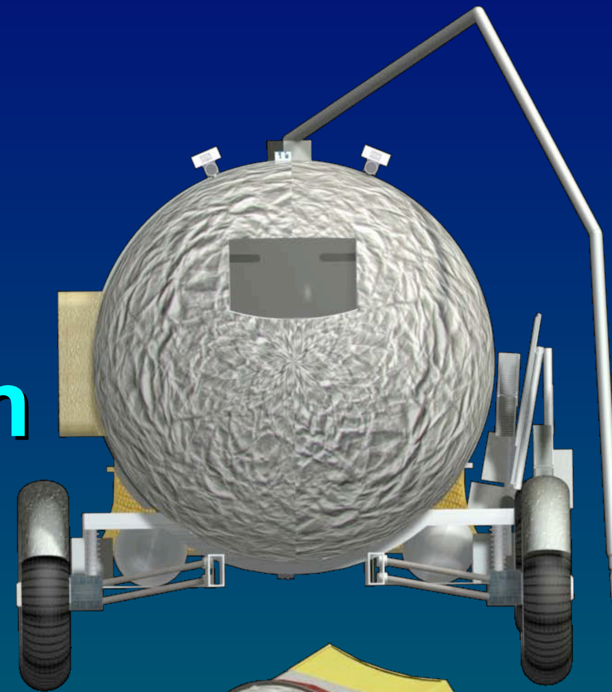
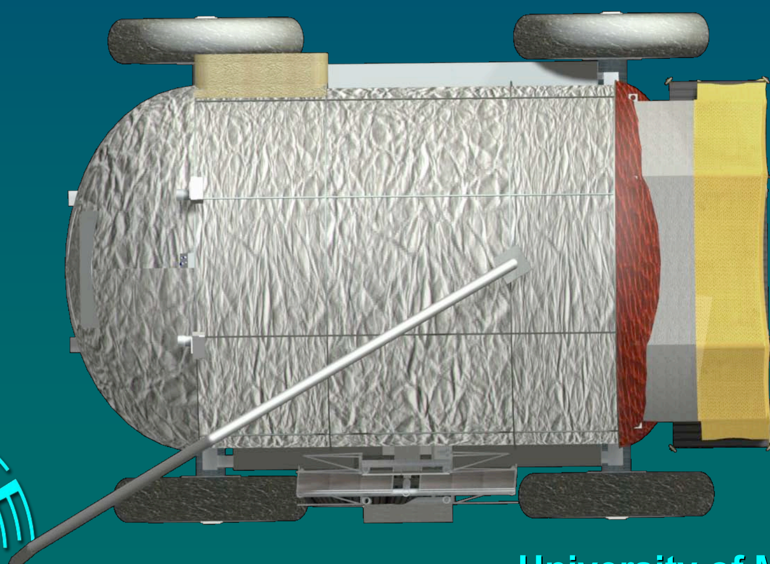
# Small Pressurized Rover
## for
# Independent Transportation
## and
# Exploration

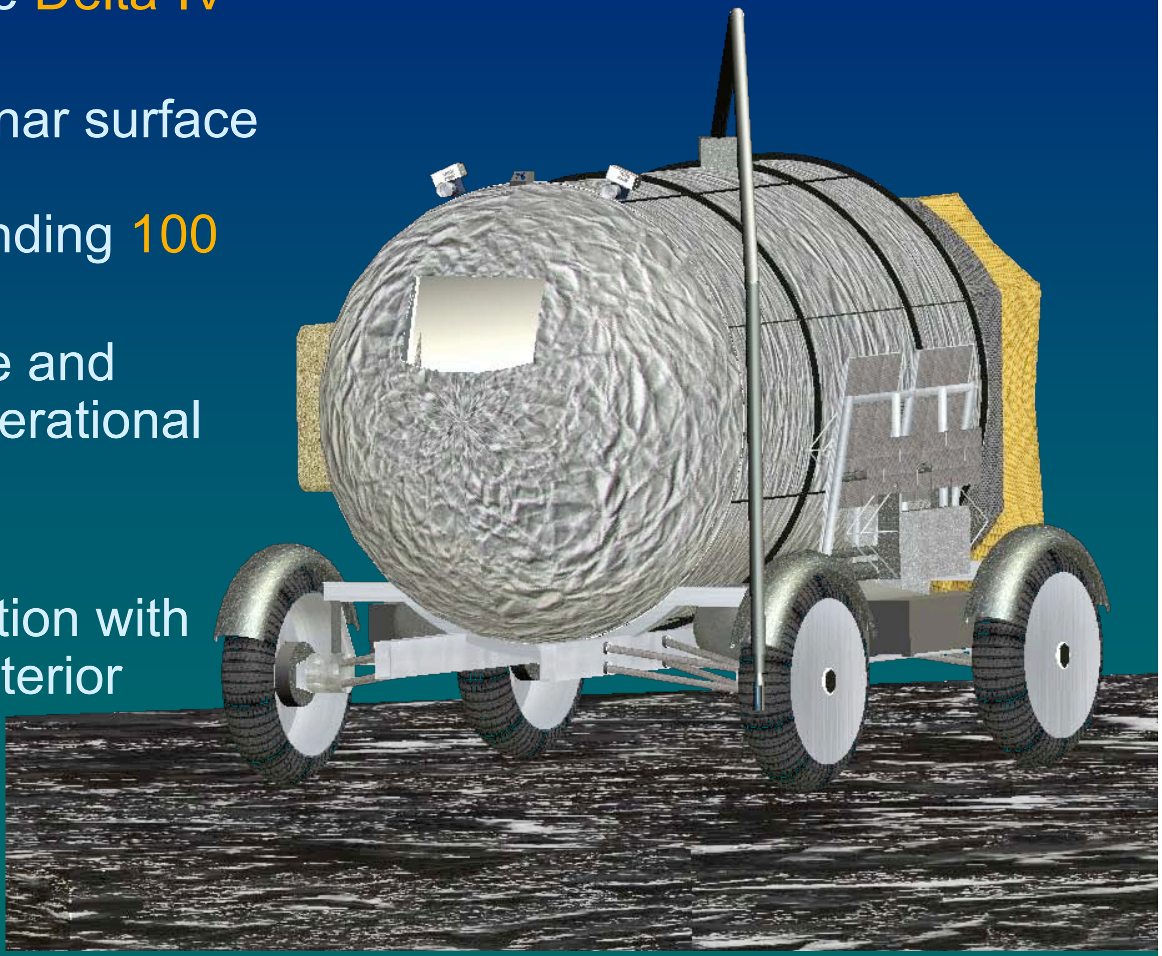




University of Maryland

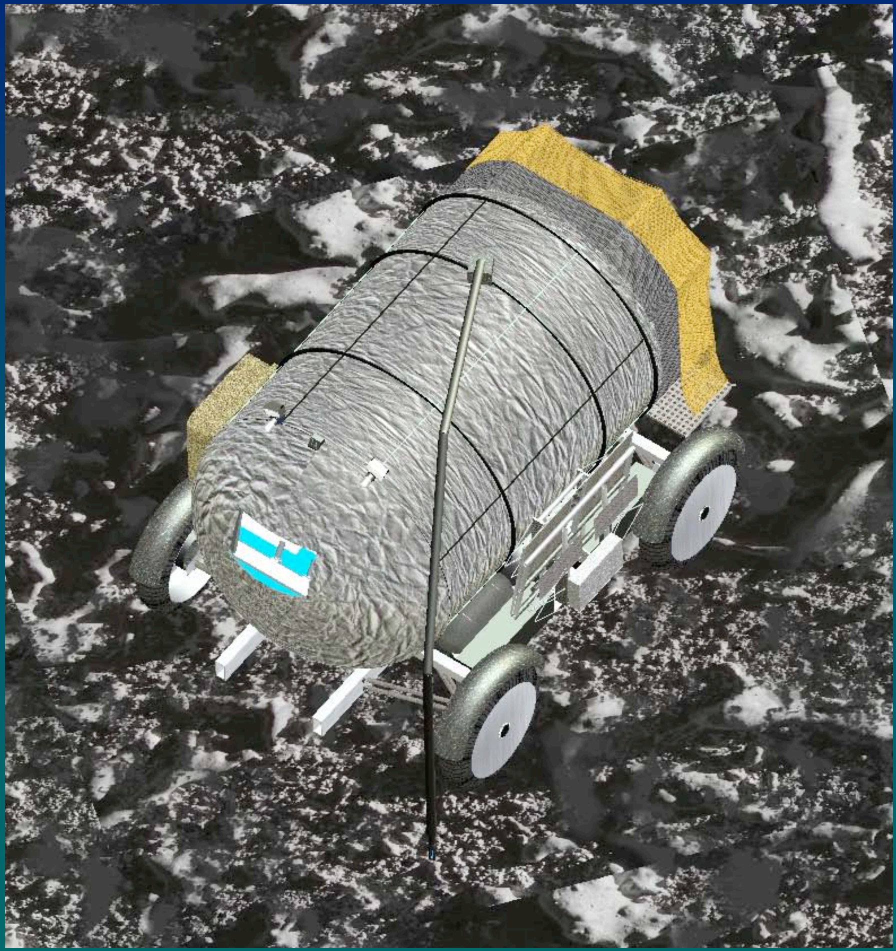
# Introduction

- Launch to moon on single Delta-IV Heavy
- Land anywhere on the lunar surface and assist a base with its exploration of the surrounding 100 km
- Allow in-situ maintenance and servicing for indefinite operational lifetime
- Fuel cell powered
- Robot arm allows interaction with local environment and exterior SPRITE systems



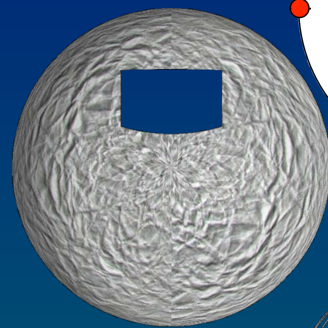
# SPRITE Capabilities

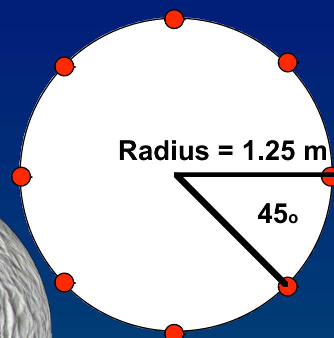
- Supports 2 crew members in a pressurized cabin for a nominal sortie length of 7 days
- Five 8-hour EVAs per sortie
- Collect 100 kg of lunar samples per sortie for return to base
- Following a worst-case failure, crew will return to base using the ERV, a small, deployable unpressurized rover

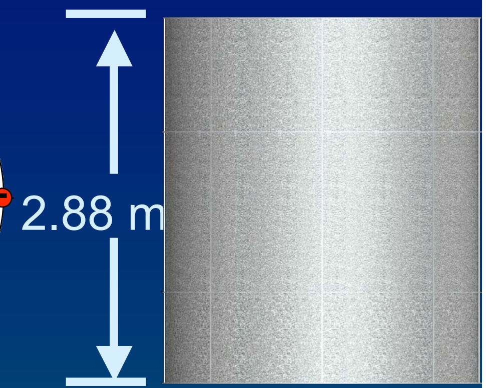


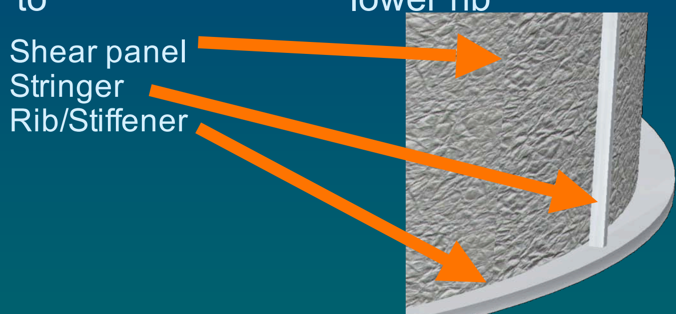
# Crew Cabin

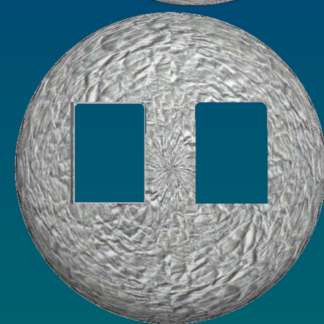
- Cylinder with 2 ellipsoidal end caps
- Ti6Al4V, 4 mm thick skin
- Total Mass (including ribs and stringers) = 505 kg
- Skin and MLI provide sufficient protection from radiation and micrometeoroids
- All stringers have hollow circular cross sections
- Supports mass of vehicle during launch ~ 3500 kg
- Analyzed using FEM
  - constrained at top rib
  - 6 g axial, 2.5 g lateral load applied to lower rib

