Mars Surface Solar Array Structures

Richard Pappa, Geoff Rose, Matt Chamberlain, and Dave Paddock

NASA Langley Research Center
Hampton, VA

Martin Mikulas

National Institute of Aerospace
Hampton, VA

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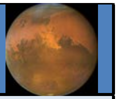
Solar Arrays With Storage (SAWS)

- **NASA Space Tech "seedling" study to develop a Mars power architecture with deployable solar arrays and regenerative fuel cells using ~10 kW modules.**
  - **Solar arrays on every lander, at least through Expedition 3 (total of 10 landers)**
  - **Multiple landers (< 1 km apart) form a power grid**
- **Two elements coordinated by GRC PM (Fred Elliott):**
  - **SAWS Solar Array – Led by LaRC with GRC support**
  - **SAWS Regenerative Fuel Cell – Led by JSC with GRC & JPL support**
- **Lays groundwork for FY18-20 project.**

Planet Properties

	Earth 	Mars 
Average Distance from Sun	1 AU	1.53 AU
Avg. Irradiance Above Atmosphere	1370 W/m^2	590 W/m^2
Tilt of Axis	23.5 deg	25 deg
Length of Day	24 hr	24.6 hr
Length of Year	365 days	687 days
Orbit Eccentricity	0.0167	0.0934
Gravity	1 g	0.38 g
Average Temperature	57 deg F	-81 deg F
Average Air Density	1.225 kg/m^3	0.020 kg/m^3
Atmosphere	Mostly N_2, O_2	Mostly CO_2

SAWS Solar Array Design Guidelines Chart 1 of 2

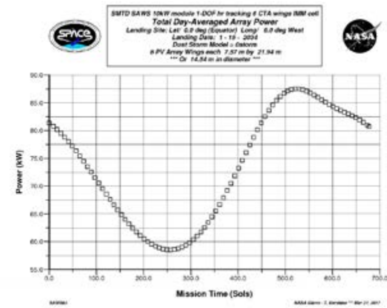
1	Autonomous deployment from lander.
2	1000 m^2 area per lander. Provides a "10 kW-class" solar power system.
3	Extensible to 1500+ m^2 area per lander for higher latitudes and dustier skies.
4	Mass goal < 1.5 kg/m^2 inc. all mechanical and electrical; 1.5 mt for 1000 m^2. Assume lightweight blanket mass of 0.5 kg/m^2.
5	Packaging goal < 10 m^3, which is ~30 kW/m^3 at 1 AU.
6	Solar array deploys in Mars 0.38 g gravity & low winds (use 0.5 g total for preliminary design).
7	Deployable on terrain with up to 0.5-m rocks, 15 deg slopes, and potentially hidden hazards (e.g., sand-filled holes).
8	Should deploy as low as possible to simplify repair but >0.5 m off ground.
9	Possibly some azimuth control over deployment direction.
10	Time to deploy: 8 hr max.

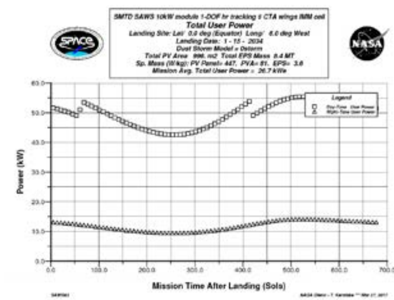
SAWS Solar Array Design Guidelines Chart 2 of 2

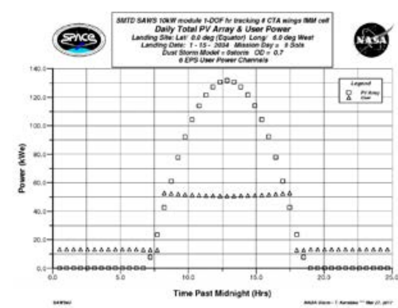
11	Solar array operates in Mars 0.38 g gravity & wind gusts (use 1.0 g total for preliminary design).
12	Must survive 120 days of 40 m/sec wind gusts in storms, and 100 m/sec peak winds (dust devil) = ~20 mph Earth winds.
13	Solar array must not tip over or twist excessively in high winds.
14	Ability to tilt arrays for dust removal and to feather in high winds.
15	Probably also need vibration, electrostatics, jets, or wipers to remove dust.
16	Evaluate cost/benefits of being retractable, relocatable, and reconfigurable.
17	Compare 29.5% XTJ/ZTJ, near-term 34% IMM4J, and far-term 37% IMM6J solar cells. Nominal solar array operating voltage is 120 V.
18	Must survive daily temperature change of ~120 C (approx. -100 C to 20 C near equator) over a lifetime >10 years.
19	Prototype hardware might be purchased under SBIR Phase 3 contracts.
20	System design, analysis, and testing will be done in house.

Power Predictions

- SAWS is developing **“10 kW-class” solar arrays** and RFC energy storage <u>technologies</u> for Mars as an alternative to nuclear power.
- Baseline 1,000 m^2 array (Chart 18) generates about 130 kW peak and 75 kW average solar power over a Martian year. Provides average **25 kW of user power** at the equator with clear skies.
- Many factors affect solar power level including:
  - Time of day, day of year, atmospheric & deposited dust, temperature, array orientation, sun tracking approach, latitude, and number of landers in grid.
- RFC is initially sized to provide 10 kW for 14 hours.
- Worst case user power in major dust storm is 5 kW nighttime, 9 kW sol avg, and 18 kW daytime.







