National Aeronautics and Space Administration

Lunar Pallet Lander (LPL)

Detailed overview of the NASA robotic lander concept

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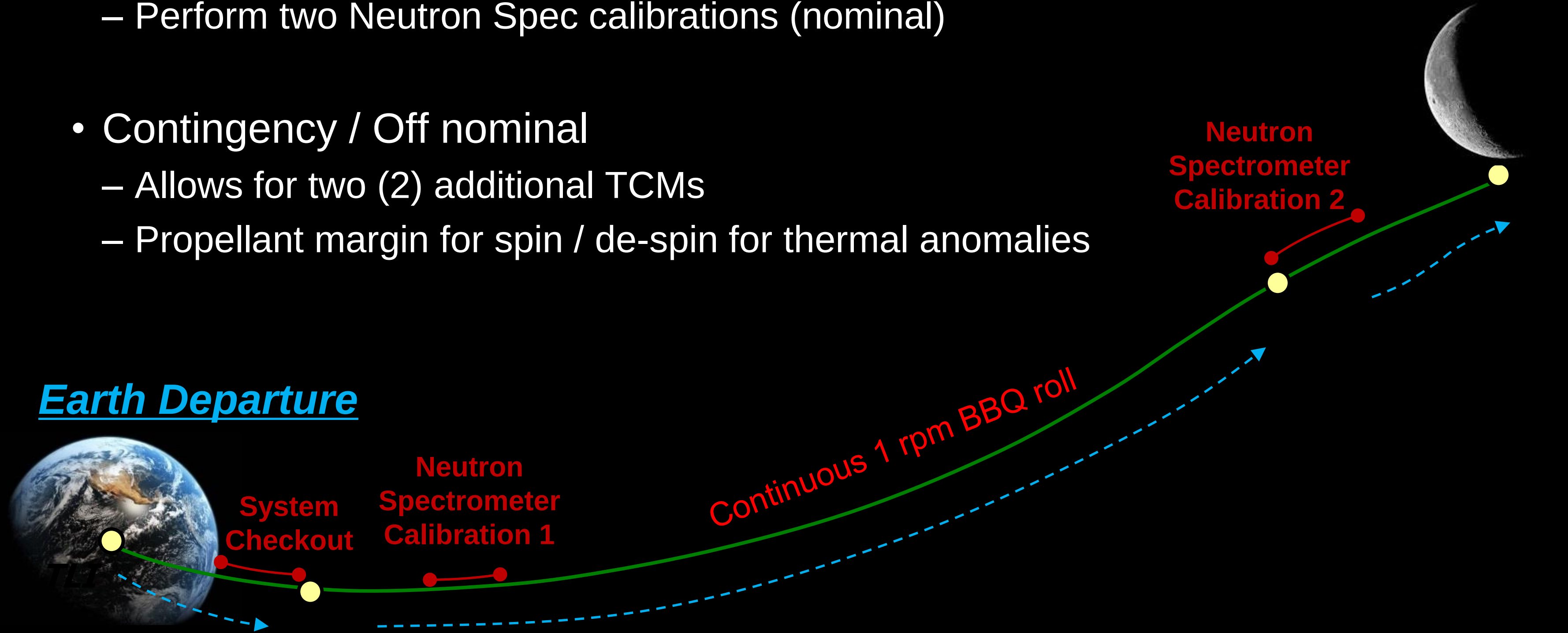
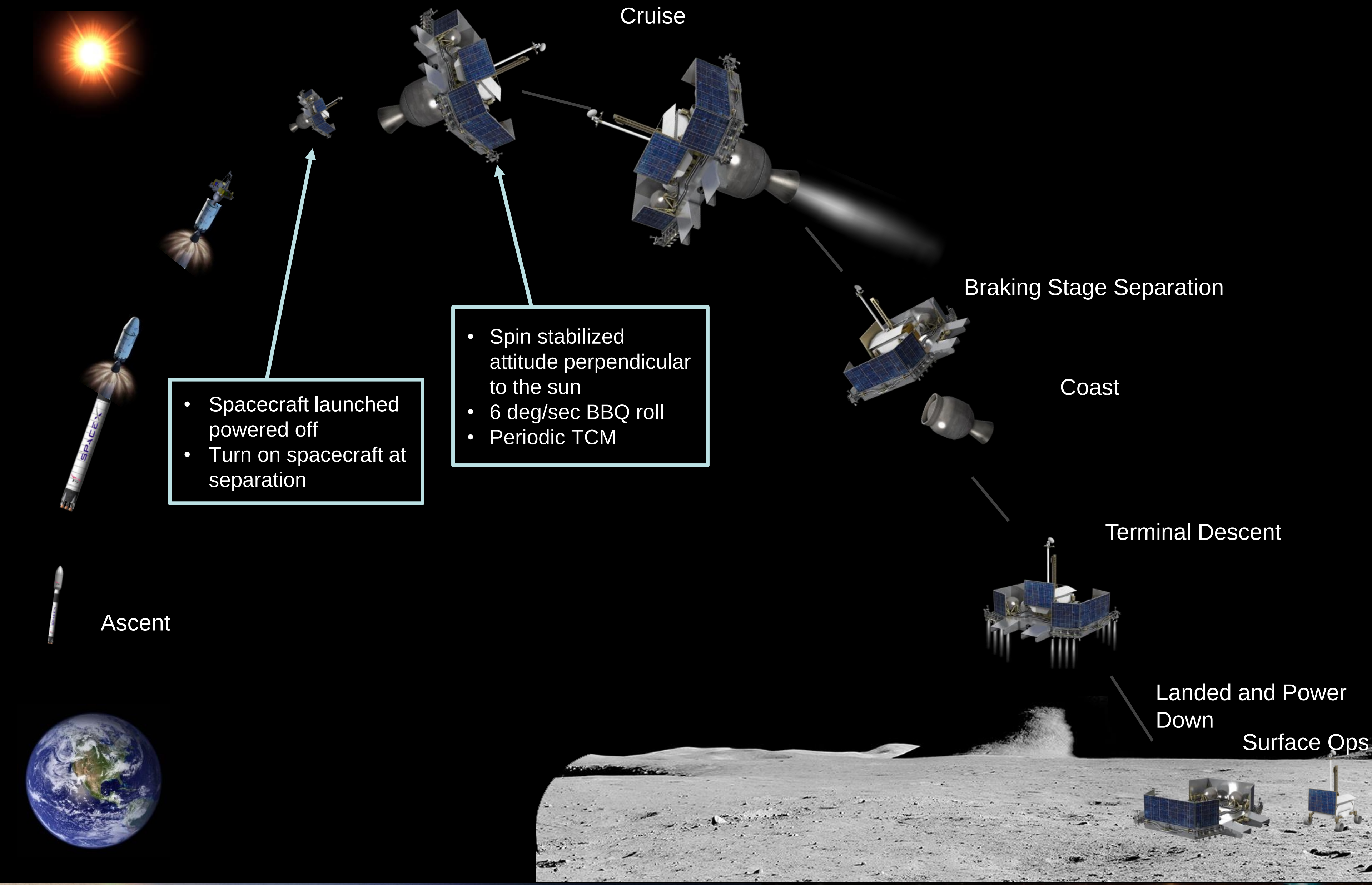
Getting There…

- Cruise Phase:
  - – 5-day direct Earth to Moon transfer w/Deep Space Network S-band
  - – Spin up to 6 deg/s using Attitude Control System (post-Trans Lunar Injection)
  - – Perform system checkout
  - – Perform two Trajectory Control Maneuvers (nominal)
  - – Perform two Neutron Spec calibrations (nominal)
- Contingency / Off nominal
  - – Allows for two (2) additional TCMs
  - – Propellant margin for spin / de-spin for thermal anomalies



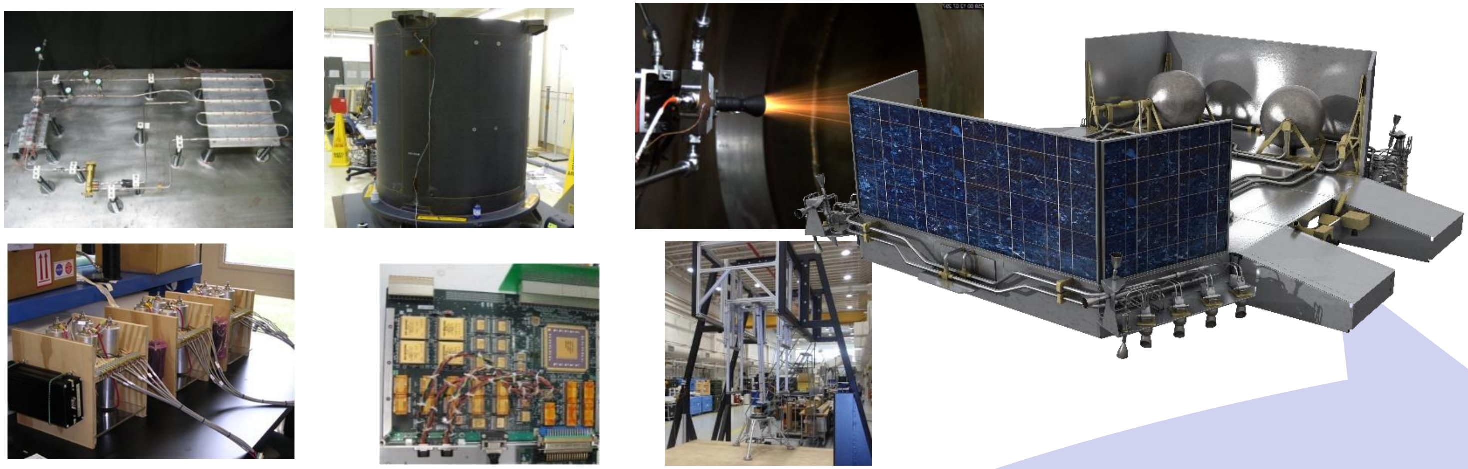
Mission Phases of Flight



- Spacecraft launched powered off
- Turn on spacecraft at separation

- Spin stabilized attitude perpendicular to the sun
- 6 deg/sec BBQ roll
- Periodic TCM

