Project Alshain:

A Lunar Flying Vehicle for Rapid Universal Surface Access

University of Maryland College Park

RASC-AL

June 2nd, 2009

Goals for a Return to the Moon

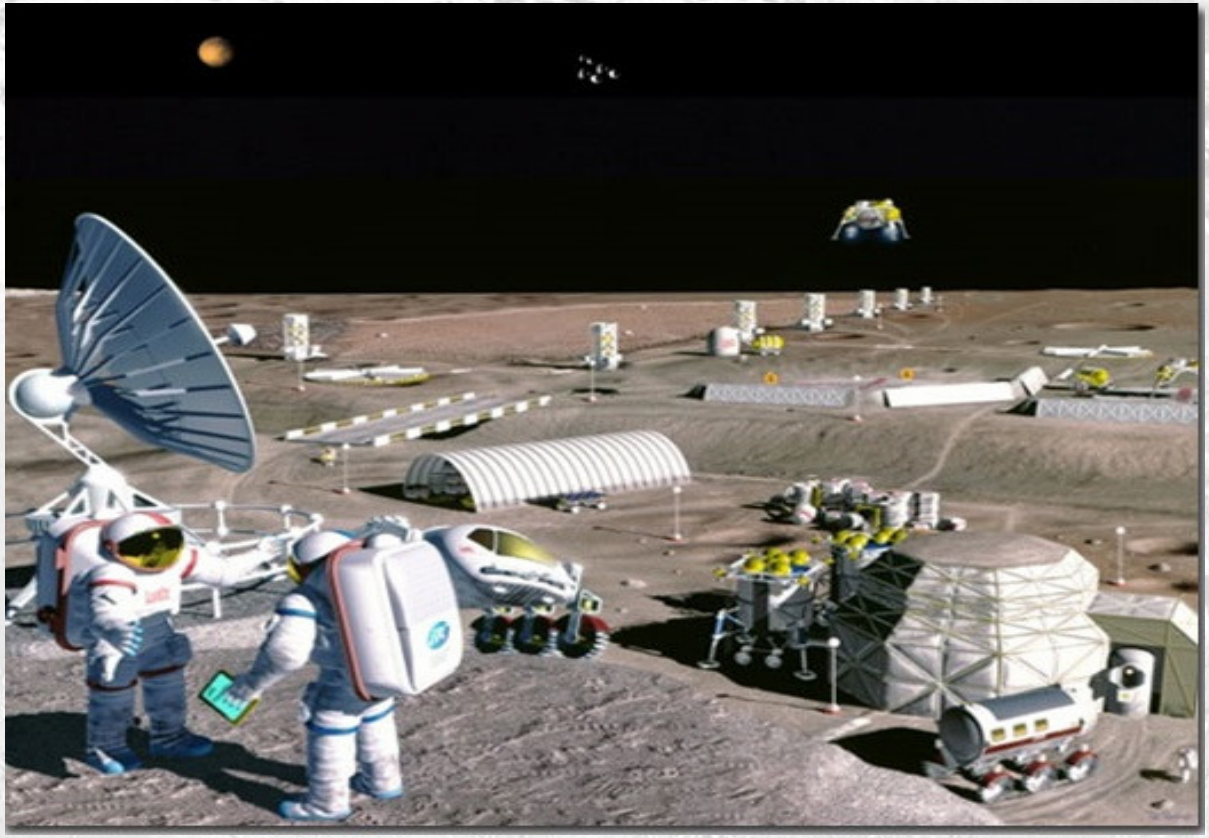


*Image Courtesy of NASA.gov

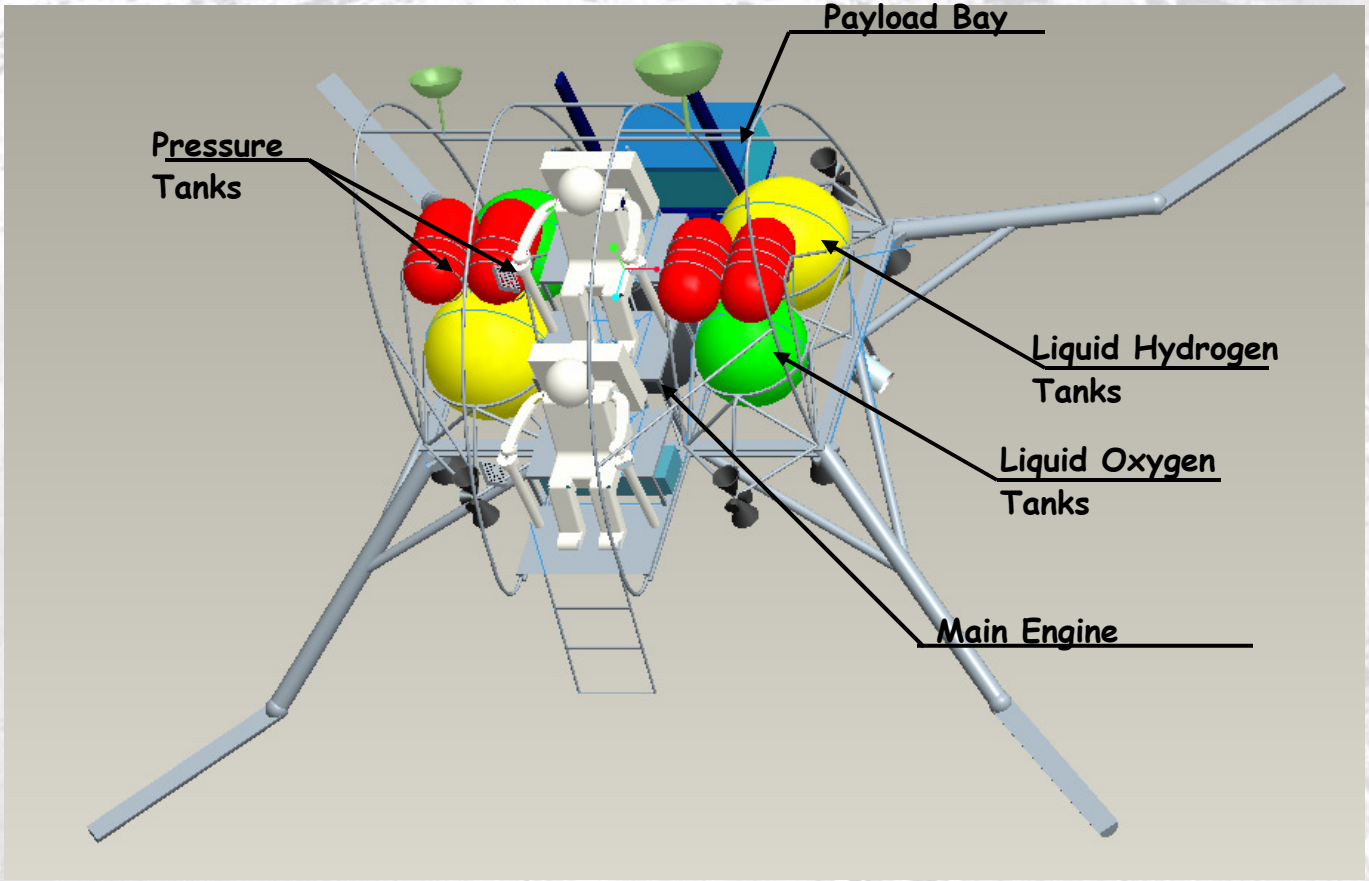
Antarctica Exploration

*Image Courtesy of Dr. Dave Akin

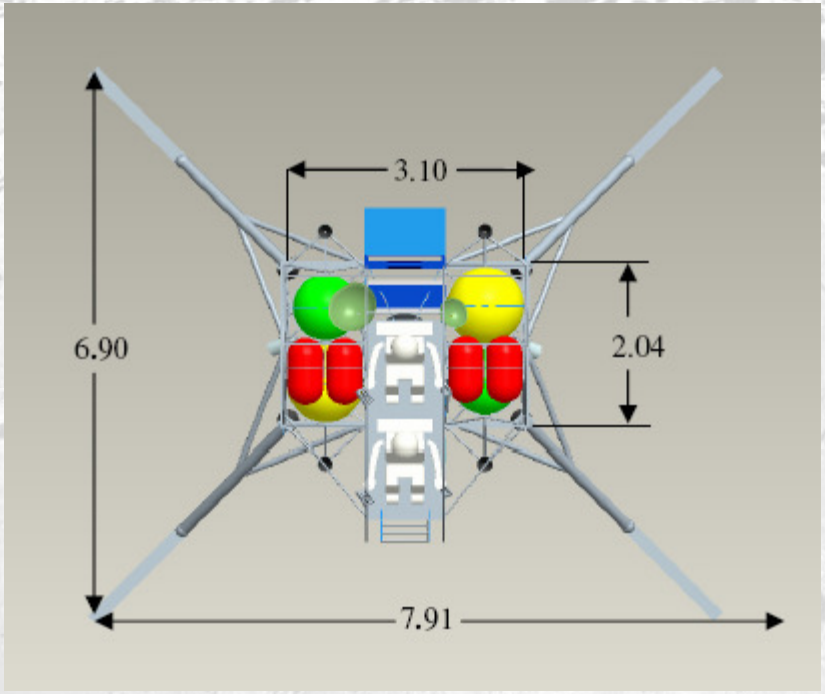
Mission Sites: Craters

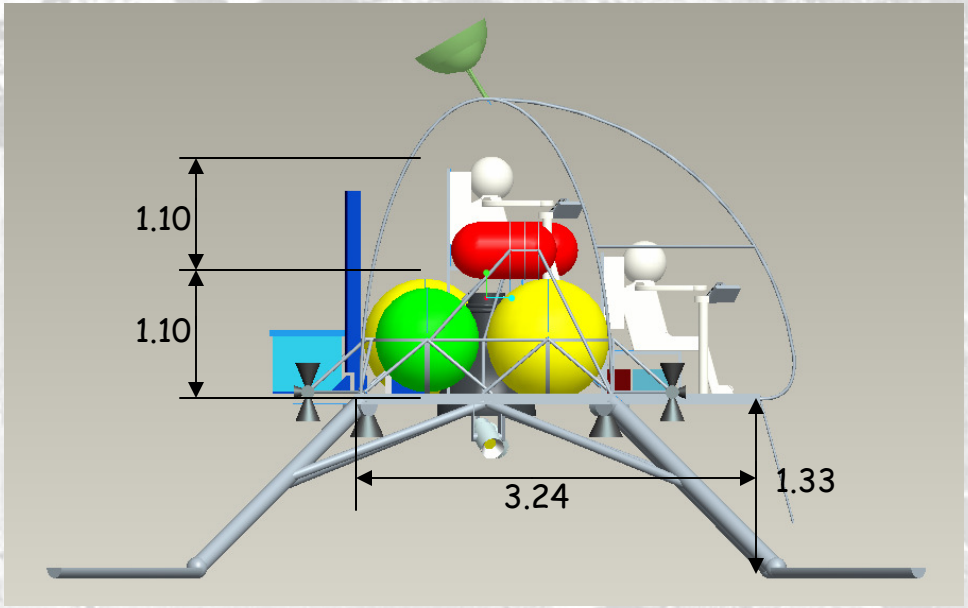
- Importance of Craters
  - Contain materials left over from the impact of meteors, comets, etc.
    - Older craters contain smaller craters within
  - The interior of several craters near the lunar south pole lie in near-perpetual darkness
    - Volatile material deposits in the crater interior are sheltered from exposure to sunlight
