AggieSat Laboratory

Synthetic Orbital Landing Area for Crater Elimination (SOLACE)

Principal Investigator: *Helen Reed, Ph.D, P.E.*
Program Manager: *Shirish Pandam, B.S. (G, AERO)*
Project Manager: *Kamalika Bose (UG, MXET)*
Chief Engineer: *Nicholas X. Siodlarz, B.S. (G, BUSI)*

06/26/24

Personnel

Command and Data Handling
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Brayden Hudson, (UG, ESET)
Aidan Jones, (UG, GENE)
Daniel Vinnik, (UG, ESET)

Communications
Lead: Thomas Honeywill, (G, ECEN)
Ayush Mishra, (UG, AERO)
Josh Wu, (UG, CPEN)

Electronics and Power Systems
Lead: Thomas Lopez, (UG, ESET)
Kyle Carlson, (UG, ECEN)
Jaret Pinkerton, (UG, MXET)

Guidance, Navigation, and Control
Lead: Travis Mason, (UG, AERO)
Joseph Carbone, (UG, AERO)
Adam Knight, (UG, AERO)

Surface, Integration, and Test Environment
Lead: Akshyat Dumka, (UG, MXET)
Kai Elmore, (UG, AERO)
Abhinav Sivakumar, (UG, MXET)
Bao Tran, (UG, AERO)

Thermal, Mechanics, and Structures
Lead: Thomas Magee, (UG, AERO, PHYS)
Brandon Elliott, (UG, AERO)
Theresia Heimer, (UG, ITED)
Pan Zhou, (UG, MEEN)

Key
UG -Undergraduate
G - Graduate

AERO - Aerospace Engineering
CPEN - Computer Engineering
ECEN - Electrical Engineering
ESET - Electronic Systems and Engineering Technologies
ENGR - General Engineering
GEOG - Geography
ITDE - Interdisciplinary Engineering
MATH - Mathematics
MEEN - Mechanical Engineering
MXET - Mechatronics Engineering
PHYS - Physics

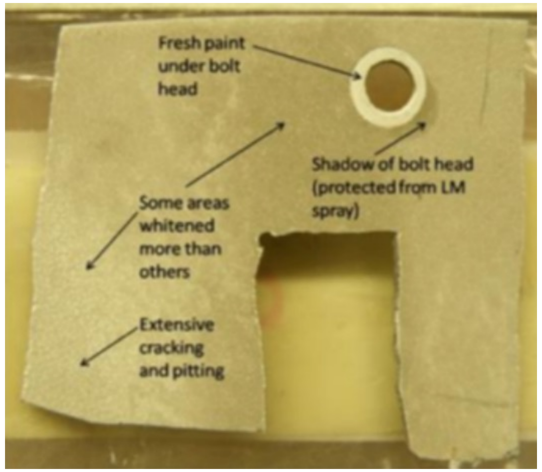
About AggieSat Laboratory

- *“The AggieSat Laboratory Student Space Program trains university students in systems engineering through hands-on experience in the design, building, testing, and operation of space-related systems.”*
- Largest university satellite program in the country
- 7 simultaneous projects this year
- AggieSat 6 – oldest project
- SOLACE – youngest project

