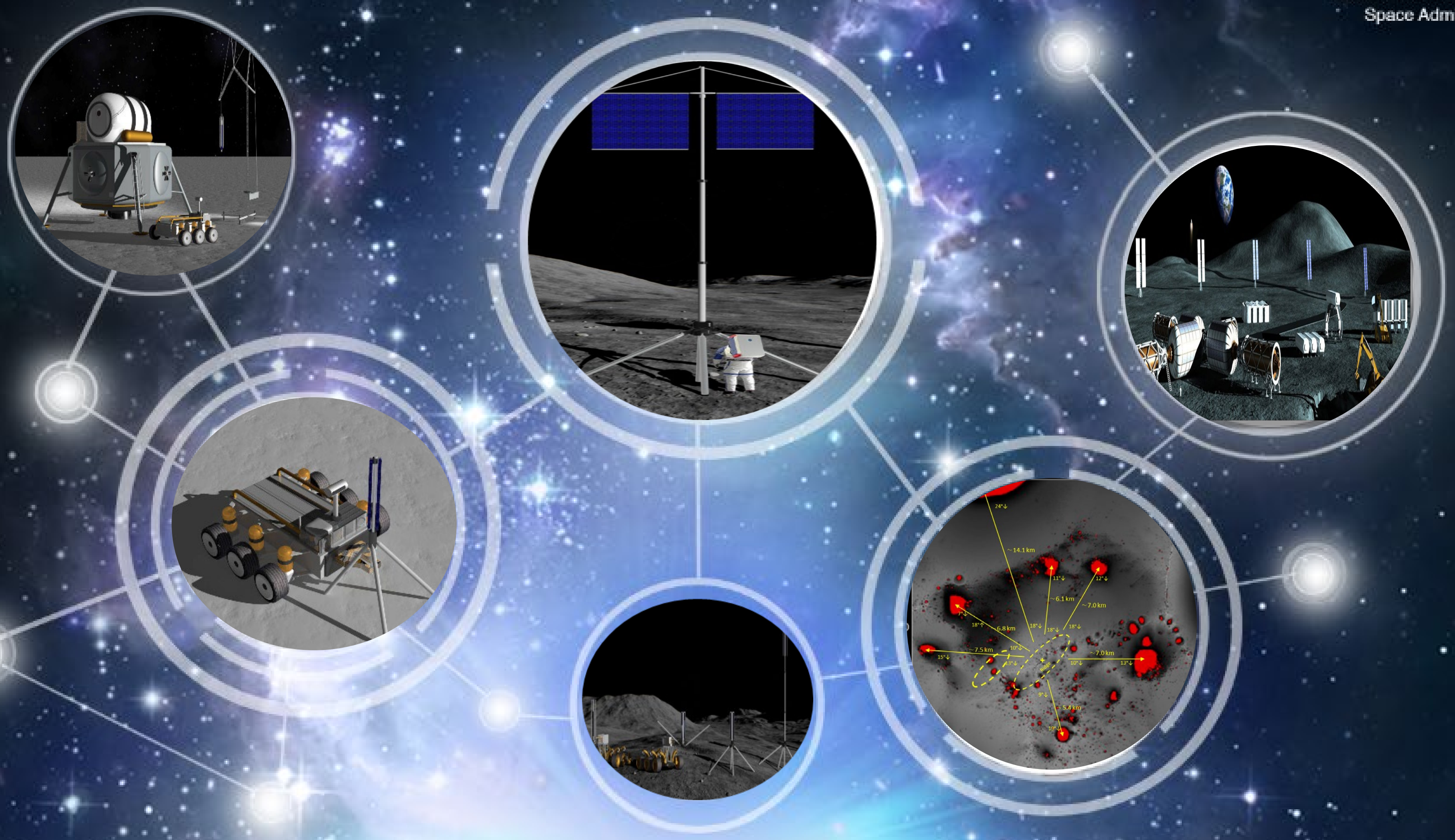
National Aeronautics and Space Administration



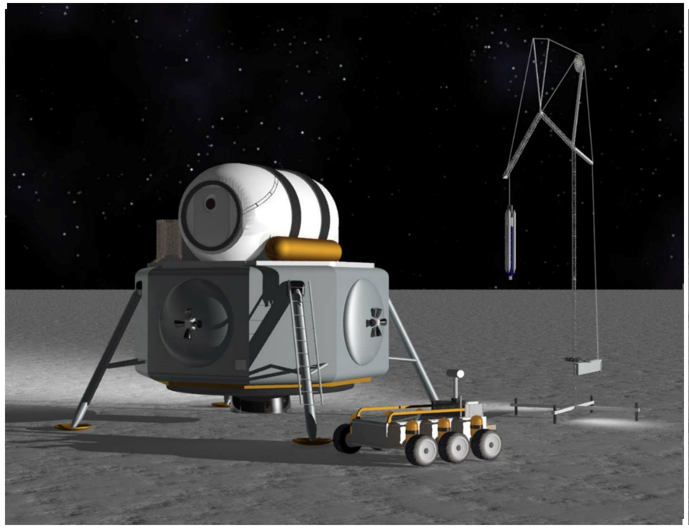
Space Technology Mission Directorate

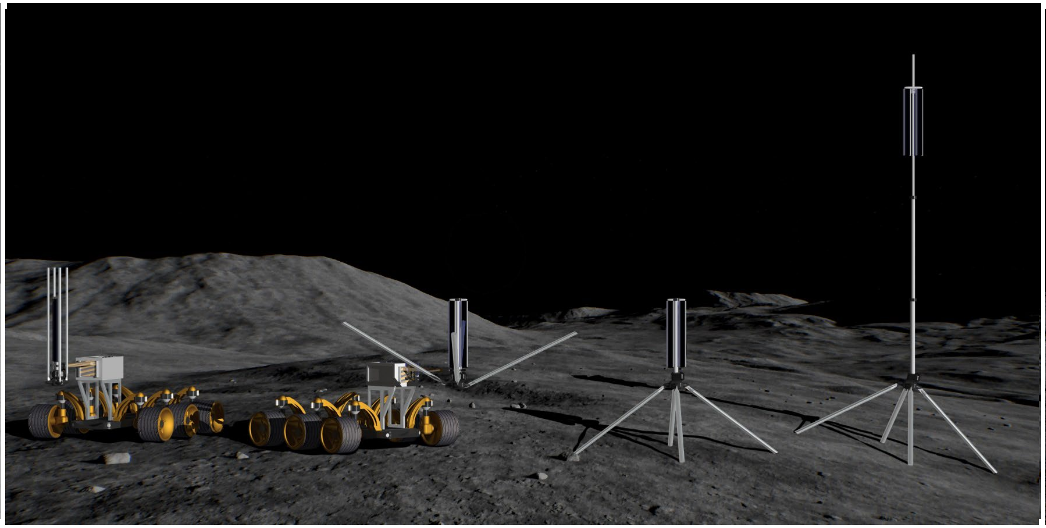
Game Changing Development Program - Vertical Solar Array Technology Project