  - South pole craters are largely unexplored and unmapped due to low visibility from Earth

Alshain


Payload Bay
Pressure Tanks
Liquid Hydrogen Tanks
Liquid Oxygen Tanks
Main Engine

Alshain





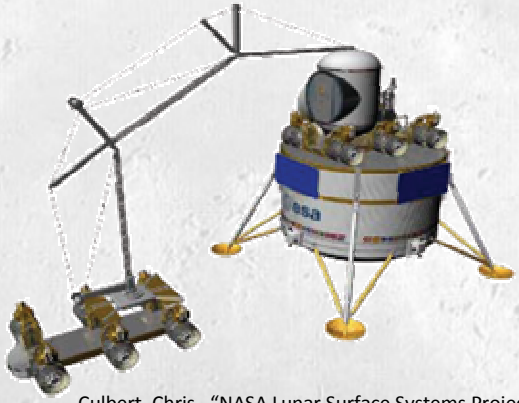
Top and Side views of the Alshain LFV: Note all dimensions are in meters

RASC-AL

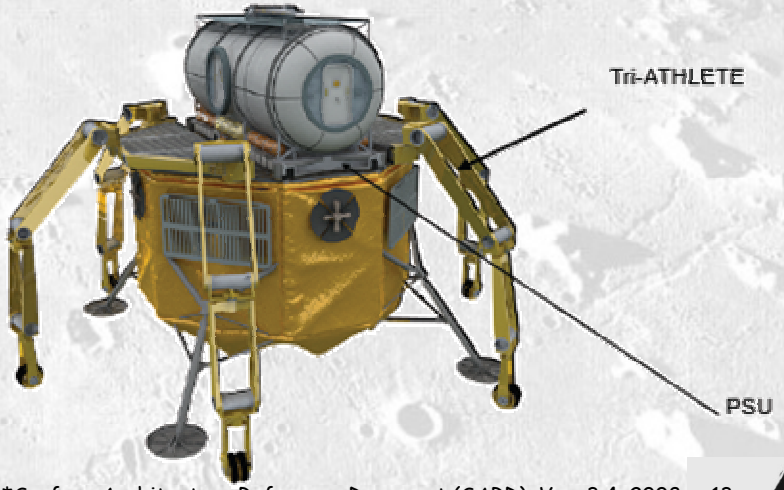
Project Alshain: University of Maryland – June 2nd 2009

Egress From Altair

- Egress from a cargo mission of Altair
- Tri-ATHLETE lifts Alshain from Altair cargo deck
  - Rolls away from lander
- LSMS removes Alshain from the Tri-ATHLETE and places on the lunar surface

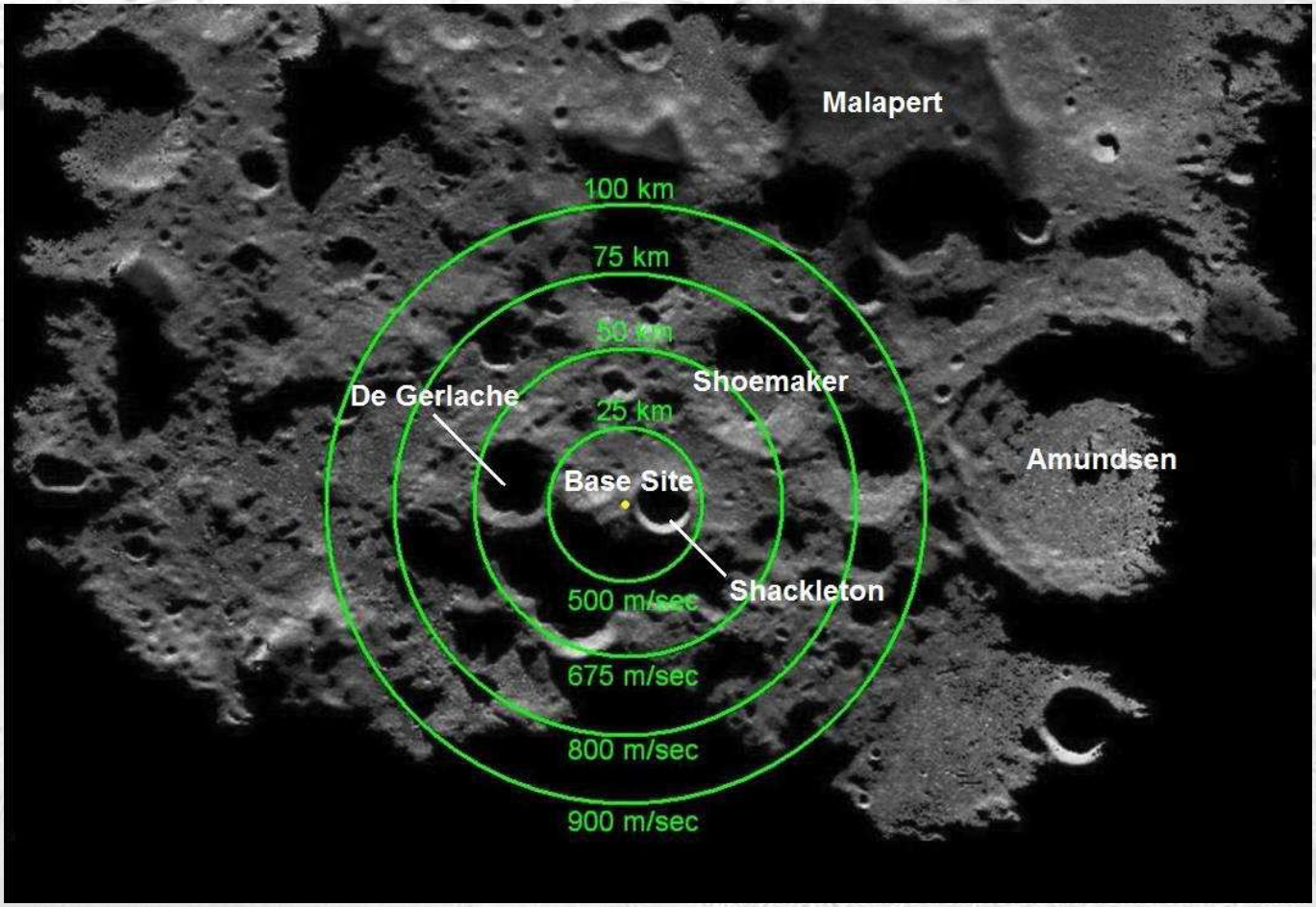


Culbert, Chris. "NASA Lunar Surface Systems Project Overview". NASA, Feb 2009, p 36.



*Surface Architecture Reference Document (SARD). Ver. 3.4. 2008. p 13.