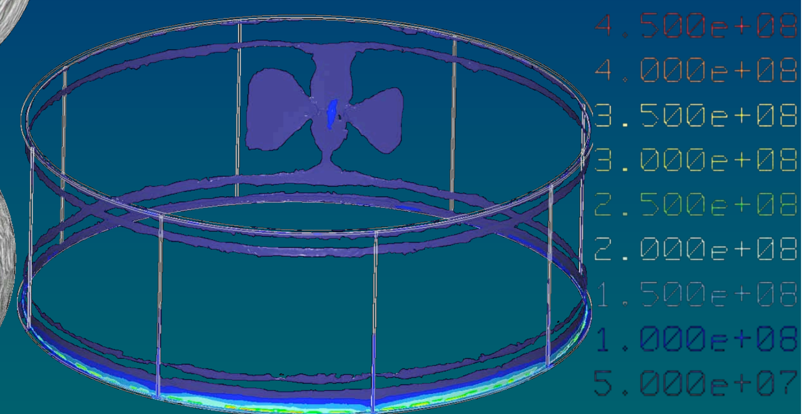




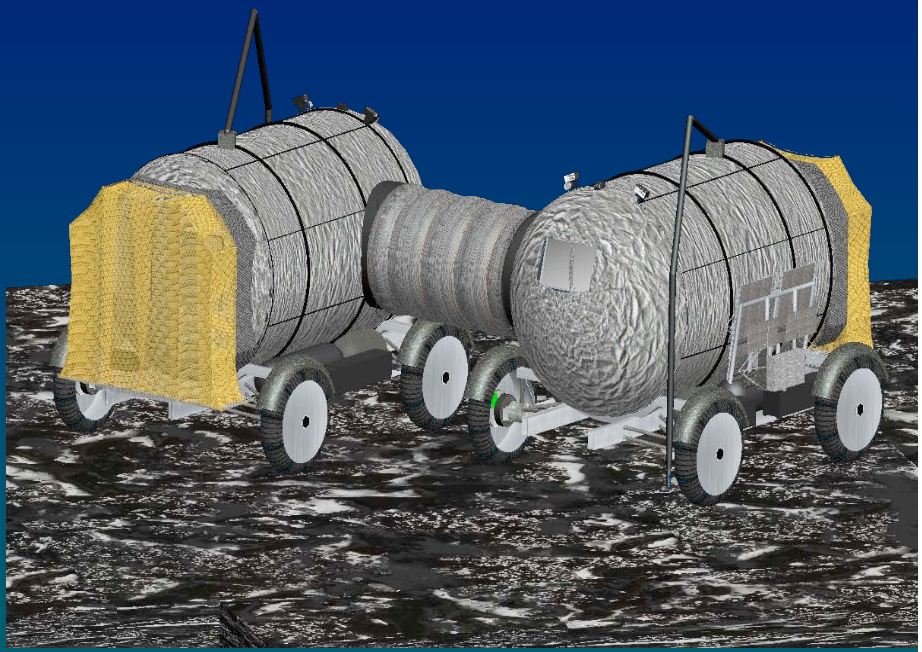






| Component | OD (m) | ID (m) | Length (m) | Mass | Design Load | MOS | SF | Failure Mode |
|---|---|---|---|---|---|---|---|---|
| Stringer | 0.055 | 0.054 | 2.88 | 12 kg | 450 MPa | 0 | 2 | Compression |
| Rib/stiffener | 0.155 | 0.141 | 7.85 | 58 kg | 450 MPa | 0 | 2 | Bending |
| Skin (4 mm) | 2.508 | 2.500 | N/A | 201 kg | 550 MPa | 0 | 2 | Local Buckling |
| Front End cap | 2.508 | 2.500 | 0.9 | 135 Kg | 550 MPa | 0 | 2 | Local Buckling |
| Rear End cap | 2.508 | 2.500 | 0.5 | 98 Kg | 550 MPa | 0 | 2 | Local Buckling |
| Total Mass | | | | 504 Kg | | | | |

# Pressurized Mating Hatch

- Provides shirtsleeve transfer of astronauts and supplies from SPRITE to base or to another SPRITE vehicle
- Inflatable membrane constrained by a titanium pantograph structure and Kevlar chords
- Transferables supported by a collapsible carbon/epoxy plank structure stowed inside SPRITE
- Contact is made by an androgynous resilient metal seal adapter



Membrane:
4.75 mm thick;
Nomex T418 pressure bladder;
20 layers; 380 micron aluminized mylar;
Teflon PTFE fabric abrasion layer

# Exterior Suits

- 2 rear entry EVA suits will be mounted similar to NASA Ames Suitport concept
- Exterior suits reduce dust infiltration
- No airlock needed
- Docking device mass is 27 kg
- Only the suit interior opens to the cabin
- Docking device operable by suited astronaut
- Protected from dust exposure and micrometeoroids by collapsible Kevlar shield

http://ails.arc.nasa.gov/Images/TechXfer/AC96-0195-21.html

# Atmosphere and Crew Consumables

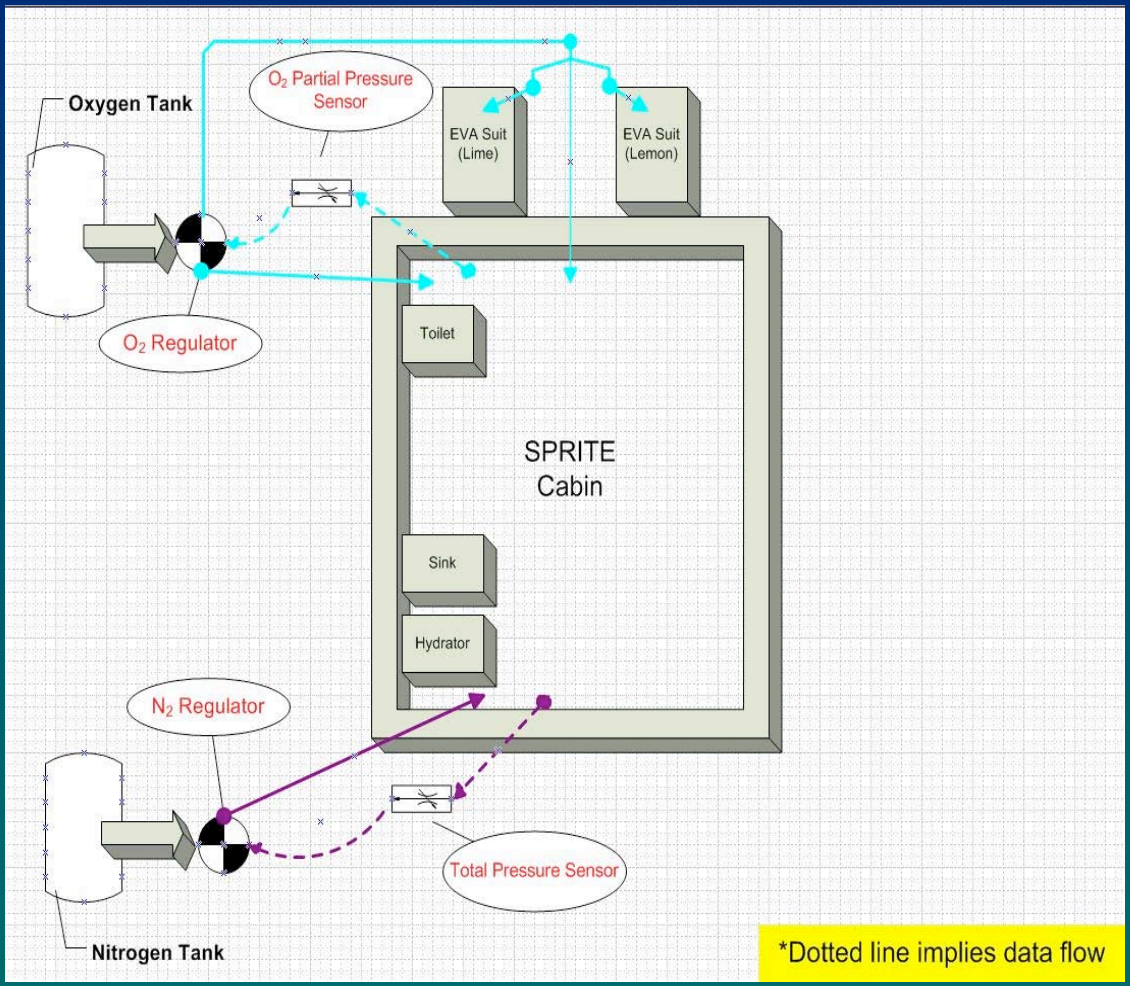
- SPRITE atmosphere:
  - Total Pressure = 8.3 psi
  - 37% Oxygen, 63% Nitrogen
- Transfers to and from base and suits require no pre-breathe period
  - Base: 14.7 psi total, 21% $O_2$, 79% $N_2$
  - EVA suits: 3.5 psi total, 100% $O_2$

Consumables required for one 7 day sortie + 3 days emergency

| | Mass (kg) | For | Storage |
|---|---|---|---|
| Oxygen | **23** | Atmosphere | Collected from fuel cell oxygen tank boil-off |
| Nitrogen | **1** | Atmosphere | Small interior tank |
| Water | **250** | Drinking, food hydration, hygiene, EVA cooling | Interior tank below floor panels |
| Food | **40** | Eating | Freeze-dried |

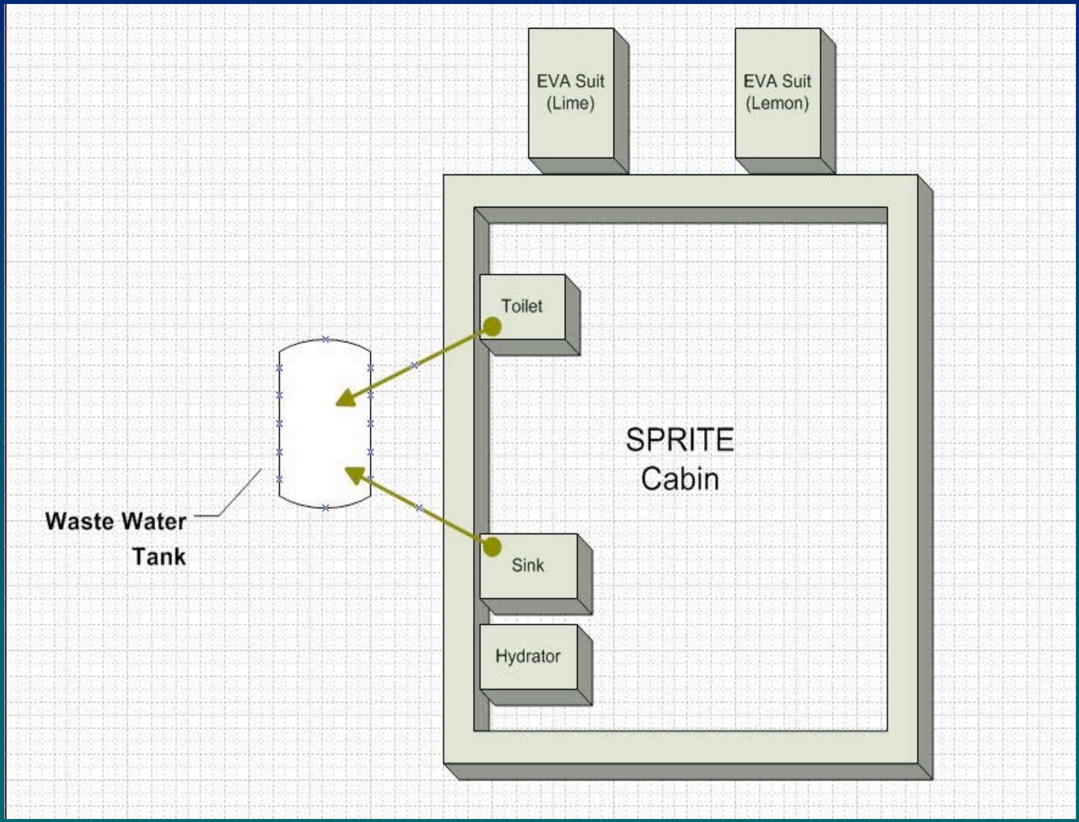
# Atmospheric Control

- Regulators will meter out gas from $O_2$ and $N_2$ tanks as needed
- $CO_2$ removal performed by LiOH canisters (40 kg required per mission)
- High Efficiency Particulate Arrestance filter removes contaminants
- In case of fire, cabin is flooded with 10 kg of $CO_2$, crew uses $O_2$ masks