Presenting: *Shirish Pandam (Program Manager)*

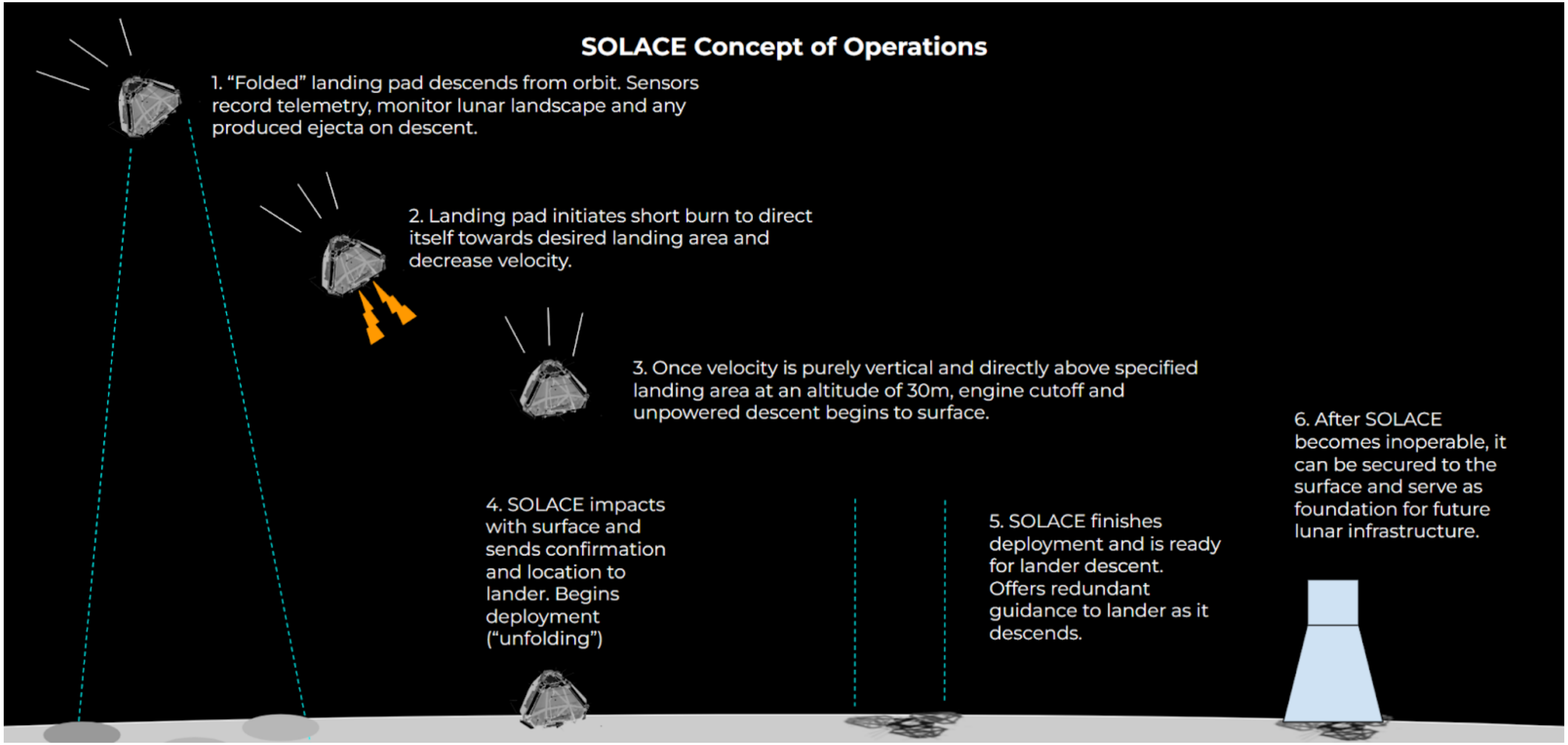
PSI-Induced Cratering and Dispersal

- Cratering: removal of local regolith to form "craters" in the surface
- Dispersal: dust and rocks blown from the landing site at high speeds
- Notable problems caused in previous planetary missions
  - Apollo missions: Engine overpressure, false velocity readings
  - Apollo 12 and *Surveyor III*: Damage to *Surveyor III* from regolith sandblasting
  - Mars Science Laboratory (MSL) and *Curiosity*: Damage to *Curiosity* from MSL's descent
- Hard to characterize
  - Best testbed is the Moon
  - Only rudimentary predictions at best of important characteristics



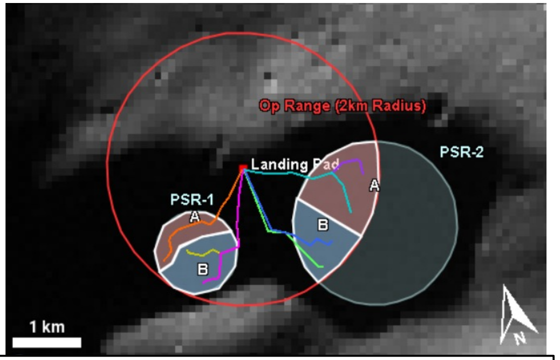
Images courtesy of Zanon, et al

SOLACE Overview



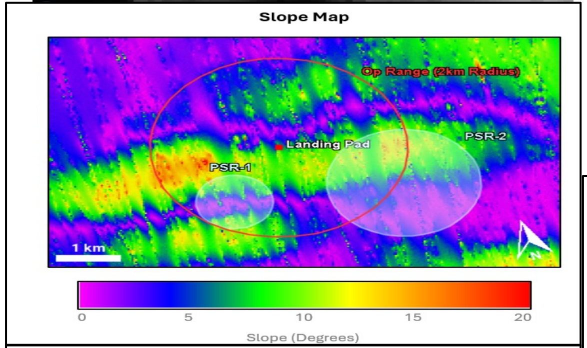
Presenting: *Kamalika Bose (Project Manager)*

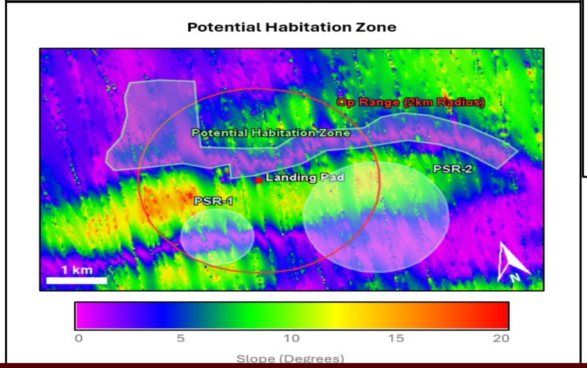
System Integration and Test Environment (SITE)