Flight Design Validation through Rigorous Prototype and Testing



Thermal & Battery Tests

Software and Avionics Tests

Propulsion Thruster Hot Fire and Lander Stability test

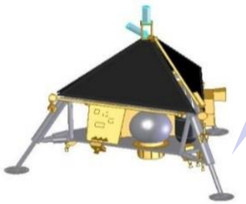
Flight Robotic Lander

Robotic Lander Prototype

GNC, Software, Avionics, Structures Test with a Pulsed Propulsion System

Cold Gas Test Article

Initial Design



Near-Earth Asteroids

Moon

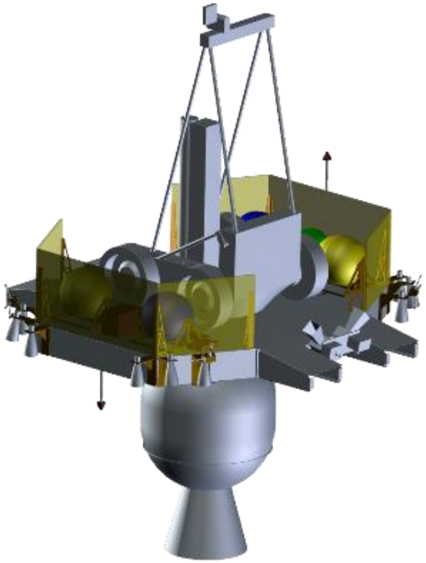
Mars / Phobos-Deimos

Integration of NASA Lander Activities

Mighty Eagle

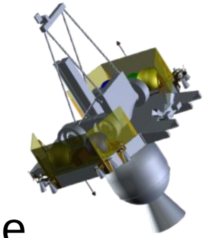
Morpheus

NASA Robotic Lander Concept



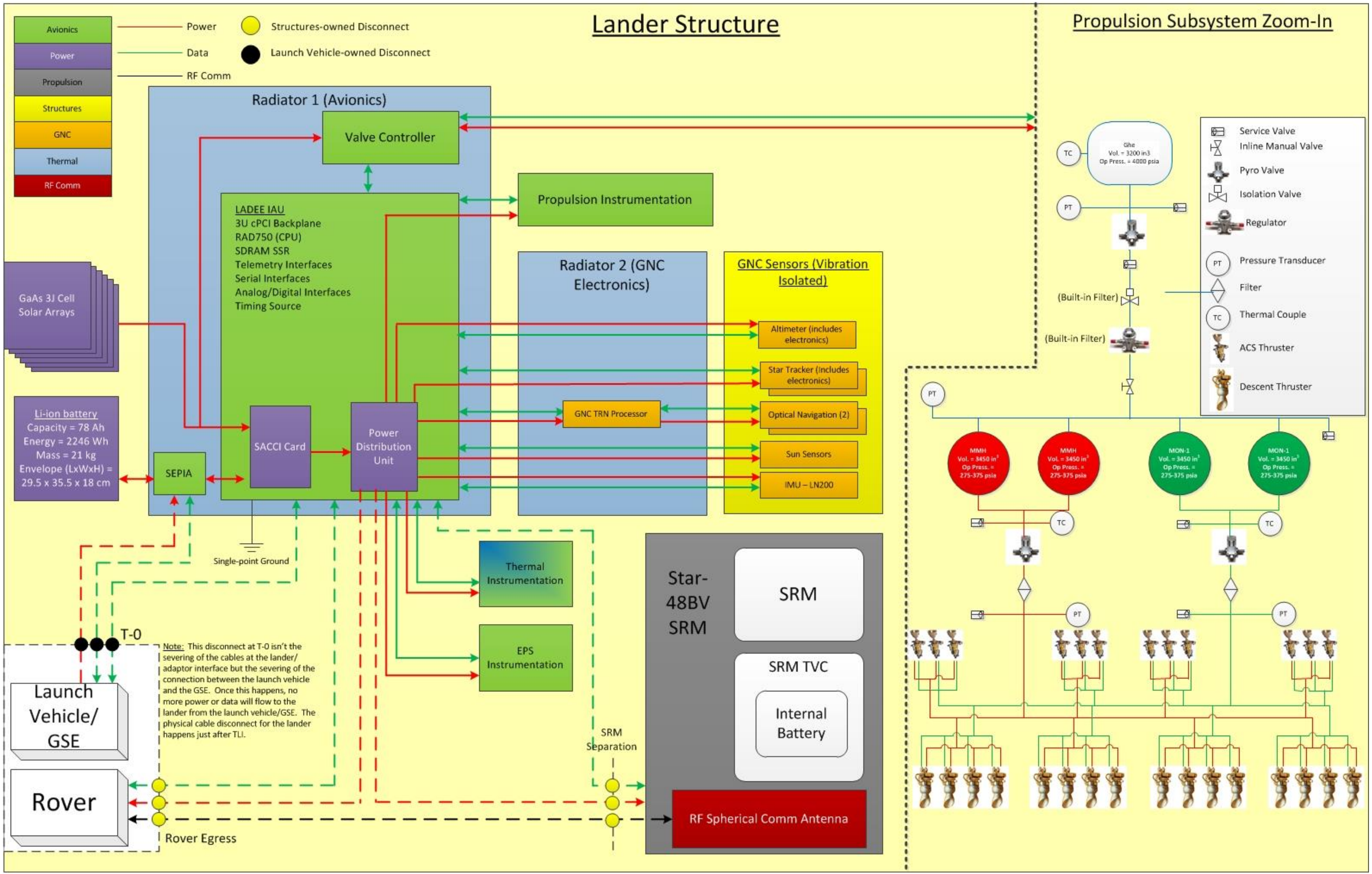
Commercial or International Partner

NASA Robotic Lander Concept



- NASA class D, requirements driven, low cost, rover delivery lunar lander (~325 kg rover + payload)
  - Single string except for personnel safety
  - This lander is low cost and will fit on a Falcon 9 V1.1
  - This lander has on-ramp or evolvable options for increased performance
  - This lander can be built with little technology development
    - Some tech development could enhance the performance
- Schedule (42 months (Funded to Launch), due to long lead items (tanks and thrusters))
  - 36 months if lander size is optimized for existing components (i.e. propellant tanks).
  - Reduced procurement cycle

Physical Block Diagram



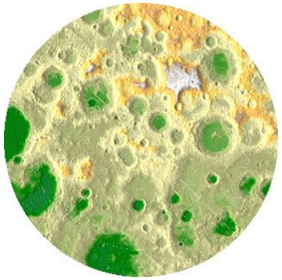
Note: This disconnect at T-0 isn't the severing of the cables at the lander/ adaptor interface but the severing of the connection between the launch vehicle and the GSE. Once this happens, no more power or data will flow to the lander from the launch vehicle/GSE. The physical cable disconnect for the lander happens just after TLI.

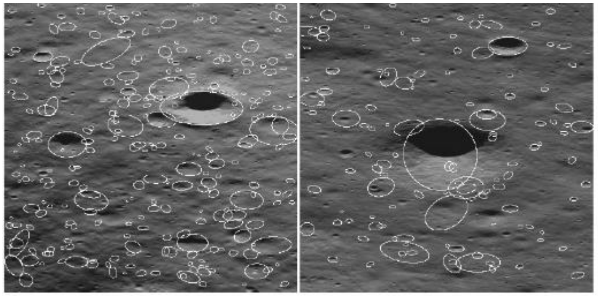
Landing Site Selection

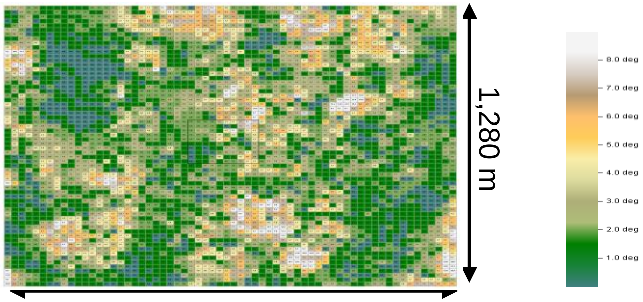
- Terrain Topography Analysis (Landing Site Selection Team, ARC)
  - Local high-resolution DEM (digital elevation model) not available for candidate sites yet.
  - Analog Malapert DEM (~5m posts) available for slope analysis.
  - New DEM commissioned of near north pole candidate site.

- Surface Features (JPL)
  - Uses LRO/NAC automated image analyses (craters, boulders).

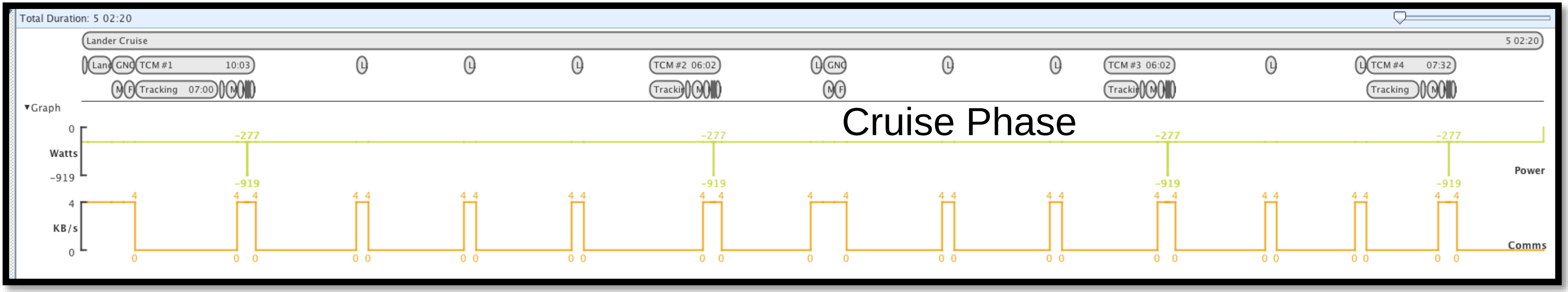
- Hazard Assessment (MSFC, JSC, APL, ARC, JPL)
  - Compares lander capability to surface characterization maps to derive hazard risk maps
  - Extrapolates high-resolution results to low-resolution data to assess risky, but unresolved, hazards