Courtesy of Tom Kerslake, GRC

Solar Array Concept Selection

Previously Proposed Concepts

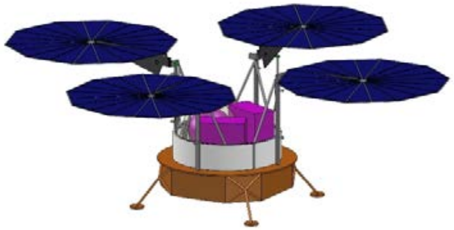
0-g Concepts: UltraFlex, ROSA, CTA

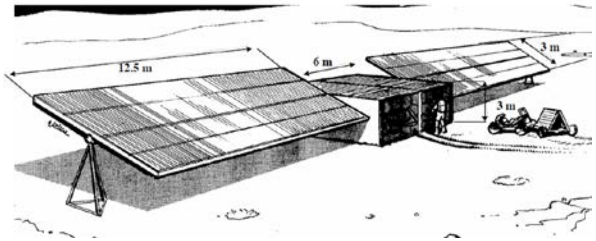
Evaluate ~10 Variations of the CTA

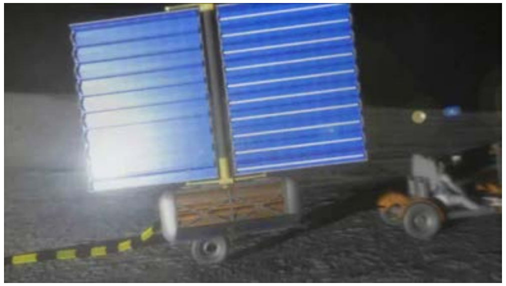
Assess SBIR Contract Innovations

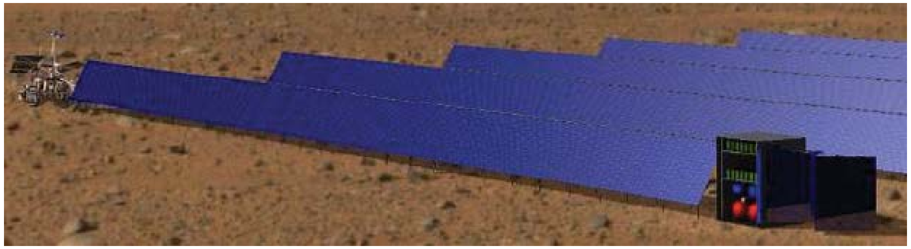
Compare with Guidelines and Assumptions

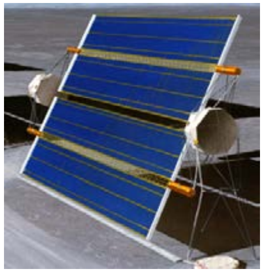
Previously Proposed Concepts Include:

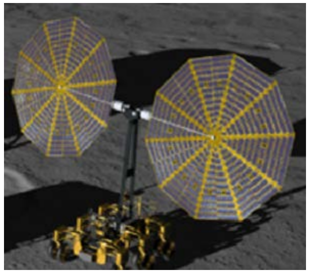




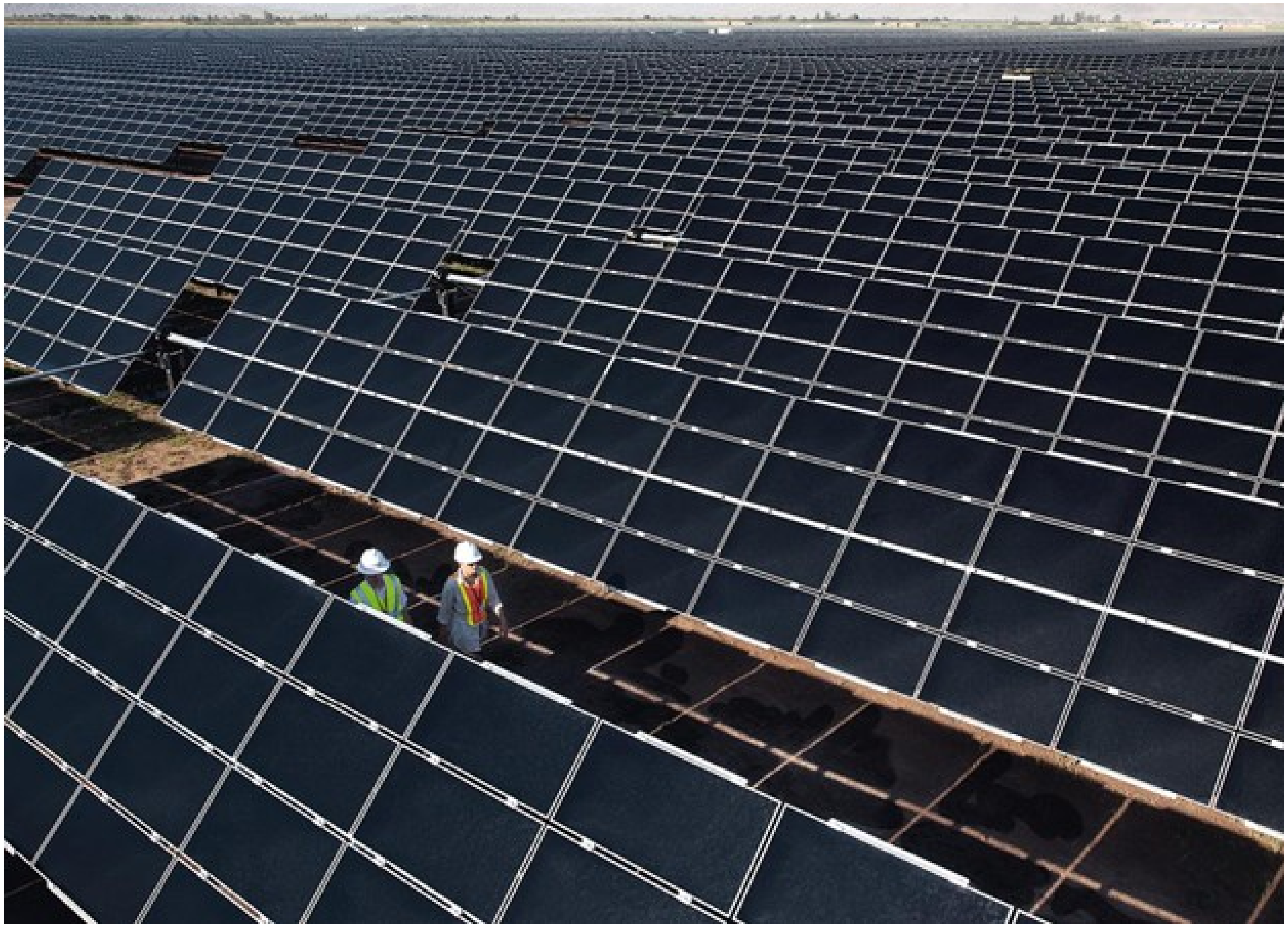








Terrestrial Systems Were Also Reviewed



Mount Signal Solar, Imperial County, CA
265 MW, 1980 acres, Largest single-axis tracker

The following charts summarize LaRC's Compact Telescoping Array (CTA), which was developed under a previous NASA Seedling Study as a 1 MW spacecraft solar array with an exceptional packing efficiency of 60 kW/m^3.

Reference: Mikulas, Pappa, Warren, Rose, "Telescoping Solar Array Concept for Achieving High Packaging Efficiency," AIAA Paper 2015-1398, Presented at AIAA SciTech Conference, January 2015.