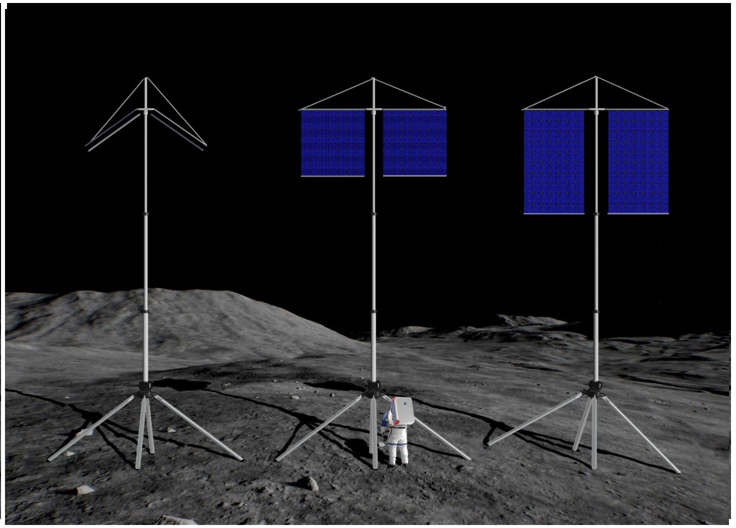
Chuck Taylor PM/Richard Pappa PI

VSAT Overview

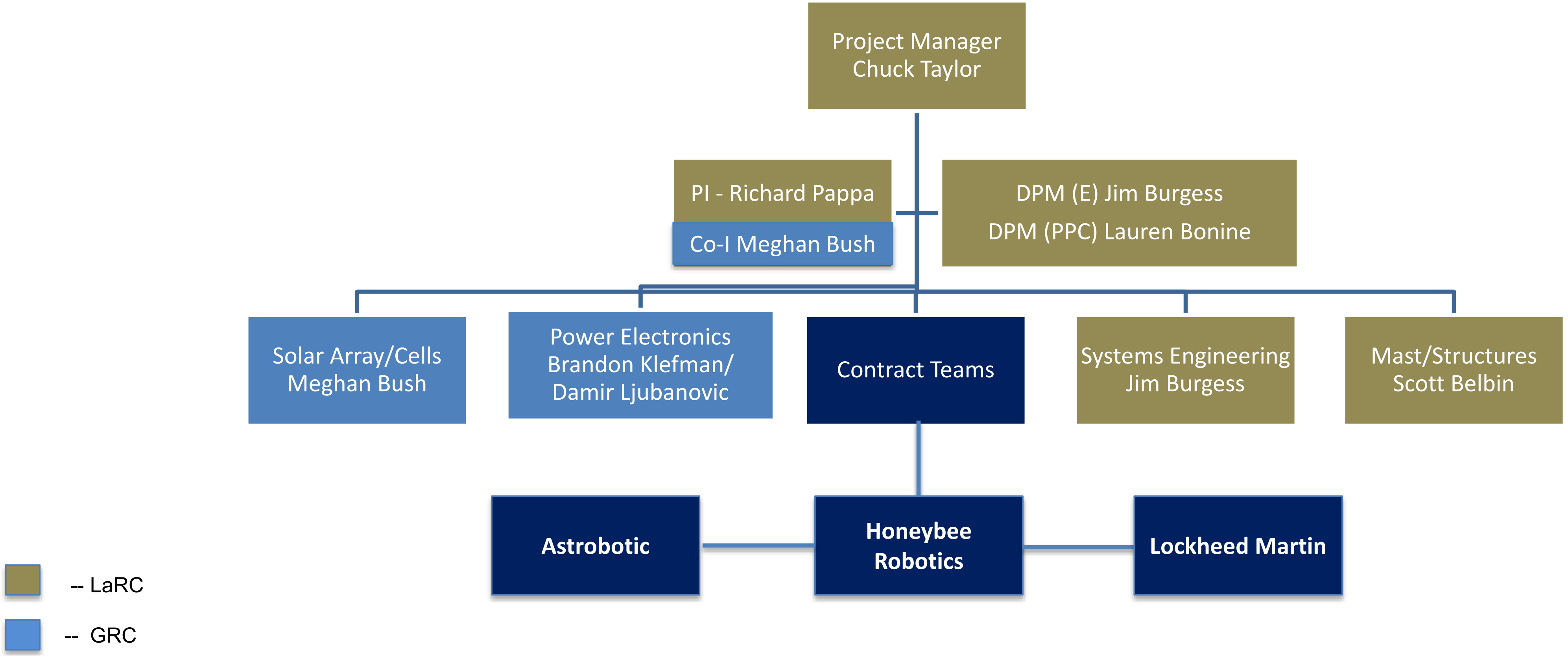
The Vertical Solar Array Technology (VSAT) project is focused on the development of solar array technologies necessary for sustained presence on the lunar surface circa 2028. Existing solar array structures and deployment system technologies are designed for either zero-g or horizontal surface deployment. VSAT is exploring vertical array deployment on extension masts of up to 20m in length in order to capture near continuous sun light at the lunar south pole.







Team Members / Project Org Slide



Mission Infusion & Partnerships

- Contributing partners and/or stakeholders
  - STMD and ESDMD sponsor the project
  - ESDMD is an obvious long-term stakeholder as the owner of future Lunar Exploration architectures

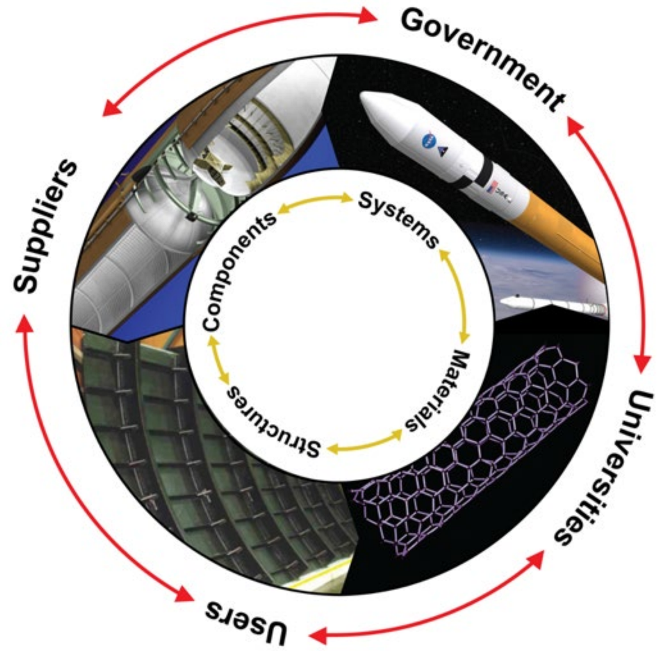
- Infusion/transition plan
  - The primary infusion path is via NASA's "Sustained Presence" period of Lunar Exploration circa 2028 and beyond
  - Providing primary power generation capability to lunar surface activities is the sole focus of VSAT
  - Transition plan calls for VSAT technology adoption by prime contractors engaged in Lunar Sustainment exploration architecture development
  - Transition may begin with Technical Demonstration Mission via a CLPS Lander

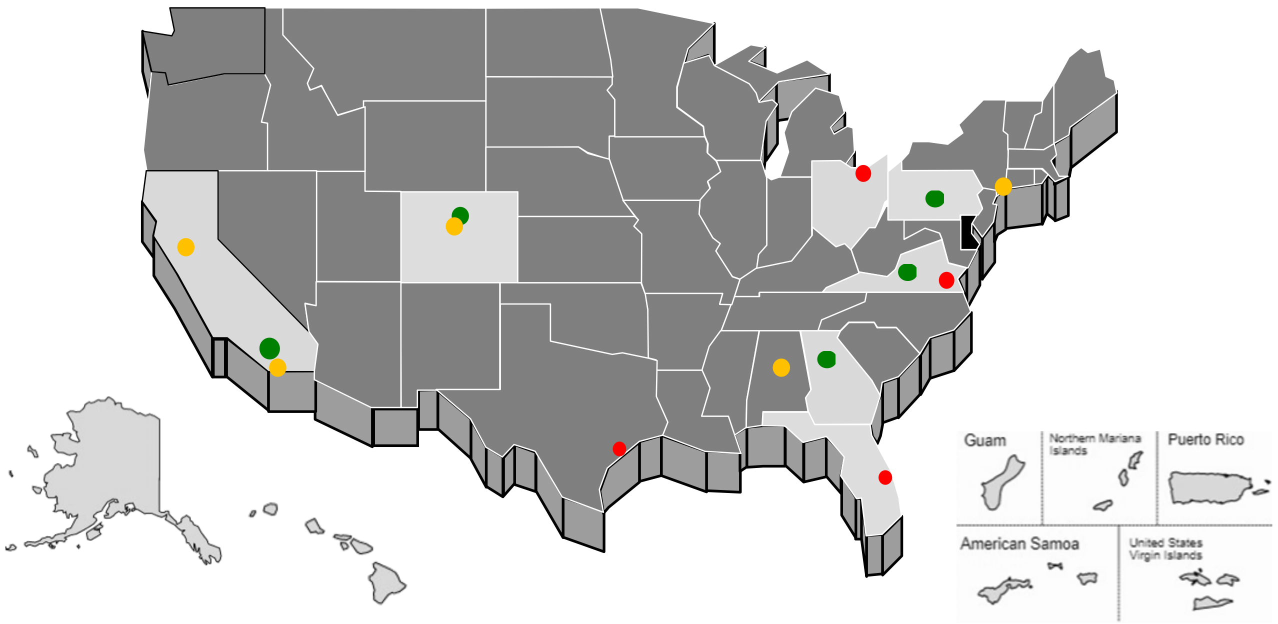
Collaborations & Partnerships

NASA Centers
- LaRC
- GRC
- KSC
- JSC

SBIR/STTR
- Dynovas
- Folditure
- Opterus
- Nexolve
- Ceres Robotics

Industry/Academia
- Astrobotic
- Honeybee Robotics
- Lockheed Martin
- VMI
- Georgia Tech ASDL