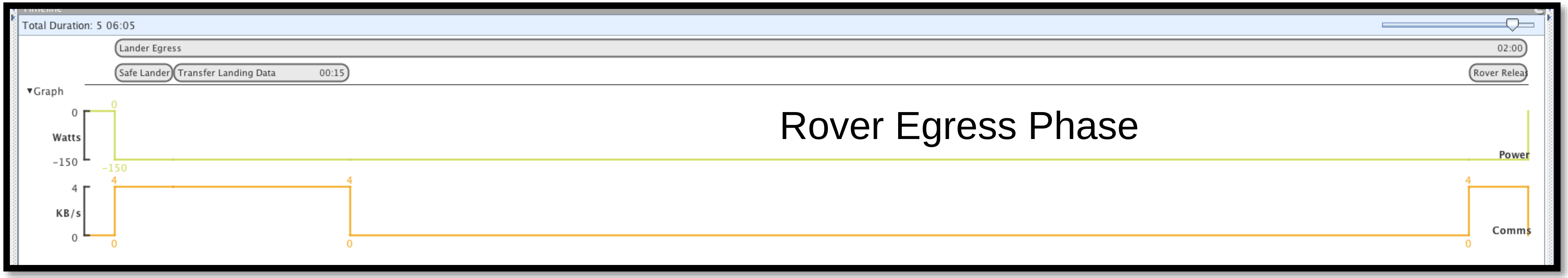




Operations Timeline


Cruise Phase


Descent and Landing Phase


Rover Egress Phase

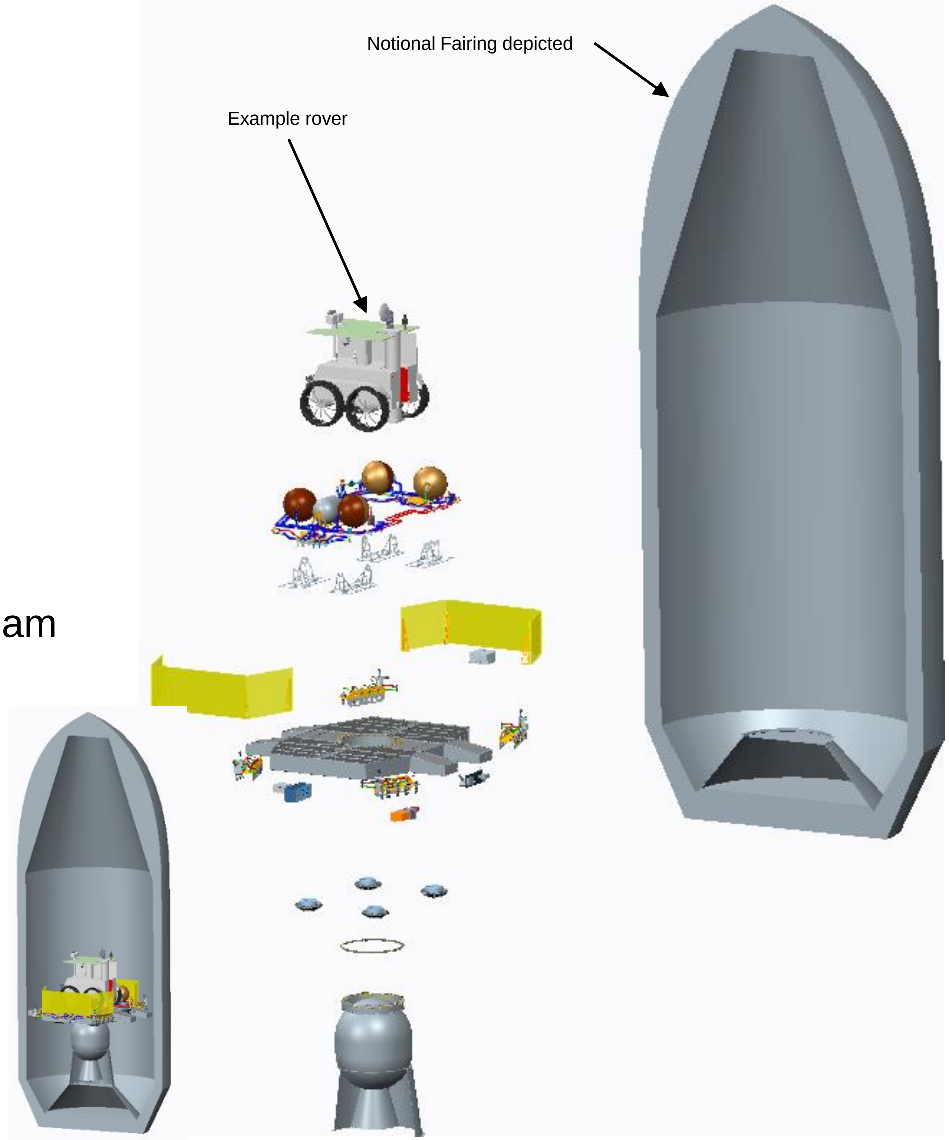
Lander Integration Considerations

- Integrated systems references:
  - Drawing tree
  - Master Equipment List (MEL)

- Component integration considerations:
  - Component maturity level
  - Proximity - power source/Thermal Radiator
  - Placement affects center of mass
  - Placement to reduce shadowing - cameras/sun sensors

- Integrated models - consistency throughout the team
  - Metric units
  - Assigned material properties
  - ProE - Creo. 2.0 CAD models

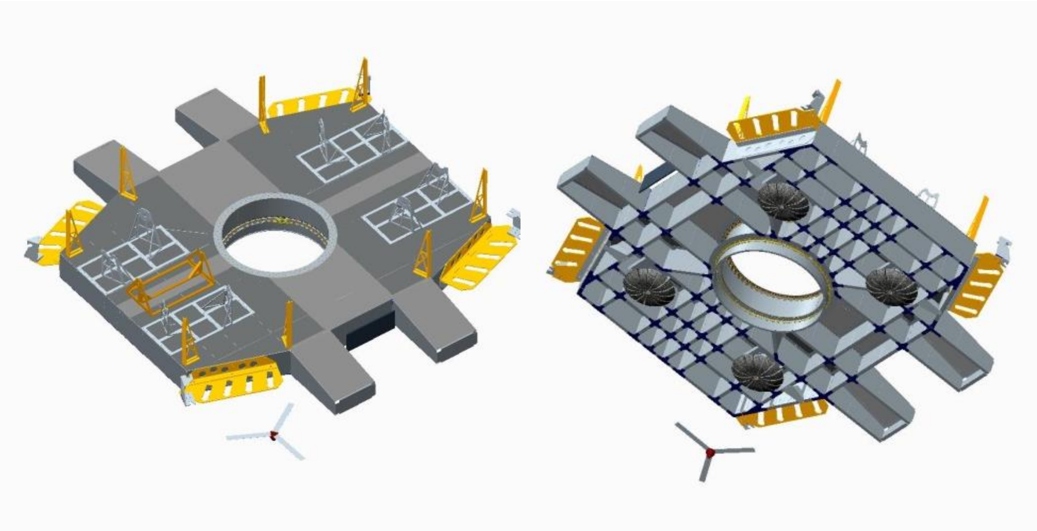
- Maturing subsystems affect the integrated design
  - Avionics - weight/placement
  - Thermal - radiators /MLI blankets
  - Power - solar arrays/battery

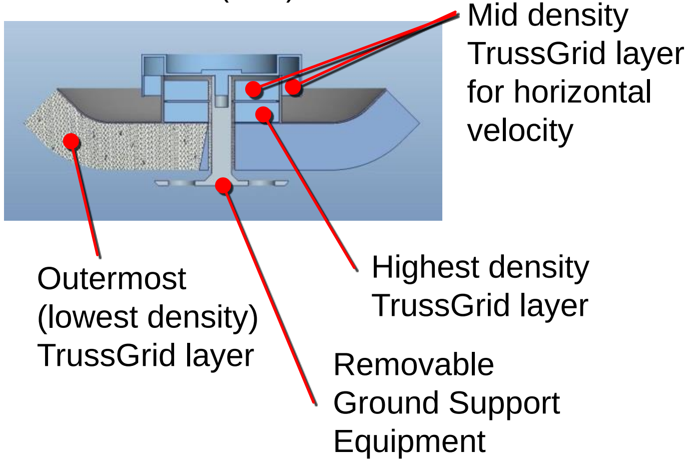


Notional Fairing depicted

Example rover

Structures Architecture





Landing Pads

219 mm (8.6”) ‘thick’

712 mm (28”) dia

Mid density TrussGrid layer for horizontal velocity

Outermost (lowest density) TrussGrid layer

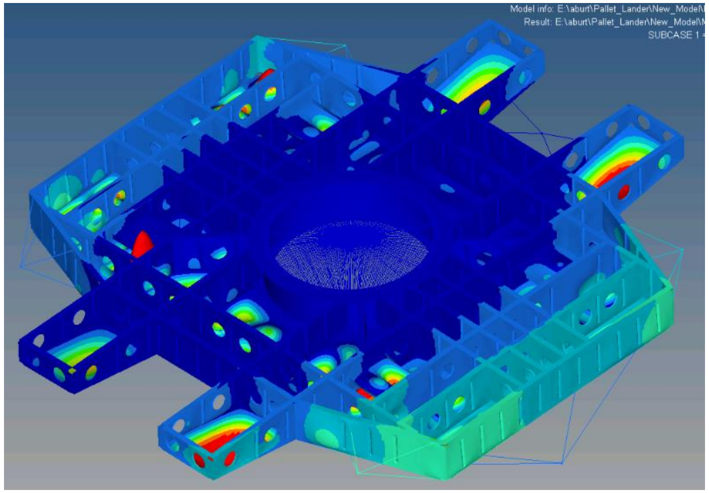
Highest density TrussGrid layer

Removable Ground Support Equipment

- Protoflight structural approach
- Prototype pallet structure build is complete

Vehicle Loads Analysis

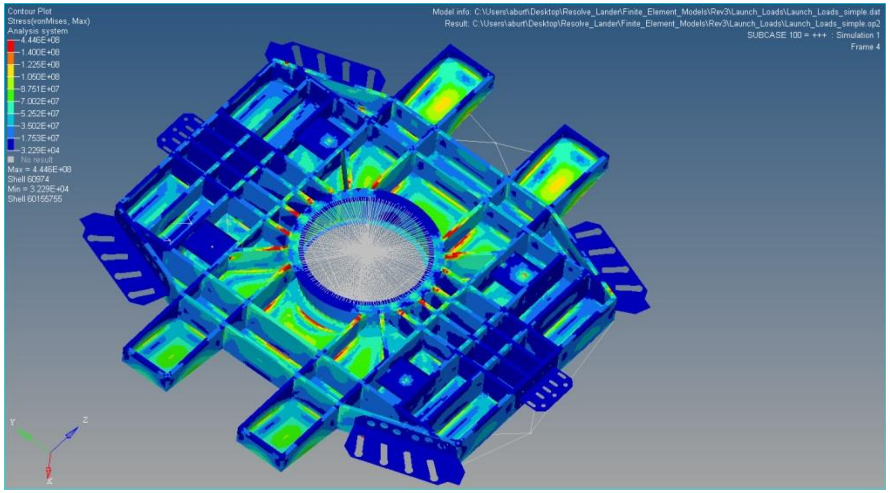
Primary Natural Frequencies



Parameters that affect natural frequencies

- How the non-structural mass is distributed
- Placement of large mass items (as well as accuracy of the mass, i.e. propellant tanks)
- Depth of beams
- Beaded patterns in beams
  - Boundary conditions fixed at the inner ring where it would be attached to the Solid Rocket Motor.
  - Primary Natural Frequencies
  - X – 23 Hz, 15% mass participation
  - Y – 38.5 Hz, 2% mass participation
  - Z - 48 Hz, 5% mass participation
  - The axial frequency does not meet the desired 35 Hz, nor the required 25 Hz
  - However, the mass participation is low so it may not be of great concern
  - Design solutions can be worked to increase the natural frequencies in this direction

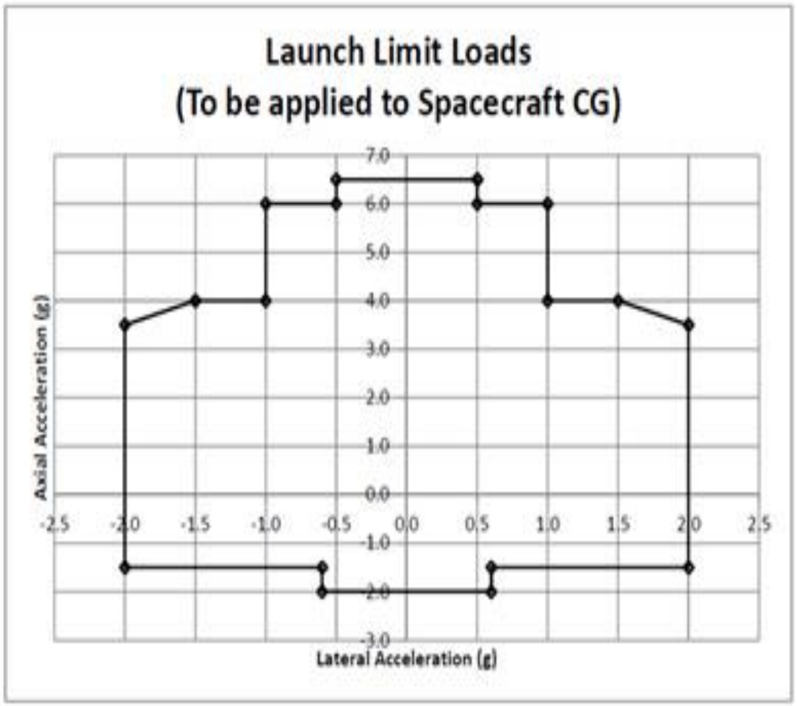
Stress



- Highest loaded areas are near the central load ring
- Other hot spots exist but need to be looked at more thoroughly as they are rigid body attach points which can produce arbitrarily high stress results
- The mass properties of subsystem components were obtained from the Master Equipment List
- The mass used is that of everything on the second stage, physically located above the Solid Rocket Motor
- Tanks and large boxes are modeled as 1D mass elements
- Other masses such as wiring, cabling, thermal insulation carried as non-structural mass smeared over the top deck
- Total wet mass = 1586 kg (3,490 lbs)