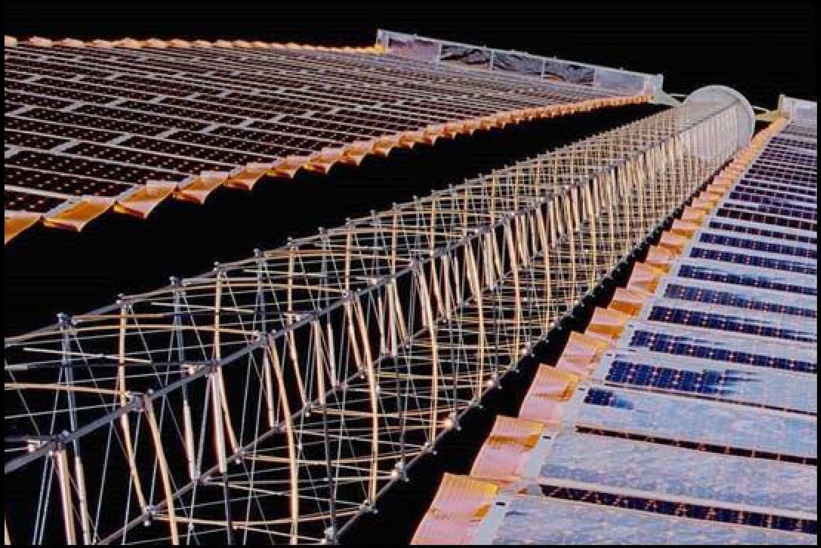
Lessons Learned From Space Station Arrays

Strengths

- High blanket packaging density, (~ 300 kW/m^3)*
- Efficient structural form (single support beam)