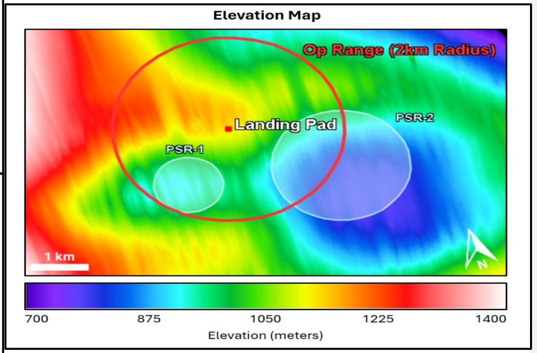


Artemis III Landing Region: HAWORTH

Landing Site Coordinate: -86.50757 °N, 342.98057 °E

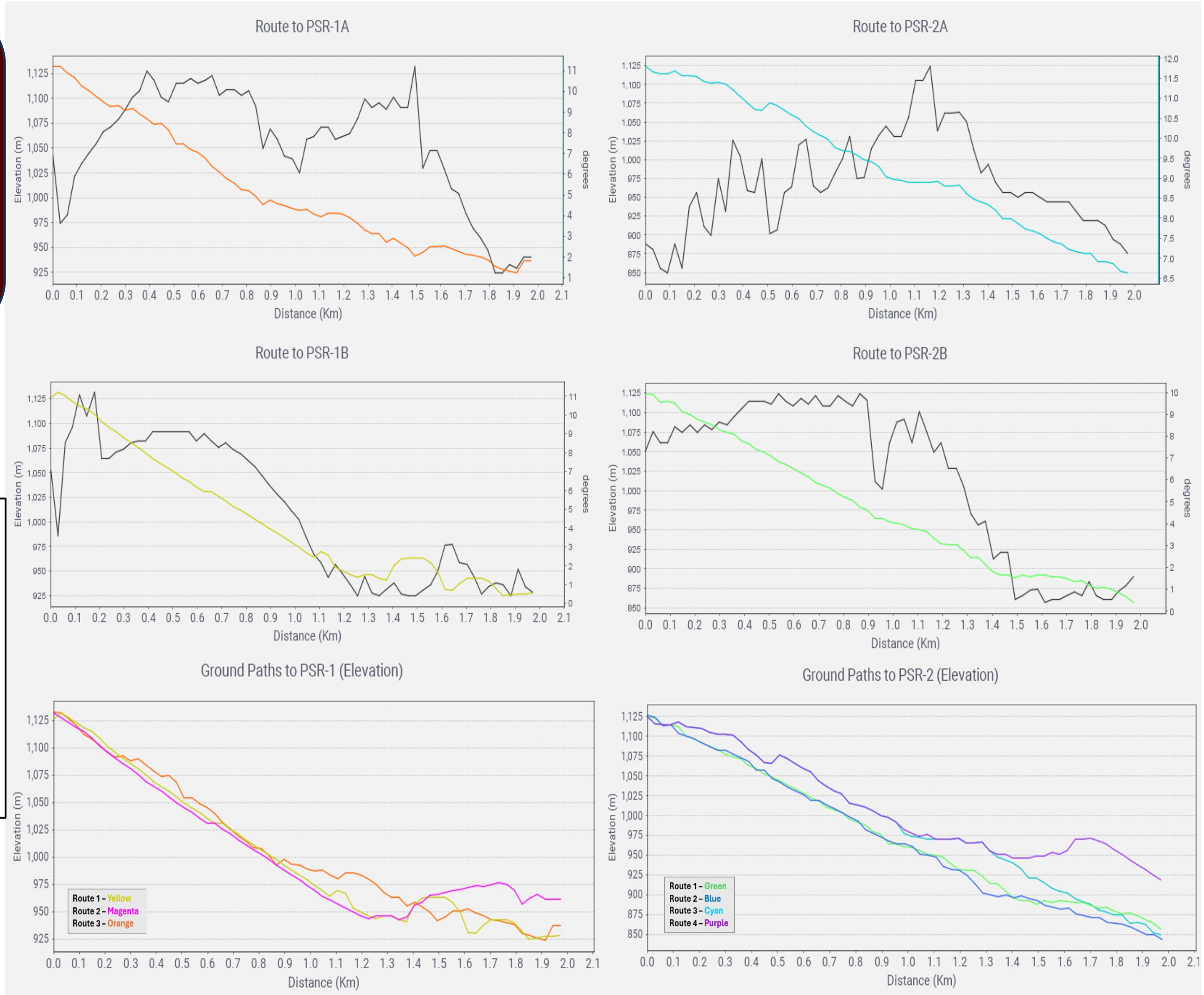






Images found using JMARS

PSR Region Pathing



Presenting: *Kamalika Bose (Project Manager)*

System Integration and Test Environment (SITE)

Particle and PSI Analysis

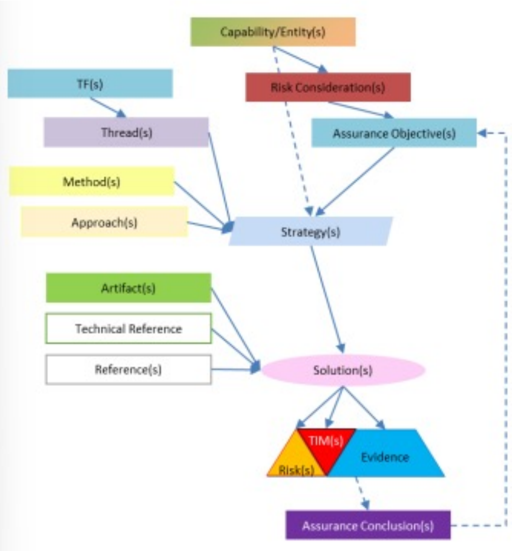
Compound	Insoluble or soluble in Water	Chemical Reactivity	Density
Silicone Dioxide	Insoluble	Non - Reactive	2.65 g/cm^3
Titanium Dioxide	Insoluble	Non - Reactive	4.23 g/cm^3
Aluminum Oxide	Insoluble	Non - Reactive	3.99 g/cm^3
Iron Oxide	Insoluble	Reactive	5.74 g/cm^3
Magnesium Oxide	Practically insoluble	Reactive	3.58 g/cm^3
Calcium Oxide	Soluble	Reactive	3.34 g/cm^3
Sodium Oxide	Insoluble	Reactive	2.27 g/cm^3
Potassium Oxide	Insoluble	Reactive	2.27 g/cm^3
Manganese(II) Oxide	Insoluble	Reactive	5.37 g/cm^3
Chromic Oxide	Insoluble	Non - Reactive	5.22 g/cm^3

Compound	Weight percent in Lunar Regolith	Most Common Form
Silicone Dioxide	42-48%	Transparent to gray powder
Titanium Dioxide	1-7%	Odorless white powder
Aluminum Oxide	12-27%	Crystalline powder (corundum)
Iron Oxide	4-18%	Reddish-brown powder
Magnesium Oxide	4-11%	White nanopowder
Calcium Oxide	10-17%	Odorless white amorphous powder
Sodium Oxide	0.4-0.7%	Odorless white powder
Potassium Oxide	0.1-0.6%	Yellow or white odorless crystalline solid compound
Manganese(II) Oxide	0.1-0.2%	Greenish powder
Chromic Oxide	0.2-0.4%	Fine light to dark green hexagonal crystals

	Mechanical similarity to regolith	Mineralogical similarity to regolith	Availability	Cost	Lunar ISRU simulatability	Total Score
Weight	5	5	3	3	4	
JSC-1	4	2	1	1	2	10
LHS-1	5	5	4	2	4	20
NU-LHT-2	4	3	4	4	2	17
Weighted Scores						
JSC-1	20	10	3	3	8	44
LHS-1	25	25	12	6	16	84
NU-LHT-2	20	15	12	12	8	67