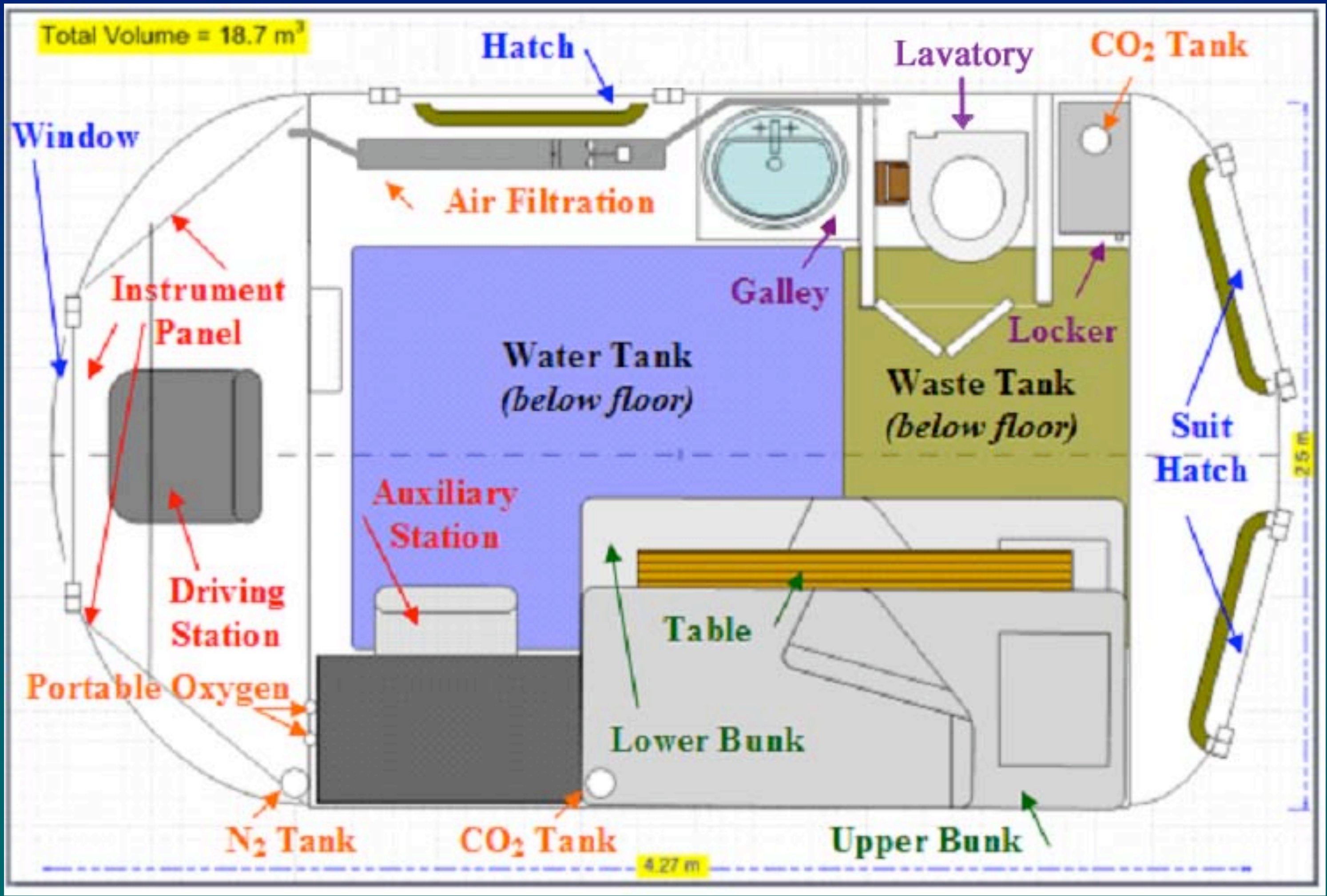


# Waste Management

- Expect 9 kg of trash
  - Dry trash stored in cans lined with bags
  - Wet trash stored in sealable plastic bags
- Toilet and solid waste storage system mass = 112 kg
- Liquid waste from galley and urine stored in tank under cabin floor

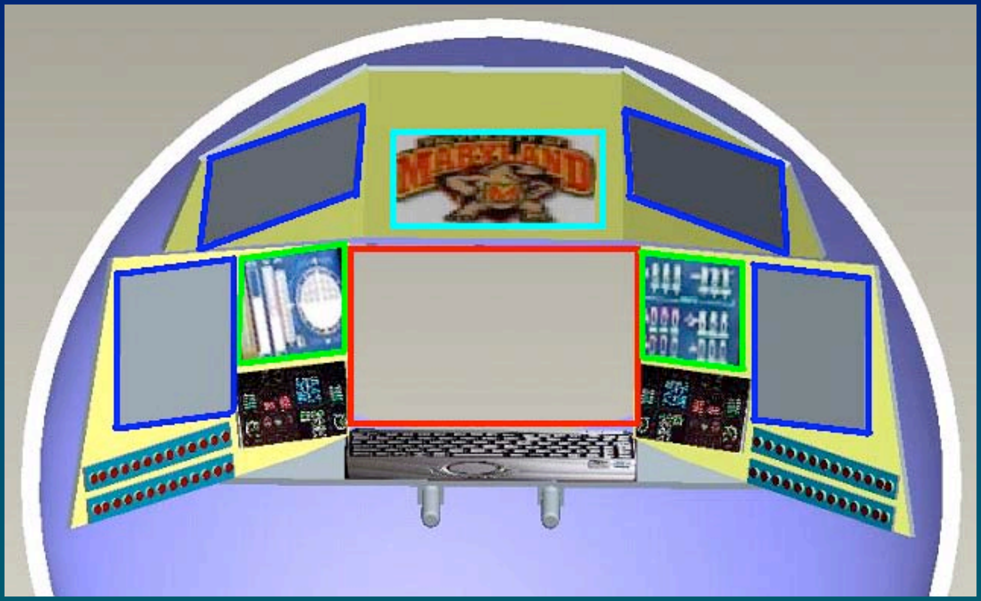


# Interior Layout



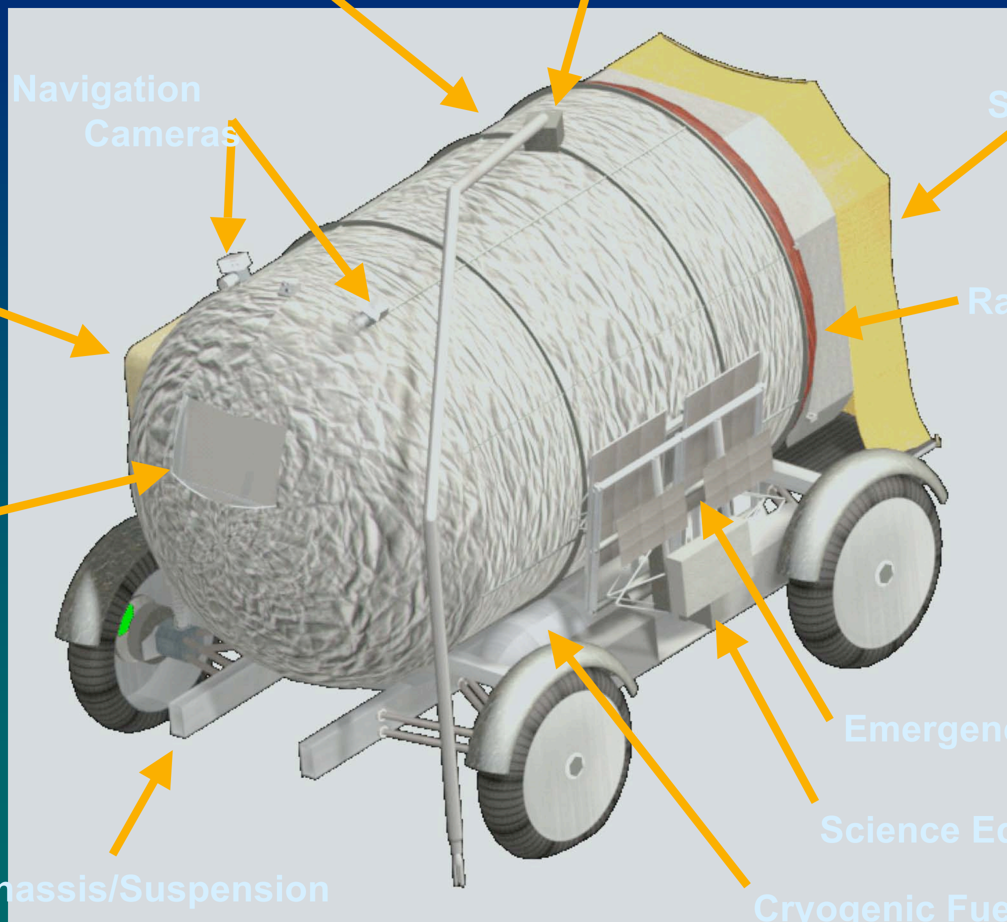
# Driving Station

- Viewing distance = 51 cm
  - Elevated floor = 60 cm
  - 95th male sitting eye level = 135 cm
  - Driver sees 65 cm in front of rover
- Window = 96 cm
- Multi-paneled, multi-function display (MFD, 4) = 60 cm
  - System stats, auxiliary camera views (nav. and obs.), robotic arm views, geographic survey
- Primary navigation display = 69 cm
- Data navigation display (2) = 50 cm

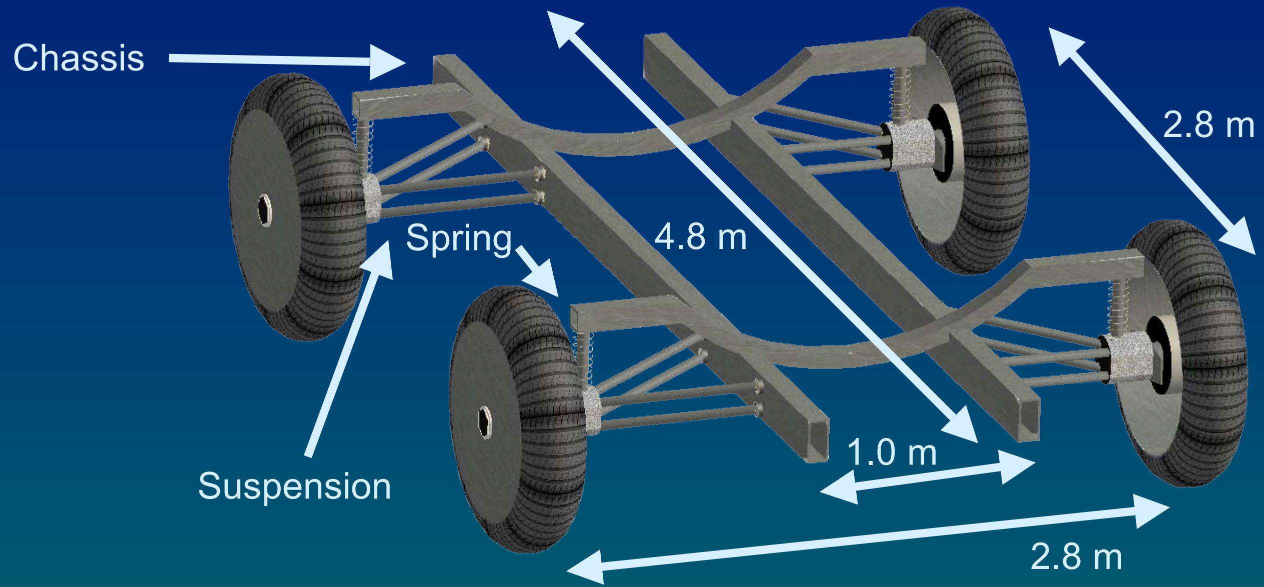


- Steering system
- Feedback loop, 2-DOF joystick
- Robotic arm, 7-DOF
- 2 - 3 DOF joystick w/ toggle
- Passenger : MFD (2) = 87 cm