Vehicle Ranging



Propulsion Analysis

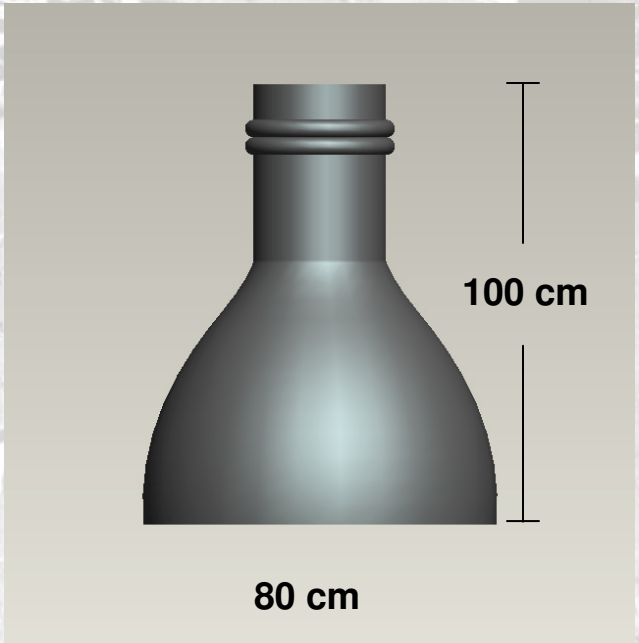
- 57 km each way designed distance
- Engine I_{SP} of 400 sec
- Payload of 500 kg
- Inert mass of approx. 1100 kg
- These assumptions lead to the following values:
  - Delta V: 1600 m/s
  - Propellant: 940 kg
    - Includes extra fuel for RCS and fuel cells and non-impulsive burn penalty
- Starting mass : 2540 kg

Tank Design Recommendation

	LH_2	LOX	Helium
Number	2	2	4 (includes spare)
Mass (each kg)	13	9.4	50 (includes He)
Pressure (MPa)	2.4	2.4	8.4
Length (cm)	NA	NA	85 cm
Diameter (cm)	100	85	46 cm

Main Engine Specs

- Single engine: 40 kN thrust
- 80 cm diameter
- 100 cm height
- Expansion ratio: 45:1
- I_{sp}: 400 s
- Combustion pressure: 2.0 MPa
- Combustion temp: 3600 K
- Total mass of 96 kg



Number of Main Engines

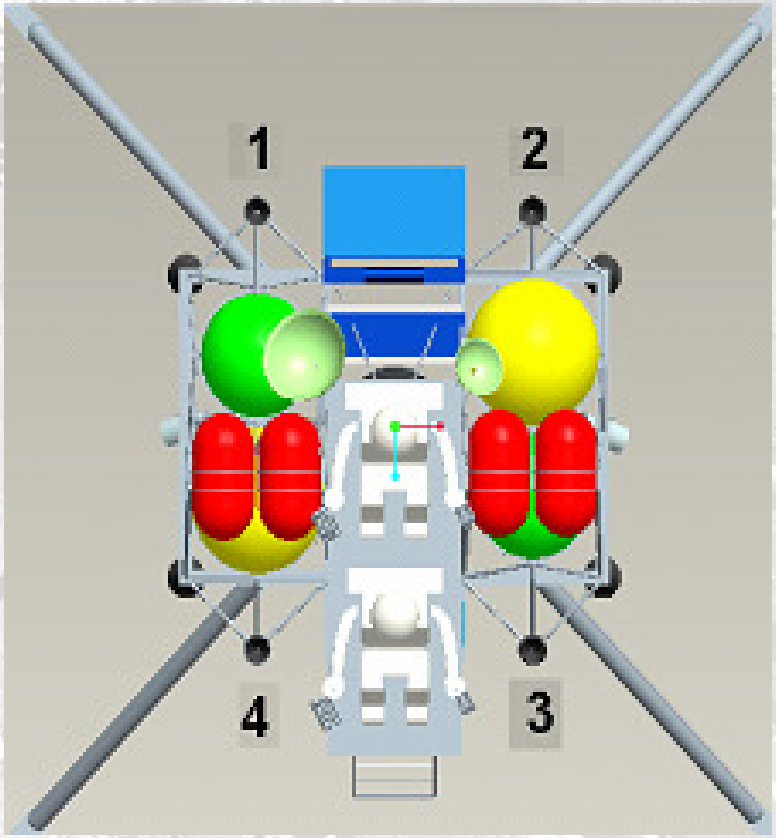
- Single engine reliability: 99.9%
- Multiple engine systems must be at least this reliable

Num. of Engines	1	2	3	4
Thrust/Engine (kN)	40	40	20	13
Total Engine Mass (kg)	96	191	143	127
Total Engine Footprint (m^2)	0.50	1.14	0.88	0.74

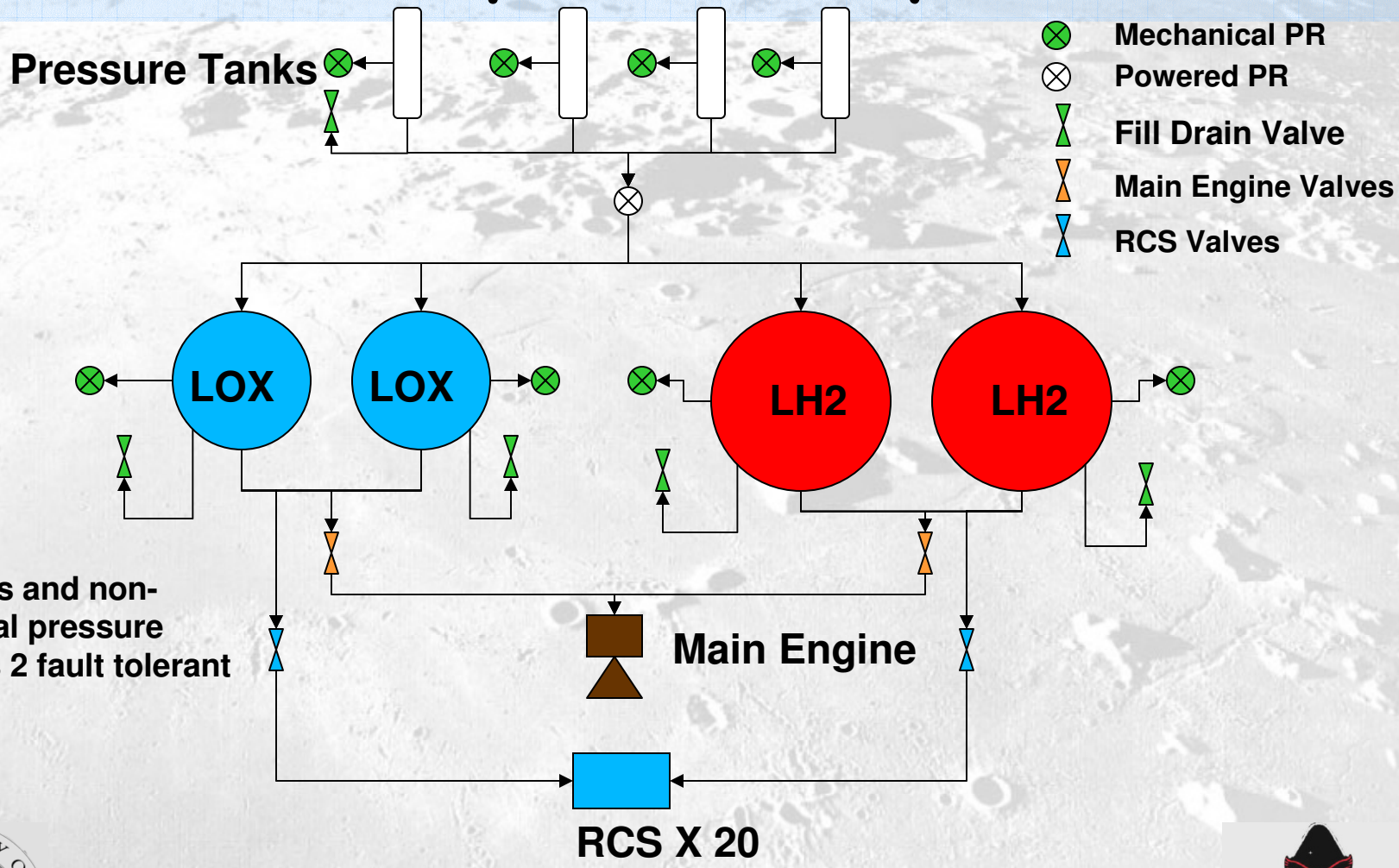
- Multiple engines are mass and size prohibitive
- Should an engine fail, 350 m/s of ΔV would be needed to slow the vehicle to a stop
- The reaction control system (RCS) can handle the load if each downward pointing thruster can produce 1000 N thrust

Reaction Control System

- All dimensions use shown origin
- Eight 300 N thrusters in x-y plane
  - 2 each on pods 1,2,3,4
  - Pods (±2.13, ±1.0) m
- Eight 1150 N thrusters in ±z direction
  - 2 each on pods 1,2,3,4
  - Pods (±2.13, ±1.0) m
- Four 1150 N thrusters in –z direction
  - Mounted underneath vehicle
  - Mounted (±1.7, ±1.45) m



Main Propulsion System



* All valves and non-mechanical pressure regulators 2 fault tolerant

Thermal Control System

- Main sources of heat flux:
  - Solar radiation
  - Planetary reflection
  - Planetary radiation
  - Power consumption
  - Astronauts

Subsystem	Operating Temperature Range
Seating Structure	Under 320 K
Avionics	250 K to 320 K
Fuel Cells	330 K
Tanks LOX LH2	 Under 20 K Under 90 K