Scale		
	1	Poor
	2	Below Average
	3	Average
	4	Above Average
	5	Excellent

Adaptive Independent Verification and Validation Plan



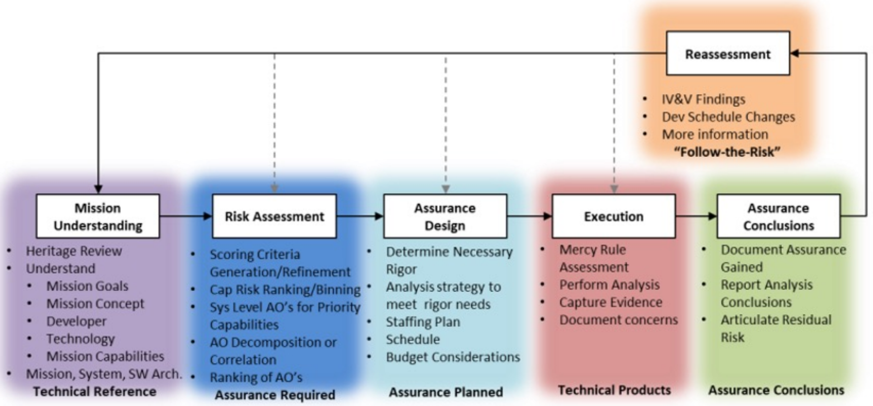
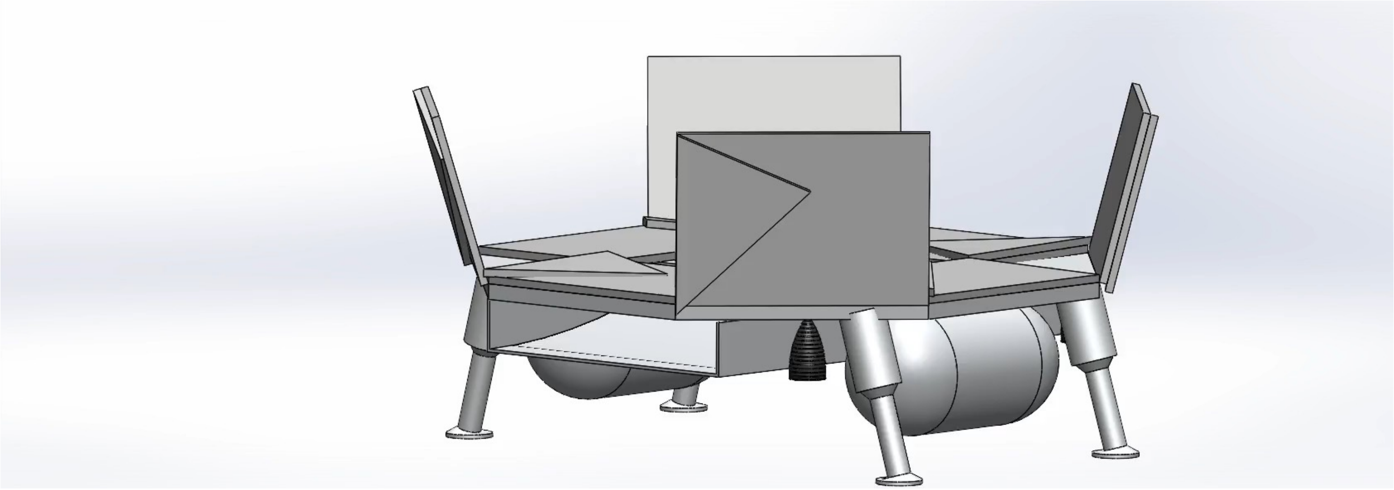


Image courtesy of NASA IV&V Program

Presenting: *Kamalika Bose (Project Manager)*

Thermal, Mechanics, and Structures (TMS)

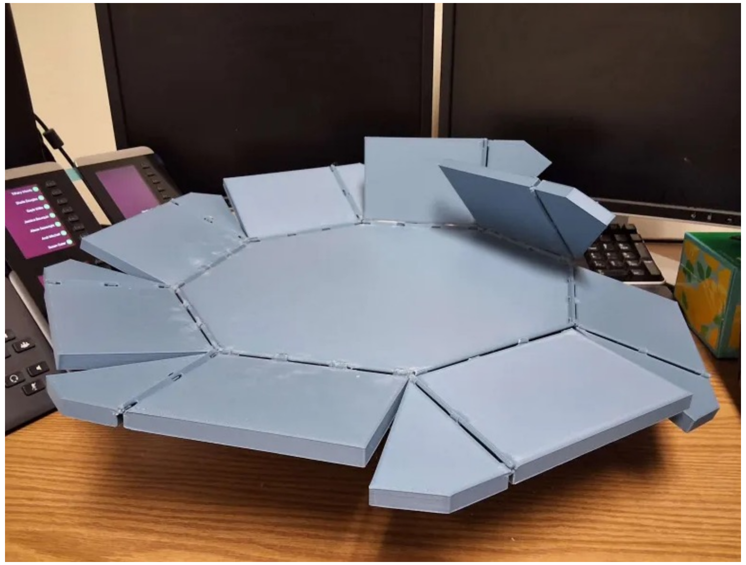
- "Bunker"-esque design
  - Lower base – houses electrical components and other sensitive equipment
  - Plume redirection system – redirects plume to one specific line of redirection
  - Grating – aids in nozzle plume redirection
  - Main landing surface – consists of 18 parts that can be stowed or deployed
  - Spring-actuated "stakes" – inject into lunar surface for pad stability on HLS descent
- Materials
  - Graphene
  - Titanium aluminide
  - Hafnium diboride