# Exterior Configuration



# Chassis, Suspension and Wheels




- **Chassis** supports weight of SPRITE during launch and driving operations
- **Suspension** system allows for clearance of 0.5 m obstacle
- **Material**: Titanium alloy
- **Total mass = 550 kg**

- **Rim and hub** design protects the motors
  - Width = 0.3 m  Diameter = 1.2 m
  - Material: Aluminum-2024-T4
- **Tire**
  - Woven mesh of zinc-coated piano wire
  - Increases traction
  - Absorbs impact load
- **Mass = 38.3 kg per wheel**

# Drive System Overview

### Driving Requirements

| Per Wheel | Peak | Continuous |
|---|---|---|
| POWER* | 4.48 kW | 1.42 kW |
| TORQUE* | 775 Nm | 163 Nm |
| Power to TOW** | 3.72 kW | 1.76 kW |
| Torque to TOW** | 1285 Nm | 305 Nm |

*- @ a speed of 15 km/hr to drive 5000 kg

**- @ a speed of 5 km/hr to drive 8000 kg

Danaher motion, Direct Drive DC Torque Motors Catalog

### Driving Motor Specifications

- *Direct Drive, High Torque Motors inside the wheel*
- Capabilities: 7 kW Peak Power, 1300 Nm Peak Torque
- Volume: 25 cm Outer Diameter, 13 cm Inner Diameter x 9 cm in Length
- Mass: 24 kg per motor

# Steering and Braking

Braking

| | |
|---|---|
| Braking Distance | 4 m |
| Time to Stop | 0.96 s |
| Comfortable Braking Rate | 4.34 $m/s^2$ |
| Coefficient of Friction* | 0.65 |
| Force to Brake | 1017 N |

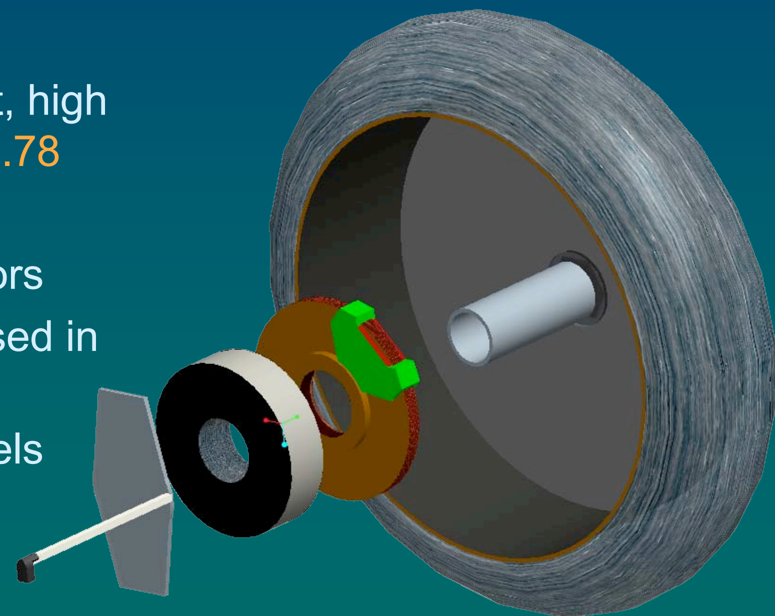
* - rated at 120 °C for kinetic friction

Turning and Steering

| | |
|---|---|
| Turning Radius | 9.5 m |
| Minimum Wheel Angle | 15° |
| Vertical Center of Gravity | 1.52 m |
| Force Delivered to Wheel | 490 N |
| Power per Wheel per Turn** | 105 W |

** @ 10.5 km/hr with a 6 cm actuator stroke length

- *Dynamic* and *Regenerative* Braking
- Carbon-Carbon Disc Brake with lightweight, high temperature tolerance; Specific gravity of 1.78
  - 2.85 cm thick x 20 cm radius
- 4-phase Regenerative braking via DC Motors
  - brings to 5 km/hr over gradual period, used in 80-90% of all instances of braking
  - transmits heat of braking to surface panels



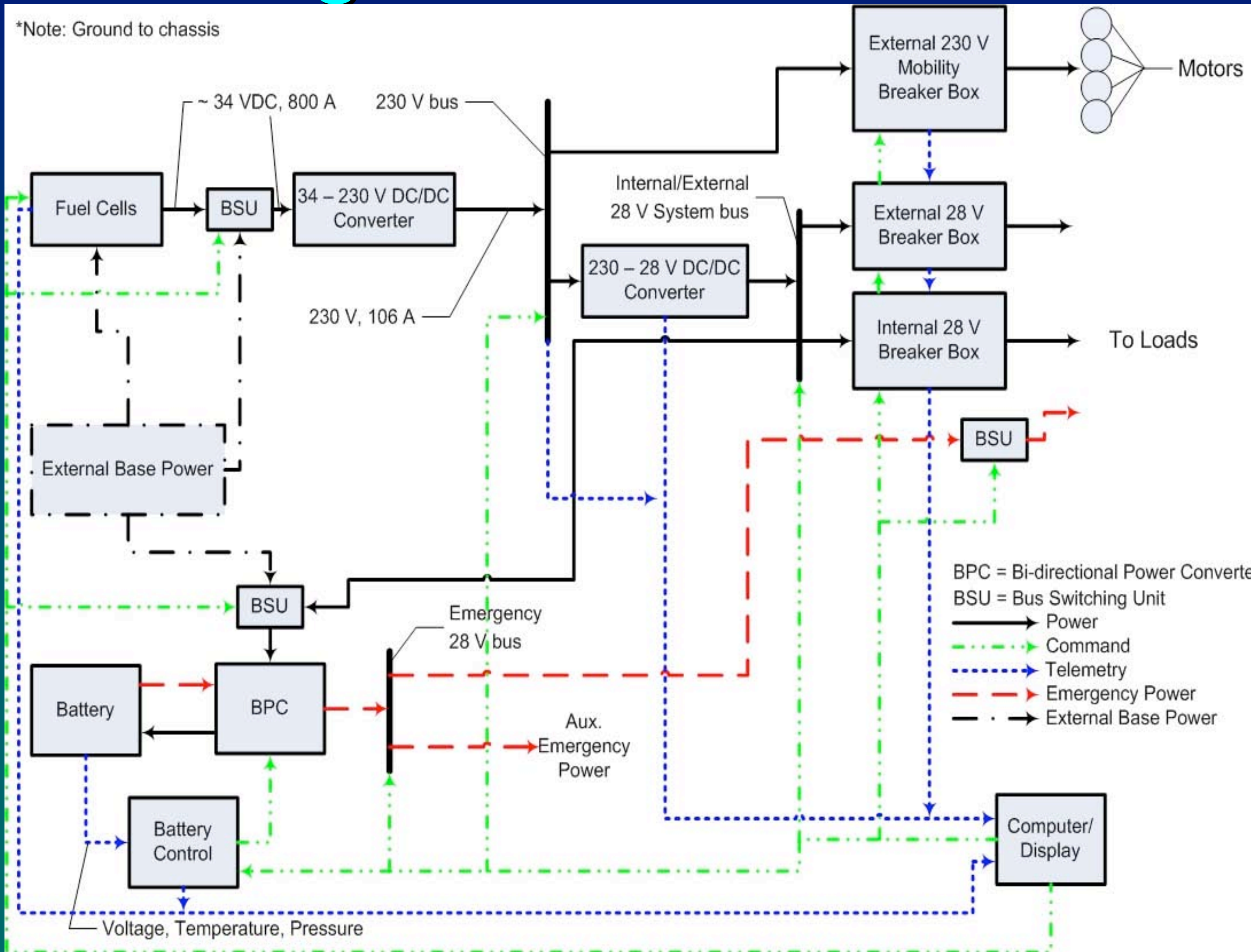
# Power Budget and Production

Energy budgeted 10 days for crew systems and 7 days for all other systems

| | Power | | Energy | |
|---|---|---|---|---|
| | Estimated (kW) | Budgeted (kW) | Estimated (kW-hr) | Budgeted (kW-hr) |
| Nominal Driving | 5.4 | 5.9 | 116 | 148 |
| Peak Driving | 18.0 | 20.0 | 31 | 38 |
| Avionics | 1.1 | 1.2 | 188 | 206 |
| Crew Systems | 2.3 | 2.6 | 519 | 618 |
| Robot Arm | 1.0 | 1.0 | 40 | 50.0 |
| **SPRITE** | **22** | **25** | **894** | **1060** |

- Proton Exchange Membrane fuel cell
- 34 Volts, 800 Amps
- Efficiency: 54 %
- Reactants stored in exterior cryogenic tanks
- Water produced stored internally beneath cabin floor
- Stack Mass: 29 kg
- 60 kg $H_2$, 475 kg $O_2$ used per sortie

# Power Management and Distribution



# Thermal Control Systems

- Passive
  - Insulation
    - Multi-layer insulation
    - 20 layers of 380 aluminized Mylar
  - Interior Cooling
    - Heat Pipes used to cool avionic
    - Copper/Water pipes used with a screen wick
    - Passive radiator to dump heat from heat pipes
    - Area: 1.3 $m^2$
    - Mass: 110 kg
- Active
  - Heat Exchanger
    - Water is pumped through the pipes at 0.3 kg/s
    - Required pump power: 15 W
    - Air is circulated over the pipes
    - Pipes made of aluminum
    - Area: 2.5 $m^3$
    - Maximum heat dissipated: 1000 W
    - Mass: 18 kg
  - Radiator
    - Made of aluminum
    - Area: 1.5 $m^3$
    - Mass: 10 kg

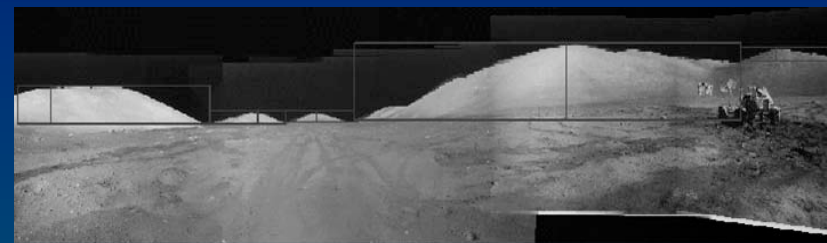
# Communications

- SPRITE capable of continuous communication with the Earth using a high gain antenna when stopped
- Communiqués destined for lunar base are relayed by Earth (or satellite at L2 if on far side of moon) due to limited line of sight
- SPRITE also capable of HDTV transmission to Earth when stopped

| | SPRITE to Earth/Base | SPRITE to EVA |
|---|---|---|
| Antenna Type | High gain | Low gain |
| Band | Ka | UHF |
| Frequency | 20 – 25 GHz | 0.9 GHz |
| Power Output | 10 W | 20 W |
| Data Rate | 50 Mb/s | 50 Mb/s |
| Link Margin | 3 – 6 dB | 4 dB |

# Surface Navigation Architecture

- Star tracker position estimate used as starting point
- Landmark Navigation uses day/night panoramic CCD camera to build digital elevation map (DEM) of horizon
- DEM is correlated with topography maps from Lunar Reconnaissance Orbiter



