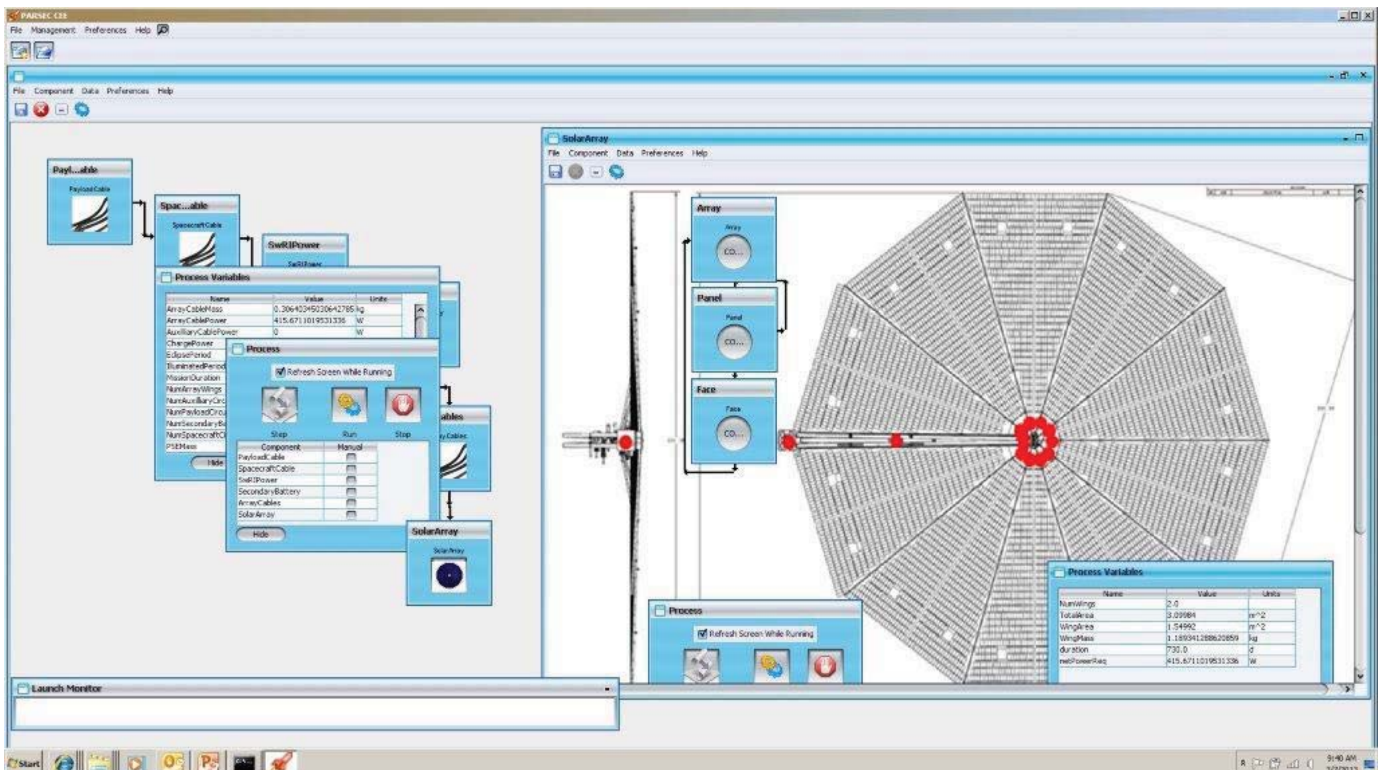
LISA Project Objectives

- Characterize the mission applications for which inflatable power systems would be most beneficial
- Develop physics-based predictive performance and sizing models for inflatable arrays.
- Perform concept design studies to characterize missions that would benefit from the technology and develop requirements for testing
- Build inflatable test article to demonstrate that all required functional elements work together to meet requirements when integrated in a laboratory environment (TRL 4)
- Test the article to demonstrate TRL 4
- Write a plan to mature the technology to TRL 6 in readiness for technology demonstration flight