Quasi-Static Load Factors Contribution

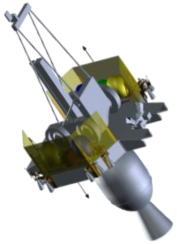
Launch Ascent



Single load case created using 6.5 G’s axial and 2 G’s lateral inputs to envelope all load cases

Braking Burn

STAR48 Operation

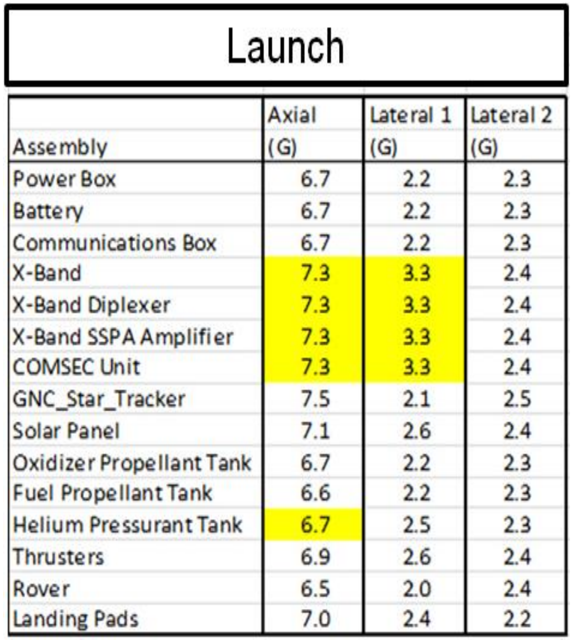


Star48 Motor	Lander		
Thrust	Mass	Acceleration	
(N)	(kg)	m/sec^2	G's
77800	1312	59.3	6.0

- The given thrust for the STAR48 for the lander vehicle mass produces 6 G’s axial acceleration.
- Lander longitudinal accelerations assume the most conservative proportion of launch quasi-static environments at 2 G’s (1/3 axial).

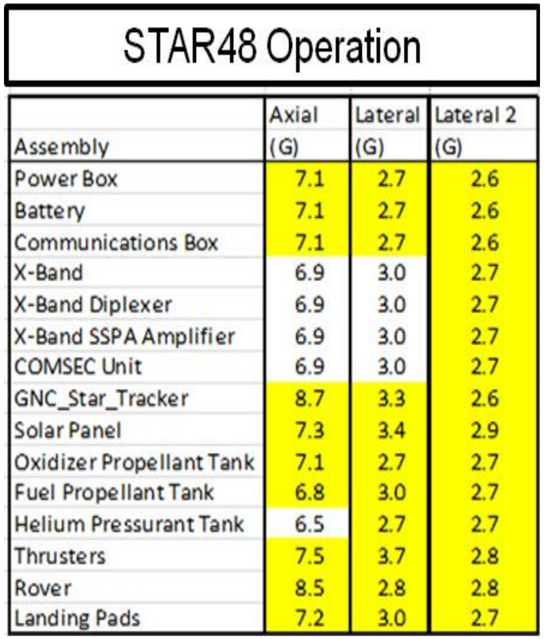
Summary of Combined Loads * for Launch and Star 48

- This dynamics analysis provides an in-depth understanding of each individual component response to all mission flight events.
- Load prediction methodology allows ample flexibility to accommodate changes in spacecraft design and launch vehicle architecture.



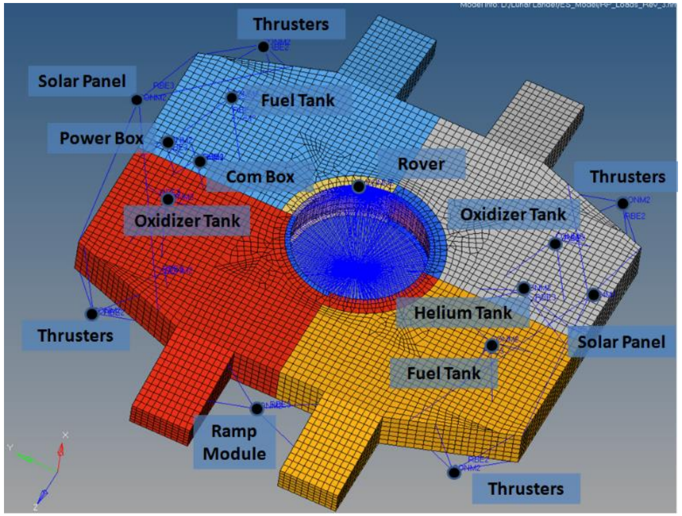
Launch

Assembly	Axial (G)	Lateral 1 (G)	Lateral 2 (G)
Power Box	6.7	2.2	2.3
Battery	6.7	2.2	2.3
Communications Box	6.7	2.2	2.3
X-Band	**7.3**	**3.3**	2.4
X-Band Diplexer	**7.3**	**3.3**	2.4
X-Band SSPA Amplifier	**7.3**	**3.3**	2.4
COMSEC Unit	**7.3**	**3.3**	2.4
GNC_Star_Tracker	7.5	2.1	2.5
Solar Panel	7.1	2.6	2.4
Oxidizer Propellant Tank	6.7	2.2	2.3
Fuel Propellant Tank	6.6	2.2	2.3
Helium Pressurant Tank	**6.7**	2.5	2.3
Thrusters	6.9	2.6	2.4
Rover	6.5	2.0	2.4
Landing Pads	7.0	2.4	2.2



STAR48 Operation

Assembly	Axial (G)	Lateral (G)	Lateral 2 (G)
Power Box	**7.1**	**2.7**	**2.6**
Battery	**7.1**	**2.7**	**2.6**
Communications Box	**7.1**	**2.7**	**2.6**
X-Band	6.9	3.0	**2.7**
X-Band Diplexer	6.9	3.0	**2.7**
X-Band SSPA Amplifier	6.9	3.0	**2.7**
COMSEC Unit	6.9	3.0	**2.7**
GNC_Star_Tracker	**8.7**	**3.3**	**2.6**
Solar Panel	**7.3**	**3.4**	**2.9**
Oxidizer Propellant Tank	**7.1**	**2.7**	**2.7**
Fuel Propellant Tank	**6.8**	**3.0**	**2.7**
Helium Pressurant Tank	6.5	**2.7**	**2.7**
Thrusters	**7.5**	**3.7**	**2.8**
Rover	**8.5**	**2.8**	**2.8**
Landing Pads	**7.2**	**3.0**	**2.7**



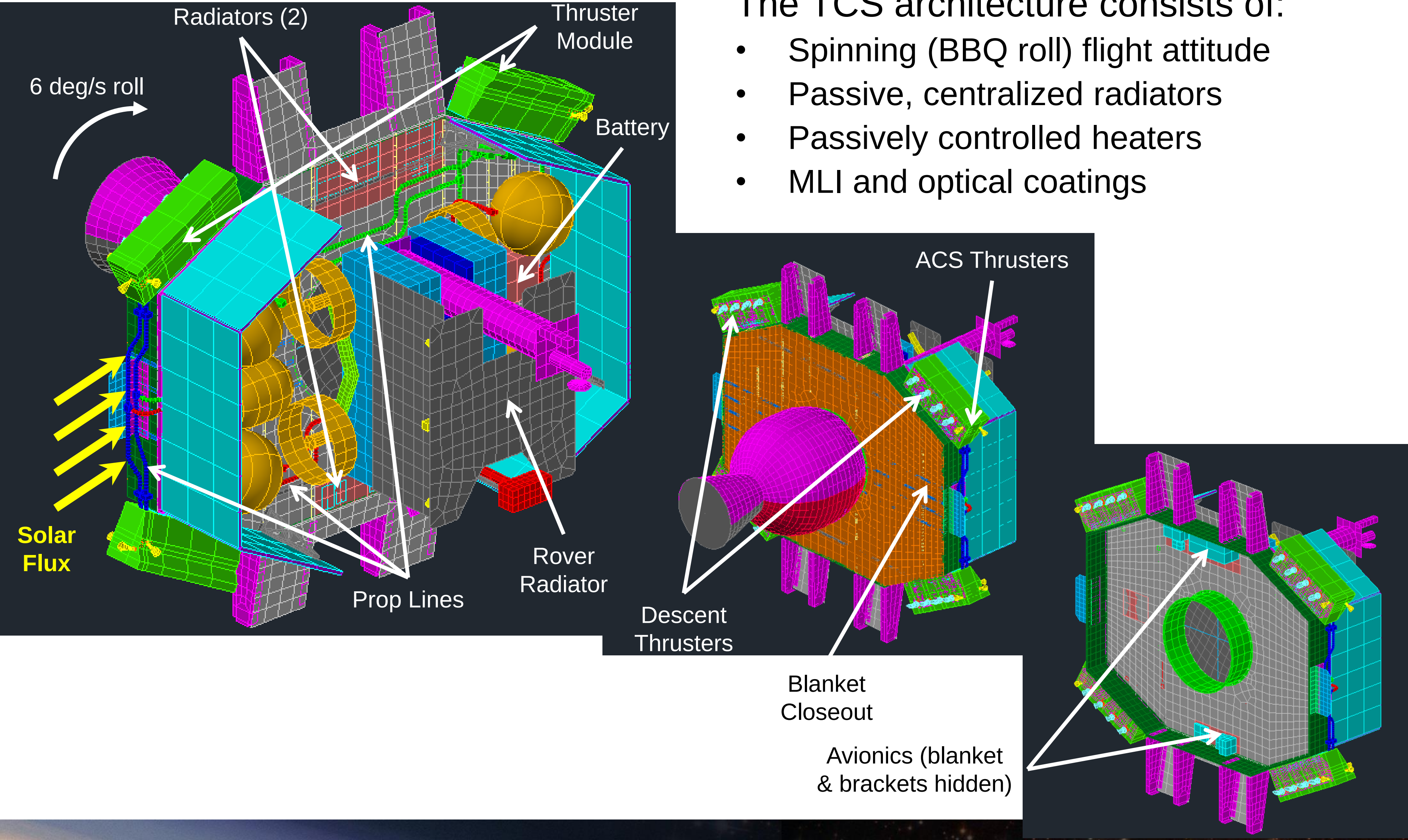
🟨 - Denotes higher load

*This is maximum predicted environment with no margin added.