Thermal Control

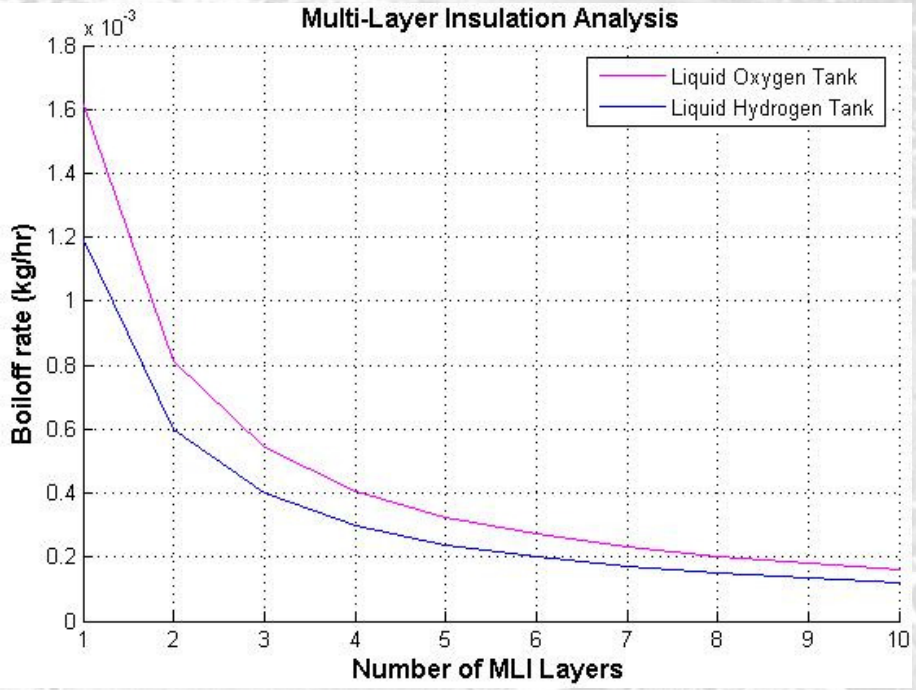
- Coating selected based on trade studies:
  -Aeroglaze A276
    - White paint
    - Solar absorption = 0.23
    - Normal emissivity = 0.90

Equilibrium temperature without coating (Al)	608 K
Equilibrium temperature with A276	285 K

- Avionics
  - Hot case
    - Optical Solar Reflectors
    - Quarz over silver
    - Silvered Teflon- Flexible OSR
  - Cold case
    - Equilibrium temp of 204 K without heating
    - Thermal Louvers chosen

Tank and Pipe Insulation

- Multi-Layer Insulation
  - Aluminized kapton (e_{eff} = 0.002)
  - Wrapped around propulsion tanks/lines
  - Covering bottom of vehicle against propulsion heat/plumes



	LOX	LH2
Tank Surface Area	2.2 m^2	3.1 m^2
Boiling Temperature	90 K	20 K
Total Boiloff (for 32 hours)	0.05 kg	0.04 kg

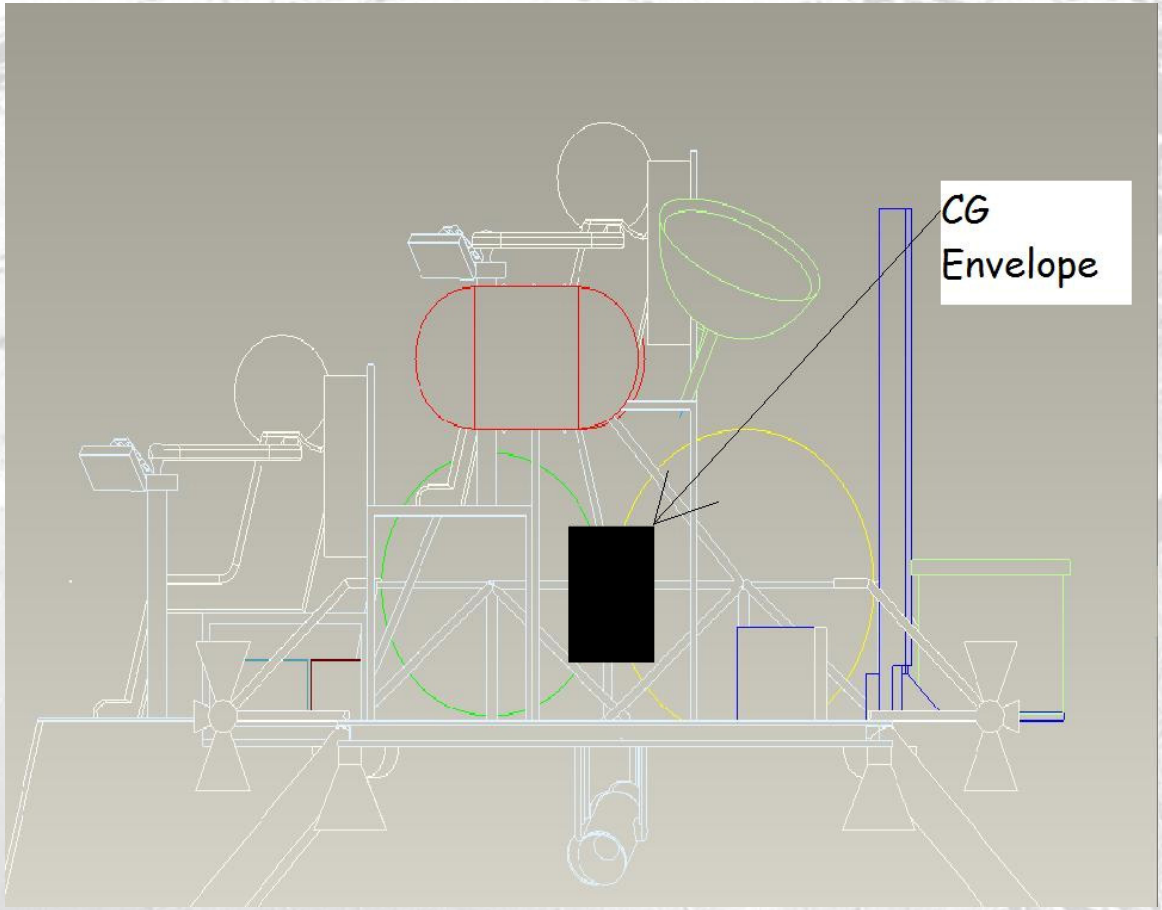
- → 1 Layer needed for each tank

Loads Table

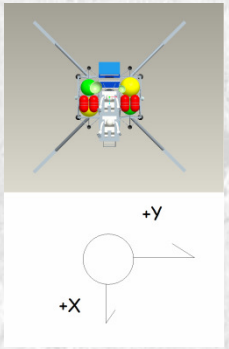
Event in Lifecycle	Type of Load	Load
Launch*	-Z	6g
Launch*	+/- X, +/-Y	2g
Launch*	+Z	2g
Launch-Steady State*	+/- X, +/- Y, +/- Z	1.9g --- 1.25g
Landing	-Z	2g
Flight-Main Engine	+Z	2g
RCS Thrusting Vertical	+/-Z	1150 N
RCS Thrusting Horizontal	+/- X, +/-Y	300 N
Kick Loading	+/- X, +/- Y, +/- Z	250 N
Rollover Loading	-Z	1.64 m/s^2

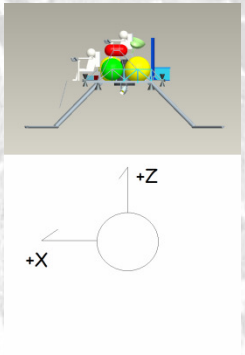
***Data taken from Delta IV Payload Manual**

Center of Gravity Results



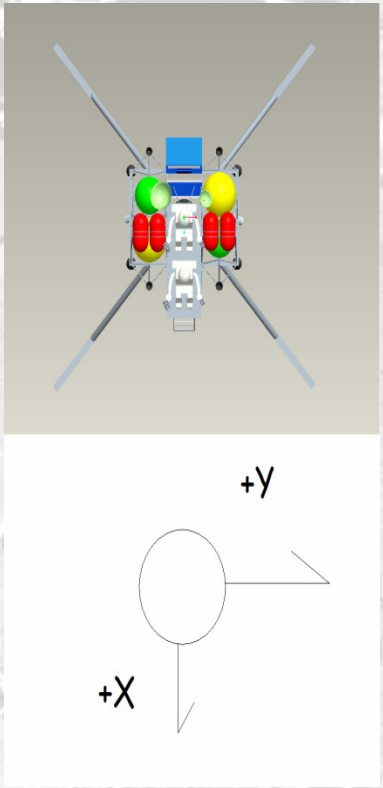
- Maximum C.G. offset
  - X: 1.6×10^{-1} m
  - Y: 8.8×10^{-4}m
  - Z: 4.3×10^{-1} m

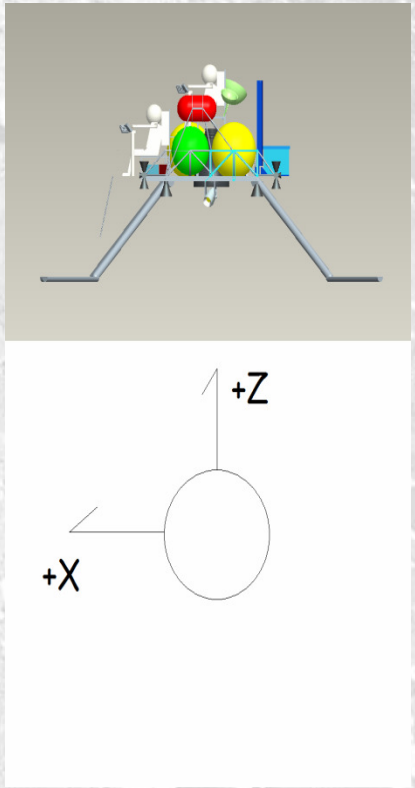




Moment of Inertia Data

Moment of Inertia	Full Vehicle	Empty Vehicle
I_{xx}	1770 kg-m^2	613 kg-m^2
I_{yy}	614 kg-m^2	295 kg-m^2
I_{zz}	1790 kg-m^2	624 kg-m^2
I_{xy}	-473 kg-m^2	-119 kg-m^2
I_{xz}	44 kg-m^2	44 kg-m^2
I_{yz}	-25 kg-m^2	-25 kg-m^2