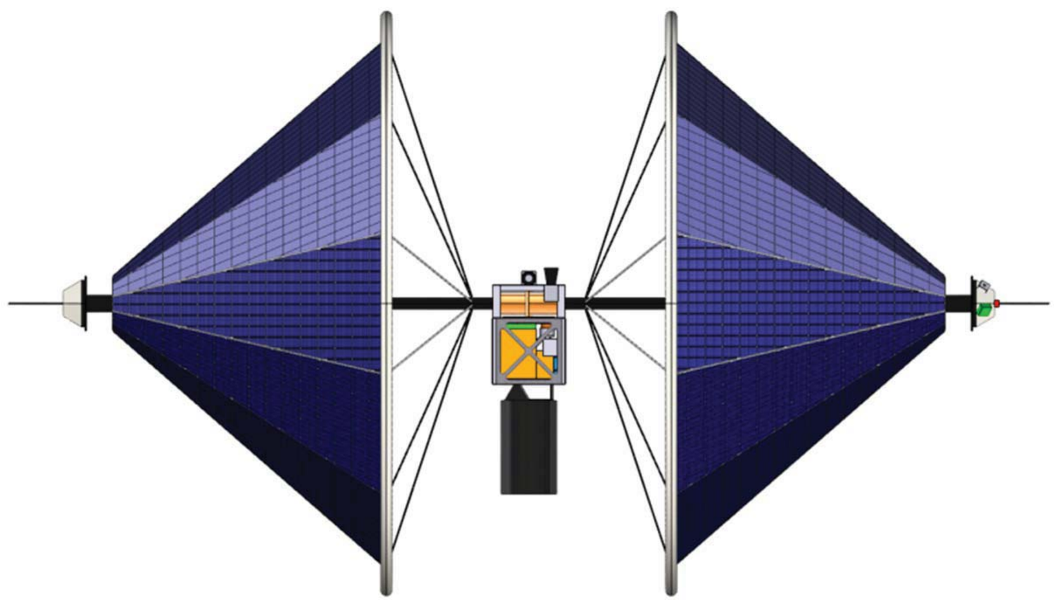
Inflatable Array Modeling

- Developed physics-based parametric performance estimation models for cells
- Developed sizing models to size inflatable arrays using cell performance models



Earth Observation Nano-Satellite

- Based on *Kestrel Eye* Demonstrator
- Total Mass < 30kg
- Software Defined Radio (10W RF)
- 10” Telescope
- 80W to Payload
- 1-2 year life

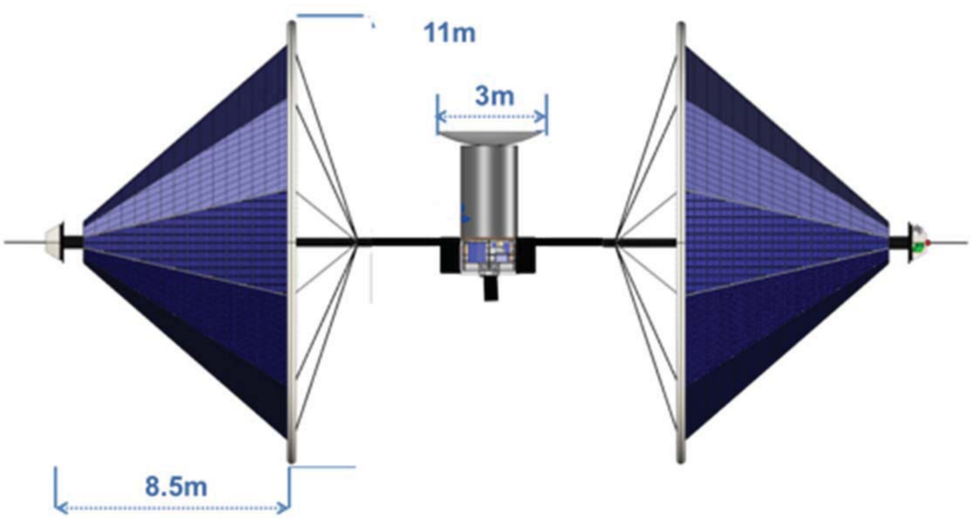


3U CubeSat Concept

- Torus-shape inflatable structure stows in 1U
- 137 W minimum power
- Array weighs 0.72 kg, 0.65m radius