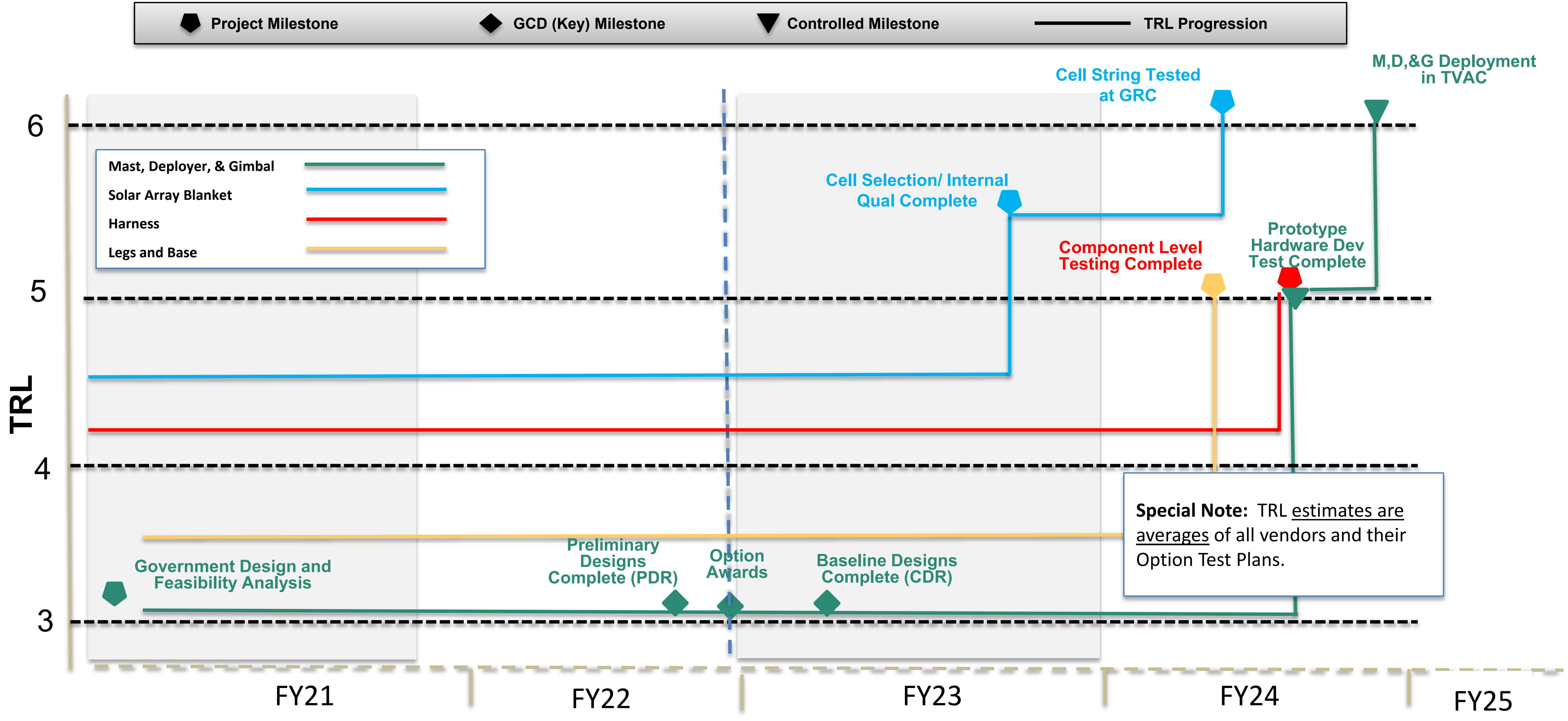
Collaborative multidisciplinary partnerships to leverage fiscal resources, ideas, knowledge & expertise.

VSAT
Technology Goals & Project Objectives

Technology Goals	
Goal #1	Autonomous system capable of vertical array deployment on extended mast on uneven terrain
Goal #2	Deployment mechanisms designed for reliable, autonomous retraction, and system mobility
Goal #3	Modular architecture component, adaptable to multiple mission architectures, designed to minimize mass and packing volume

Project Objectives	
Objective #1	Develop Design Reference Mission and Designs
Objective #2	Solicit competitive awards to industry to study (1) above and develop their own designs for a Lunar South Pole VSAT concept
Objective #3	Award hardware development contracts to one or more vendor for the development of a prototype VSAT system
Objective #4	Build and Test VSAT prototype hardware with an objective of reaching TRL 6 by project completion

VSAT
Lifecycle Milestone/Maturity Schedule



Status/Accomplishments

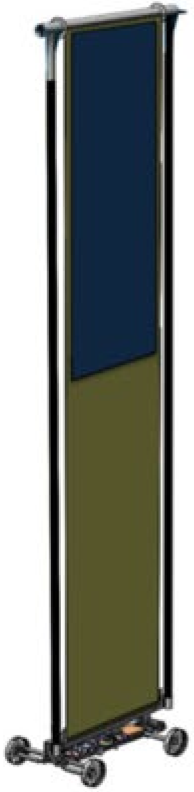
- During the Base Period five vendors completed initial designs and analyses to approximately a PDR level
- Three contractors received Option Awards:
  - Astrobotic
  - Honeybee Robotics
  - Lockheed Martin
- During Option Phase each vendor will develop and test a prototype that will be tested in TVAC conditions at JSC Chamber A in 2024
  - The goal is for all three designs to reach TRL 6 through this testing
- All three vendors have successfully completed their Detailed Design Reviews
  - ~CDR for their prototypes under test
- Project completed their GCD Technical Assessment Periodic Review in April 2023
- All three vendors are in final stages of design, procurement, and initial component fabrication
- Final TVAC testing at JSC will occur May through August of 2024

Three Designs From 10,000 Feet

Astrobotic

4.3 m

20.8 m



Honeybee Robotics

7.9 m

18.1 m

Lockheed Martin

4.2 m

19.2 m

Notable Design Features

Astrobotic	• Based on ROSA Solar Array • Self-propelled cart • 3 DOF parallel manipulator gimbal assembly • Proposed high-voltage AC power transmission
Honeybee Robotics	• Helical metal-band mast based on drill concept • Larger 12” diameter mast and wider solar cell area • New miniature silicon solar cells (mPower DS200)
Lockheed Martin	• Towed cart based on LM/GM lunar mobility vehicle • Thin-wall (0.019-0.026”), rolled lenticular mast • Heritage avionics

Sub-Contractors

Astrobotic	• Redwire DSS: ROSA solar array • GRC: Universal Modular Interface Converter (UMIC) • KSC: Electrodynamic Dust Shield
Honeybee Robotics	• mPower: “DragonSCALES” small Si solar cells • Ingenium: Thermal analysis • Opterus: Composite flex hinges
Lockheed Martin	• GM: Batteries and Lunar Mobility Vehicle tech • Goodyear: Wheels • KSC: Electrodynamic Dust Shield
All	• JSC: Chamber A thermal-vac tests

Honeybee Robotics

What is it?