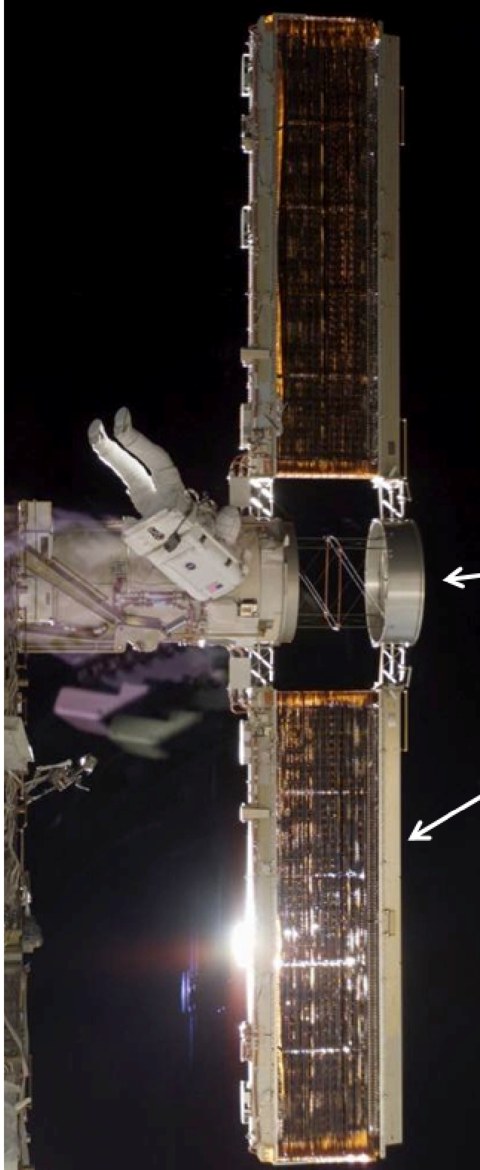
Weaknesses for non-ISS use

- Poor total array packing density, (~ 12 kW/m^3)*
- Large, heavy canister



***Converted to today's 30% cell efficiency**

Approach for Improved Performance

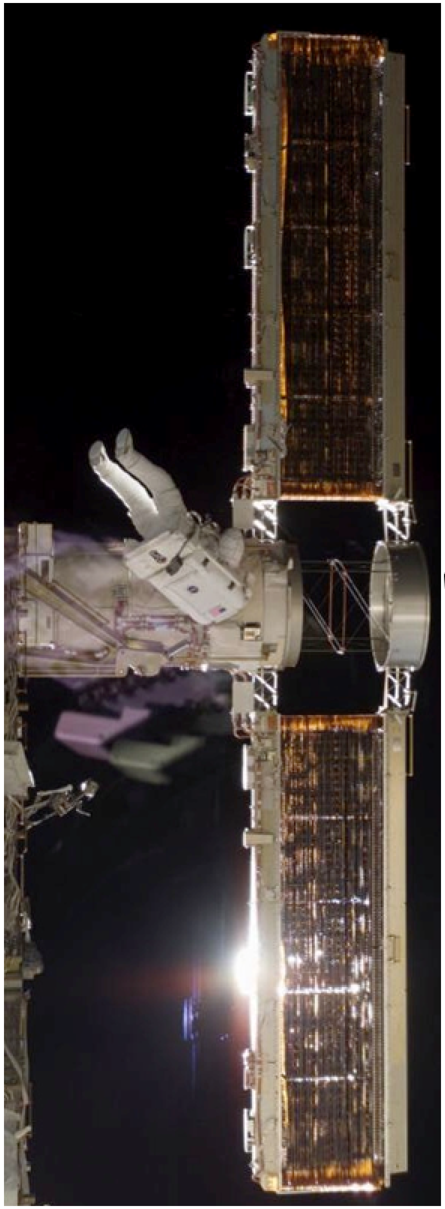


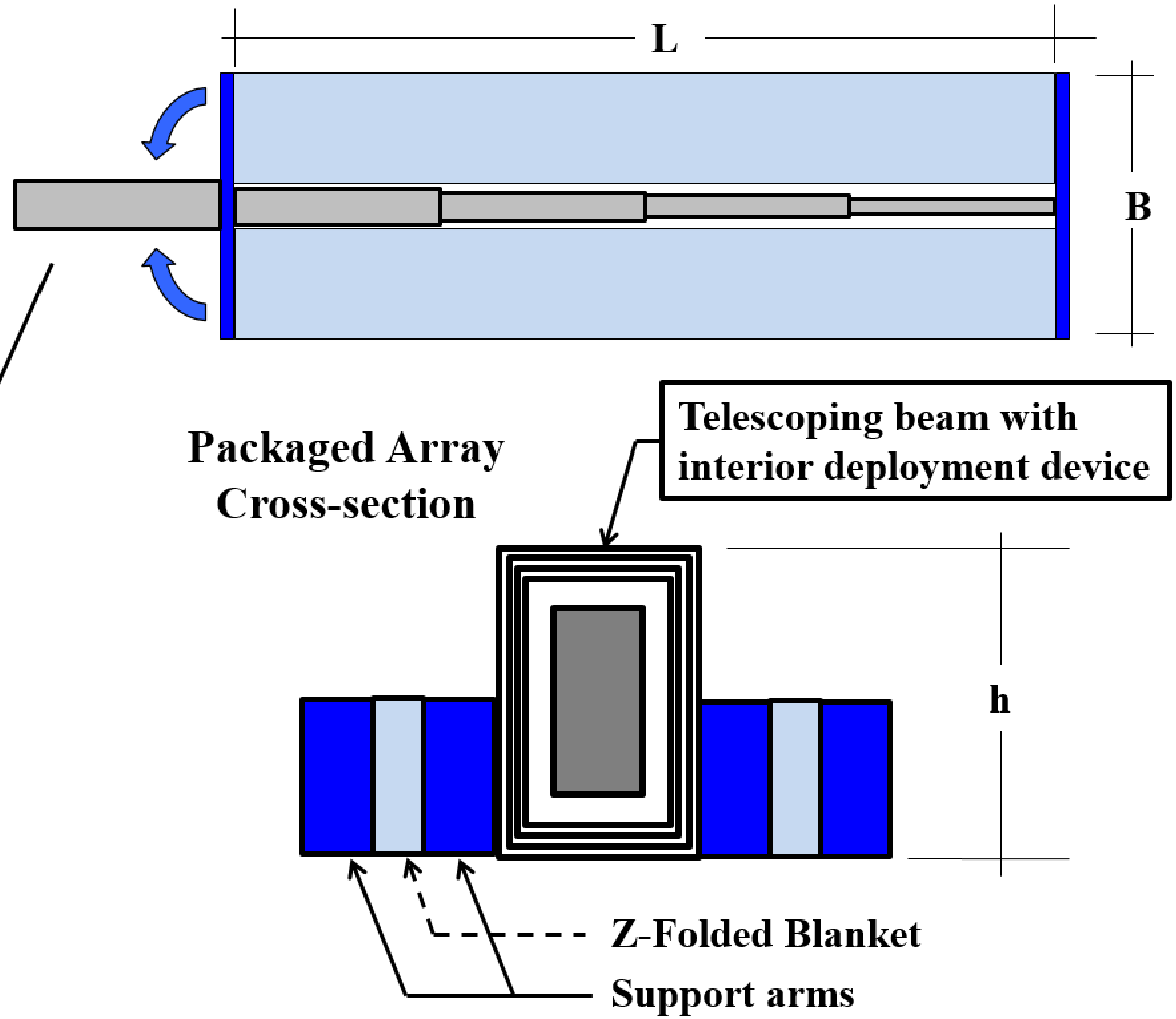
Two changes to the ISS arrays required to enable the specific power goal of 60 kW/m^3

1 Integrate structure and canister

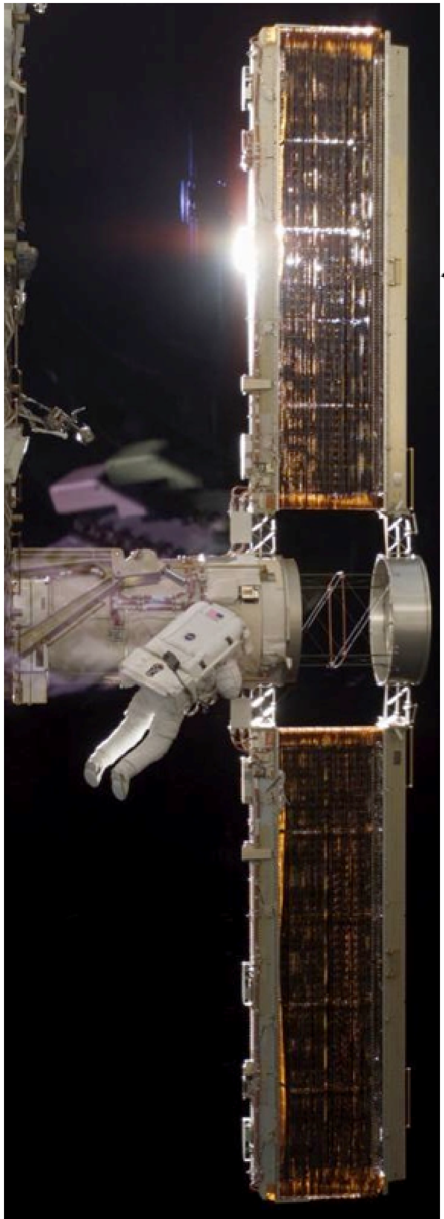
2 Reduce volume of support arms

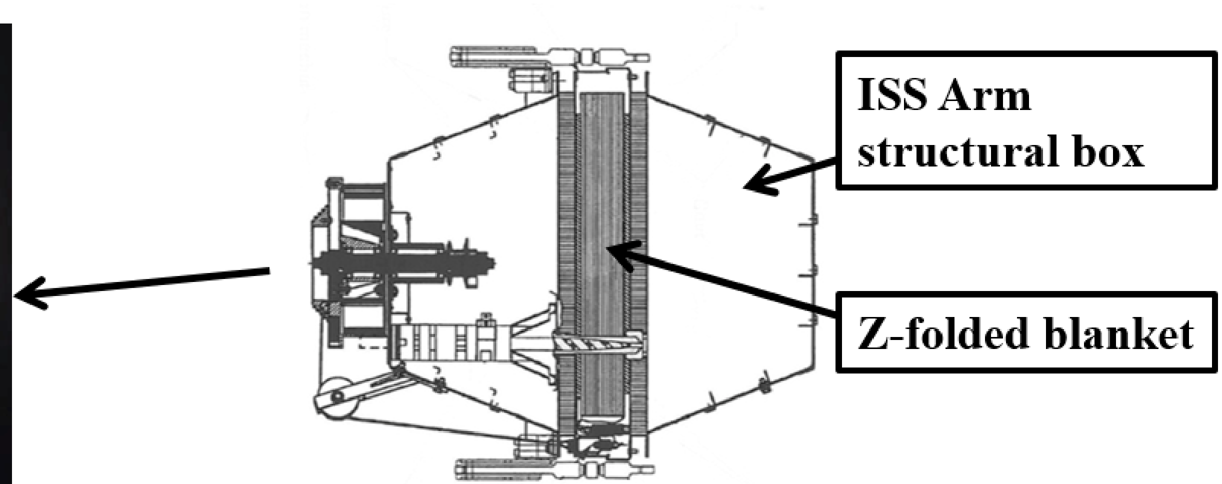
1 - Introduce Telescoping Primary Support Beam