Solar Electric Saturn Explorer

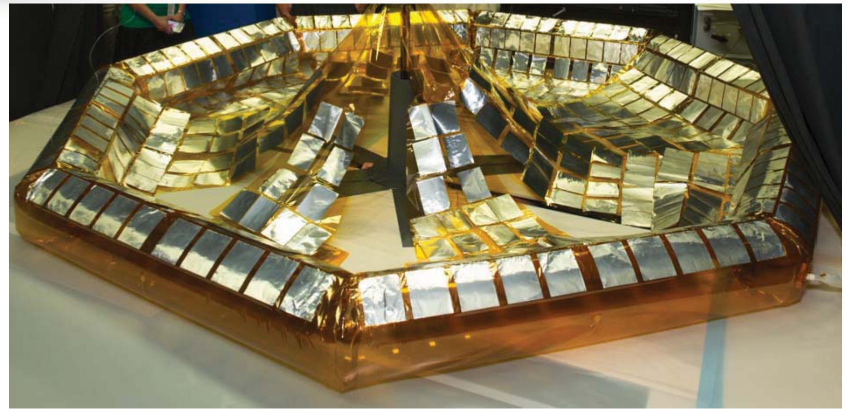
- Replaced power system on a previous Saturn planetary science study vehicle
- Compared LISA power system to ultraflex
- Mass savings 62kg