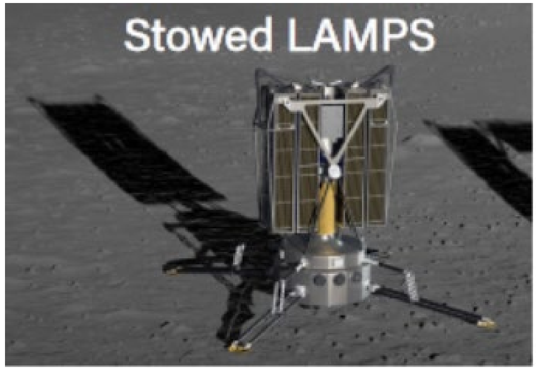
- LAMPS:Lunar Array Mast & Power System
- 10kW solar power
- Autonomous deploy/stow
- 10-year Lunar South Pole environment

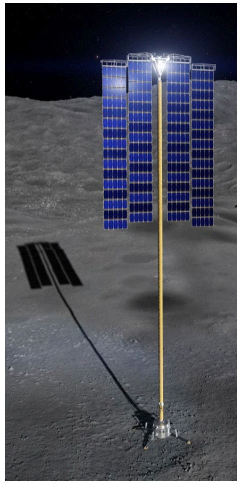
Technologies Matured in Option Phase

- Deployable/Retractable mast
- Accordion folded solar sails using flexible solar power modules
- Solar sail stowage
- High power flat umbilical & storage reel

Key Milestones & Status

✓ Oct 2022 – Kick off
✓ Dec 2022 – Concept review
✓ Jun 2023 – Design Review
- Dec 2023 - Component tests
- Feb 2024 – Subsystem tests
- May 2024 – TVAC at JSC Chamber A

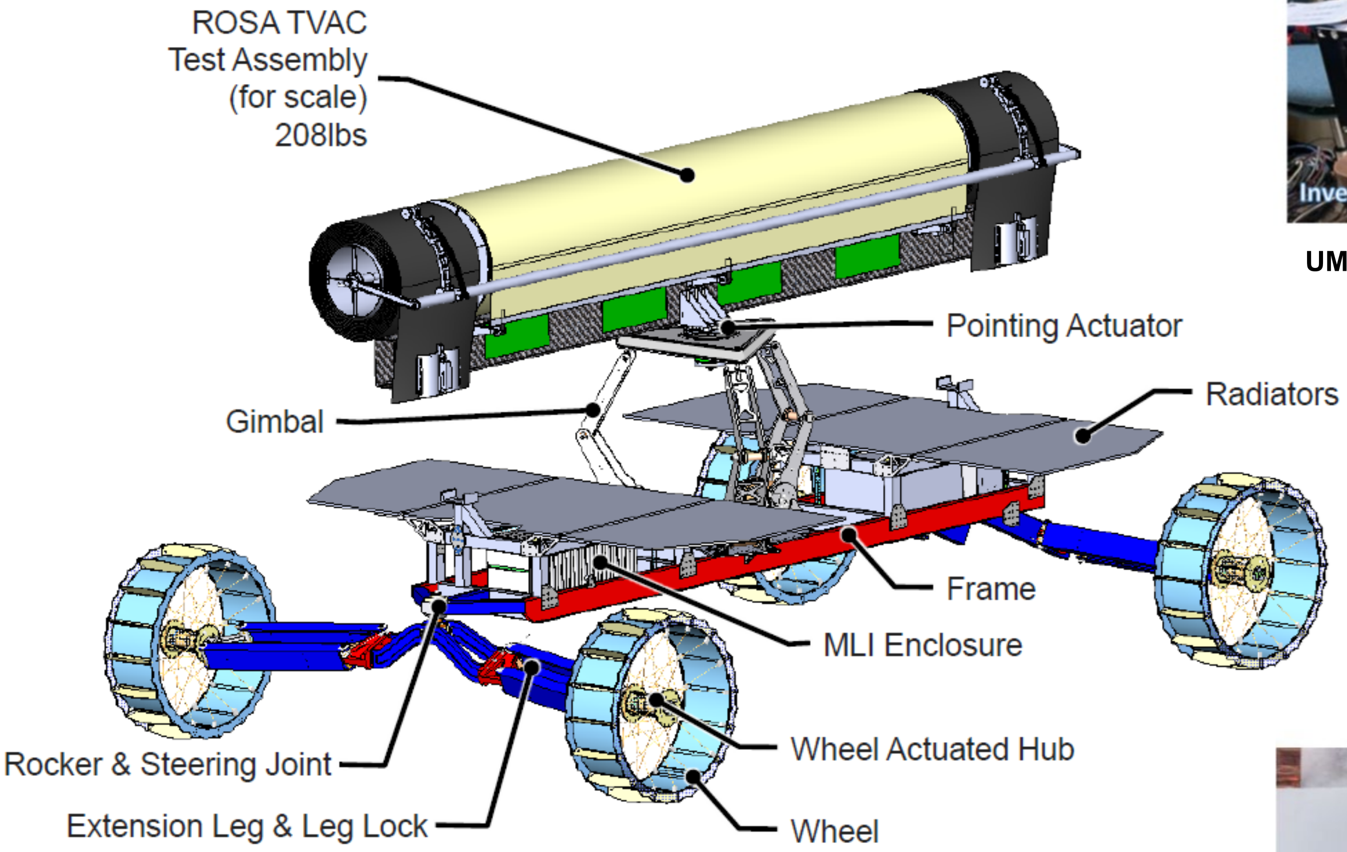


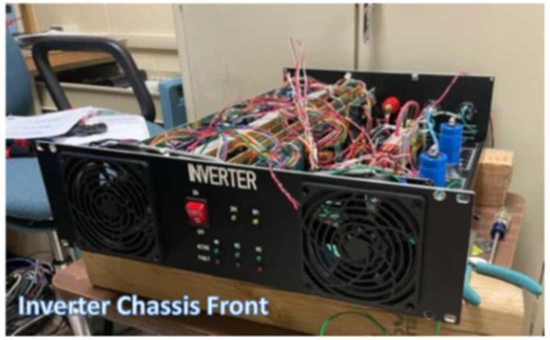

LAMPS Concept Lunar Deployment


Prototype Mast Deployment

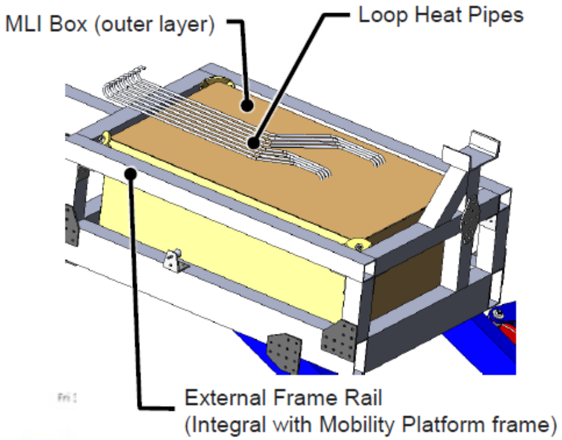

LAMPS in TVAC

Astrobotic (Mobility Platform)





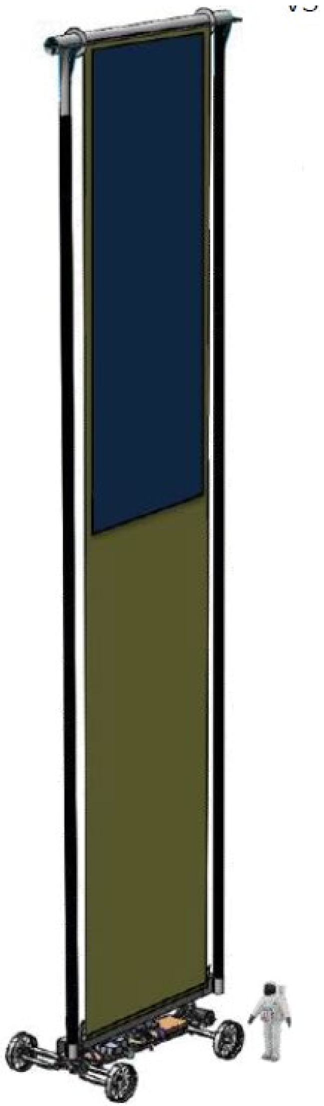
UMIC Chassis 3 KV Power Distribution Under Development