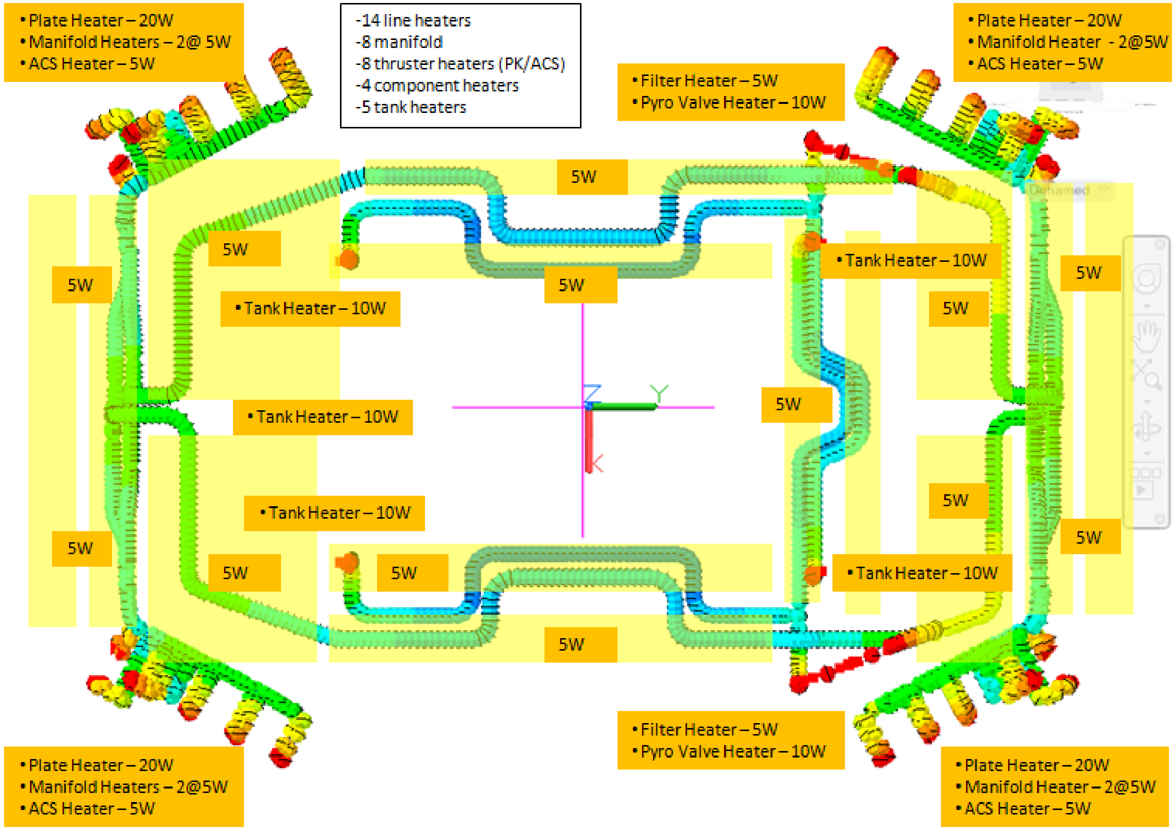
Current Thermal Control Approach & Features

The TCS architecture consists of:

- Spinning (BBQ roll) flight attitude
- Passive, centralized radiators
- Passively controlled heaters
- MLI and optical coatings



Propulsion Heater Zones and Heater Sizing



- Plate Heater – 20W
- Manifold Heaters – 2@ 5W
- ACS Heater – 5W

-14 line heaters
-8 manifold
-8 thruster heaters (PK/ACS)
-4 component heaters
-5 tank heaters

- Filter Heater – 5W
- Pyro Valve Heater – 10W

- Plate Heater – 20W
- Manifold Heater - 2@5W
- ACS Heater – 5W

- Tank Heater – 10W

- Tank Heater – 10W

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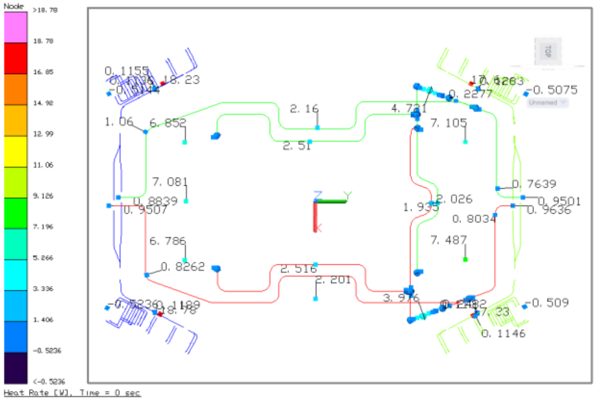
- Filter Heater – 5W
- Pyro Valve Heater – 10W

- Plate Heater – 20W
- Manifold Heaters – 2@5W
- ACS Heater – 5W

- Plate Heater – 20W
- Manifold Heater – 2@5W
- ACS Heater – 5W

- Heater Zones: 70 total (largest contributor is propulsion with 45 zones)
- Heater zones were defined for nominal conditions, and are being evaluated for suite of other scenarios.
- Each heater is passively controlled – no redundancy assumed



Heat Rate [W], Time = 0 sec

Total Heater Power:

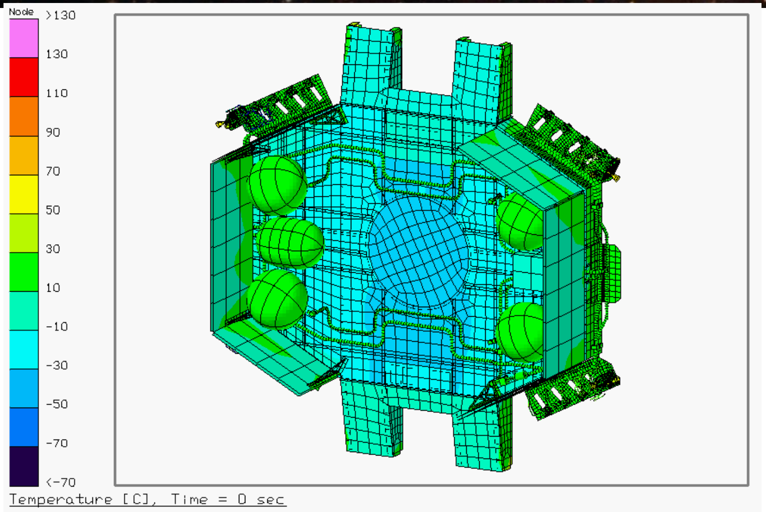
Expected peak heater power draw (Nominal case): 185W
Expected average heater power draw (Nominal case): 100W

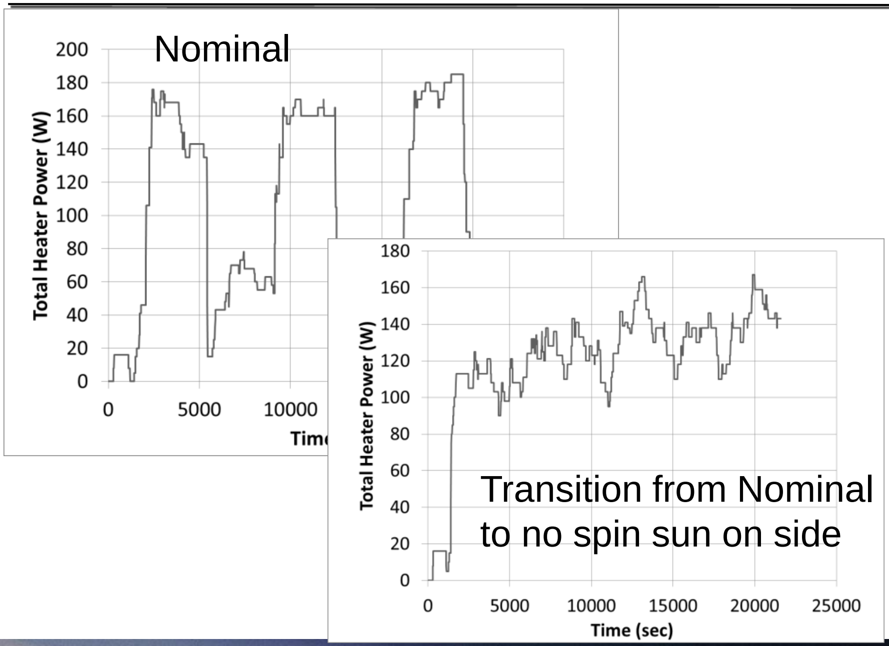
Lander Level Thermal Analyses

Latest Studies

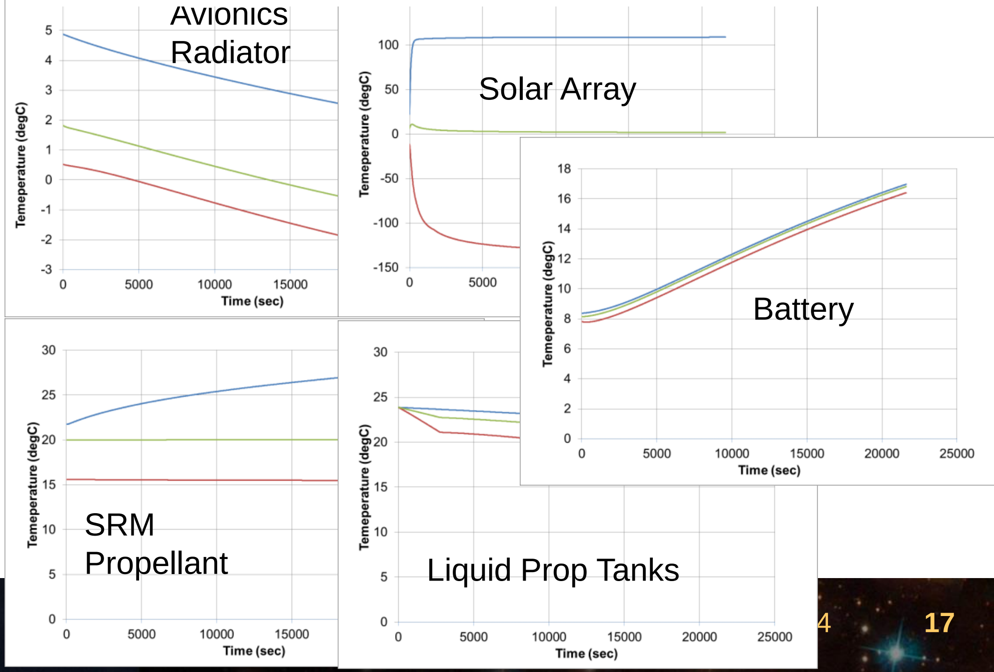
Goals:

- Investigate nominal & transient pointing cases to evaluate component temperature variations and heater power needs
- Pointing cases represent an attempt to bracket the potential behavior encountered during planned & unplanned attitude changes
- Includes all updated subsystem models
- Nominal: 6 deg/s spin with spin axis perpendicular to solar vector.