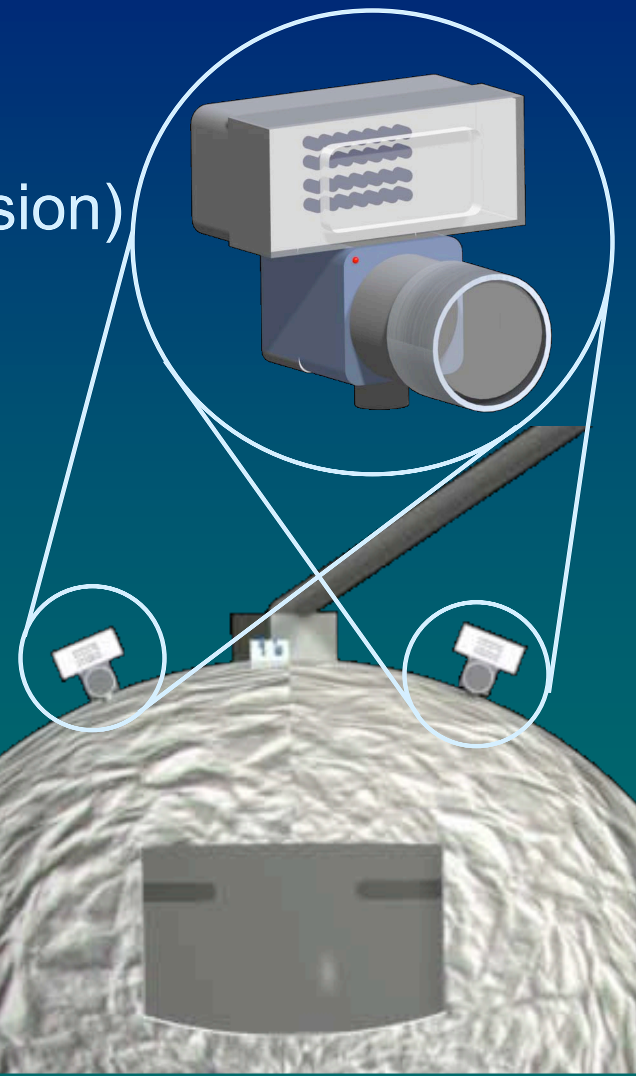
http://www-2.cs.cmu.edu/afs/cs/project/viper/www/Results/

| | Viper 1997 | SPRITE 2016 |
|---|---|---|
| Accuracy | 180 m | 100 – 180 m |
| Pre Processed Storage Region | 100 MB (10 x 20 km) | 500 MB (10 x 100 km) |
| Time | 10 s | 10 – 15 s |
| Night range | N/A | ~ .8 km* |

* Based off of generation 4 night vision technology

# Obstacle Detection/Avoidance

- Detects, characterizes, and tracks obstacles from 0 m - 50 m
- 3 stereo camera pairs (1 pair night-vision)
  - 6 m – 50 m coverage
  - 2 x 200 W headlights for night operations
- 2 3D laser scanners
  - 0.5 m – 6 m coverage
- Autonomous driving computer
  - 0.5 second path generation around local obstacles



# Computers, Networking, and Data Storage

- Primary network ~ 57.6 Mbps
- Vehicle/Crew health ~ 1 kbps
- Data Storage ~ 25 GB capacity
- 1 RAD6000 general purpose computer
  - 33 MHz, 35 MIPS, 128 MB RAM
- 2 RAD750 navigation computers
  - Command drive-by-wire system
  - Process landmark navigation
  - Process crew route planning, update stored maps
- 1 autonomous driving computer (ADC)
  - Maxwell Technologies SCS750 (space-qualified super computer)
  - 800 MHz, 1800 MIPS, 256 MB RAM
- 1 RAD750 obstacle processing computer for laser rangefinders
- 2 Notebook Computers

# Typical Sortie

- Nominal sortie includes
  - Day 1: 100 km traverse
  - Days 2 – 6: EVA, 10 km traverse
  - Day 7: 100 km traverse back to base
- Each traverse segment may include up to 1000 m of ascent/descent

## Sample Day Schedule

| Time Segment | Activity | Time (hrs) |
|---|---|---|
| 00:00 - 06:00 | Sleep | 6 |
| 06:00 - 06:30 | Hygiene | 0.5 |
| 06:30 - 07:15 | Breakfast | 0.75 |
| 07:15 - 07:45 | EVA Prep | 0.5 |
| 07:45 - 15:45 | EVA | 8 |
| 15:45 - 16:15 | Doff suit | 0.5 |
| 16:15 - 16:45 | Hygiene | 0.5 |
| 16:45 - 17:00 | Review of EVA Activities | 0.25 |
| 17:00 - 17:45 | Dinner | 0.75 |
| 17:45 - 18:45 | Reposition | 1 |
| 18:45 - 20:45 | Complete Earlier Notes | 2 |
| 20:45 - 21:45 | Personal Time | 1 |
| 21:45 - 22:00 | Hygiene | 0.25 |
| 22:00 - 00:00 | Sleep | 2 |

# Base Operations

- Base provides all consumables and some scientific instruments
- Umbilical provides 2.5 kW of power for life support and avionics
- Upon arrival at base, the following components will be assembled and/or attached:
  - Emergency Return Vehicle (ERV)
  - Robotic arm
  - Scientific instruments
  - Spacesuits

**Supplies Provided by Base**

| Item | Mass (kg present on sortie) |
|---|---|
| Hydrogen | 60 |
| Oxygen | 500 |
| Nitrogen | 1 |
| Food | 40 |
| Initial Water Supply | 12.5 |
| $CO_2$ | 10 |
| HEPA filters | 19 |
| Lithium Hydroxide | 60 |
| Emergency Batteries | 20 |
| Science | 332 |
| ERV Batteries | 49 |
| ERV Consumables | 22 |
| **TOTAL** | **1126** |

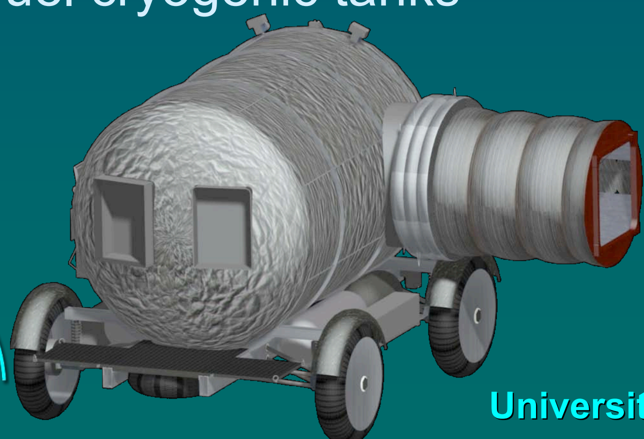
# Turnaround Activities

**Maintenance and repair**

- Inspect all major rover components for damage
- Repair or install replacements if necessary
- All external repairs done on EVA
- Consumable replenishment
- Refit all crew consumables for a nominal sortie
- Refuel cryogenic tanks

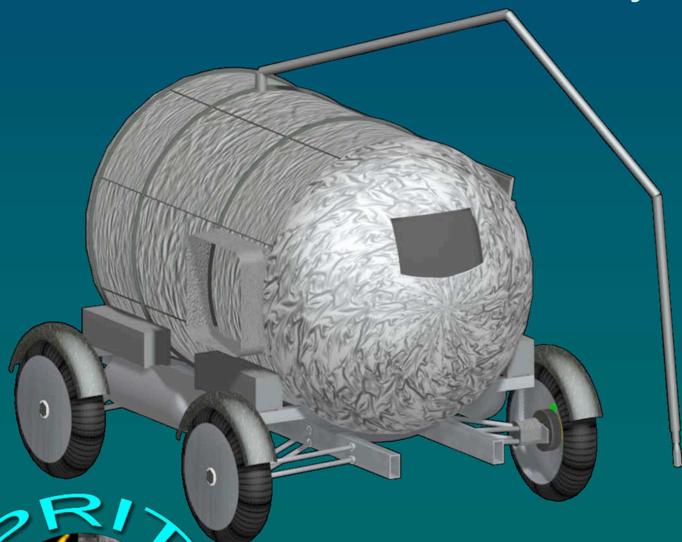
**Science activities**

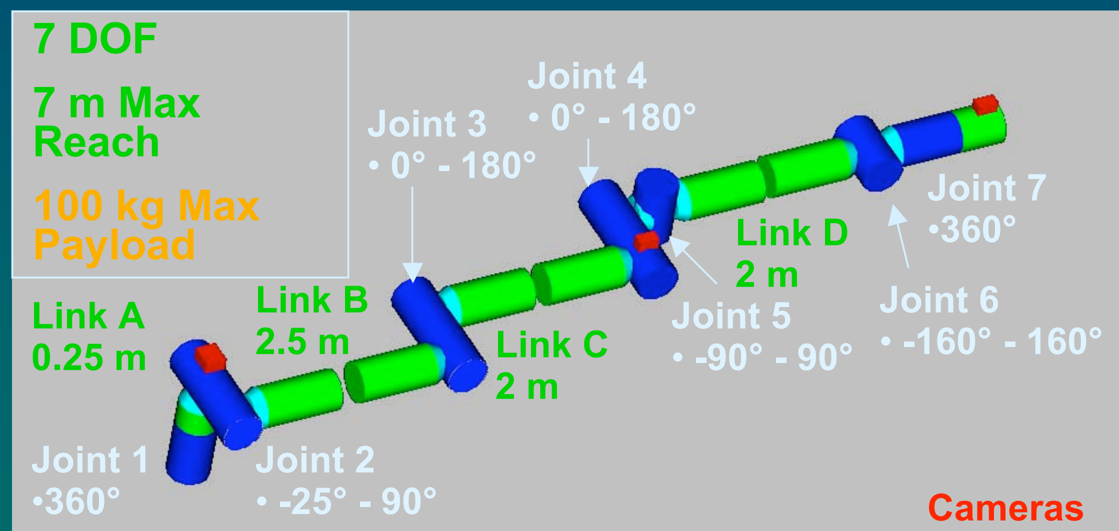
- Transfer of return samples to base
- Scientific experimentation
- Data analysis
- Load science packages for next sortie
- Mission planning
- Plan next sites to visit
- Science experiments vary with sortie
- Switch out EVA suits if there is a crew change



# Robotic Manipulator

- Provides access to environment/SPRITE exterior without EVA
  - Uses for science, visual inspection/repair, hatch deployment
- Changeable end effectors: gripper, rock abrasion tool, others as needed
- Capable of direct and supervisory control
- Collision avoidance by camera





# SPRITE Science

## Science Capabilities

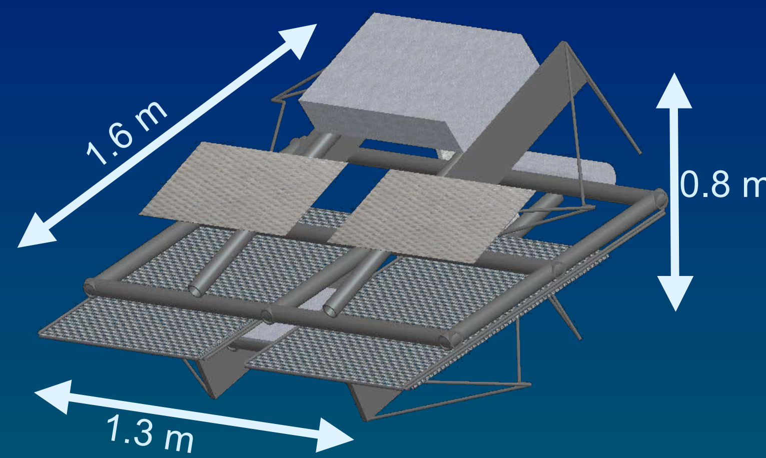
- SPRITE's science investigations will include:
  - Seismometry
  - Heat flow
  - Magnetometry
  - Atmospheric monitoring
  - Sample collection
- Each EVA will match or surpass the scientific return of a typical Apollo J-Class EVA
- Nominal sortie will collect 100 kg of samples for further analysis at base