MLI Enclosure Avionics/Battery Box

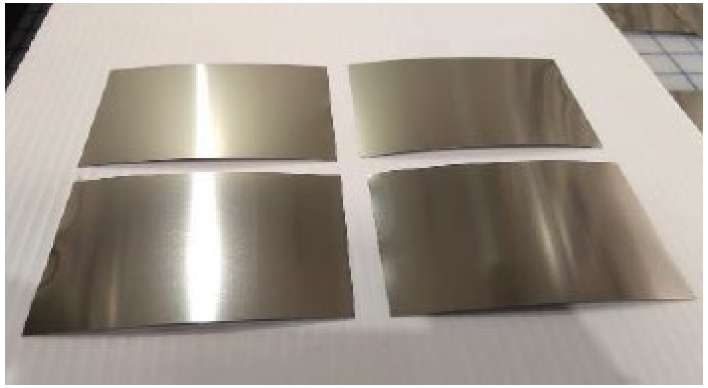
Electronic Dust Shield Testing

Astrobotic (ROSA)



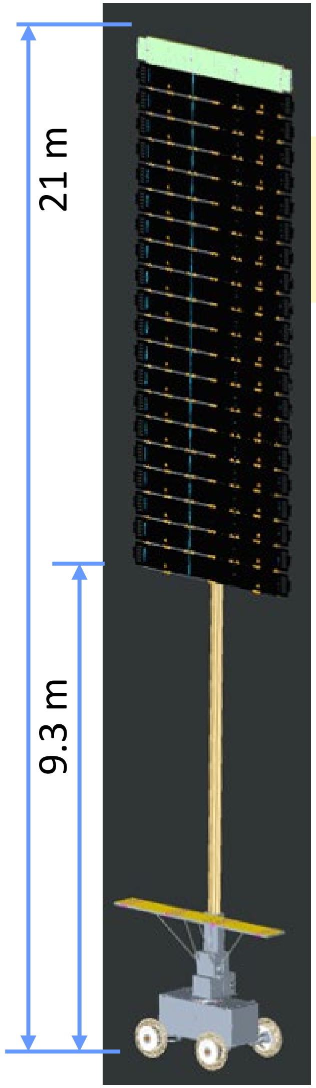
Deployment Retraction Testing

Carbon Laminate Mandrel Tube



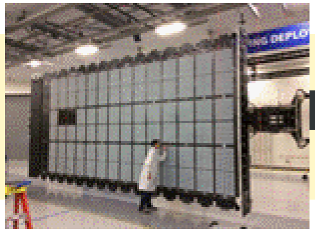
Completed Cell Mass Simulators

Lockheed Martin Design

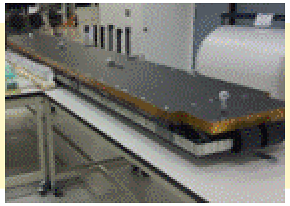


Deployed

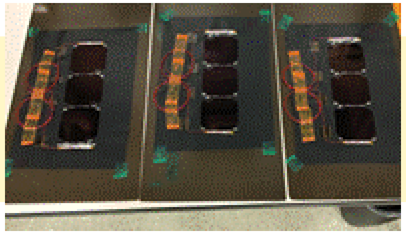
Flight heritage Multi-Mission (MM) solar blanket, container, mast, and deployer system



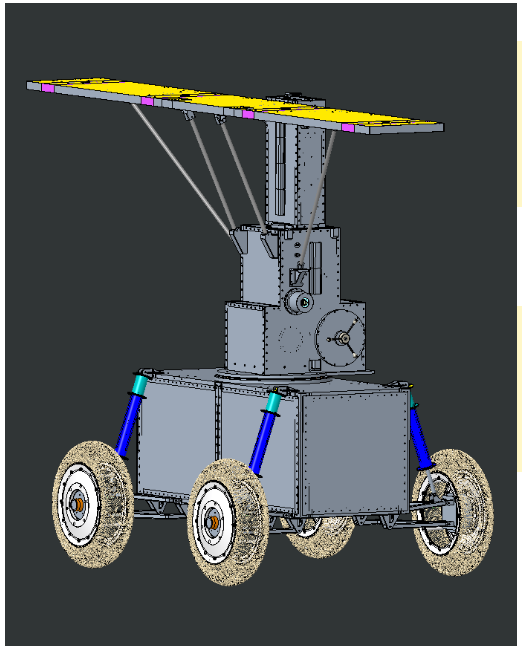
MM Solar Array



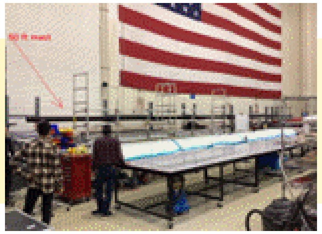
Blanket Assembly Container

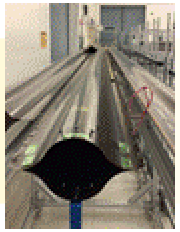


Delivered Solar Cell Coupons



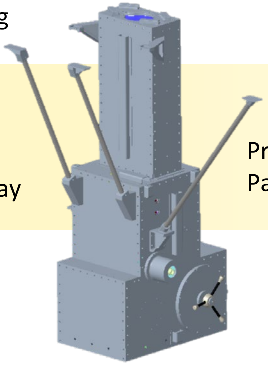
Stowed





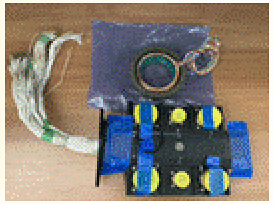
Mast samples ready for deployer testing

MM deployer modified
to also retract solar array



Prototype
Parts in Work

Deployer rollers



Slip ring

Machined deployer parts

Deployer motor

Lockheed Martin Design

Dust Mitigation

Radiator Coatings
Solar Cell Coatings
Mechanical Seals

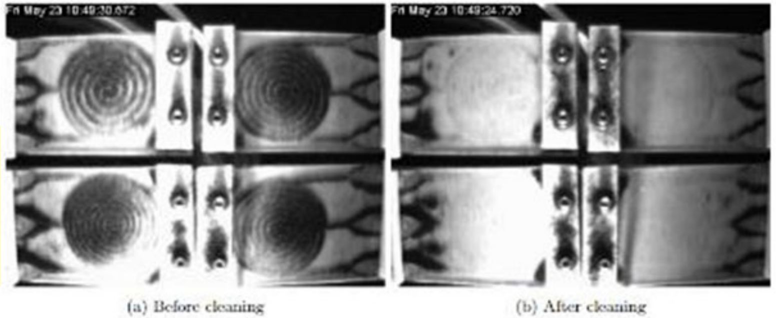
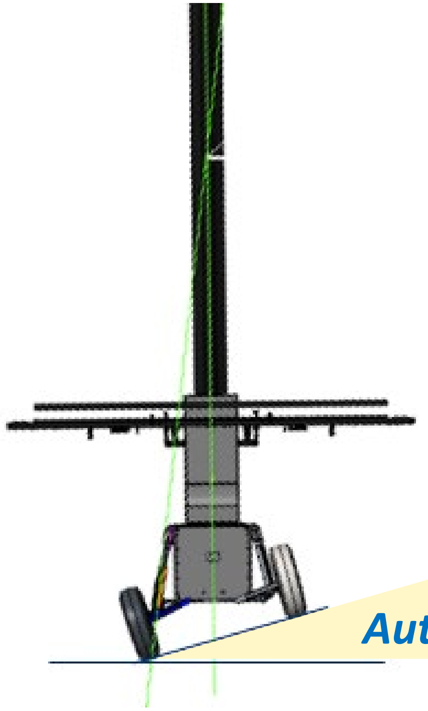