Transition from Nominal to No spin; Sun-side

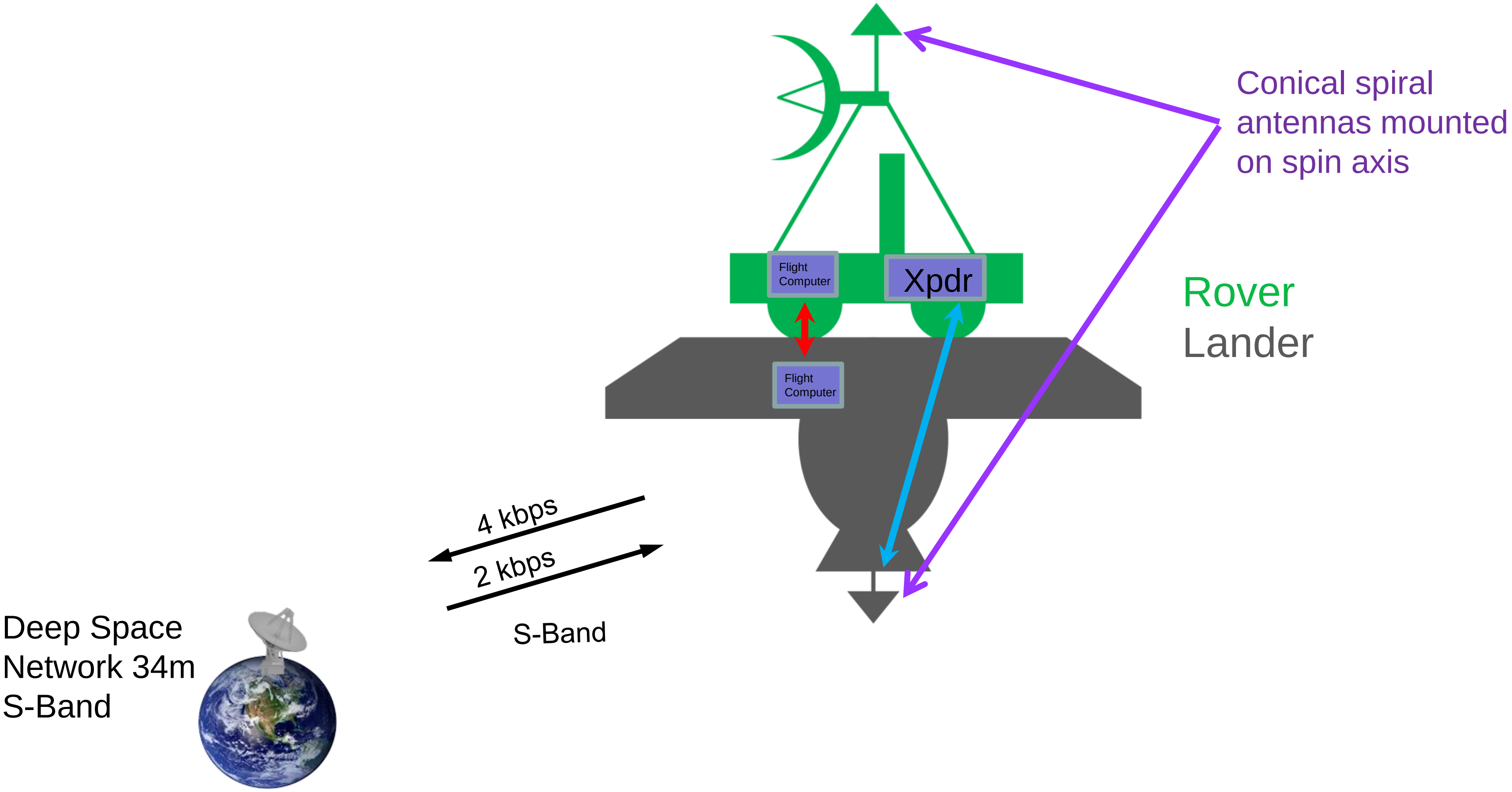


Baseline Architecture Configuration: Cruise

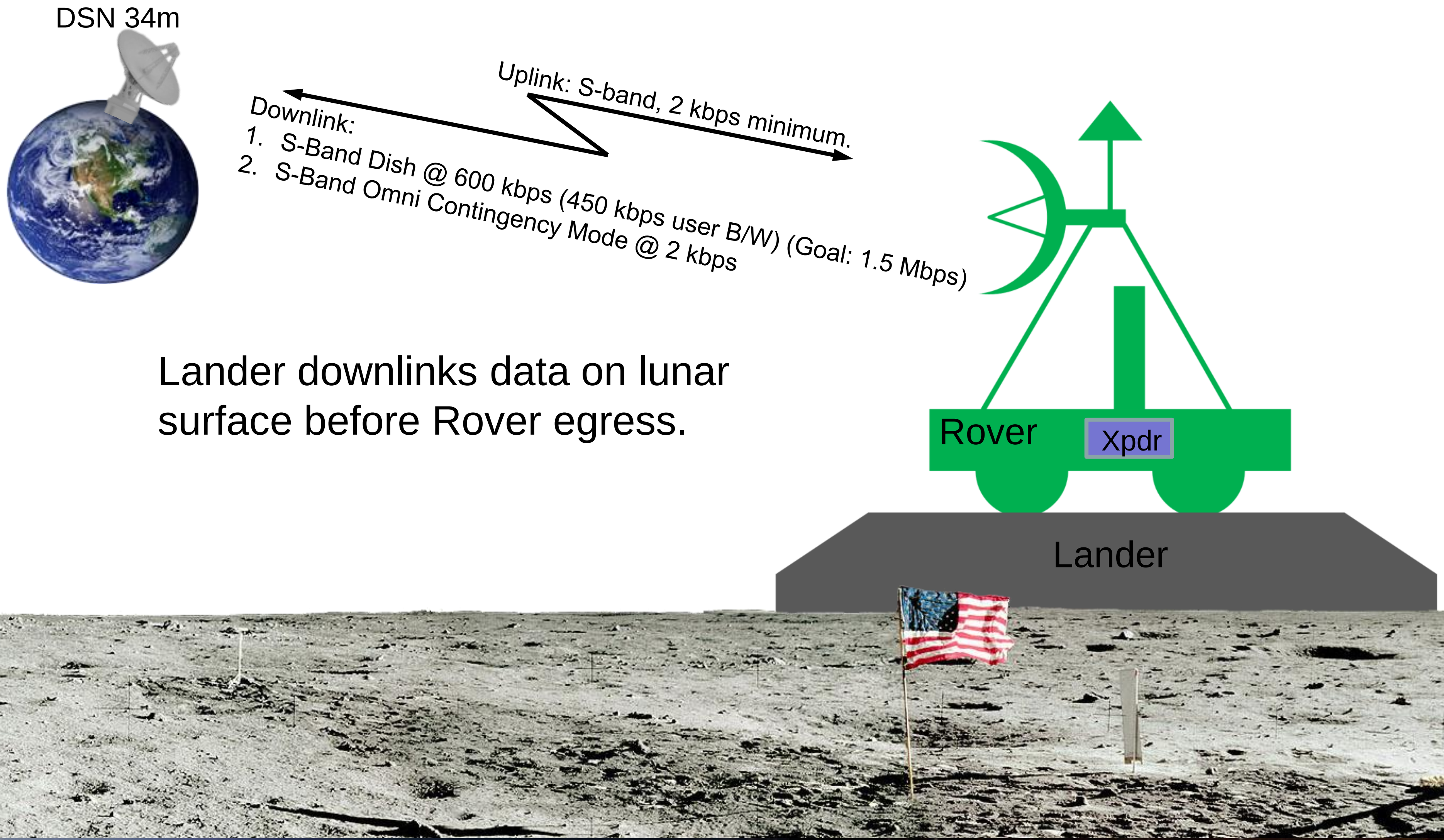
Rover Direct-To-Earth Comm

(Data Umbilical + Coaxial Cable)

(All communication hardware on Rover; Lander has an omni antenna to provide coverage)

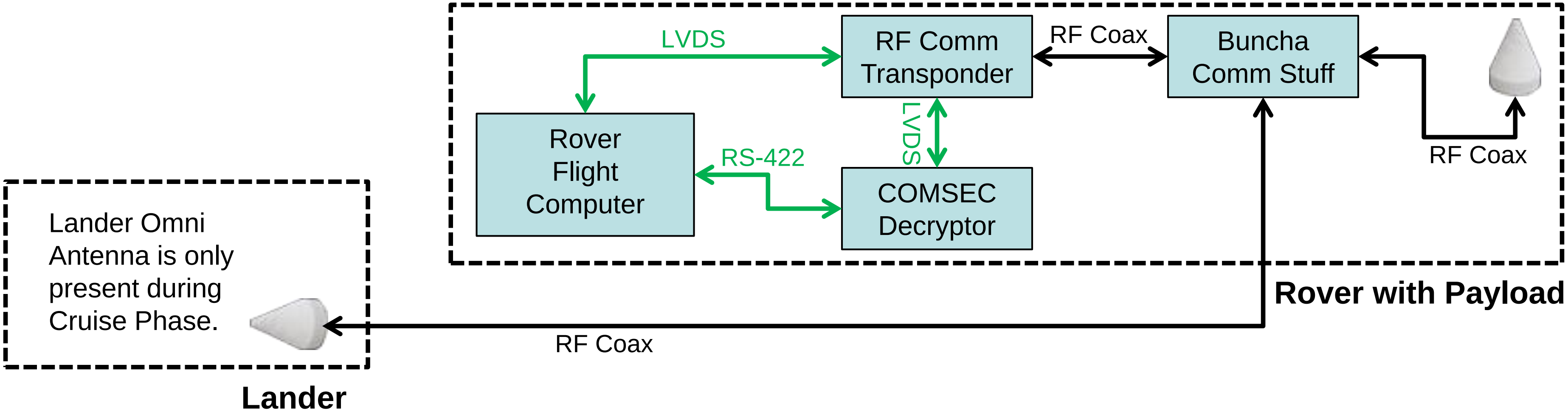


Current Architecture Configuration: Surface



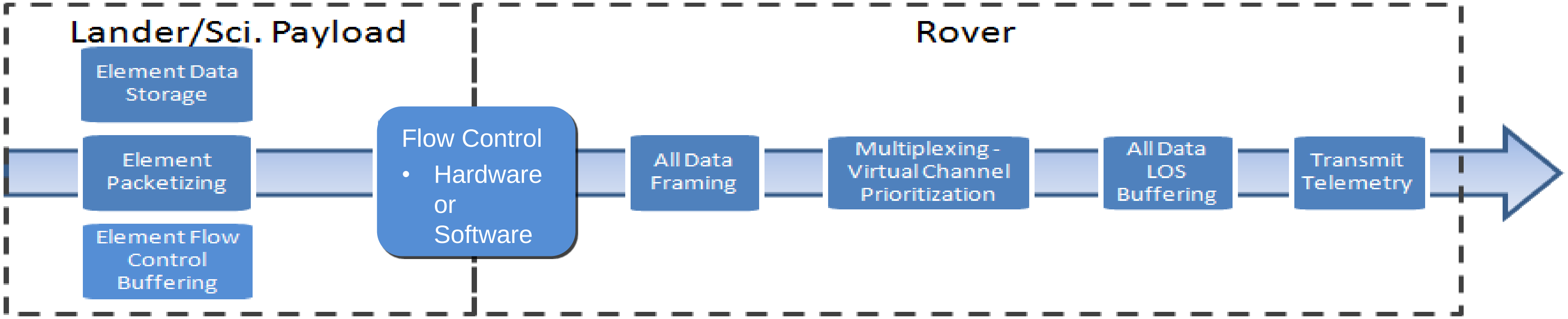
Lander downlinks data on lunar surface before Rover egress.