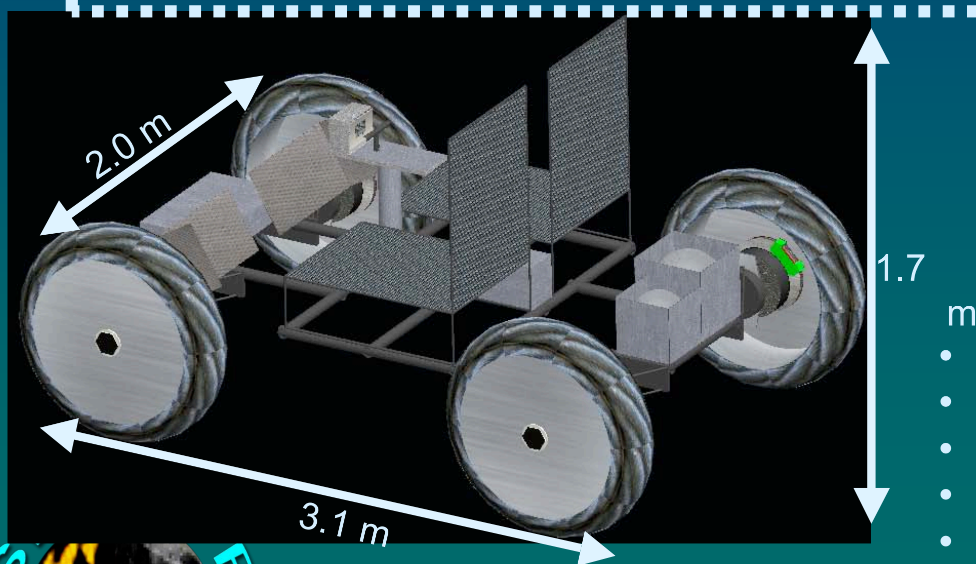
## Science Instruments

- Sample collection tools and containers
- Mini-TES mounted to instrument mast to map local mineral distribution
- SPRITE Lunar Surface Experiment Package (SLSEP)
  - RTG power source
  - Experiments communicate with Earth for several years
  - Mass = 25 kg
- Astronauts will create HDTV and digital photographic records for documentation purposes

# Emergency Return Vehicle (ERV)

- ERV is attached to the side of SPRITE
- Wheels are removed
- Forward and rear chassis sections fold inward
- Chairs collapse
- Control pedestal removed and attached to the back of the folded ERV
- ERV is launched disassembled



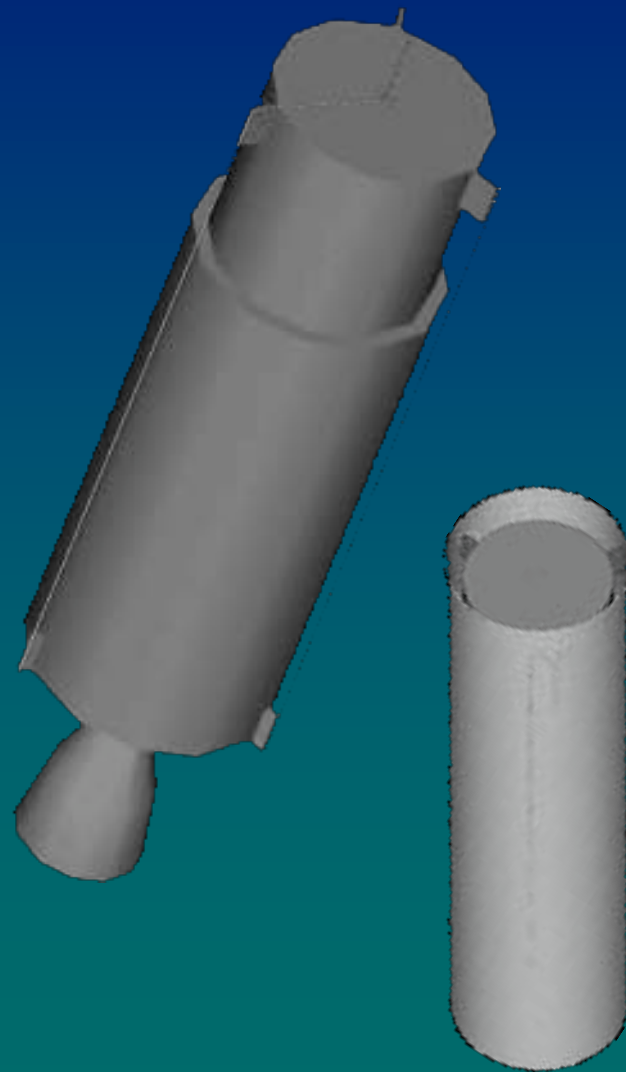

| Box Contents | Length (m) | Width (m) | Height (m) |
|---|---|---|---|
| ERV Wheels | 4.4 | 1.1 | 0.3 |
| ERV | 1.6 | 0.7 | 0.2 |

- Designed for 8 hour return at 15.6 km/hr
- Enough consumables for 10 hours
- 2-DOF joystick positioned with navigation box
- 4 battery powered motors – 1 per wheel
- Dry mass: 245 kg
- Rolling mass: 677 kg

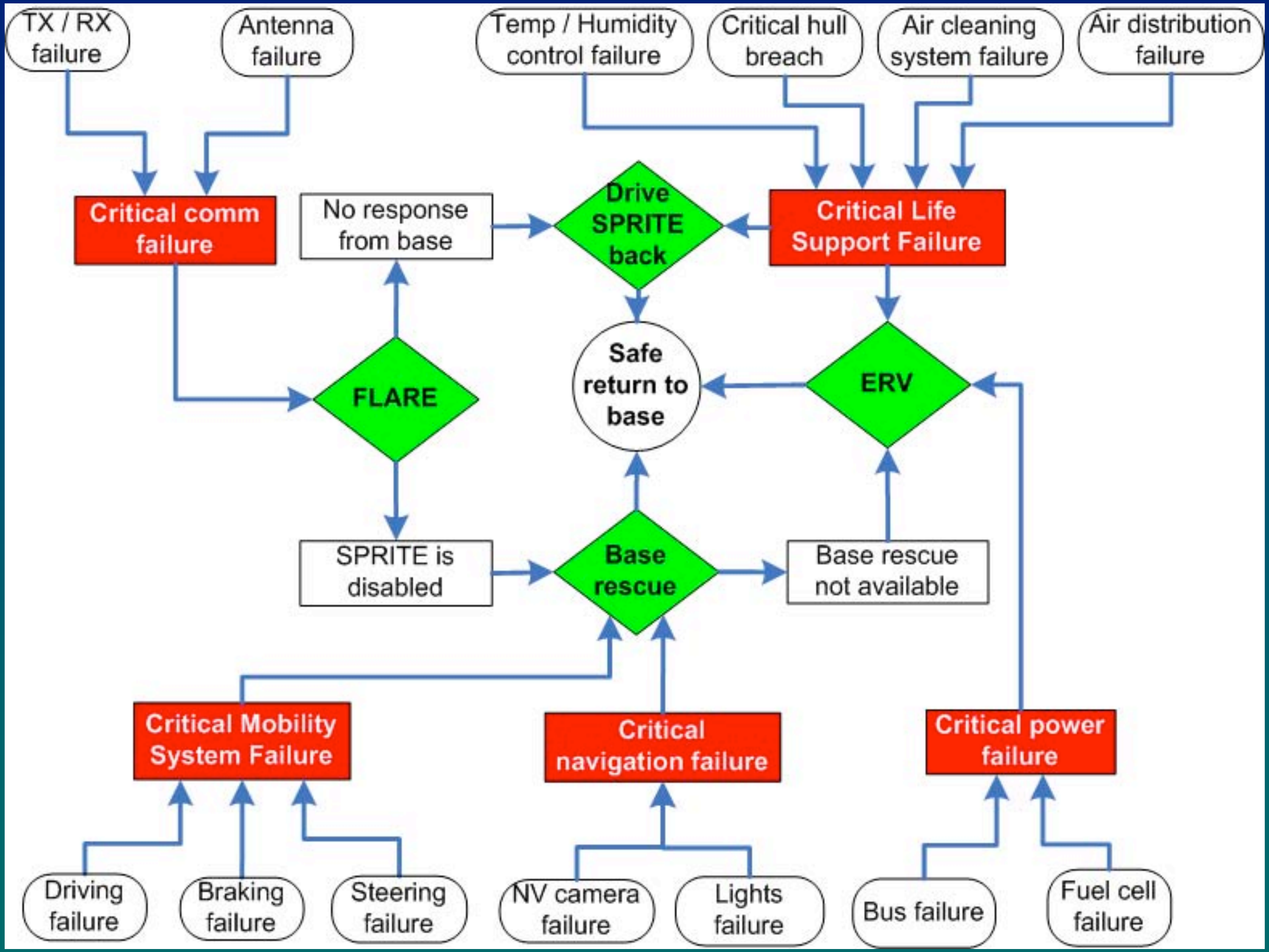
# FLARE

## Flying Locator and Assistance Requesting Equipment

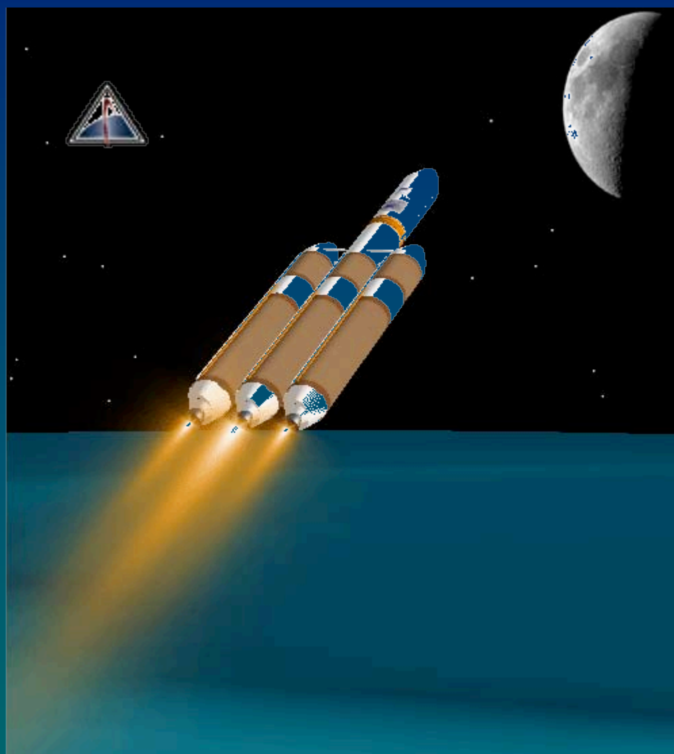
- Emergency communications package to provide direct over-the-horizon communication with the base
- Provides 9 minutes of communication with the base
- Two canister launched solid rockets propel a radio relay package vertically to within view of the base and SPRITE
- Crew can activate FLARE from inside cabin or EVA
- Operates one voice relay channel and one data channel Data channel loops critical information:
  - Distress code
  - Timestamp
  - Last position update
  - Life support sensor fingerprint
- Receipt of FLARE distress code immediately triggers an alarm at the base, both channels are recorded at the base
- Each unit weighs 12 kg



# Contingency Operations



# From the Earth to the Moon



Credit AGI Viewer (STK Software)

## Principle Requirements

- Launch on a Delta-IV Heavy
- Land accurately anywhere on the moon

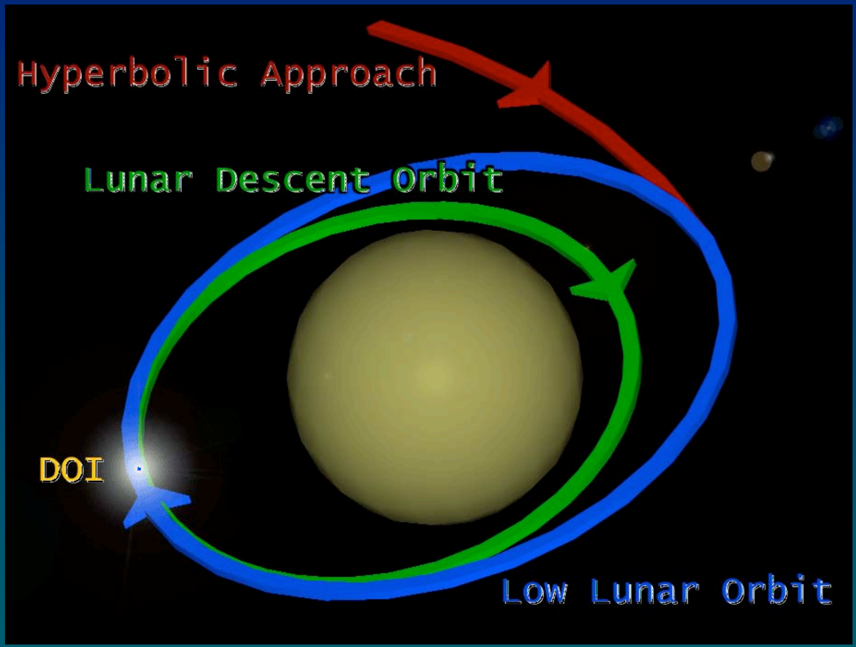
## Translunar Injection

- Translunar insertion payload of 9960 kg
- Trajectory optimization performed by NASA