Figure from *History and Flight Development of the Electrodynamic Dust Shield*



Auto-leveling

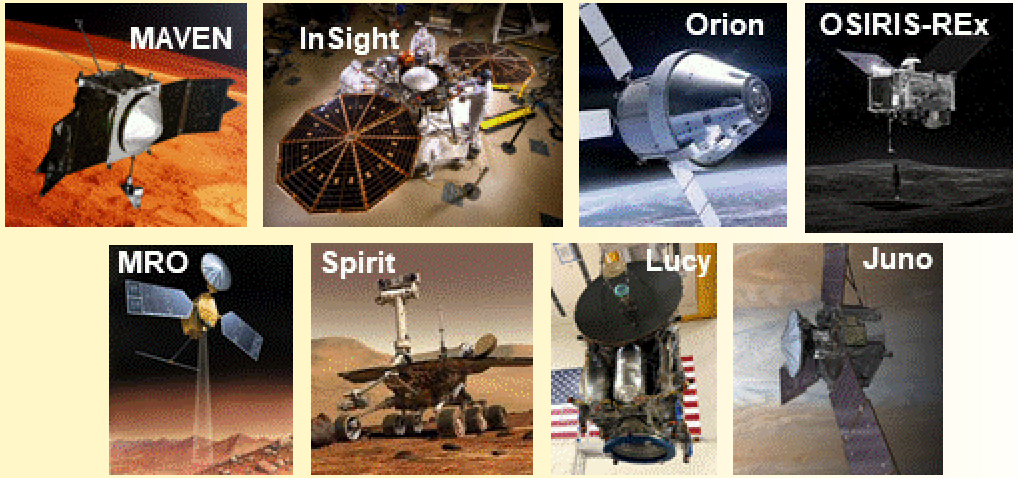
Next Generation Goodyear Tires

Thermal & Avionics TRL 6 – 9

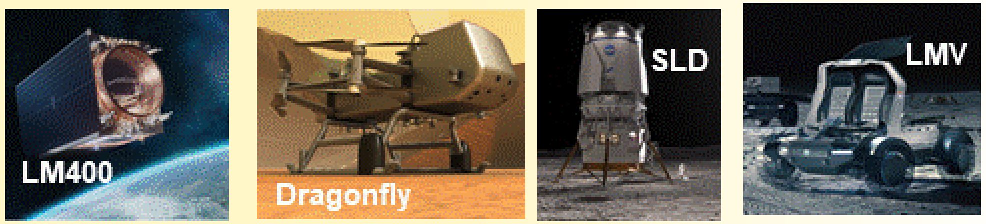
Radiators & MLI
Heaters & Switches
Temp Sensors

S-Band Comm
Low Gain Antennas
PDDU & Batteries

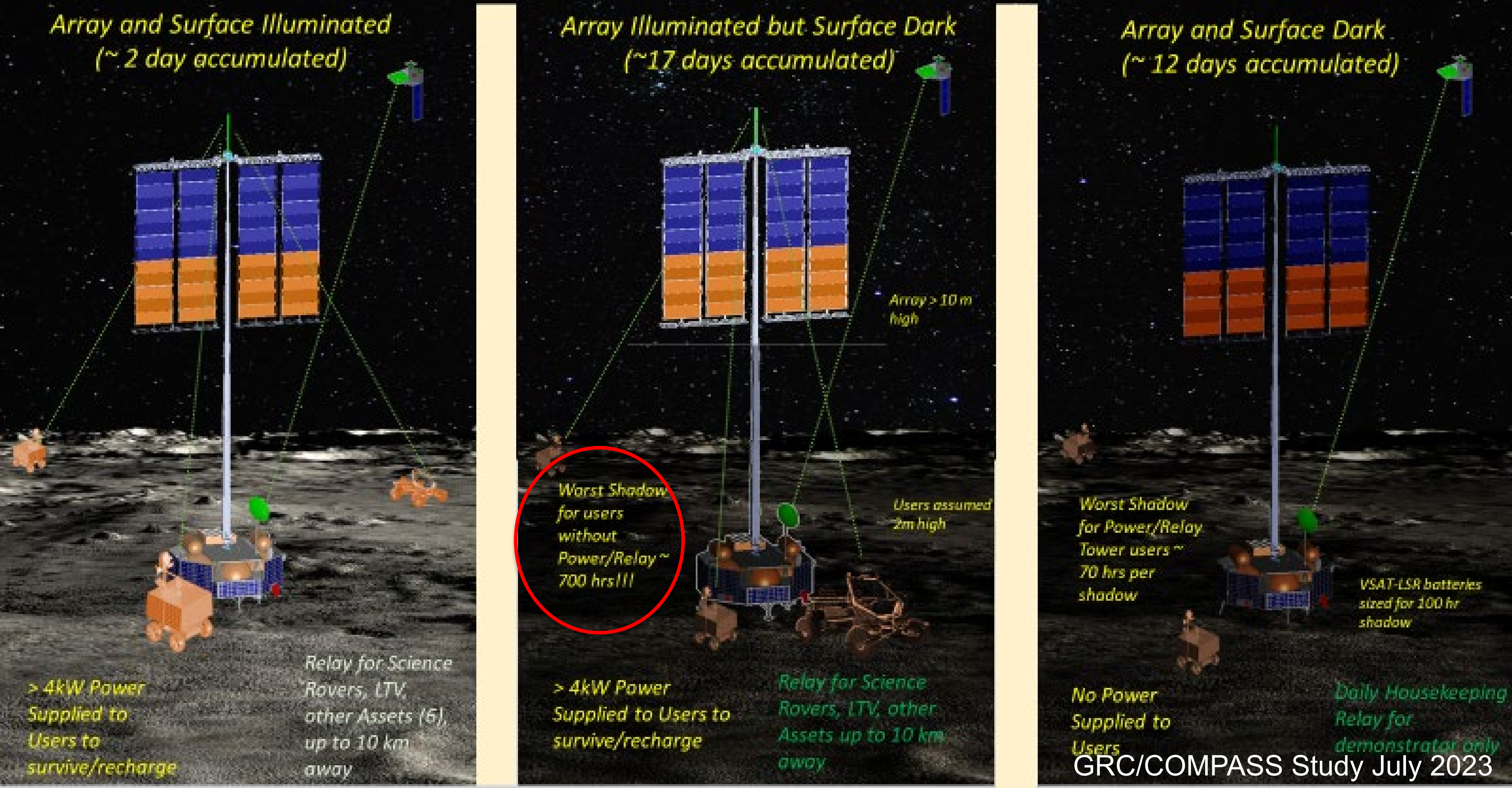
Flight Heritage



In Development



Operating CONOPs during a Winter Month, Shackelton Ridge (March 2029)



GRC/COMPASS Study July 2023

Project Assessment Summary

Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Technical – System mass above Project goals at PDR for all selected vendor designs Cost – Schedule – Programmatic -
Annual					Technical – System mass is stable and withing limits of CLPS lander, CR has been filed to modify KPP Schedule – There is a potential for issues related to TVAC scheduling in 2024 Programmatic -

Plans Forward and Transition / Infusion Plan

- Immediate infusion plan is to advertise the three selected vendor prototype efforts as possible steppingstones to both NASA and Industry efforts to put Power Architectures on the Lunar Surface

- Internal to STMD we will advocate for the VSAT project to begin work on a “Next Steps” Flight Demonstration solicitation where industry will be encouraged to build a flight version of the their VSAT concept for demonstration on the Lunar Surface circa 2028-2029.