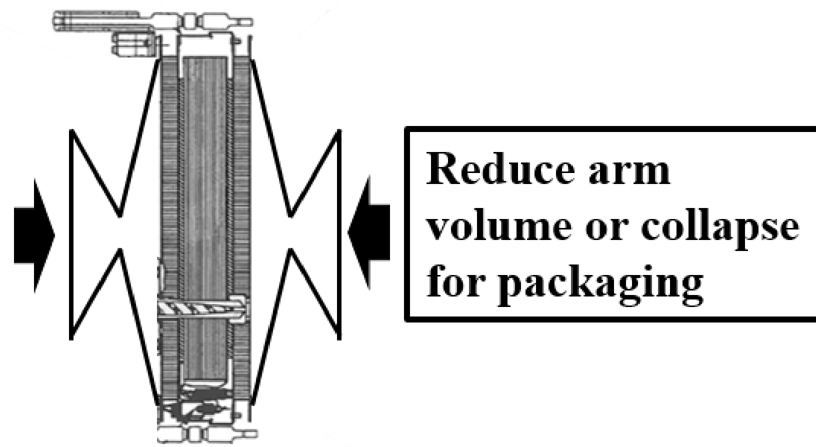


2 - Reduce Volume of Support Arms

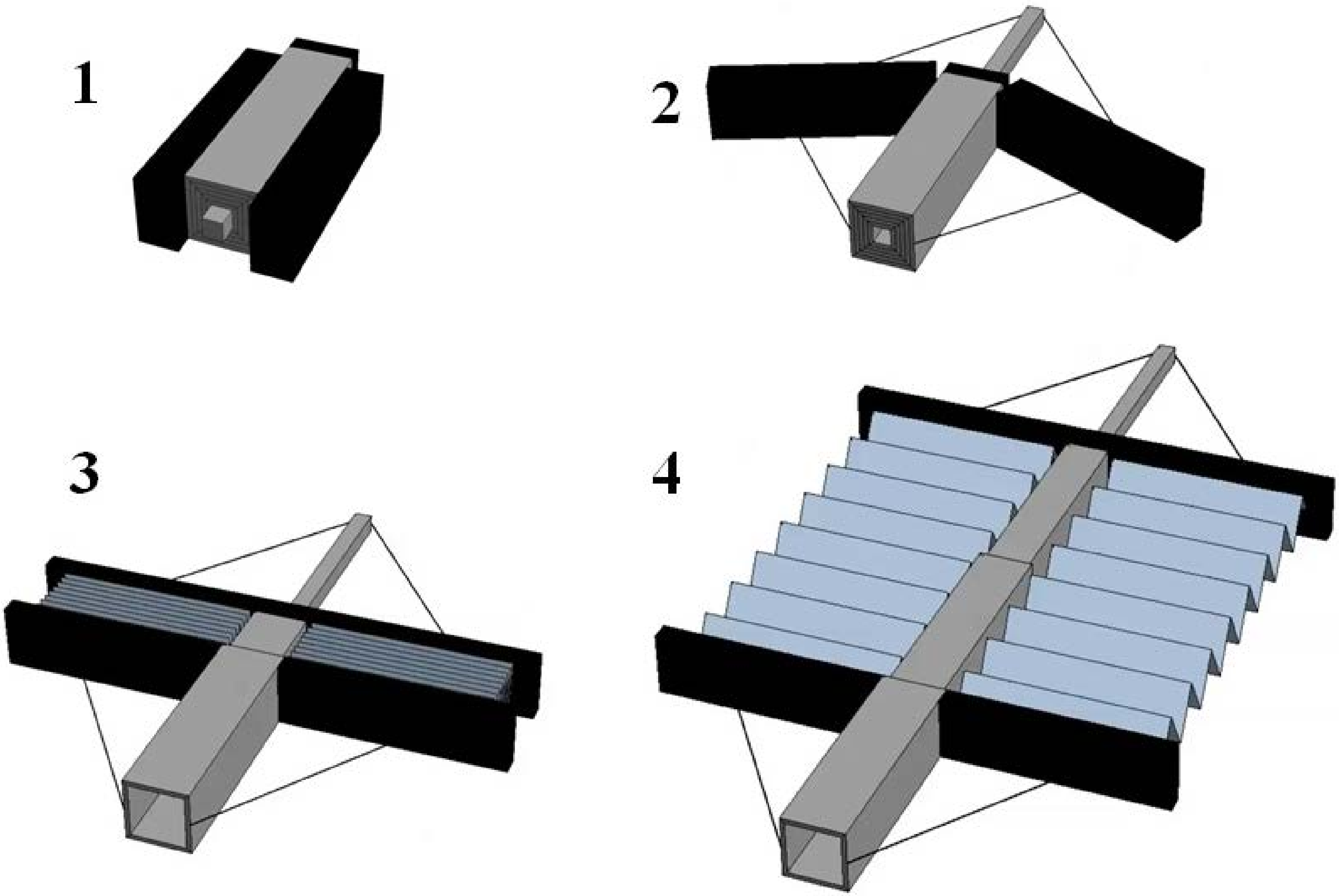




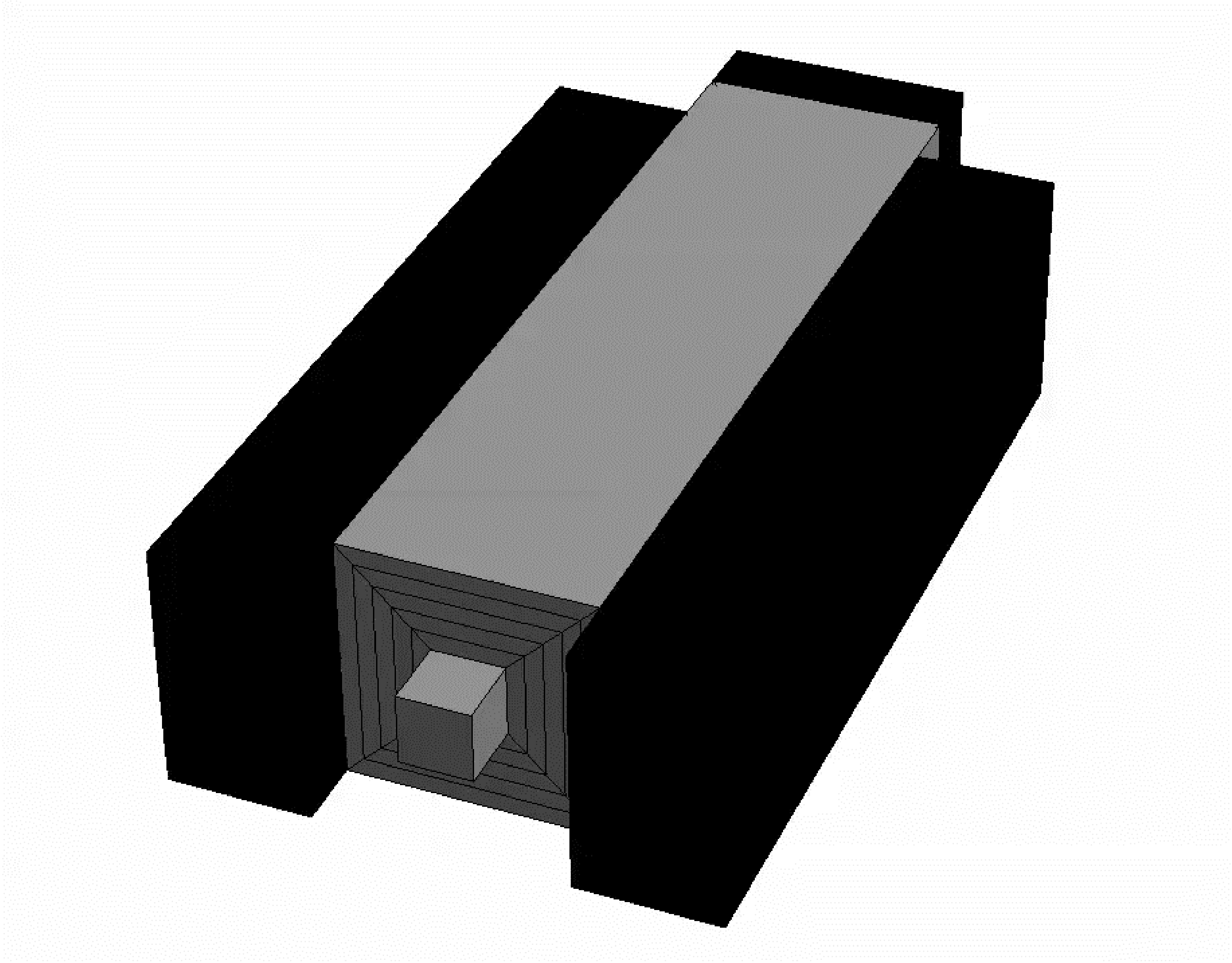
Cross-section of space station blanket support arm



LaRC's Compact Telescoping Array (CTA) Conceptual Deployment



CTA Deployment Animation



Compact Telescoping Array (CTA) Comments

➢ Positive Features

- Structure is its own deployment canister.
- Telescoping boom widely used in construction equipment.