## Operational In-Transit Systems

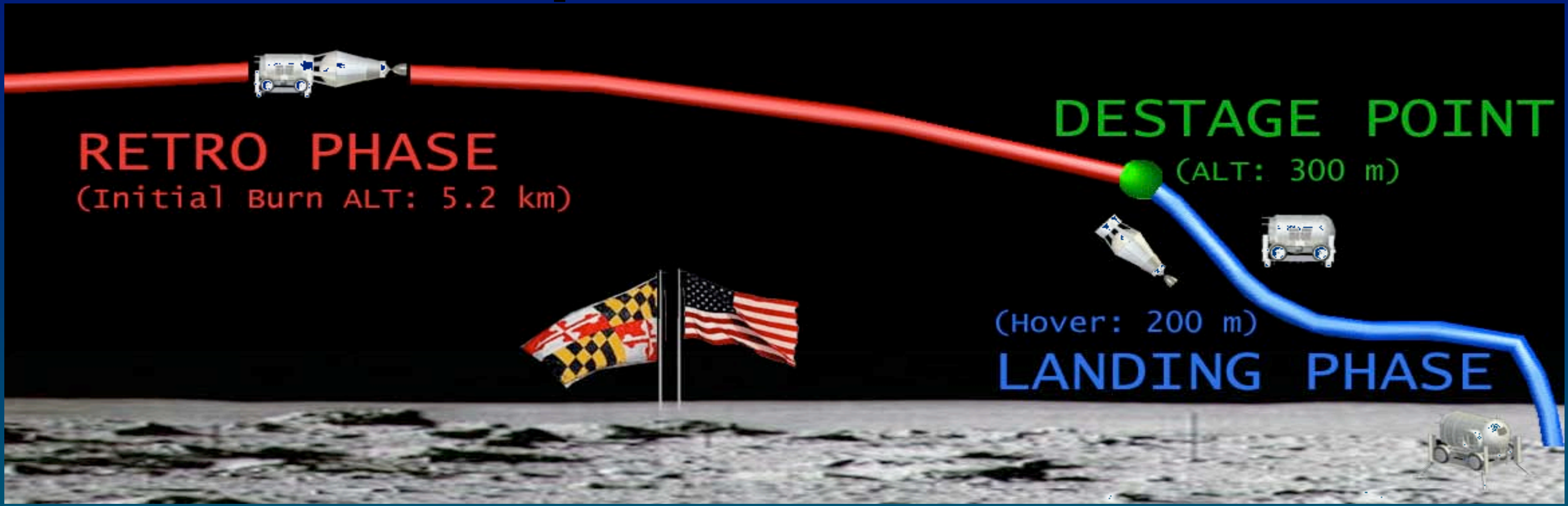
- Active cryogenic cooling
- GN&C avionics
- RCS attitude control
- Telemetry and monitoring systems

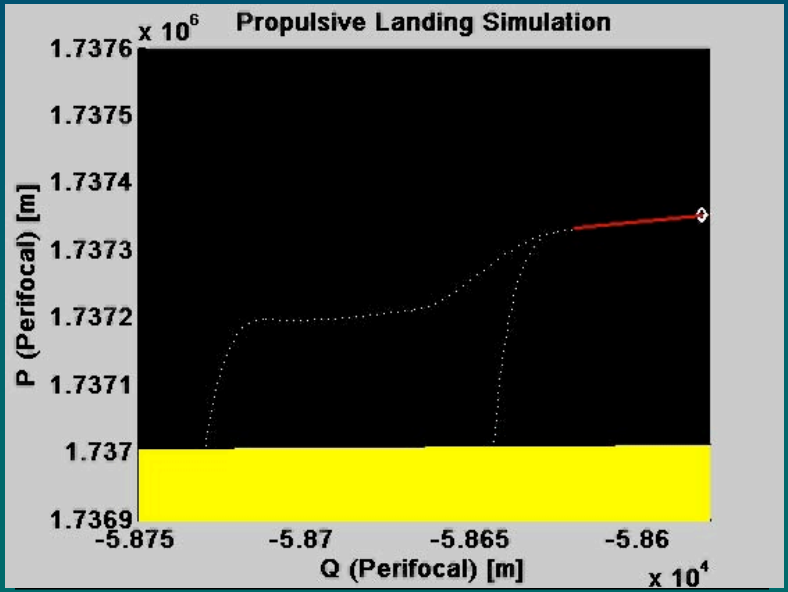
# Selenocentric Maneuvers




| BURN / MANEUVER | SYSTEM | ΔV [km/s] | $M_P$ [kg] | ΔT [s] |
|---|---|---|---|---|
| Lunar Orbit Insertion | Retro | .816 | 1682 | 101 |
| Descent Orbit Insertion | RCS | .022 | 63 | 450 |
| Propulsive Descent Retro Phase | Retro | 1.71 | 2652 | 160 |
| Propulsive Descent Landing Phase | Landing | .099 | 172 | 76 |

# Propulsive Descent

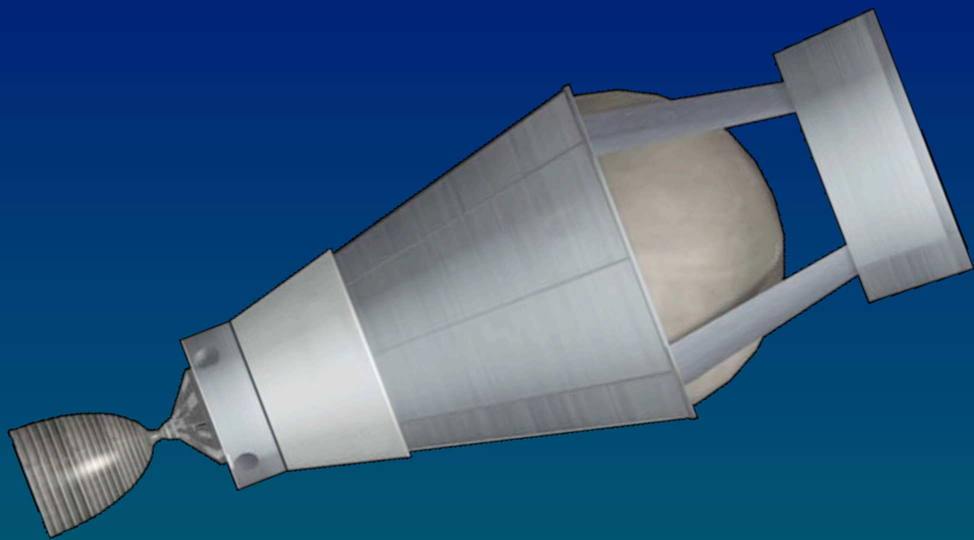


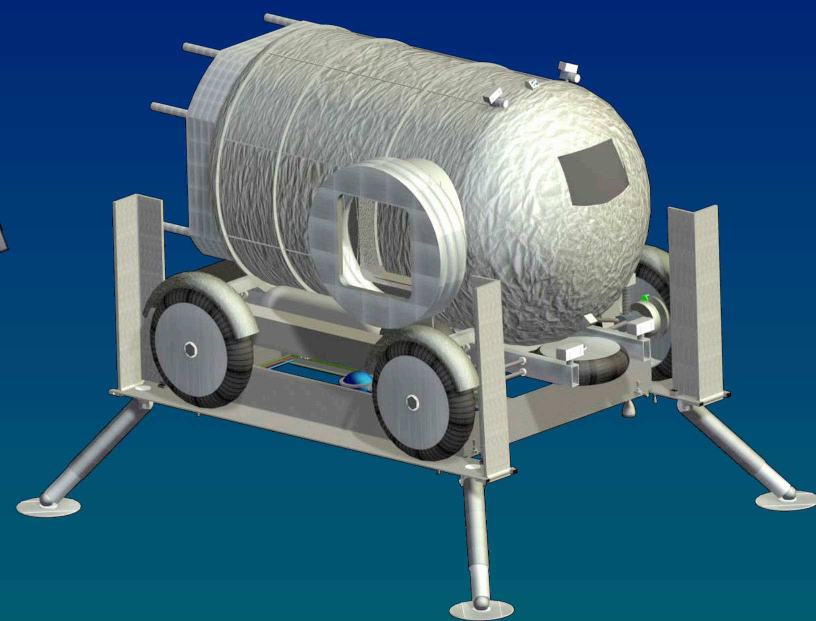




**Landed Mass: 4250 kg**

**(Includes landing craft dry mass)**

# Propulsion Systems





**Retro Stage**

- RL-10A-3A engine
  - 73400 N Thrust, 449 s ISP
  - 4º capable gimble
  - Restartable
- 4 RCS monopropellant thrusters
  - Attitude control and course corrections
  - Requires 30 kg of Hydrazine