Education/Public Outreach

EPO Involvement

- Participated in multiple LSIC working group meetings
- Funded 4 Student Interns at LaRC
- Funded 2 Student Interns at VMI
- Funded 1 Graduate Student at GT ASDL
- Mentored 2 Governors School High School Interns

EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead	
None	

Summary

- Completed Base Period VSAT design and analysis
- Completed Prototype design reviews and have begun fabrication
- All three vendors will conduct TVAC testing of their designs May - August next year
- The three approaches are very different and represent unique approaches to providing power on the lunar surface

Back Up

Project Plan - Milestone Status

Milestone Title (Mirror Project Plan)	Baseline Date	Actual Date	Variance Explanation
Status of milestones due since March 2022			
Milestone Title	10/1/17		Expected to slip 1 month due to test facility availability
Milestone Title	10/15/17	10/12/17	Completed ahead of schedule
Status of milestones due between September 1, 2022 – March 30, 2023	**Baseline Date**	**Planned Date**	
Milestone Title	11/1/17		Delays with the widget
Milestone Title	11/15/17		Delay of abc, CR submitted

VSAT

Risk Summary

Report date: 8/18/2023 **Trend since:** 6/30/2023

Likelihood	1	2	3	4	5
5					
4		VSAT-005	VSAT-001	VSAT-004	
3			VSAT-002 VSAT-007 VSAT-009	VSAT-008	
2				VSAT-006	VSAT-003
1					VSAT-010

Consequence

(RISK ID number shown as reference in 5x5 matrix)

Rank	Trend	Category	Approach	ID	Title
1	→	Sc Te	M	VSAT-004	Low TRL for Astrobotic PMAD Architecture
2	→	Te Sc	M	VSAT-008	Lockheed Martin Mast Retractibility
3	→	Te	R	VSAT-001	HBR Heat Rejection System
4	↓	Te	R	VSAT-003	Lockheed Martin Mast Buckling
5	→	Te Sc	W	VSAT-002	Astrobotic/Lockheed Martin Maturity of KSC EDS System
6	→	Co Te	W	VSAT-007	Contractor Cost Growth in an FFP Environment
7	→	Sc Te	W	VSAT-009	HBR Solar Cell Maturity
8	→	Te	R	VSAT-006	HBR Solar Array Mechanisms Dust Protection
9	→	Te	R	VSAT-005	HBR Unregulated Power to User
10	→	Te	R	VSAT-010	HBR Mast Unraveling

Co Cost Sc Schedule Te Technical Sa Safety

M Mitigate R Research W Watch A Accept E Elevate C Close Opportunity

☐ New ↑ Worsening ↓ Improving → No Change

VSAT

Risk: Low TRL for Astrobotic PMAD Architecture

Risk Identification								
Risk ID	**Risk Title**					**Risk State**	**Current LxC**	**Criticality**
VSAT-004	Low TRL for Astrobotic PMAD Architecture					Open	4x4	High
Statement Given that the Astrobotic PMAD architecture is designed around high voltage power transfer that is still at reasonable low TRL, there is a risk that the architecture elements will not be sufficiently developed to qualify as TRL 6 by the end of the VSAT Option period. This has multiple impacts as problems with design stemming from poor efficiency, heat generation, and mass growth will have ripple effects across the entire Astrobotic design.								
Context Astrobotic's power architecture relies heavily on the success of the Universal Modular Interface Converter (UMIC) development to support its 3-kV AC power grid and bidirectional power transfer. Concern that the UMIC will not be completed and delivered in time for TVAC testing to prove TRL6.								
Category 1	**Category 2**	**Approach**	**VSAT POC**	**Type**	**Discipline**	**Component**	**Category**	**Closure Date**
Sc	Te	Mitigate	Ljubanovic	Development P	Electrical	Avionics	Design	4/19/2024

Risk History & Handling Plan										
Action	**Description**	**POC**	**Cost ($)**	**Start Date**	**End Date**	**Status**	**L**	**C**	**RS**
Mitigate	UMIC Test at GRC	GRC	N/A		10/2/23	Active			
Mitigate	UMIC Delivery	GRC	N/A	10/2/23	10/2/23	Planned			
Mitigate	UMIC Test at Astrobotic	Ast	N/A	3/11/24	4/19/24	Planned			

Status: initial testing of the Universal Modular Interface Controller (UMIC), to be performed at Glenn Research Center (GRC), will begin to reduce this risk. Additional UMIC testing will be performed at Astrobotic next year.

VSAT

Risk: LM Mast Retractability

Risk Identification					
Risk ID	**Risk Title**	**Risk State**	**Current LxC**	**Criticality**	
VSAT-008	Lockheed Martin Mast Retractibility	Open	3x4	Moderate	

Statement

Given that the LM lenticular mast has not proven that the design is capable of retraction and proper stowage of wiring harness, there is a possibility that this will fail during testing, causing the system to not meet TRL advancement expectations and increase cost and schedule of product development.

Context

Category 1	Category 2	Approach	VSAT POC	Type	Discipline	Component	Category	Closure Date
Te	Sc	Mitigate	Pappa	Development P	Mechanical	Solar Array	Design	7/1/2024

Risk History & Handling Plan

Action	Description	POC	Cost ($)	Start Date	End Date	Status	L	C	RS
Mitigate	Test new retractor	LM	N/A	4/30/24	7/1/24	Planned			

Status: System Deployment/Retraction Test (Ambient) is scheduled for 4/30/24, to occur before TVAC testing starting in July.

VSAT

Risk: HBR Heat Rejection System

Risk Identification					
Risk ID	**Risk Title**		**Risk State**	**Current LxC**	**Criticality**
VSAT-001	HBR Heat Rejection System		Open	4x3	Moderate

Statement

There are several unknowns in Honeybee's present thermal analysis concerning heat generation and radiator sizing.

Context

NASA does not have clear insight into the designed system thermal/heat rejection system or the legs and leveling components for the proposed LAMPS system. NASA requested a delta design review of the base to include the avionics bay, thermal system, mast deployer, legs and the electromechanical systems.

Related risk = HBR-014, Thermal Model Maturity

Category 1	Category 2	Approach	VSAT POC	Type	Discipline	Component	Category	Closure Date
Te		Research	Blandino	Flight/Mission	Thermal		Design	9/30/2023

Risk History & Handling Plan

Action	Description	POC	Cost ($)	Start Date	End Date	Status	L	C	RS
Research	Perform thermal analysis and present results to NASA.	HBR	N/A	6/1/23	9/15/23	Active			

Status: Honeybee did not provide new information in this area at the Detailed Design Review. NASA issued a concern to Honeybee requesting additional information in this area A sensitivity study and updated thermal analysis is in progress and will be reported in September.

VSAT

Risk: LM Mast Buckling

Risk Identification					
Risk ID	**Risk Title**		**Risk State**	**Current LxC**	**Criticality**
VSAT-003	Lockheed Martin Mast Buckling		Open	2x5	Moderate

Statement

Given that the LM mast is a thin walled composite lenticular column, there is a possibility that the mast will buckle under the mass of the arrays in a lunar gravity environment, causing mission failure.

Context

Related Risk = LM-027, Mast Buckling

Category 1	Category 2	Approach	VSAT POC	Type	Discipline	Component	Category	Closure Date
Te		Research	Wright	Flight/Mission	Structural	Solar Array	Design	

Risk History & Handling Plan

Action	Description	POC	Cost ($)	Start Date	End Date	Status	L	C	RS
Research	Both analytical and experimental data will be required to fully retire this risk.	LM	N/A						
Mitigate	Perform buckling tests	LM	N/A			Proposed			

Status: LM increased layup with more composite material and updated analysis (risk recently reduced 3x5 to 2x5). Still need more information about CTE issue. Risk will remain open until buckling testing is completed.

VSAT

Risk: Title

Risk Identification									
Risk ID VSAT-002	**Risk Title** Astrobotic/Lockheed Martin Maturity of KSC EDS System					**Risk State** Open	**Current LxC** 3x3	**Criticality** Moderate	
Statement Given that both Astrobotic and LM are reliant on EDS technology from KSC, there is a chance that this dust removal technology is not at TRL 6 by the end of the VSAT Option									
Context Astrobotic and LM not carrying risks specifically associated with EDS technology maturity.									
Category 1 Te	**Category 2** Sc	**Approach** Watch	**VSAT POC** Taylor	**Type** GCD Developm	**Discipline**	**Component**	**Category** Design	**Closure Date**	

Risk History & Handling Plan									
Action	**Description**	**POC**	**Cost ($)**	**Start Date**	**End Date**	**Status**	**L**	**C**	**RS**

Status: The VSAT team at GRC is working with KSC dust mitigation team to better understand is risk.