Configuration of Lander communications



Lander Omni Antenna is only present during Cruise Phase.

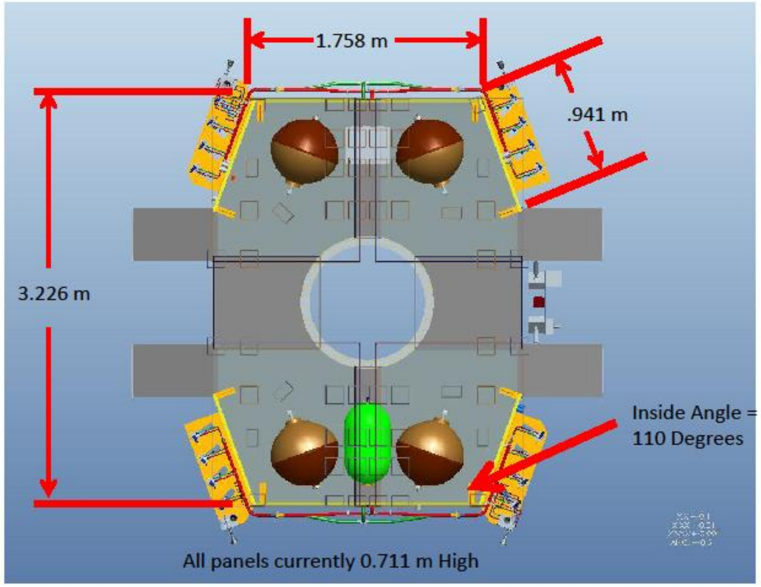
Results of recent trade

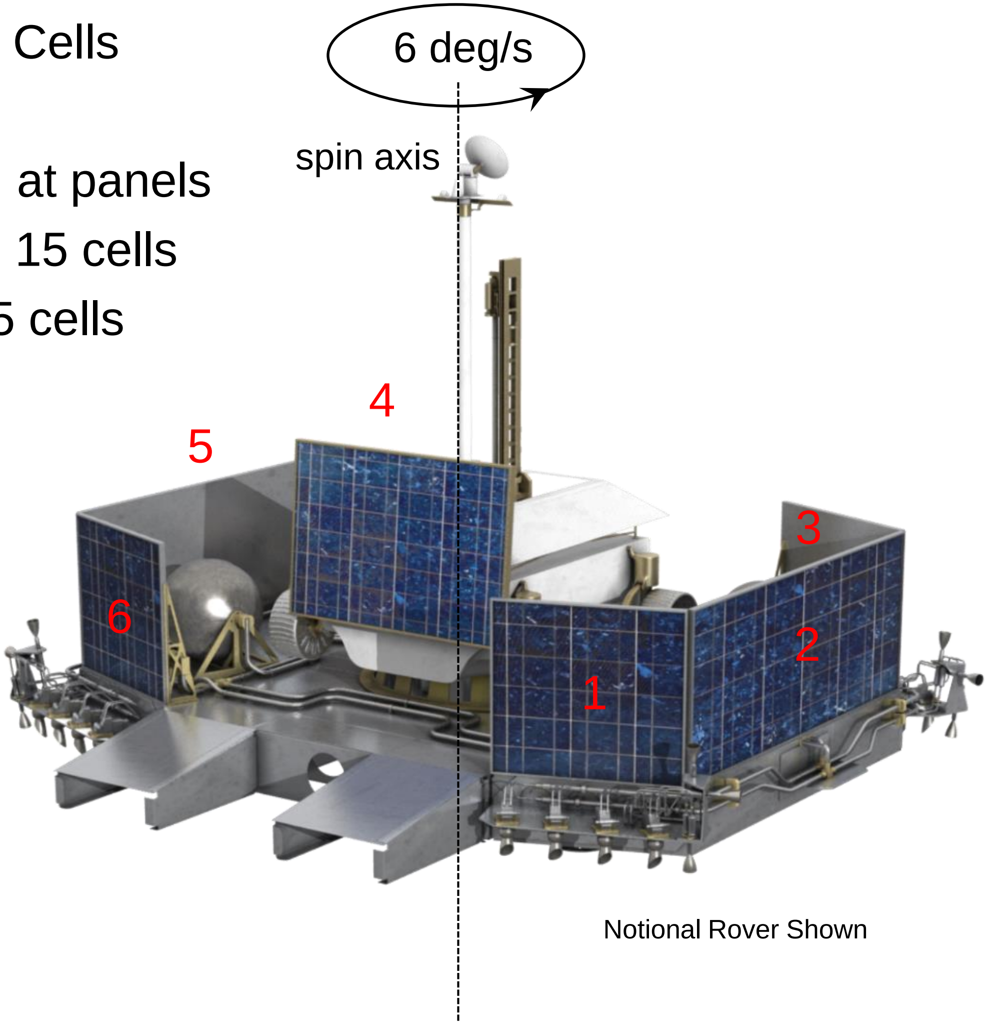


Flow Control
- Hardware or Software

Electrical Power System Layout

- Triple Junction Gallium Arsenide Cells
- ~29.5% efficient
- 6 Panels, ~488 W, 13.53 A Avg at panels
  - (2) 1.758 x .711(m), 24 strings, 15 cells
  - (4) .94 x .711(m), 13 strings, 15 cells





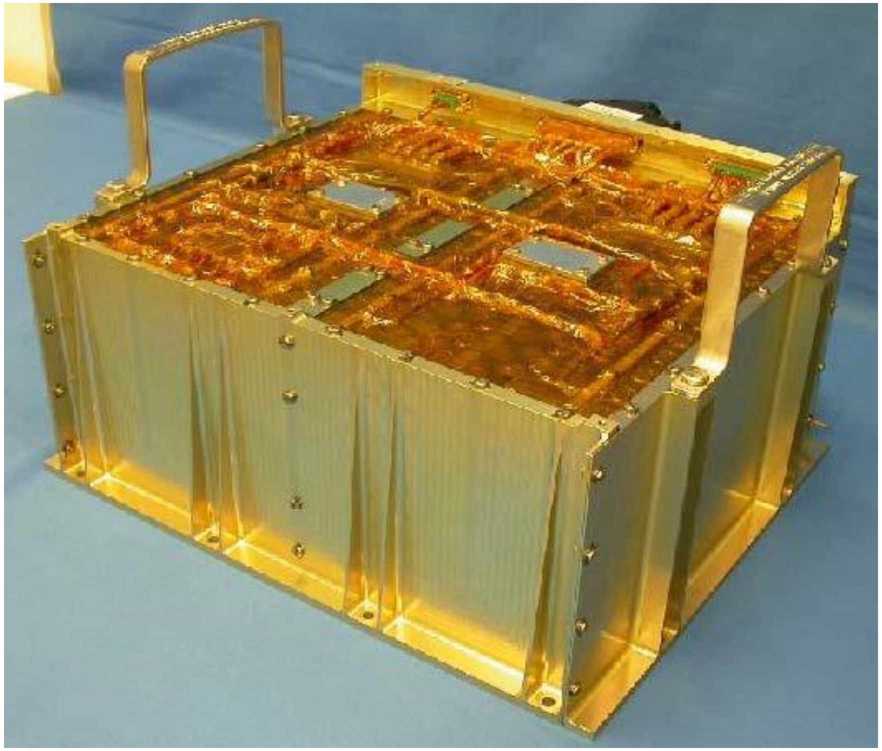
Notional Rover Shown

Energy Storage - ABSL BTP 8S52P

- Store Electrical Power
  - 78 Ampere Hour Lithium Cobalt Oxide Battery
  - 21 Kg Flight Configuration
  - 295 mm x 355 mm x 180 mm (l x w x h)
  - 416 Sony 18650HC cells, CID, PTC,
  - Burst Disc, Mandrel Safety Device

Test data for 42 day-night real time lunar cycles

Sony 18650HC

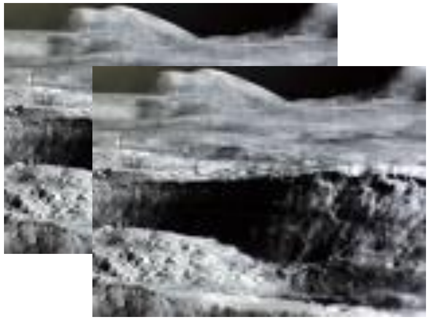


3-DoF Guidance Trajectory Performance Analysis

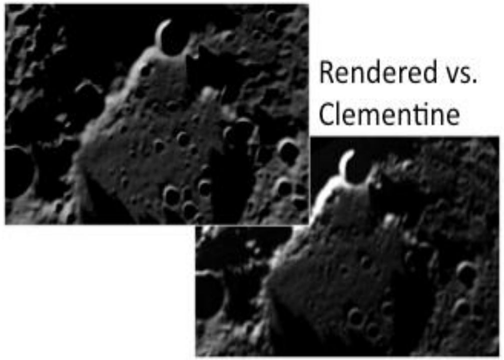
- Summary of results with Closed-loop Guidance, Perfect Navigation and Flight Control
  - Slow burning SRM will drive the descent starting conditions
  - Fast burning SRM will drive the liquid propellant load and liquid phase guidance logic
  - Increasing the heliocentric transfer time does not improve the initial descent conditions
    - Longer transfers go beyond the Moon’s orbit and then back
    - Stay near the Hohmann transfer time (~5 days)
  - Increasing the liquid thrusters thrust and specific impulse (Isp) does improve the payload capability

Optical Navigation Status

- Updated position and velocity estimation algorithms into a single refactored version of the APLNav algorithm that can perform both phases in order to maximize code reuse
- Optimized the rendering algorithm C code and onboard map structures to minimize processing time for position estimation algorithm
- Performed a benchmark test of the updated position estimation code to estimate processing load on a flight processor