Presenting: *Nicholas Siodlarz (Chief Engineer)*

Thermal, Mechanics, and Structures

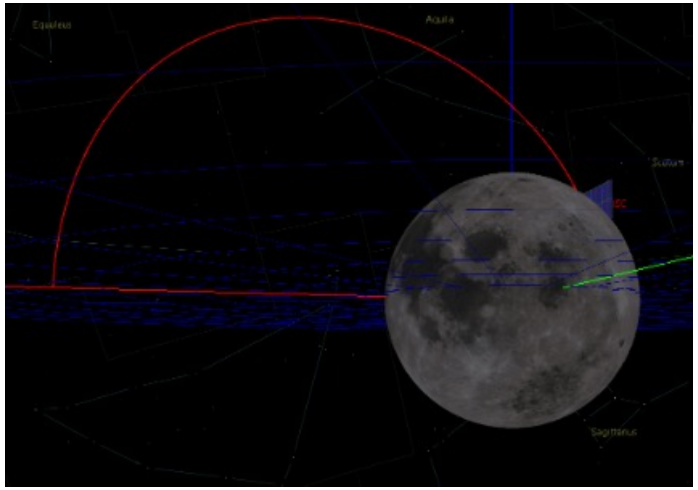
- Propulsion
  - Four liquid-propelled boosters provide descent and attitude control
  - Engine gimbals
    - Enable attitude control
    - Gimbal to lunar parallel to limit PSI on descent
  - Methalox was chosen over hydrazine
- Overall characteristics
  - Dry mass of 14.38 metric tons
  - Wet mass of 25.38 metric tons
  - Stands 1.4 m tall, occupies a total volume of 18.28 m^3
  - Pad landing surface can withstand temperatures up to 3600 K
  - Pad can withstand loads up to 162 kN



Presenting: *Nicholas Siodlarz (Chief Engineer)*

Guidance, Navigation, and Control (GNC)

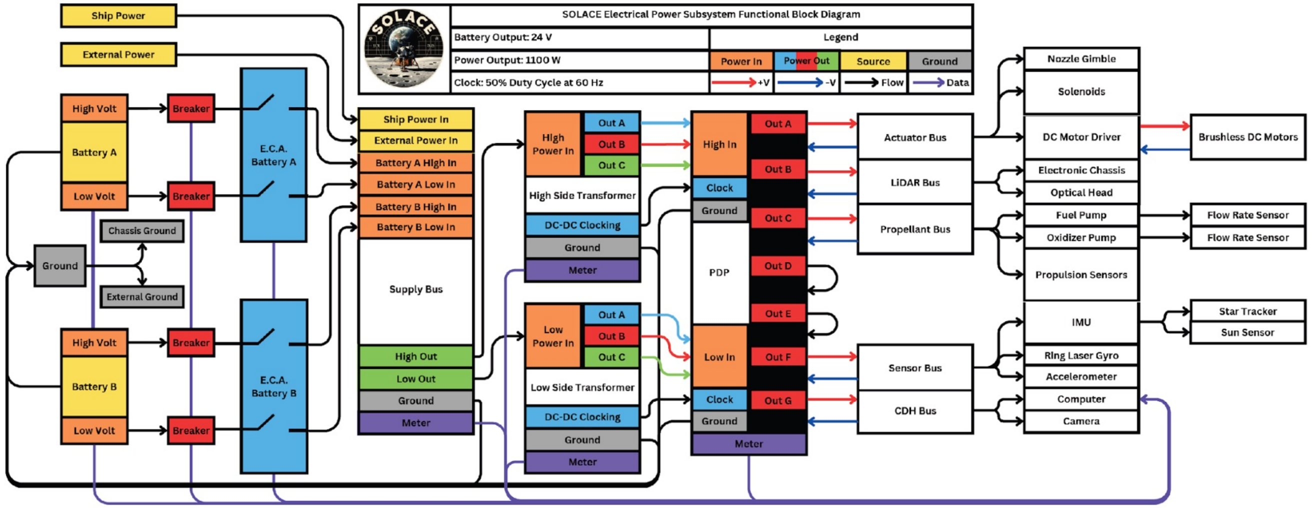
- Guidance System
  - Employs a novel machine learning algorithm trained on previous lunar landing videos
  - Identifies safe landing zones on descent
  - Identifies abort trajectories in the event of off-nominal scenarios
  - Nominal trajectory analyzed in NASA General Mission Analysis Toolkit (GMAT)
- Navigation System
  - IMU – Honeywell HG1900 IMU
  - LiDAR – NASA's Navigational Doppler LiDAR
  - Star tracker – RocketLab ST 16HV star tracker
  - Sun sensor – RedWire Coarse Sun Sensor (Cosine Type)



- Control System
  - Gimballing boosters can be used for attitude and descent control

Presenting: *Cindy Qiu (GNC)*

Electrical Power Subsystem (EPS)



System	Component	Manufacturer	Power	Voltage	Current	Quantity
Sensor Array	Navigation Doppler Lidar	NASA Langley	80 W	28 VDC	2.857 A	1
	GG1320 Ring Laser Gyro	Honeywell	1.6 W	15 VDC	0.107 A	1
	HG1900 IMU	Honeywell	3 W	5 VDC	0.6 A	1
	Coarse Sun Sensor	RedWire	0 W	TBD	0.0013 A	1
	ST-16HV Star Tracker	RocketLab	0.5 W - 1 W	9 - 34 VDC	0.056 A (MAX)	1
	TMP64 Thermistor	Texas Instruments	0 W	5.5 VDC	0.0 A	4
	Accelerometer	NASA JPL / UCLA	0.058 W	TBD	TBD	1
Computer	Jetson AGX Orin	NVIDIA	15 - 60 W	12 VDC	5.0 A (MAX)	1
	IMX586 Camera	ArduCam	1.19 W	5 VDC	0.238 A	1
Control	PD82152B BLDC Motor	Transmotec	120 W	24 VDC	7.2 A	4
	SDU-.75 WA Solenoids	Moog	10 W	24 VDC	0.42 A	16
	MCF8315C Driver	Texas Instruments	1 W	4 - 35 VDC	4.0 A	4
Propulsion	Fuel Pump	NASA Glenn	500 W	TBD	TBD	4
	Oxidizer Pump	NASA Glenn	500 W	TBD	TBD	4
	Gimble	NASA Marshall	TBD	TBD	TBD	4
Totals:			4790.848 W (MAX)			

EPS Key Features:

- External power plug-ins and permanent grounding capability
- DC-DC clocking for PWM
- Metering at each stage for monitoring
- Dedicated busses for other subsystems
- Transformers to provide a wide range of potential input voltages

EPS Sensor Array:

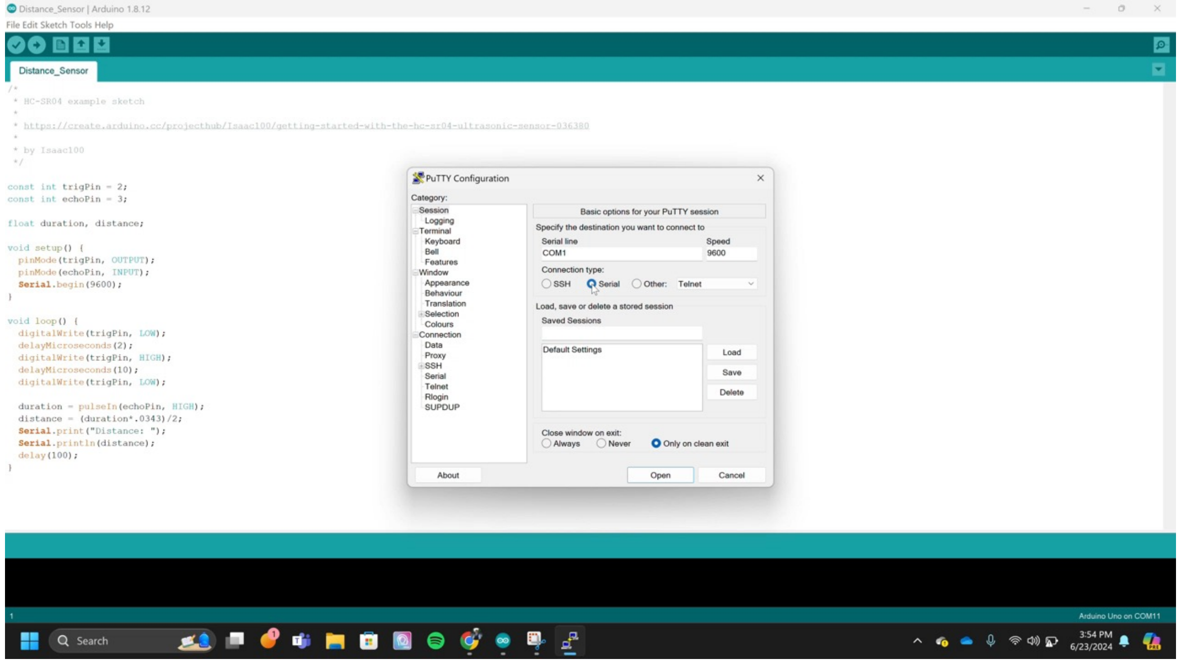
- NASA Navigational Doppler Lidar
- Honeywell Ring Laser Gyro
- Honeywell IMU
- RedWire Sun Sensor
- RocketLab Star Tracker
- Texas Instruments Thermistors
- NASA Designed Accelerometers

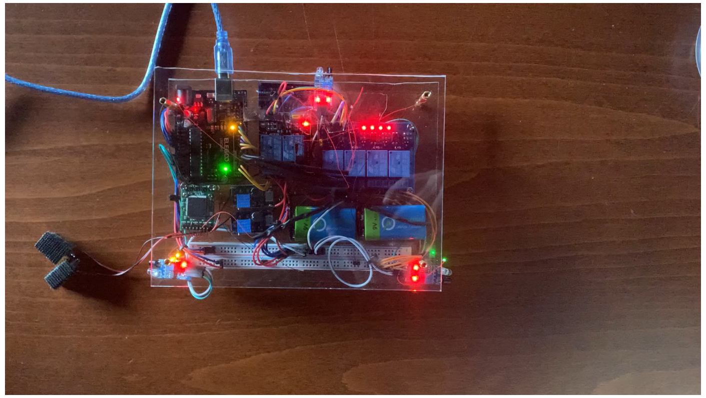
EPS Mechanical:

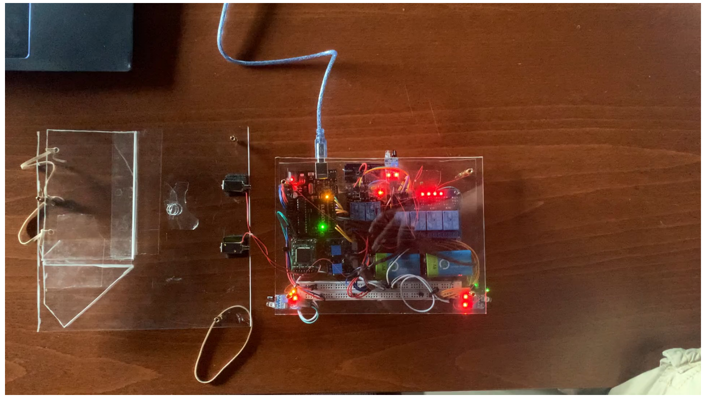
- Transmotec Brushless DC Motors
- Moog Solenoids
- Texas Instruments DC Motor Drivers
- NASA Designed Propulsion Gimbels
- NASA Designed Propulsion Pumps

Presenting: *Thomas Lopez (EPS Lead)*

Electrical Power Subsystem (EPS)



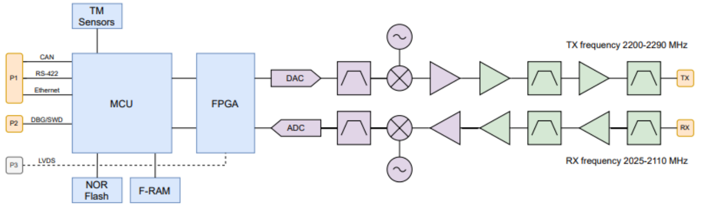


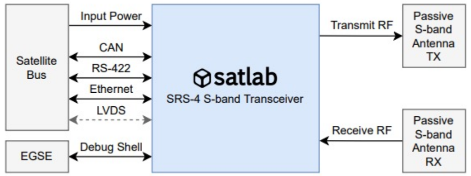


***Presenting:** Thomas Lopez (EPS Lead)*

Communications (COM)