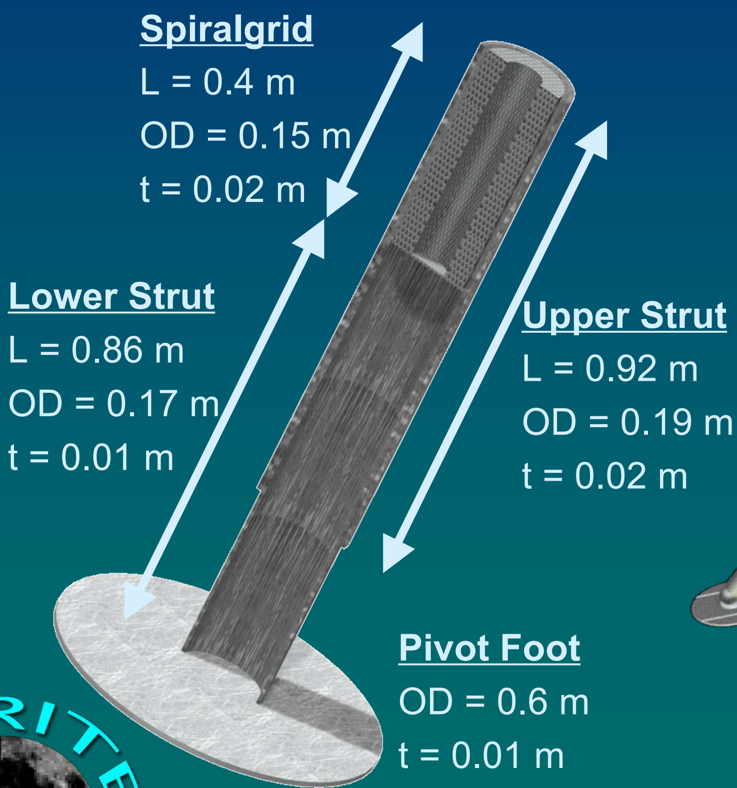
**Landing Stage**

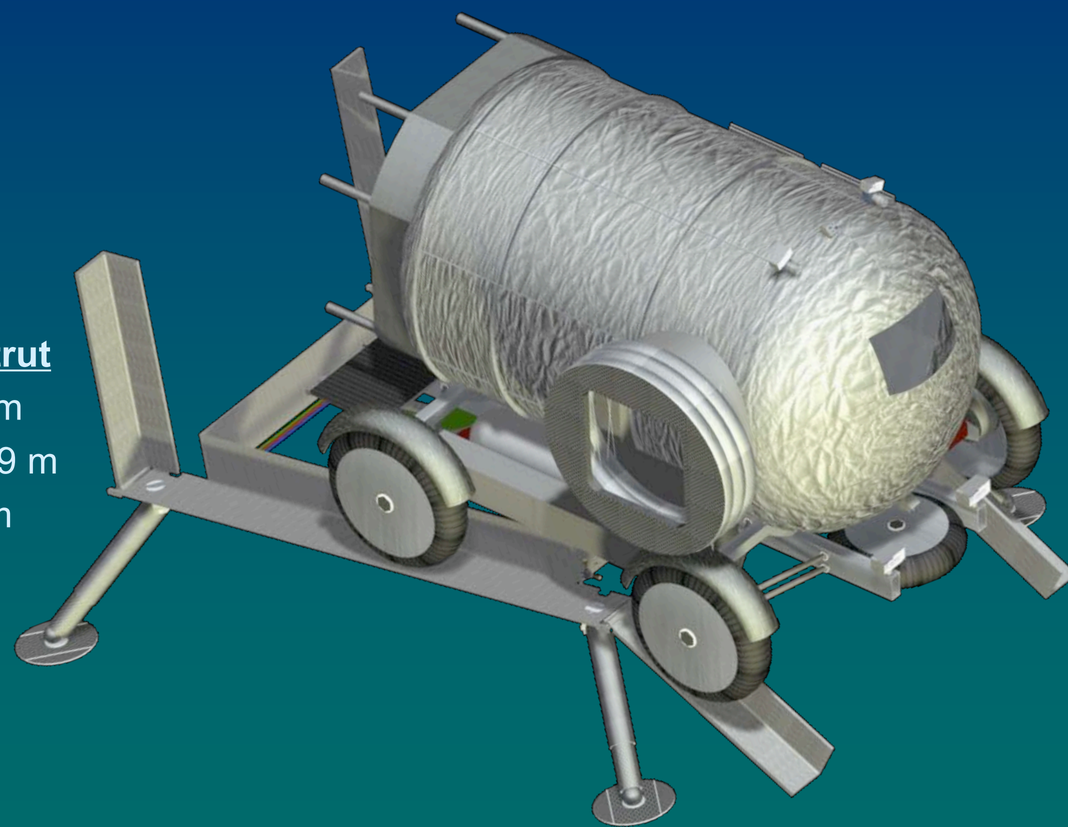
- 4 Multi-Use thrusters
  - 5640 N Thrust, 292 s ISP
  - 2 diagonally-opposed MUTs can be lost without a landing failure
- 16 RCS bipropellant thrusters
- Stage fueled by MON/UDMH

# Landing Structure

- Landing legs 1.26 m long located at each corner on a 45° angle.
- 108 kg (4 legs) Al 7075-T6
- Minimizes KE transferred to SPRITE

- Deployable L-beam ramps 1.8 m long aligned with wheels of SPRITE
- 97 kg (4 ramps) Al 7075-T6

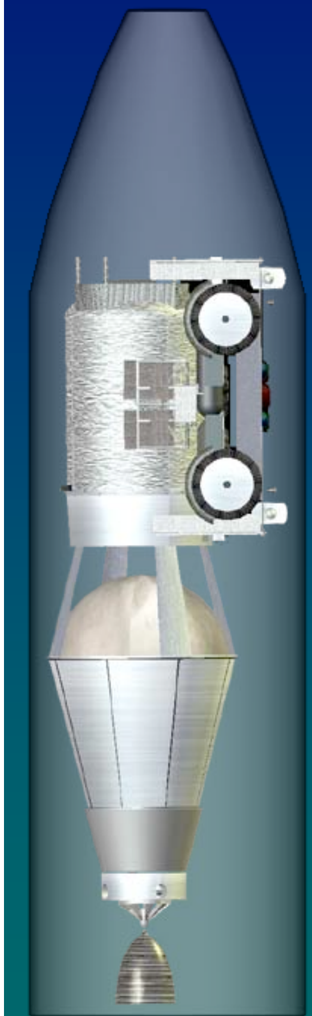


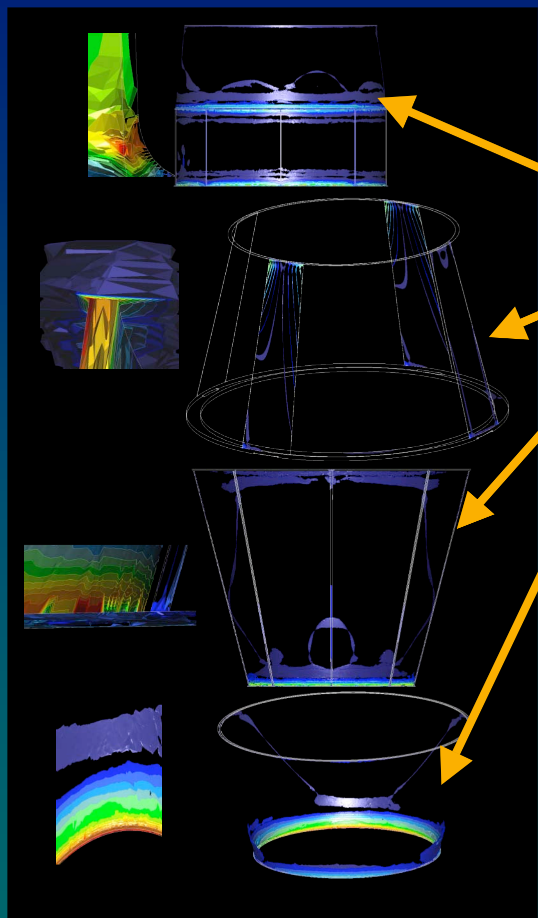



# Descent and Landing GNC

- Critical GNC Hardware
  - Inertial Measurement Units
    - Fiber optic gyro based
    - Senses pitch, yaw, roll & acceleration rates
  - Star Trackers
    - Detects star patterns & magnitudes
    - Reference for IMU
  - Guidance Computers
    - Calculates position, velocity, acceleration, and attitude
- Landing Control System
  - 3 Microwave Scan Beam Landing Systems
    - Finds slant range, azimuth, and elevation relative to moon base
    - Data used to compute steering commands
  - 2 radar altimeters
  - 2 Earth-moon limb sensors
    - Additional attitude data for navigation filter
  - Guidance Computer checks nominal and actual approach velocities to ensure soft landing
- Hovers 200 m from surface and image landing area from two positions 70 m apart to build a stereo image (< 0.2 m error)
- After processing, calibrate lander position with an absolute distance to ground measurement and continue descent

# Launch Support Structure





| Interface | Load | Mass | MOS | SF | Failure |
|---|---|---|---|---|---|
| Rover Support | 450 MPa | 21.3 kg | 0.3 | 2 | Local Buckling |
| LH2/Rover | 700 MPa | 98.8 kg | 0.0 | 2 | Local Buckling |
| LH2/LOX | 300 MPa | 158 kg | 0.0 | 2 | Local Buckling |
| LOX/Retro | 700 MPa | 53.5 kg | 0.6 | 2 | Local Buckling |

- Designed to conform with structure to minimize volume and mass
- Supports mass of vehicle during launch Analyzed using FEM
- Constrained on top
- 6 g axial, 2.5 g lateral load

Delta IV Isogrid Fairing

# Program Timeline and Costs

**Timeline**

- Development and Production to take place from 2005-2016
- Beginning in 2014, coordination with Boeing for integration of SPRITE into Delta-IV Heavy must begin
- SPRITE ready for launch on January 1, 2016
- Program will operate on 3 month life-cycles

**Total Cost: $2.87B**

**Costs**

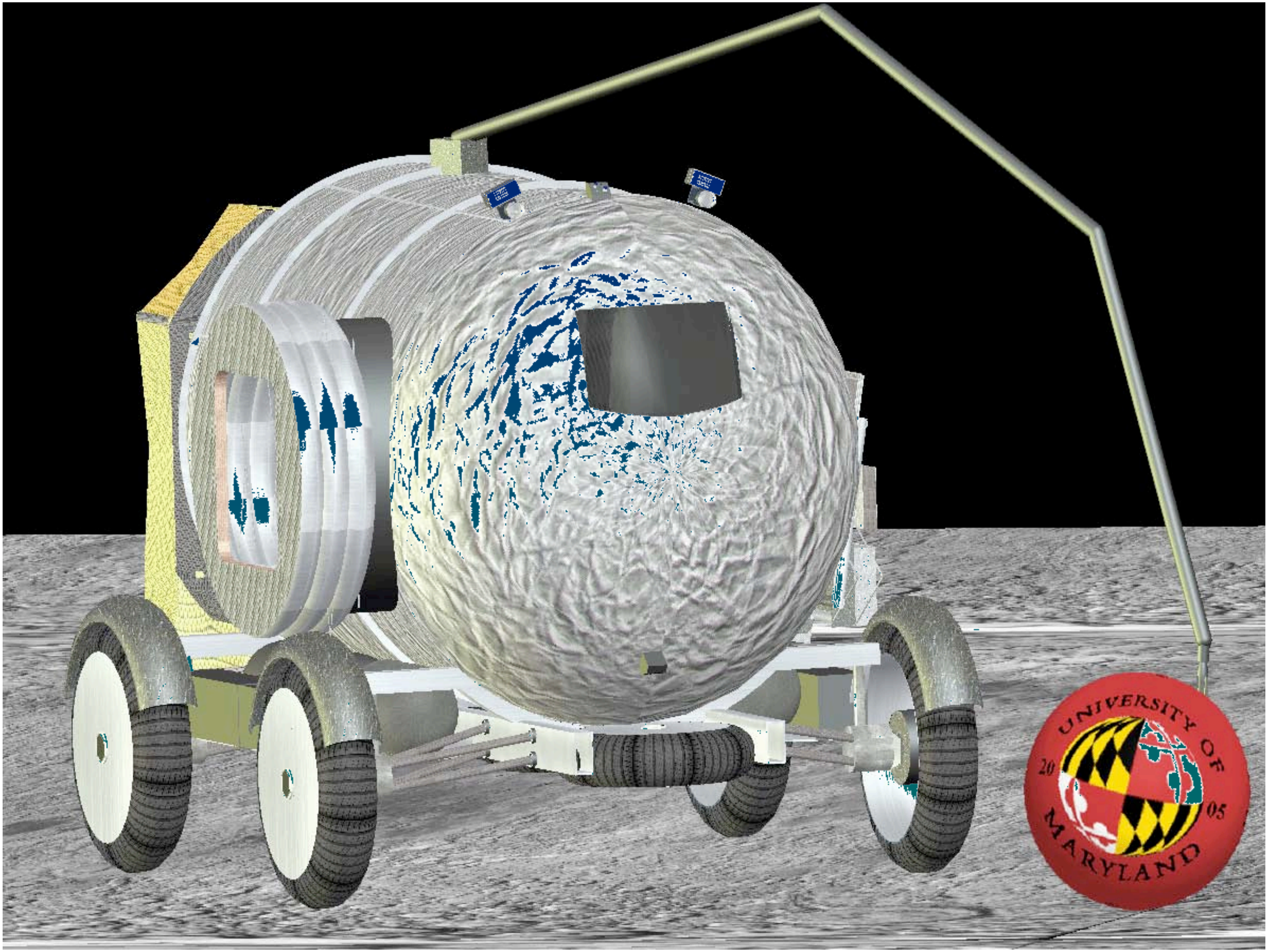
- Costs estimated using NASA cost models
  - JSC Advanced Missions
  - JSC Spacecraft model
  - GSFC vehicle and component level CER's
- Robotic Arm is exception
  - Cost estimated based upon relatively similar robotic arm cost

| Item | Cost ($M 2005) |
|---|---|
| SPRITE | 2270 |
| Landing Structure | 36 |
| ERV | 11 |
| Robotic Arm | 300 |
| Retro Engine | 5 |
| Launch | 250 |

# Community Outreach

- Students, faculty, and members of the local aerospace community watched and asked questions at SPRITE's:
  - Preliminary Design Review
  - Critical Design Review

- Maryland Day
  - On April 30$^{th}$, the University of Maryland allowed thousands of guests to explore campus
  - SPRITE team manned table in the Space Systems Laboratory showcasing the project and answering questions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