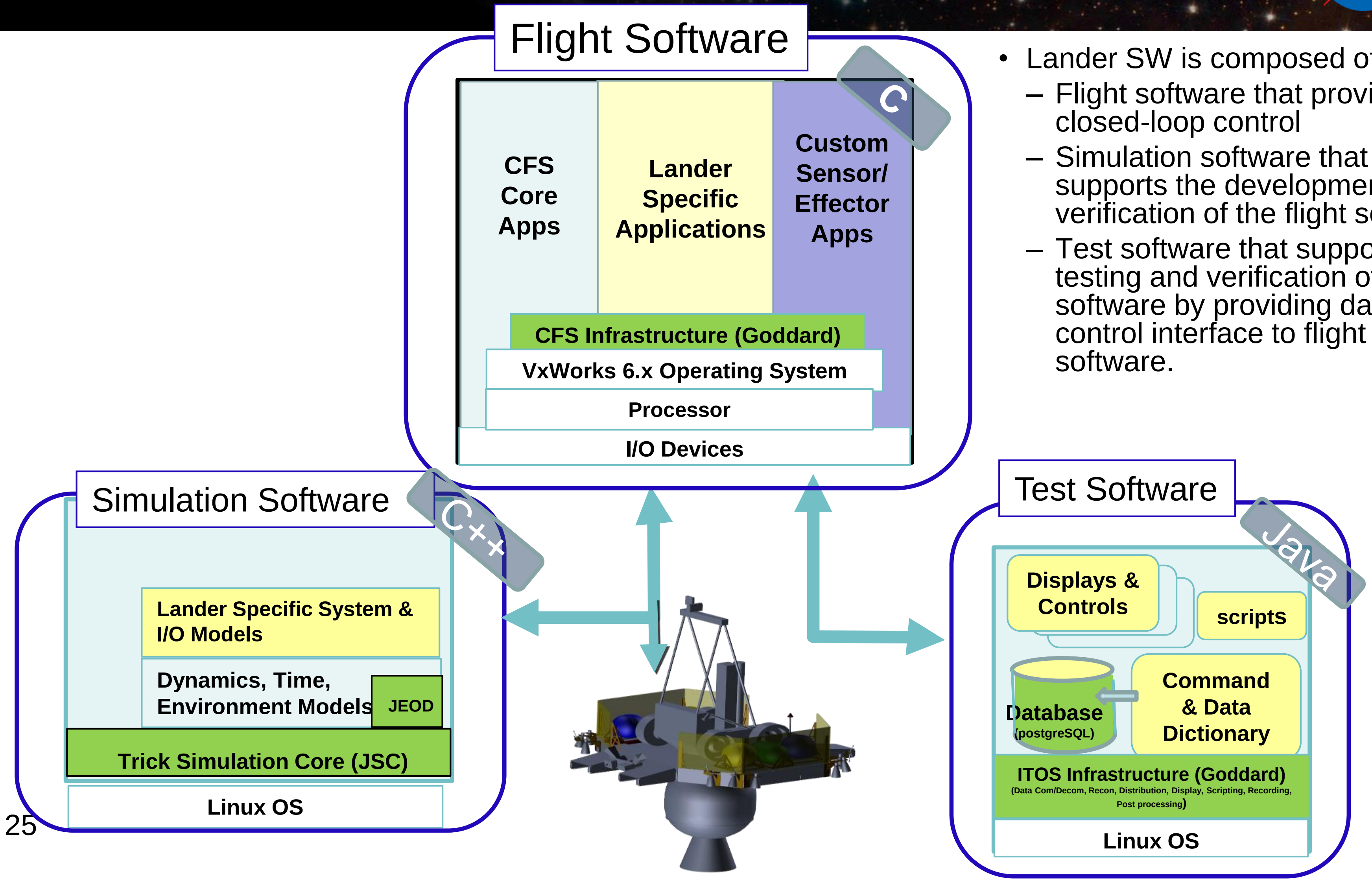


Velocity Estimate



Position Estimate

Software Overview



Flight Software

C

CFS Core Apps

Lander Specific Applications

Custom Sensor/ Effector Apps

CFS Infrastructure (Goddard)

VxWorks 6.x Operating System

Processor

I/O Devices

Simulation Software

C++

Lander Specific System & I/O Models

Dynamics, Time, Environment Models

JEOD

Trick Simulation Core (JSC)

Linux OS

Test Software

Java

Displays & Controls

scripts

Database (postgreSQL)

Command & Data Dictionary

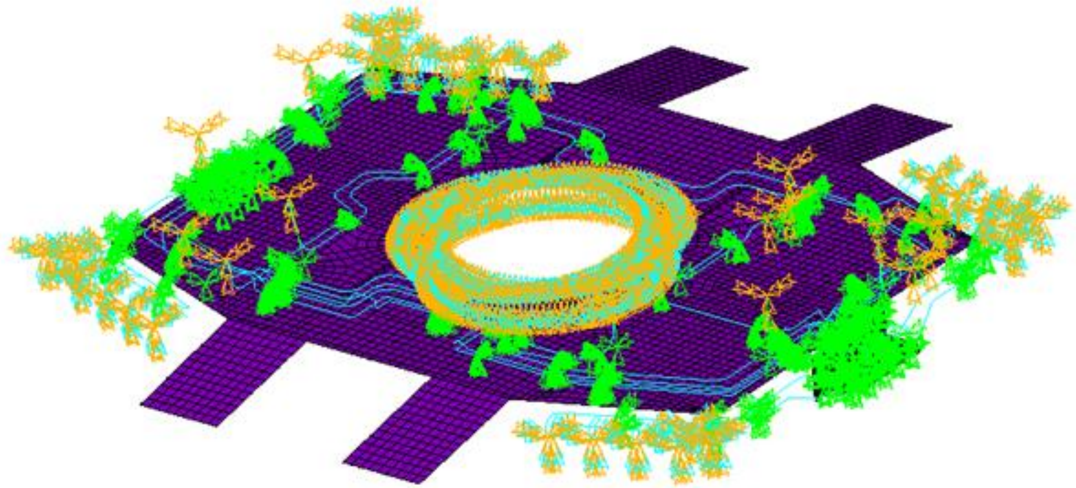
ITOS Infrastructure (Goddard)
(Data Com/Decom, Recon, Distribution, Display, Scripting, Recording, Post processing)

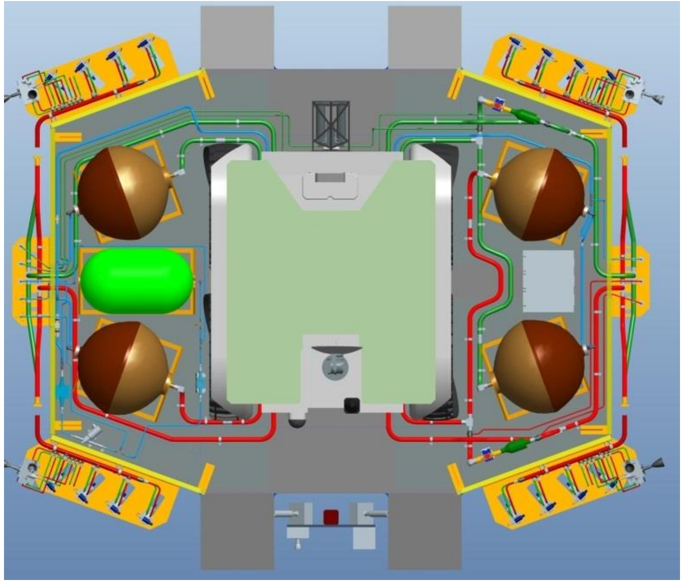
Linux OS

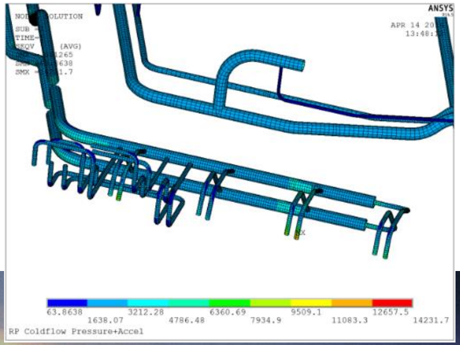
- Lander SW is composed of
  - Flight software that provides closed-loop control
  - Simulation software that supports the development and verification of the flight software
  - Test software that supports the testing and verification of flight software by providing data and control interface to flight software.

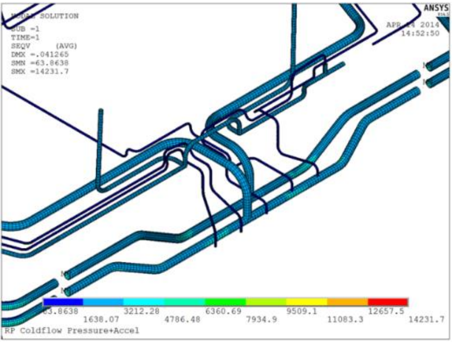
Propulsion Design Maturation

- Propulsion system layout and mechanical design
  - Completed early design of flight system
  - Released feed line system and integration drawings
  - Provided detailed Master Equipment List and propulsion/structure interfaces



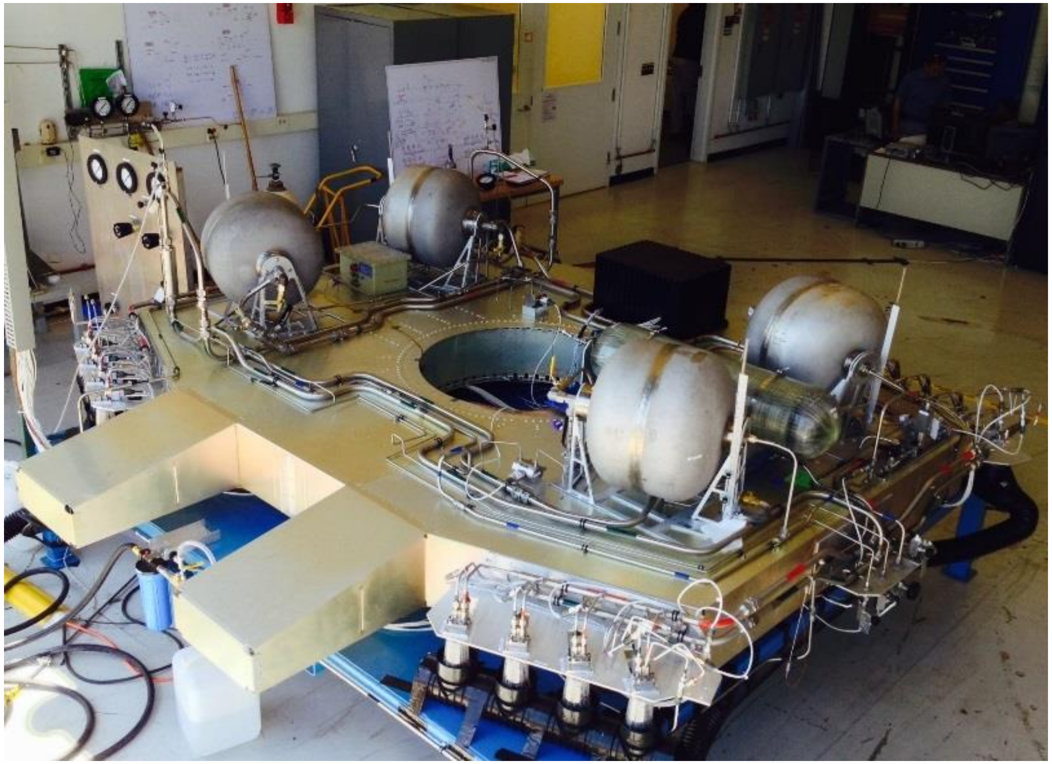






Cold Flow Testing

- Testing is complete
  - Test setup is based on flight design drawings with redline on modification



Propulsion components being installed on the lander structure

Summary

- NASA has developed a low cost, requirements-driven robotic lander concept
  - Design and analysis are partially complete
  - NASA looks forward to a partnership for completing a robotic lunar lander for the Resource Prospector Mission