- Not popular for space structures because most applications favor short packages. However, longer package is compatible with launch vehicles for manned Mars missions.
- Capable of high axial deployment force.

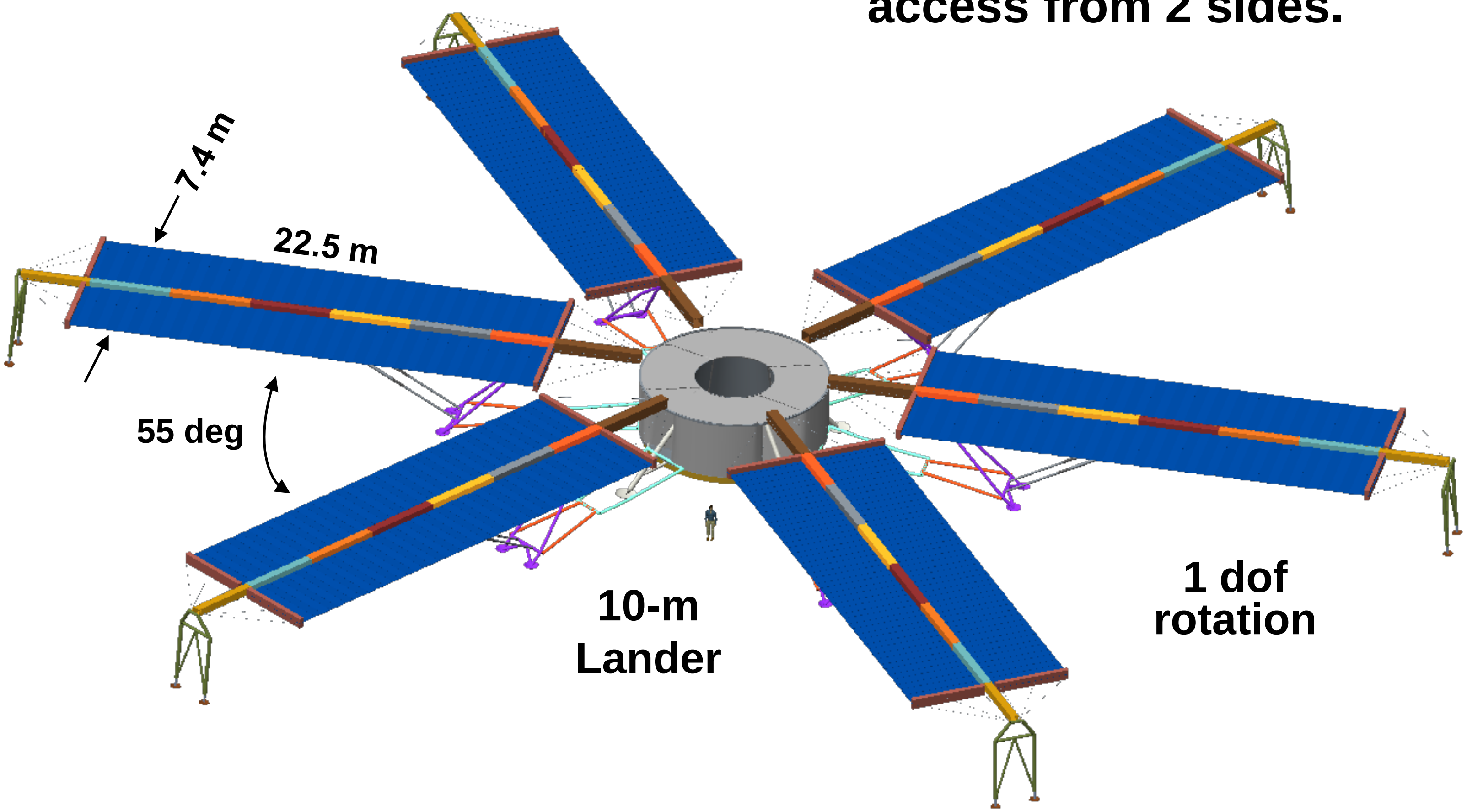
➢ Major Challenges include

- Lightweight “linear motor” for actuation.
- Lateral stability of deploying elements before lockup.
- Telescoping composite trusses, compact blanket support arms, mechanisms.
- Guy wire packaging, deployment, and tensioning.
- Deployable, drop-down legs that allow array rotation.