- SRS-4 Full-Duplex High-Speed S-Band Transceiver
  - Operates on ITU-approved S-Band frequencies centered at 2250 MHz
  - 16-QPSK modulation scheme with compatibility for CCSDS channel coding
  - Variable transmit symbol rate up to 10 MB/s
  - Bitrate up to 12.5 MB/s when communicating with NVIDIA Jetson Nano
  - Average power output of 4W at a gain of 9 dBi, max gain of 11 dBi
- IQ-Spacecom S-Band Patch Antenna
  - Designed to operate at a center frequency of 2250 MHz with max 11 dBi gain
  - 50 MHz bandwidth
- Lunar Environmental Impacts
  - Lunar Regolith Permittivity: 3 F/m
  - Conductivity: 10E-14 S/m Sun, 10E-9 S/m dark
  - 5-10 dB estimated loss
  - Lunar ground acts as a reflector and absorber below S-band

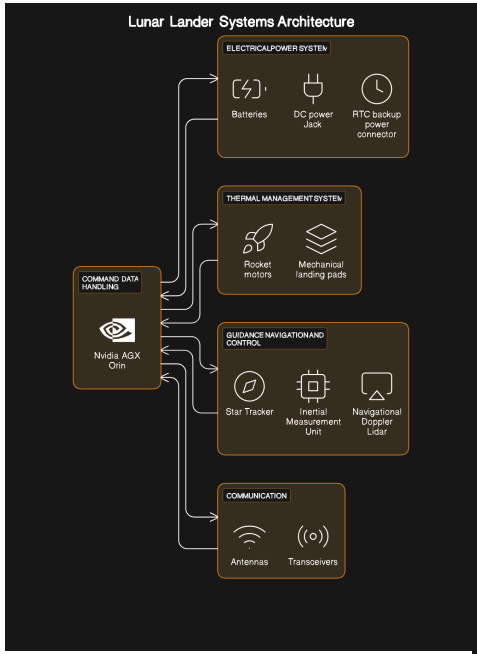


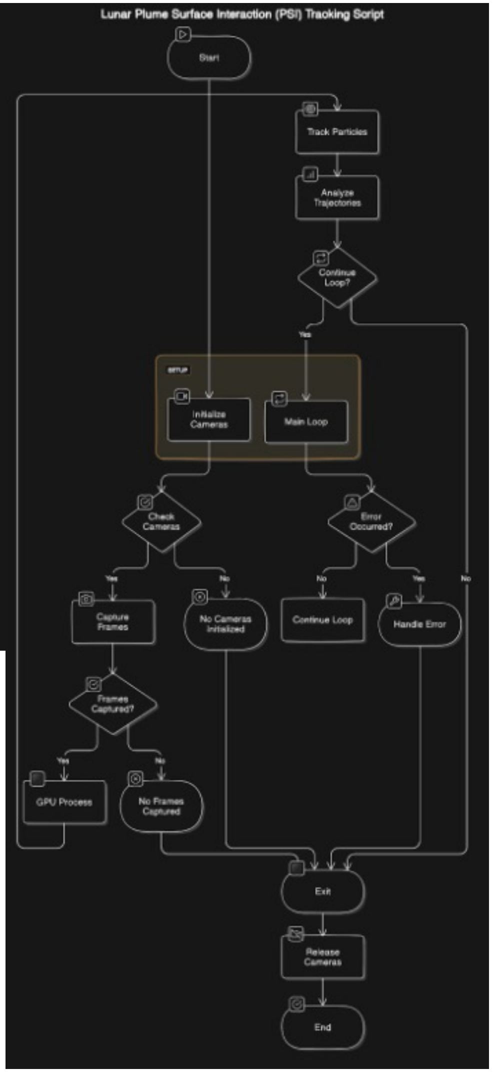


Images courtesy of SatLab SRS-4 data sheet.

Command and Data Handling (CDH)

- Components
  - NVIDIA Jetson AGX Orin
  - 3 ArduCam IMX586 48MP Camera Modules
- Hierarchical State Machine (HSM)
  - Reacts to asynchronous and nondeterministic inputs
  - Structured and flexible management framework
- PSI Monitoring
  - 3D particle tracking velocimetry
  - Cameras rotate to lunar parallel once descent has been completed





Presenting: Nicholas Siodlarz (Chief Engineer)

System Merit

- Performance
  - Adheres to HuLC constraints and guidelines
  - Unique position to act as a testbed for emerging technologies, such as machine-learning driven guidance
- Technology Readiness
  - Most incorporated technologies are TRL 9
- Risk
  - Low risk solution
  - Anticipated risks were analyzed, and mitigation strategies were developed
- Programmatic Implementation
  - Designed to be compatible with any proposed HLS or other landing system
  - Designed to function nominally in a wide variety of lunar regions

		Severity				
		Insignificant	Minor	Moderate	Major	Severe
Likelihood	Almost Certain					
	Likely			4		
	Possible			2	5	1, 3
	Unlikelyh		3f, 5f	1f		
	Rare	4f	2f			

1: SOLACE is a projectile
2: Accelerated degradation
3: Failed deploy
4: Descent brownout
5: Departs from trajectory

1f: Stakes
2f: Titanium aluminide
3f: Spring-loaded actuators
4f: Robust regulation
5f: Intelligent aborts

Costing

- Total estimated cost of SOLACE's lifetime development, launch, and operations is $1944.9M
  - $290.5M for non-recurring costs (NRC)
  - $1051.8M for recurring production costs
  - $189.9M for launch and $370.2M for operations
  - Values calculated with NASA's Project Cost Estimation Capability (PCEC)

Synthetic Orbital Landing Area for Crater Elimination (SOLACE) Lifetime Cost Estimation