Structural Materials

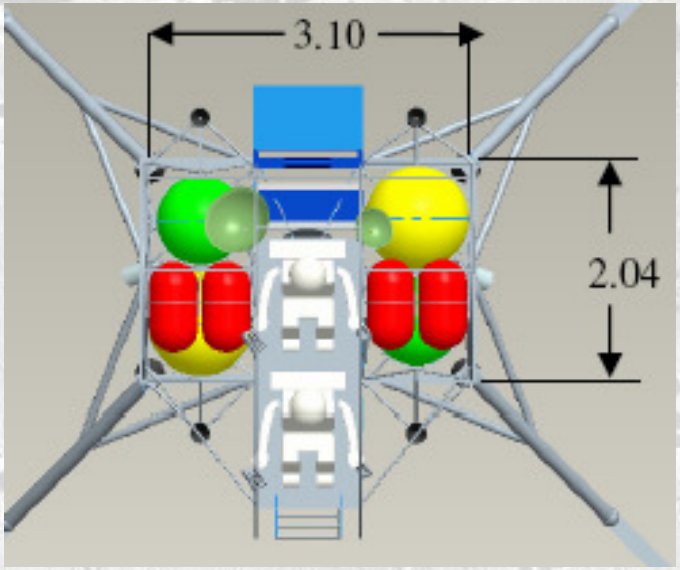
- Aluminum 6061-T6
  - Density: 2700 kg/m^3
  - Yield stress: 276 MPa
- Low density
- Easy to machine

- Ti-10V-2Fe-3Al
  - Density: 4650 kg/m^3
  - Yield stress: 1170 MPa
- High strength-to-weight

- c175 copper beryllium
  - Density: 8750 kg/m^3
  - Yield stress: 240-380 MPa
  - Elastic Modulus: 125-130 GPA
- Functioning spring at ~80K
- TRL 3

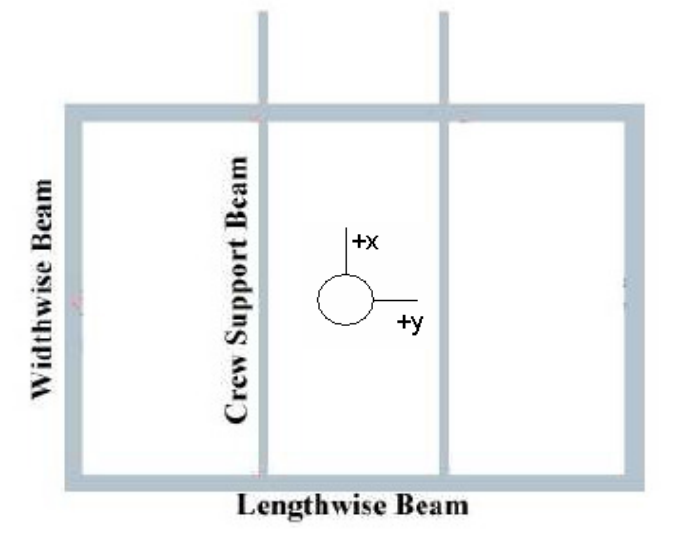
Design Rationale

- Considerations
  - Mass minimization
  - Crew accessibility
- Concerns
  - Landing loads near corners
  - Take-off load in center
  - Moments created in X and Y directions



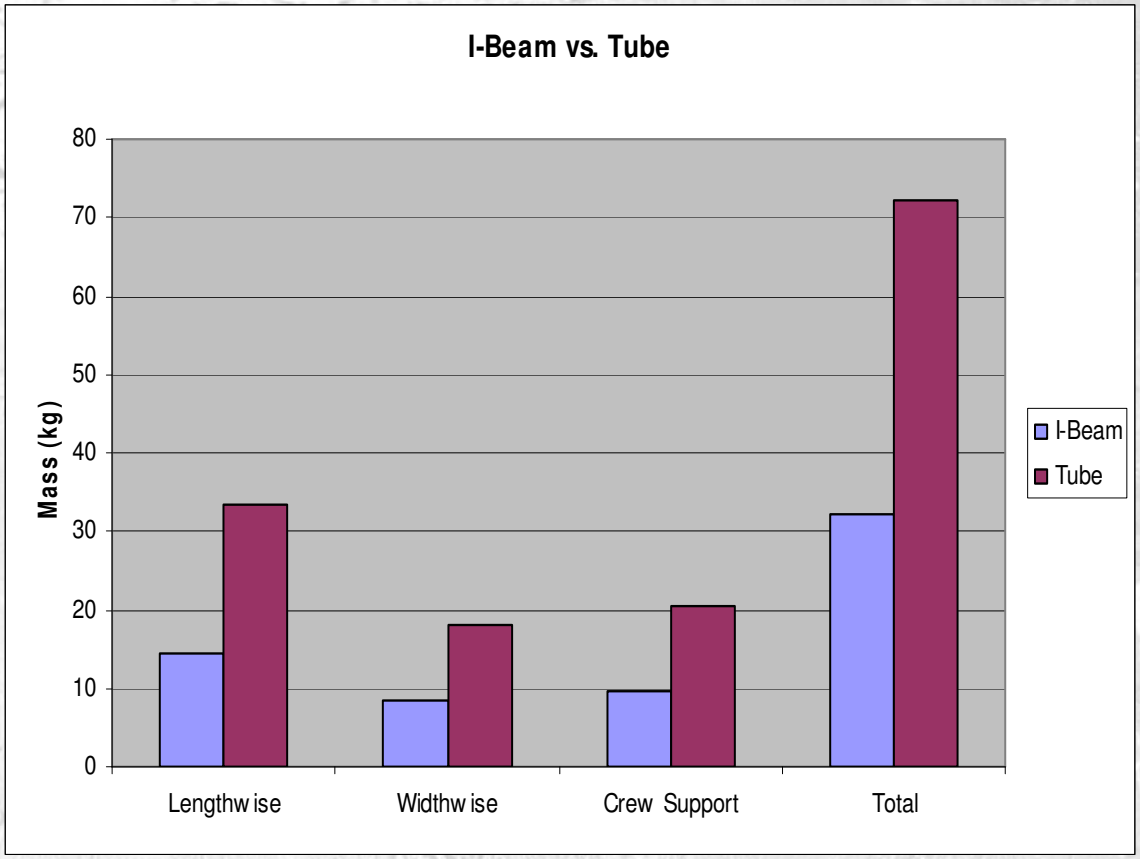
Support Base

- I-Beam base provides strength for stowed configuration
  - Landing gear removed for transit
- Low attachment point for landing gear
- Open area for large beam placement
  - Allows for more compact configuration
- Requires attachment structure
  - Fuel tanks, pressurant tanks, crew, engines, etc.



Beam Analysis

- Singularity function used for sizing
- I-Beams
  - Web thickness
    - Euler buckling
    - Shear strength
  - Flange thickness
    - Moment forces
- Tubular beams
  - Thickness
    - Shear strength
    - Moment forces

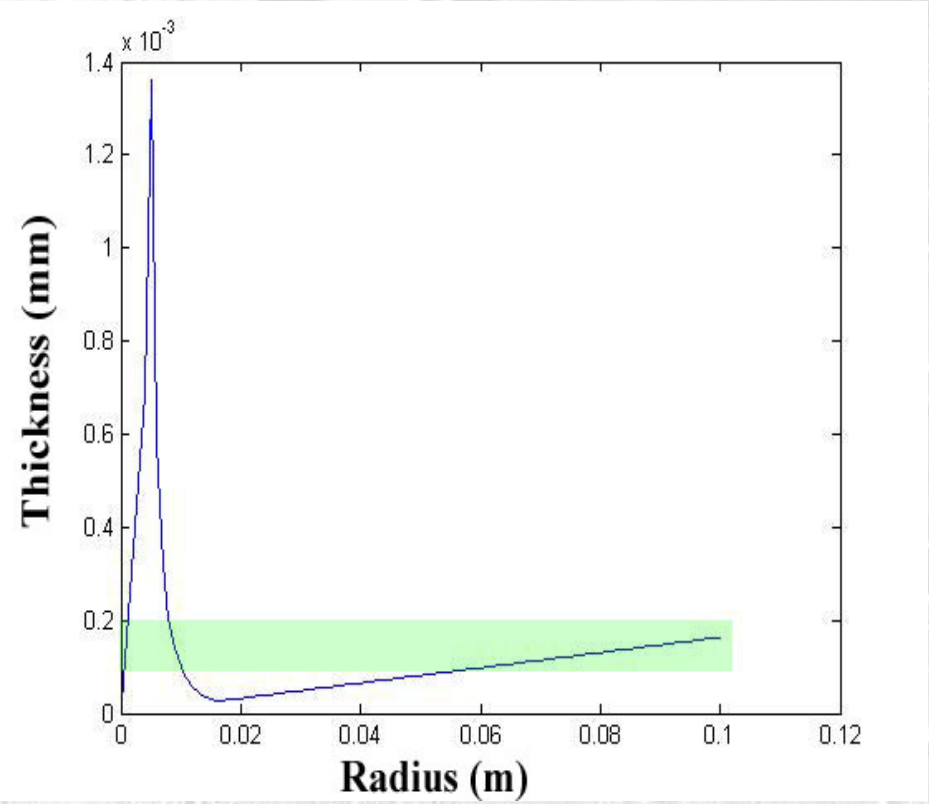


I-Beam Inventory

Piece Designation	Applied Shear (kN)	Applied Moment (kN-m)	Length (m)	Flange Thickness (mm)	Web Thickness (mm)
Lengthwise	12.5	30.0	3.2	10.4 11 actual	2
Widthwise	1.9	18.3	2.2	5.8 6 actual	2
Crew Support	4.7	4.5	3.24	2.1 2.5 actual	2
	Breaking Shear (kN)	Breaking Moment (kN-m)	Mass (kg)	Safety Factor	Margin of Safety (%)
Lengthwise	72.5	43.9	19.75	1.4	4.62
Widthwise	72.5	26.6	8.35	1.4	3.87
Crew Support	33.1	5.1	5.25	1.4	15.66