LISA Concept: On-Orbit Deployment

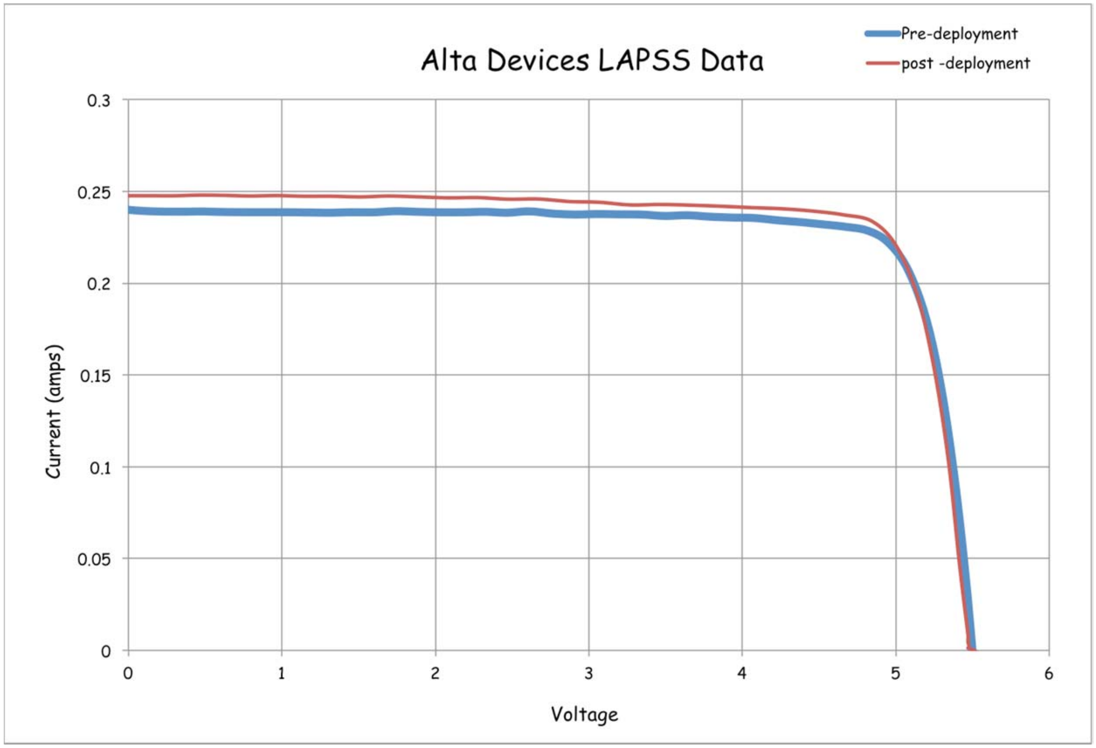
Test Article Development

- Realistic inflatable test article designed from concept studies
- Kapton inflatable structure covered with thin-film cell substrate material and 5 functioning cells. Substrate patches wired realistically
- Electrically tested functioning cells before inflation and after inflation



Electrical Test Results

- Complete I-V curves taken before and after inflation
- LAPSS testing confirms that array performance not negatively impacted by inflation



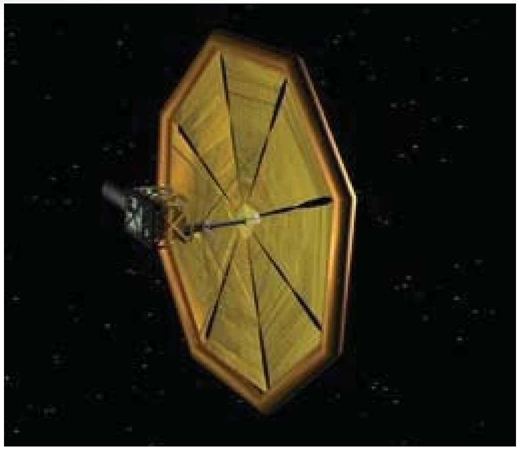
Technology Readiness Level Assessment

Subsystem	2012 TRL Score*	2013 TRL Score*	Comments
Printed Photovoltaics / Diodes	2 (51% to a 3)	4 (50% to a 5)	
Interconnectivity System	2 (2% to a 3)	4 (51% to a 5)	
Printing Technology / Manufacturability System	2 (81% to a 3)	6 (81% to a 7)	Vendor changed during TIP project; new vendor has higher TRL approach with less capability but capability was sufficient to support TIP effort
Deployment Mechanism	1 (0% to a 2)	9	Selected a COTS solution during the TIP project that met all system requirements
Inflatable Structure	n/a	4 (57% to a 5)	Not evaluated at start of process because it was not designed; design solution achieved and advanced to TRL 4 during TIP project
Test System	n/a	4 (27% to a 5)	

- TRL Assessments conducted at project start and after deployment test indicate significant increase in TRL to level 4

Potential Applications

- Space
  - Small satellites
  - Solar electric vehicles
  - Power systems for habitats
  - Weather monitoring satellite
  - Ground stations



- Military
  - Portable power systems for troops in the field
- Consumer
  - Alternatives to generators for disaster relief, camping, etc.
  - Emergency power sources for travelers, campers

Conclusions

- Lightweight inflatable solar arrays provide a feasible power solution for a wide variety of mission types, based on preliminary concept studies
- Increasing the Stowed-Volume Specific Power allows for much more robust power systems to be integrated into smaller spacecraft, habitats, and ground systems
- Placement of arrays around entire inflatable structure eliminates the need for pointing

Forward Work

- Leverage existing research and development on inflatable structures as well as thin film and printable solar array technologies
- Perform additional studies to assess the feasibility of additional inflatable shapes and structures as well as deployable structures
- Expand trade space to consider additional applications, including military and terrestrial
- Assess additional thin film and printable solar array vendors
- Develop higher fidelity test article featuring integrated solar power system
- Conduct testing in a simulated environment