Units Conversion Factor: 1.000

FY2024 $M — Inflation Factor: 1.187

WBS #	Level	Line Item Name/Description	Non-Recurring	Design & Development	System Test Hardware	Flight Unit	Recurring Production	Non-Allocated	Operations	TOTAL	Fee + Burden	TOTAL w/Fee + Burden
0	1	System Name	$ 290.5	$ -	$ -	$ -	$ 1,051.8	$ 232.4	$ 370.2	$ 1,944.9	$ -	$ 1,944.9
1.0	2	Project Management	$ 19.1	$ -	$ -	$ -	$ 44.4	$ -	$ -	$ 63.5	$ -	$ 63.5
2.0	2	Systems Engineering	$ 10.6	$ -	$ -	$ -	$ 17.1	$ -	$ -	$ 27.6	$ -	$ 27.6
3.0	2	Safety and Mission Assurance	$ 15.5	$ -	$ -	$ -	$ 34.0	$ -	$ -	$ 49.5	$ -	$ 49.5
4.0	2	Science/Technology	$ -	$ -	$ -	$ -	$ -	$ 42.6	$ -	$ 42.6	$ -	$ 42.6
5.0	2	Payload(s)	$ 7.1	$ -	$ -	$ -	$ 15.6	$ -	$ -	$ 22.7	$ -	$ 22.7
5.01	3	Payload Management	$ 2.5	$ -	$ -	$ -	$ 5.8	$ -	$ -	$ 8.3	$ -	$ 8.3
5.02	3	Payload System Engineering	$ 0.8	$ -	$ -	$ -	$ 1.3	$ -	$ -	$ 2.1	$ -	$ 2.1
5.03	3	Payload Product Assurance	$ 0.3	$ -	$ -	$ -	$ 0.8	$ -	$ -	$ 1.1	$ -	$ 1.1
5.10	3	Instruments - EMPTY ROLLUP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
5.x	3	Payload I&T	$ 3.5	$ -	$ -	$ -	$ 7.7	$ -	$ -	$ 11.2	$ -	$ 11.2
6.0	2	Flight System \ Spacecraft	$ 190.3	$ -	$ -	$ -	$ 810.6	$ -	$ -	$ 1,000.9	$ -	$ 1,000.9
6.01	3	Flight System Project Management	$ 1.0	$ -	$ -	$ -	$ 2.3	$ -	$ -	$ 3.3	$ -	$ 3.3
6.02	3	Flight System Systems Engineering	$ 1.8	$ -	$ -	$ -	$ 2.9	$ -	$ -	$ 4.7	$ -	$ 4.7
6.03	3	Flight System Product Assurance	$ 4.6	$ -	$ -	$ -	$ 10.0	$ -	$ -	$ 14.6	$ -	$ 14.6
6.10	3	Spacecraft	$ 168.1	$ -	$ -	$ -	$ 762.6	$ -	$ -	$ 930.7	$ -	$ 930.7
--	4	Structures & Mechanisms	$ 18.0	$ -	$ -	$ -	$ 670.3	$ -	$ -	$ 688.3	$ -	$ 688.3
--	4	Thermal Control	$ 0.1	$ -	$ -	$ -	$ 0.0	$ -	$ -	$ 0.1	$ -	$ 0.1
--	4	Electrical Power & Distribution	$ 1.4	$ -	$ -	$ -	$ 1.1	$ -	$ -	$ 2.5	$ -	$ 2.5
--	4	GN&C	$ 0.5	$ -	$ -	$ -	$ 0.7	$ -	$ -	$ 1.2	$ -	$ 1.2
--	4	Propulsion	$ 142.2	$ -	$ -	$ -	$ 84.4	$ -	$ -	$ 226.6	$ -	$ 226.6
--	4	Communications	$ 0.9	$ -	$ -	$ -	$ 1.2	$ -	$ -	$ 2.1	$ -	$ 2.1
--	4	C&DH	$ 5.0	$ -	$ -	$ -	$ 4.9	$ -	$ -	$ 9.9	$ -	$ 9.9
6.x	3	Flight System I&T	$ 14.9	$ -	$ -	$ -	$ 32.8	$ -	$ -	$ 47.6	$ -	$ 47.6
7.0	2	Mission Operations System (MOS)	$ 19.2	$ -	$ -	$ -	$ 66.9	$ -	$ 370.2	$ 456.3	$ -	$ 456.3
--	3	MOS/GDS Development (Phase B-D)	$ 19.2	$ -	$ -	$ -	$ 66.9	$ -	$ -	$ 86.1	$ -	$ 86.1
--	3	Mission Ops & Data Analysis (Phase E)	$ -	$ -	$ -	$ -	$ -	$ -	$ 370.2	$ 370.2	$ -	$ 370.2
8.0	2	Launch Vehicle/Services	$ -	$ -	$ -	$ -	$ -	$ 189.9	$ -	$ 189.9	$ -	$ 189.9
9.0	2	Ground Data System (GDS)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10.0	2	System Integration, Assembly, Test & Check Out	$ 28.7	$ -	$ -	$ -	$ 63.3	$ -	$ -	$ 91.9	$ -	$ 91.9
11.0	2	Education & Public Outreach	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

	Reserves %	TOTAL w/Reserves	TOTAL w/Fees, Burdens, &
Reserves	0%	$ 1,944.9	$ 1,944.9

***Presenting:** Nicholas Siodlarz (Chief Engineer)*

Design, Test, and Evaluation (DTE) Scheduling

- Major milestones
  - System assembly concludes 2 years into DTE
  - Testing and evaluation concludes 4.2 years into DTE
  - Launch occurs 4.5 years into DTE
  - Expected primary objective lifetime is 10 years

Milestone	ET (YY:MM:DD)	Milestone	ET (YY:MM:DD)
Components Procurement	00:00:00	Environmental Testing	02:06:00
Sensor Testing	00:03:00	Subsystem V&V	03:04:00
Structure Assembly	01:00:00	System V&V	04:02:00
Structure Testing	01:03:00	Day in the Life Testing	04:02:15
EPS/CDH/GNC/COM Assembly and Integration	02:00:00	Launch Preparation	04:05:00
EPS/CDH/GNC/COM Testing	02:03:00	Flight	04:06:00

***Presenting:** Nicholas Siodlarz (Chief Engineer)*

Thanks for listening!