Truss Member Analysis

- Failure Types
  - Compressive/tensile stress
  - Euler buckling
  - Tubular buckling
- Minimum 2mm thickness
- Mass minimized according to possible thickness and radii

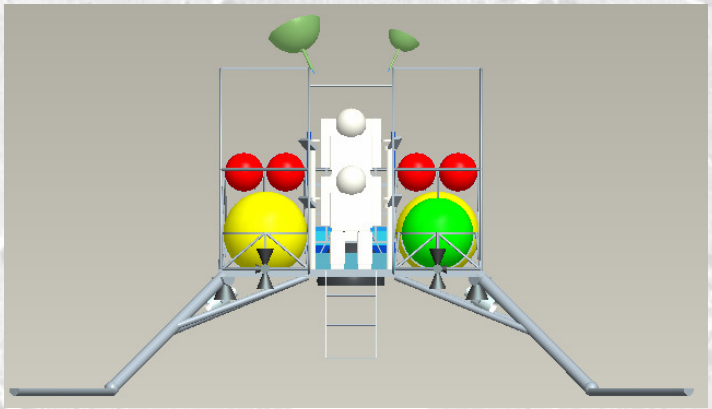


Tube Inventory

Piece Designation	Applied Load (kN)	Thickness (mm)	Radii (mm)	Length (m)	Margin of Safety (%)
Pressurant Rear	2.9	2	14	1.46	5.9
Pressurant Front	2.5	2	11	1.1	3.0
Fuel Tank (1) (2)	1.5	2	8	.78	18.3
Fuel Tank (3)	1.7	2	8	.78	1.4
Fuel Tank (4) (5)	0.25	2	5	.78	37.5
Fuel Tank (6)	2.7	2	10	.78	36
Fuel Tank (7)	2.8	2	10	.78	31.1
Rocket Support	3.8	2	16	1.56	13.2
Support Crossbeams	2.8	2	15	1.55	22.2
Landing Gear Support	106	2	45	1.56	1.9

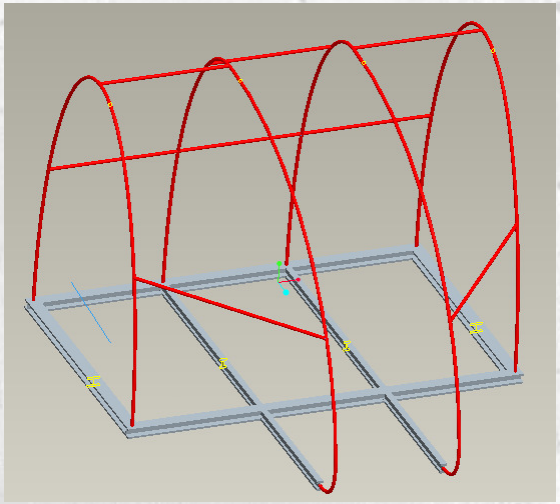
Landing Gear

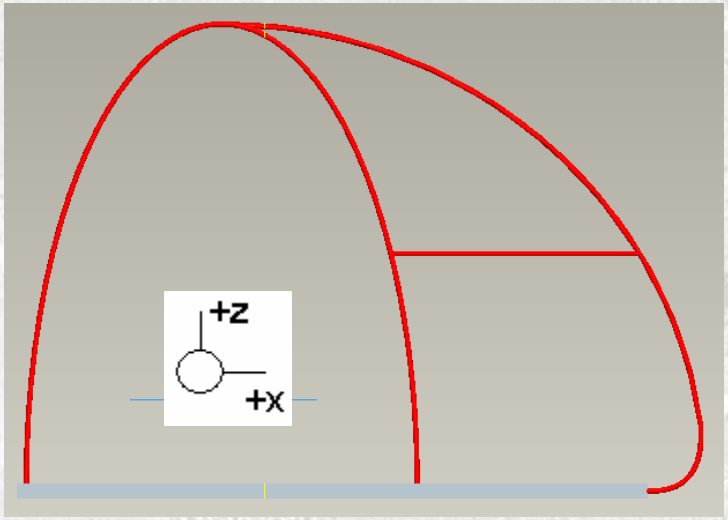
- Torsional Springs
- Footpad Linear Springs
- Leg length: 2.84m
  - Vertical leg stroke=.82 m
  - Uncompressed height: 1.33m
  - Compressed height: 0.51 m
- Footpad length: 1.64 m
- Springs ratchet lock



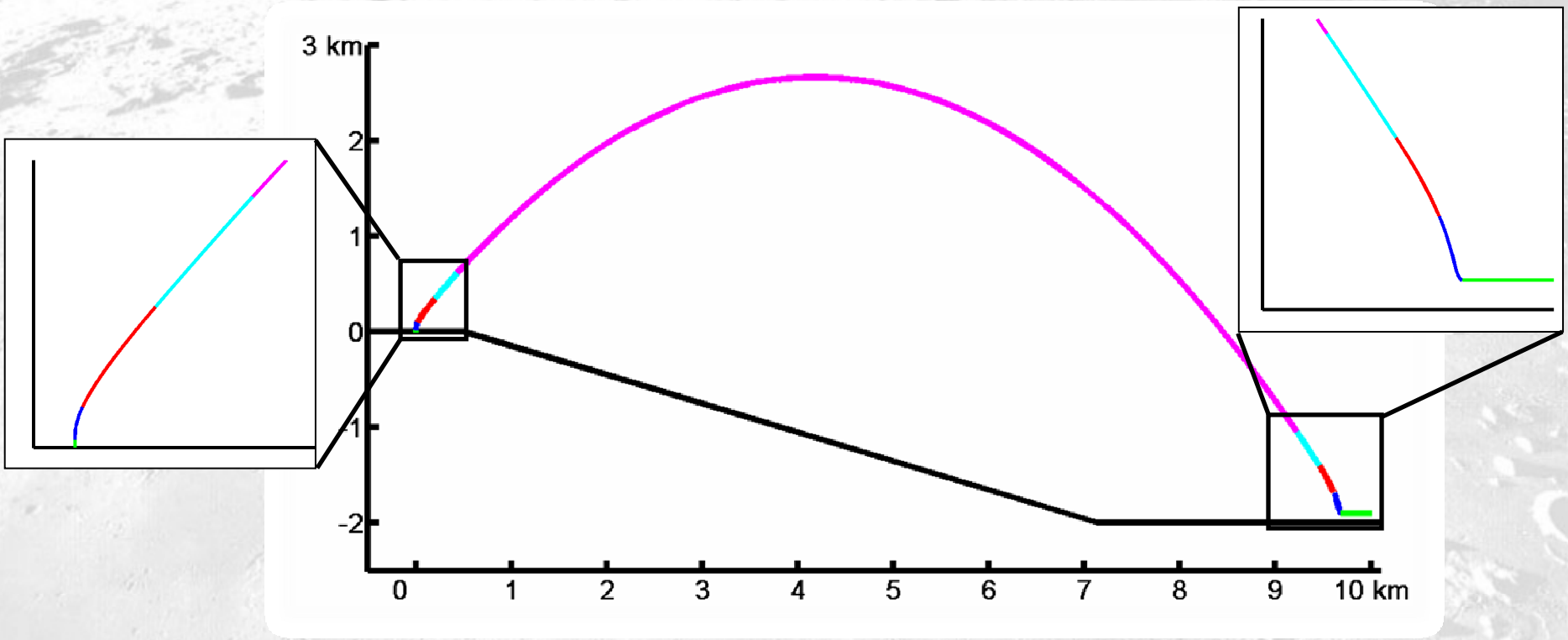
Roll Cage

- Provide protection against tipping/rollover of vehicle
- Must protect crew while allowing for ingress/egress
- Must be able to handle rollover loading
- Must protect mission-critical systems from damage