VSAT

Risk: Contractor Cost Growth in an FFP Environment

Risk Identification									
Risk ID	**Risk Title**						**Risk State**	**Current LxC**	**Criticality**
VSAT-007	Contractor Cost Growth in an FFP Environment						Open	3x3	Moderate
Statement									
Given that all VSAT contracts are FFP contracts, there is a possibility that vendors will run into cost issues as the project continues, and this in turn may force contractors to reduce technical effort to stay within cost.									
Context									
Category 1	**Category 2**	**Approach**	**VSAT POC**	**Type**	**Discipline**	**Component**	**Category**	**Closure Date**	
Co	Te	Watch	Taylor	Development P				9/30/2024	

Risk History & Handling Plan									
Action	**Description**	**POC**	**Cost ($)**	**Start Date**	**End Date**	**Status**	**L**	**C**	**RS**
Watch	Monitor for specific cost issues	Taylor	N/A	9/30/22	9/30/24	Active			

Status: Continue to watch for potential issues.

VSAT

Risk: HBR Solar Cell Maturity

Risk Identification								
Risk ID VSAT-009	**Risk Title** HBR Solar Cell Maturity					**Risk State** Open	**Current LxC** 3x3	**Criticality** Moderate
Statement Given that HBR has chosen to use Si cell technology for their array, there is a probability that the Si cells will not be qualified for GEO/Lunar use by the end of the project.								
Context								
Category 1 Sc	**Category 2** Te	**Approach** Watch	**VSAT POC** Bush	**Type** Development P	**Discipline** Electrical	**Component** Solar Array	**Category** Design	**Closure Date**

Risk History & Handling Plan										
Action	**Description**	**POC**	**Cost ($)**	**Start Date**	**End Date**	**Status**	**L**	**C**	**RS**
Watch	DS200 Qualification testing	Bush							

Status: Awaiting completion of testing for the DS200.

VSAT

Risk: HBR Solar Array Mechanisms Dust Protection

Risk Identification								
Risk ID	**Risk Title**					**Risk State**	**Current LxC**	**Criticality**
VSAT-006	HBR Solar Array Mechanisms Dust Protection					Open	2x4	Moderate
Statement Given that the HBR Solar Array Deployment system includes multiple motors, actuators, and joints at the top of the mast that will be unprotected from the lunar dust environment, there is a possibility that these mechanisms will bind or exhibit unusual wear.								
Context								
Category 1	**Category 2**	**Approach**	**VSAT POC**	**Type**	**Discipline**	**Component**	**Category**	**Closure Date**
Te		Research	Belbin	Flight/Mission	Mechanical	Solar Array	Design	

Risk History & Handling Plan										
Action	**Description**	**POC**	**Cost ($)**	**Start Date**	**End Date**	**Status**	**L**	**C**	**RS**
Research	Evaluate HBR design	Belbin	N/A			Planned			
Mitigate	Risk reduction testing					Proposed			

Status: Langley team will be evaluating design and review for opportunities for risk reduction testing.

VSAT

Risk: HBR Unregulated Power to User

Risk Identification								
Risk ID VSAT-005	**Risk Title** HBR Unregulated Power to User					**Risk State** Open	**Current LxC** 4x2	**Criticality** Moderate
Statement Given that the present HBR design does not provide for the regulation of solar array power, there is a high probability that an additional PMAD component will have to be designed and procured, or individual customers will have to ensure that their system architectures include the solar array regulation function.								
Context								
Category 1 Te	**Category 2**	**Approach** Research	**VSAT POC** Ljubaonvic	**Type** Flight/Mission	**Discipline** Electrical	**Component** Avionics	**Category** Design	**Closure Date**

Risk History & Handling Plan									
Action	**Description**	**POC**	**Cost ($)**	**Start Date**	**End Date**	**Status**	**L**	**C**	**RS**
Research	TIM to discuss further	HBR				Planned			

Status: Have requested a Technical Interchange Meeting with HBR to discuss this risk.

VSAT

Risk: HBR Mast Unraveling

Risk Identification					
Risk ID	**Risk Title**	**Risk State**	**Current LxC**	**Criticality**	
VSAT-010	HBR Mast Unraveling	Open	1x5	Moderate	

Statement

Given that the DIABLO mast contains a significant number of rivets must remain in the corresponding holes in adjacent bands, there is the possibility due to excessive motion or fatigue enough of the rivets will pull out of the holes, fail, or fail the edges of the holes, resulting in a catastrophic failure of the mast.

Given that the structural integrity of the DIABLO mast requires thousands of rivets to remain in corresponding holes in adjacent bands, there is a possibility that excessive motion or fatigue will cause the mast will unzip, resulting in collapse of the solar array.

Context

Concern is that rivets may loosen or tolerance may very etc and there maybe a “spontaneous disassembly”

Category 1	Category 2	Approach	VSAT POC	Type	Discipline	Component	Category	Closure Date
Te		Research	Pappa/Wright					

Risk History & Handling Plan

Action	Description	POC	Cost ($)	Start Date	End Date	Status	L	C	RS
Research	Hold TIM to discuss	HBR			TBD	Planned			

Status: Have requested a Technical Interchange Meeting with HBR to discuss this risk.

VSAT Key Performance Parameters (KPP)

Key Performance Parameters				
Key Performance Parameter	**Units**	**State of the Art**	**Threshold Value**	**Project Goal**
KPP 1: Terrain Stability	Terrain Slope in degrees, combined with mast height	N/A	10^o / 5	15^o / 10
KPP 2: Mast Height[1]	Meters	N/A	5	10
KPP 3: Autonomous Deployment and Retraction	Deployment and Retraction Cycles	1	5	10
KPP 4: Specific Power[2]	W/kg	100	45	65
Known Mission Requirements:				
Array Power[2]		50kW	10kW	
Sun Tracking	Single Axis Degree Rotation	360	360	
Thermal Environment[3]	Degrees Celsius	-180C +175C	-180C +175C	
Specific Stowed Volume[2]	kW/M3	60	40	60

Notes:

1) Mast Height – Mast height measured from the surface to the point at which the solar array blanket attaches to the lower cross boom.

2) State of the Art refers to Zero-G solar array, Threshold and Goal values calculated for entire system mass at array Beginning of Life (BOL)

3) Thermal Environment - System must be capable of surviving and operating in Lunar South Pole thermal environment (-180C^0 to 175C^0) without external systems

Technical Assessment

Technical Capability Elements	TRL			TRL Verification
	Entry	Exit	Current	
Array Deployment Drive Unit	3	6	3	Option Test Period (MS ID C5)
Array Gimbal	3	6	3	Option Test Period (MS ID C5)
Array Blanket	4	6	4	Option Test Period (MS ID C5)
Harness/PMAD	4	6	4	Option Test Period (MS ID C5)

Assessment is based on GRD, several vendors proposed significant heritage sub-system reuse from zero G assets

<Project Name> Key Performance Parameter (KPP) Status

Key Performance Parameters						
Parameter	Units	State of the	Threshold	Project	C	for the provided / ected Exit Value
<KPP paramete						mate based on / e Carlo analysis
<KPP paramete						antiated based / P ground test (4)
<KPP parameter						Verified

Notes:
Technical Basis of E
(1) SOA comparison
(2) Terrestrial day/ni ... addtl. cycles.
(3) SOA comparison t
(4) Test concluded M
(5) Lunar Equator day

Please provide KPP Current Status updates via the **Measuring Advancements of KPP Evolution (MAKE) tool**:

Location on Teams: 'MAKE' ---> 'MAKE_FY22_APR ---> Files (Identify the Excel file for your project)

This location can be found via this Link

Complete the table on this slide of the APR presentation via either:

1) Utilizing the 'PowerPoint Table' tab from MAKE and then copy and paste status information on this slide

2) Entering data in both the MAKE tool and on this slide template

(contact Will Grier – will.j.grier@nasa.gov for further help)

If KPPs have not yet been approved via PCD or PP, please keep this note:

KPPs are not yet in an approved state.