SAWS Baseline Design
Using Six CTA Solar Array Wings

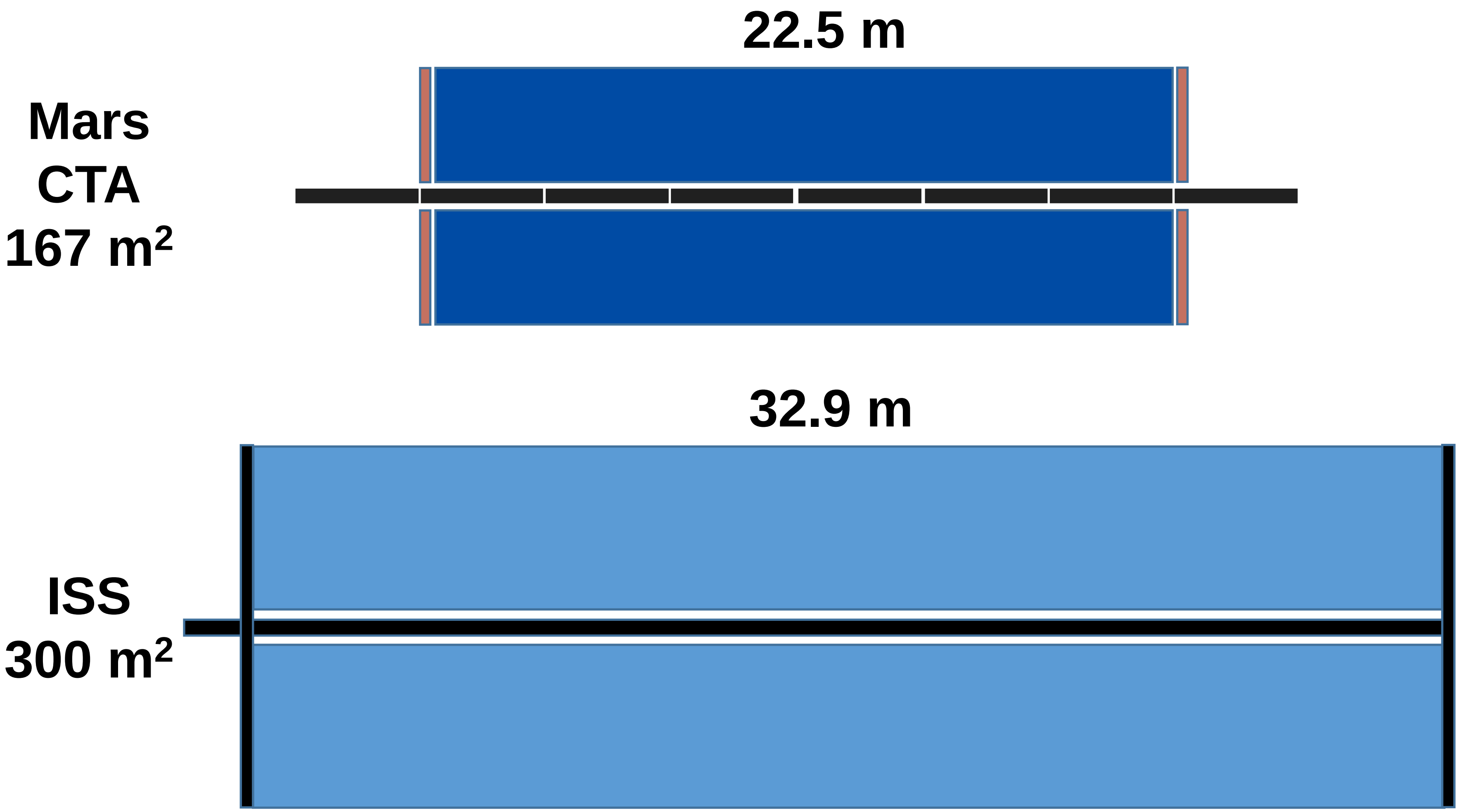
1000 m² total solar cell area.

Array spacing allows cargo access from 2 sides.