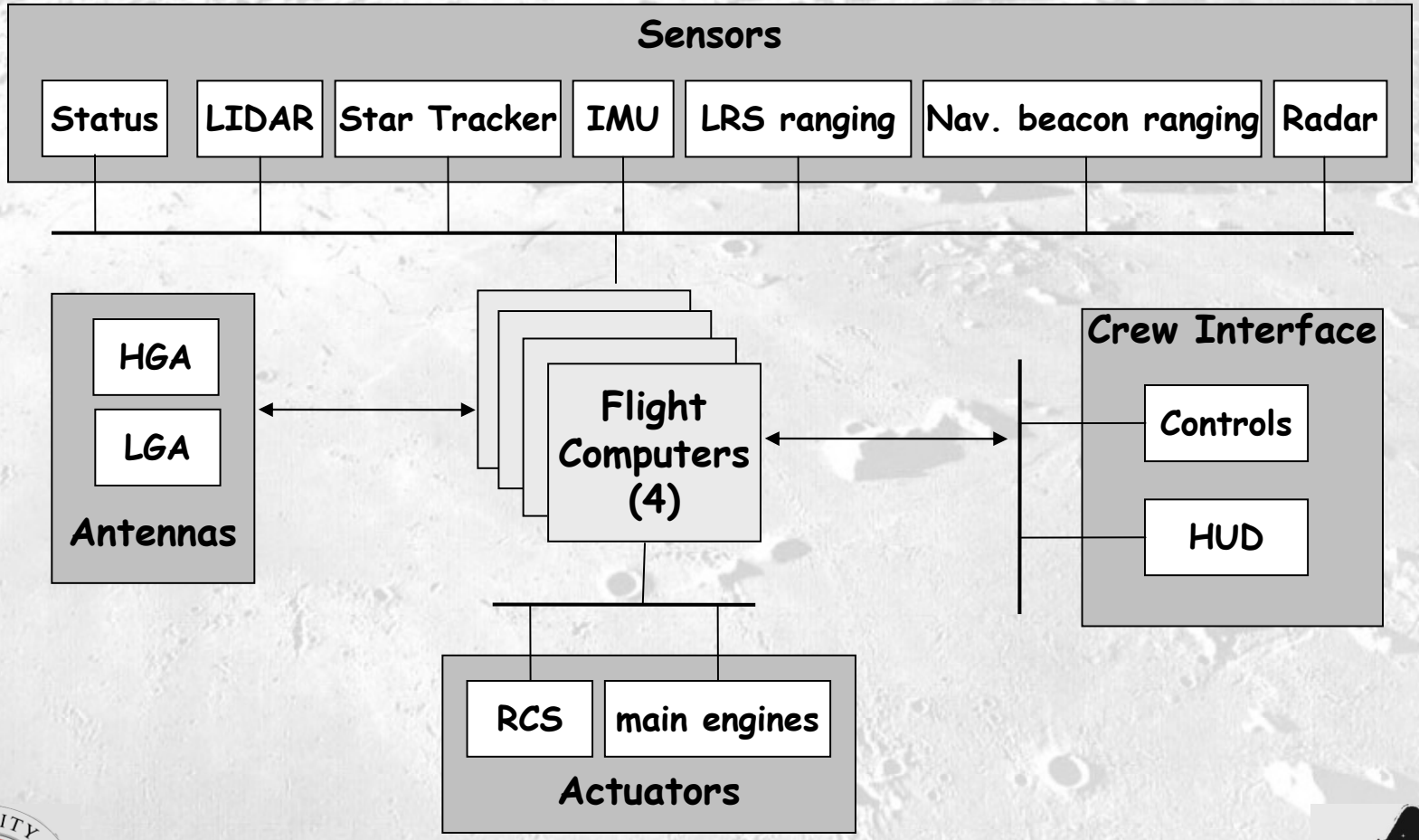
Nominal Flight Plan



acc/decelerating and pitching
acc/decelerating
pitching
coasting
propulsive glide

RASC-AL
Project Alshain: University of Maryland – June 2nd 2009

GNC


Sensors
Status
LIDAR
Star Tracker
IMU
LRS ranging
Nav. beacon ranging
Radar
HGA
LGA
Antennas
Flight Computers (4)
Crew Interface
Controls
HUD
RCS
main engines
Actuators

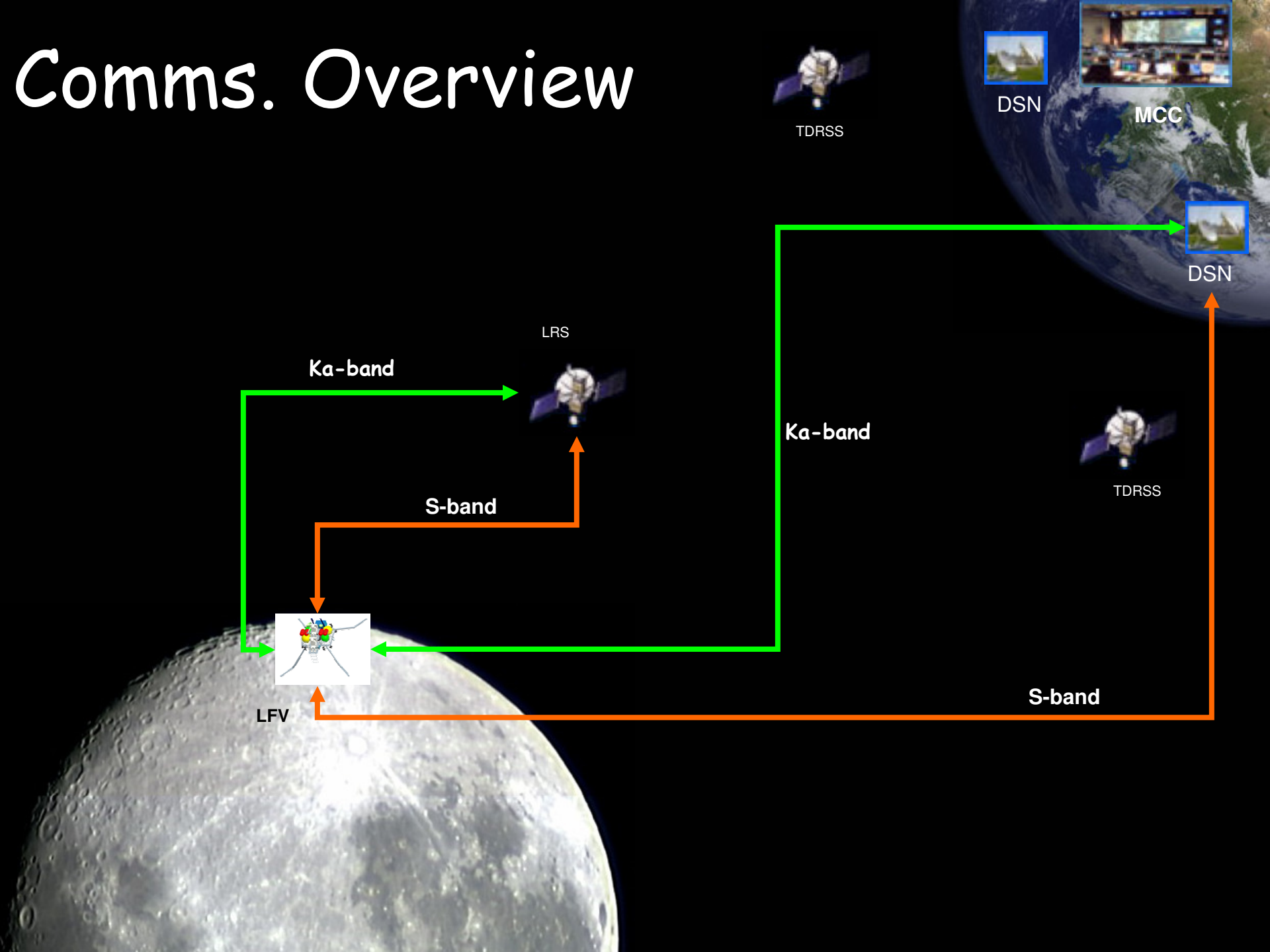
Control Modes

- Autonomous
  - Default mode
  - Vehicle conducts lidar scan to identify safe landing spot
  - Pilot (if present) can redesignate landing spot
- Manual
  - Automatic control loop maintains pilot-specified rates
- Teleoperation
  - Lidar scan transmitted to pilot
  - Vehicle hovers while awaiting a decision