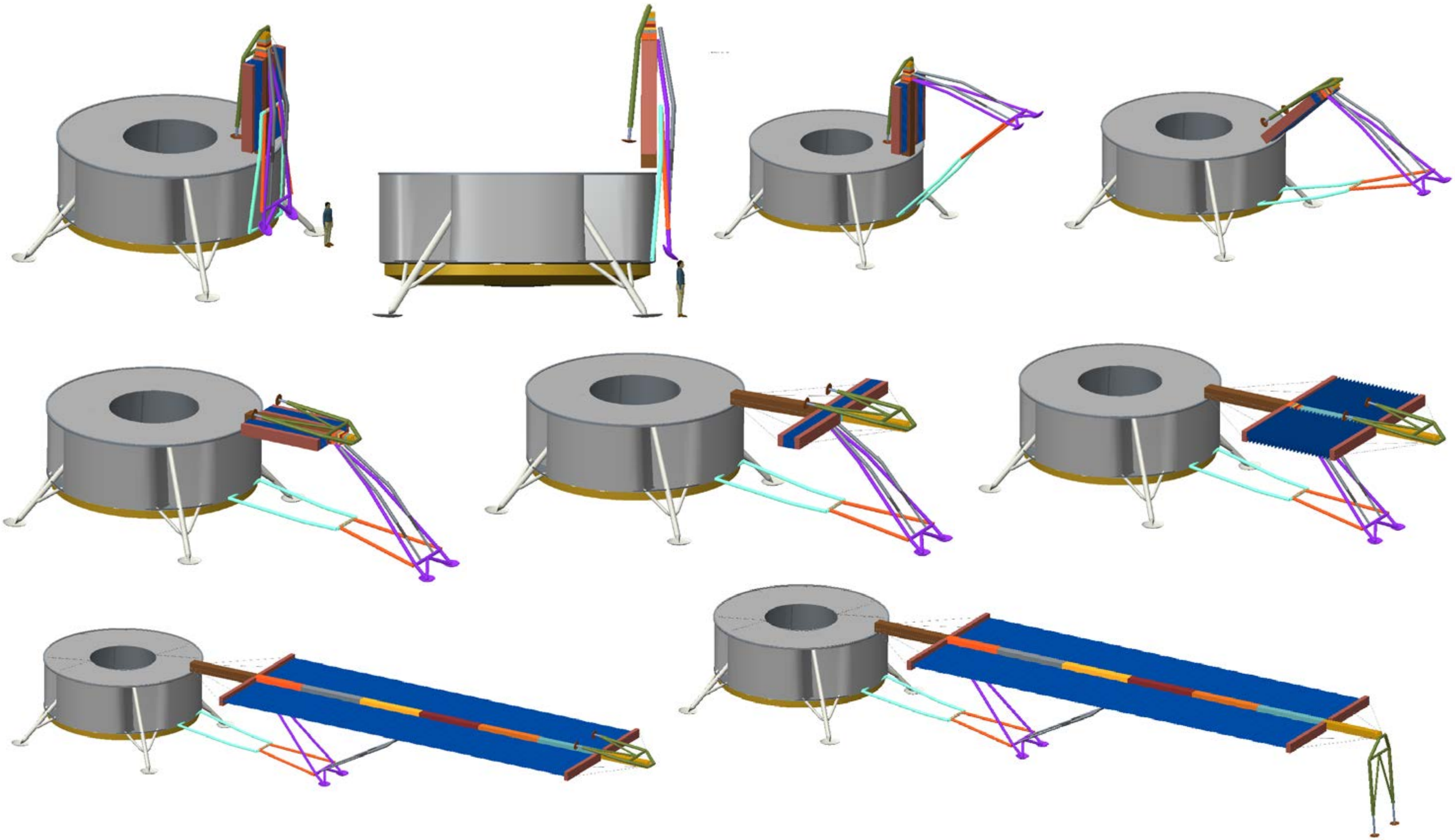


Note: Other Numbers of CTA Solar Array Wings are Possible (TBD).

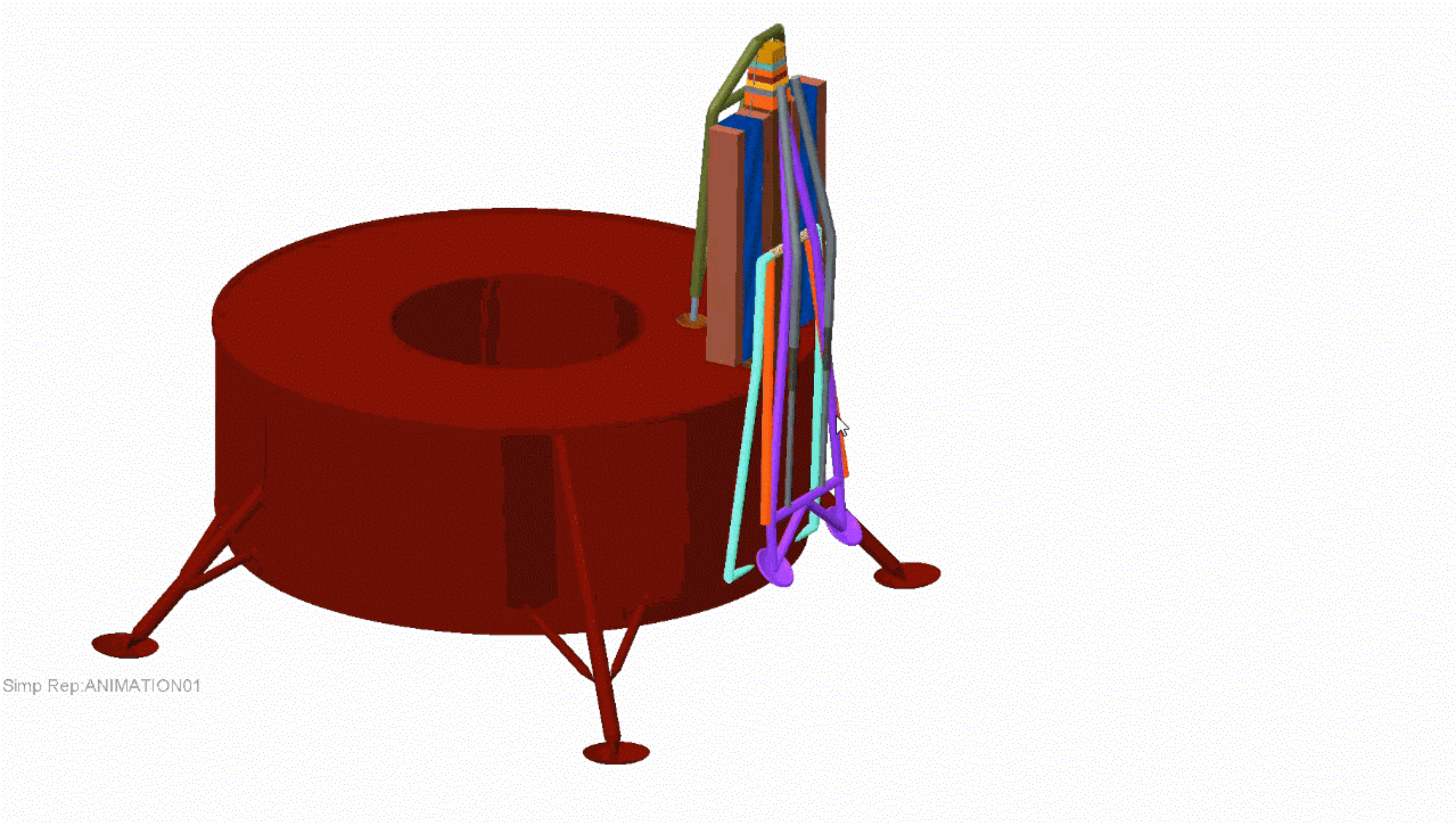
Size Comparison with ISS Solar Array Wings



Baseline Solar Array Conceptual Deployment



Baseline Solar Array Deployment Animation



Conclusions

- A 10 kW-class lightweight solar array concept for Mars developed using LaRC's Compact Telescoping Array.
- Solar arrays will recharge regenerative fuel cells for power through long eclipse periods (dust storms).
- Solar array design challenges include autonomous deployment/assembly, wind loads, and dust removal.
- Many trade studies underway to mature the design.
- New SBIR Phase 1 contracts supporting this project will be announced in mid-April 2017.

Acknowledgments

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