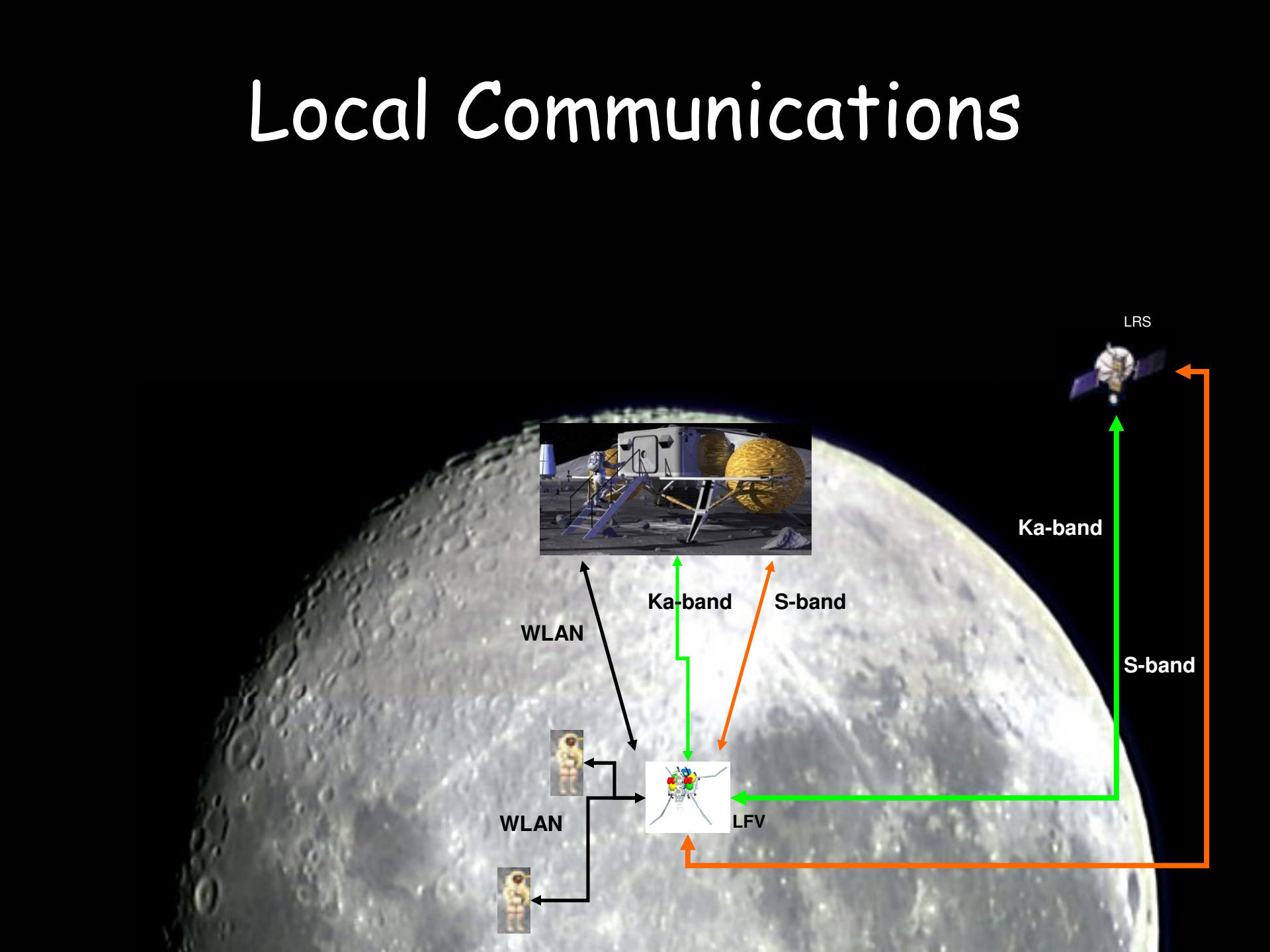
Navigation

- Navigational information available
  - LRS ranging for initial position estimate (10m accuracy)
  - Star trackers for initial attitude estimate
  - High accuracy inertial measurement units required
- Error budget for reference models shows 40-meter achievable navigational accuracy for 57 km hop
- NASA ALHAT program goal to identify hardware and software systems for autonomous navigation and hazard avoidance for lunar landing systems
  - Current design incorporates LIDAR, radar, and IMU's

Comms. Overview



Local Communications



Antennas

- Voice, sensor, tracking, telemetry and command data will be transmitted over S-band omni antennas, when HGA pointing cannot be guaranteed
- High-gain antenna (HGA) will be used for high-bandwidth mission data link while stationary or hovering
  - Primary HGA dish sized at 66 cm for minimum effective system mass (includes power and thermal), capable of 100 mbps direct to Earth
  - Backup HGA dish sized at 30 cm for minimum mass, capable of 30 mbps direct to Earth

Link Budget

- Each antenna has a communication link both to the LRS and direct to Earth (DTE)
- Assumed use of 34 m DSN antenna in both S- and Ka-band
- Sufficient link margin estimated at 6 dB

	Ka-band LRS (26 GHz)	S-band LRS (2.2 GHz)	Ka-band DTE (26 GHz)	S-band DTE (2.2 GHz)
Tx Gain	42 dB	2.0 dB	42 dB	2.0 dB
Tx Power	1.2 W	26 W	3.7 W	7 W
Rx Gain	46 dB	25 dB	77 dB	55 dB
Eb/No required	9.4 dB	9.4 dB	13.5 dB	3.5 dB

Avionics Mass Estimate

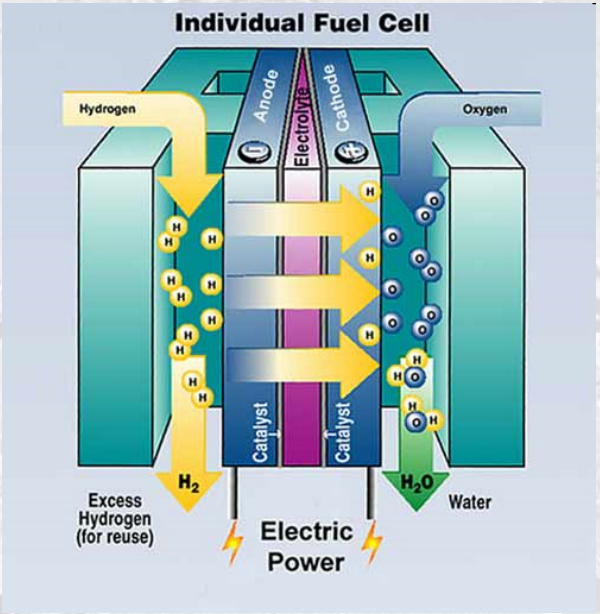
Components:	# of units	Total Mass (kg)
LIDAR	1	11
Radar	2	19
Star Trackers	2	2
Video Cameras	2	3
Inertial Measurement Unit	4	12
Parabolic Antennas/Amplifiers	2	12
Status Monitoring Instruments		5
Box/Casing/Wiring		58
Computers / Circuit Cards	4	
Housekeeping Input/Output Card		
S& Ka-Band Communications Card		
Multifunction Analog Card / Backplane		

Total: 122 kg

Power System

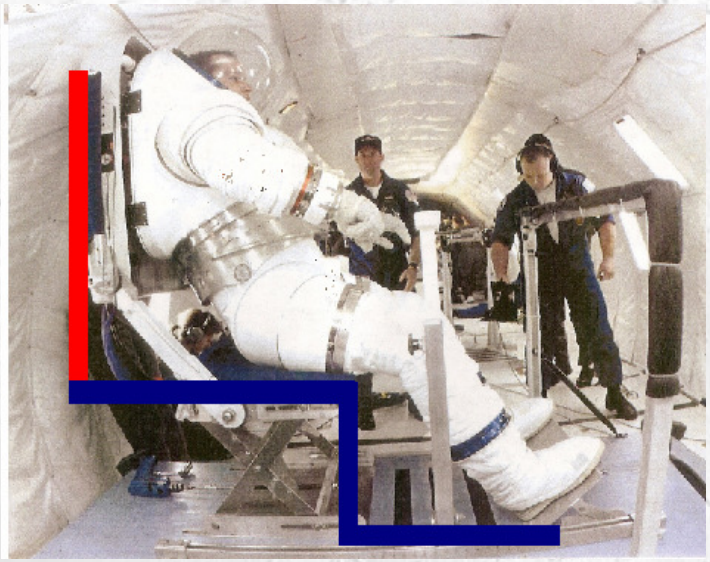
- Use batteries for power, fuel cells for energy.
- 4 kg of Li-ion phosphate batteries
- 2-700W PEM fuel cells: 6kg
  - Fuel vaporized by regenerative heating before entrance to fuel cell
- 4 kg of piping
- 20 kg of primary batteries
- System mass: 34 kg
- PMAD unit used for power distribution

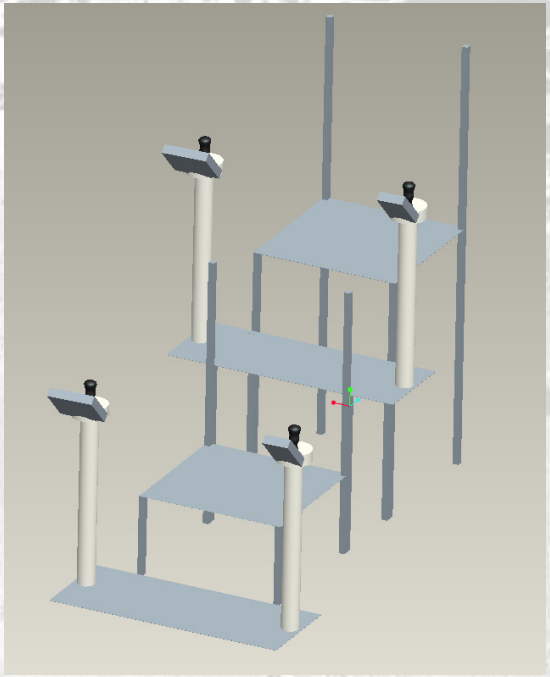
Scenario	Power (W)	Duration	Energy (Wh)
In-Flight	11560	6 min	156
Landed	720	8 hours	5800
Contingency	600	24 hours	14000

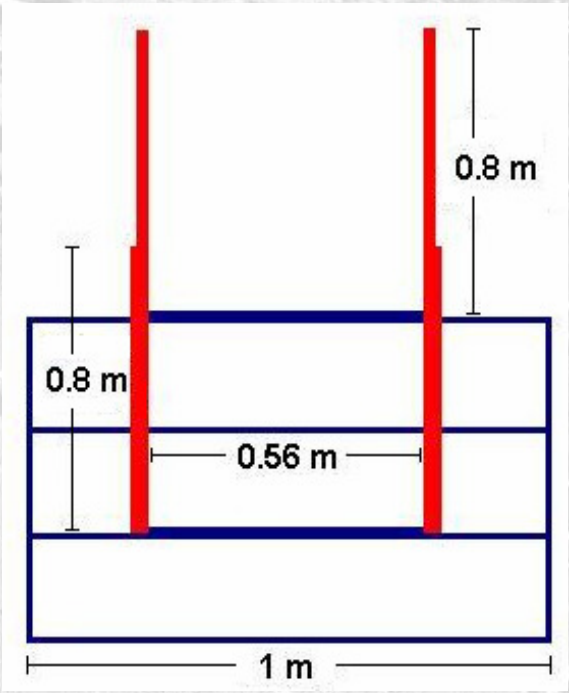


http://www.chem.umass.edu/masscrest/fuelingthefuture/researchteams.html

Seating and Restraints





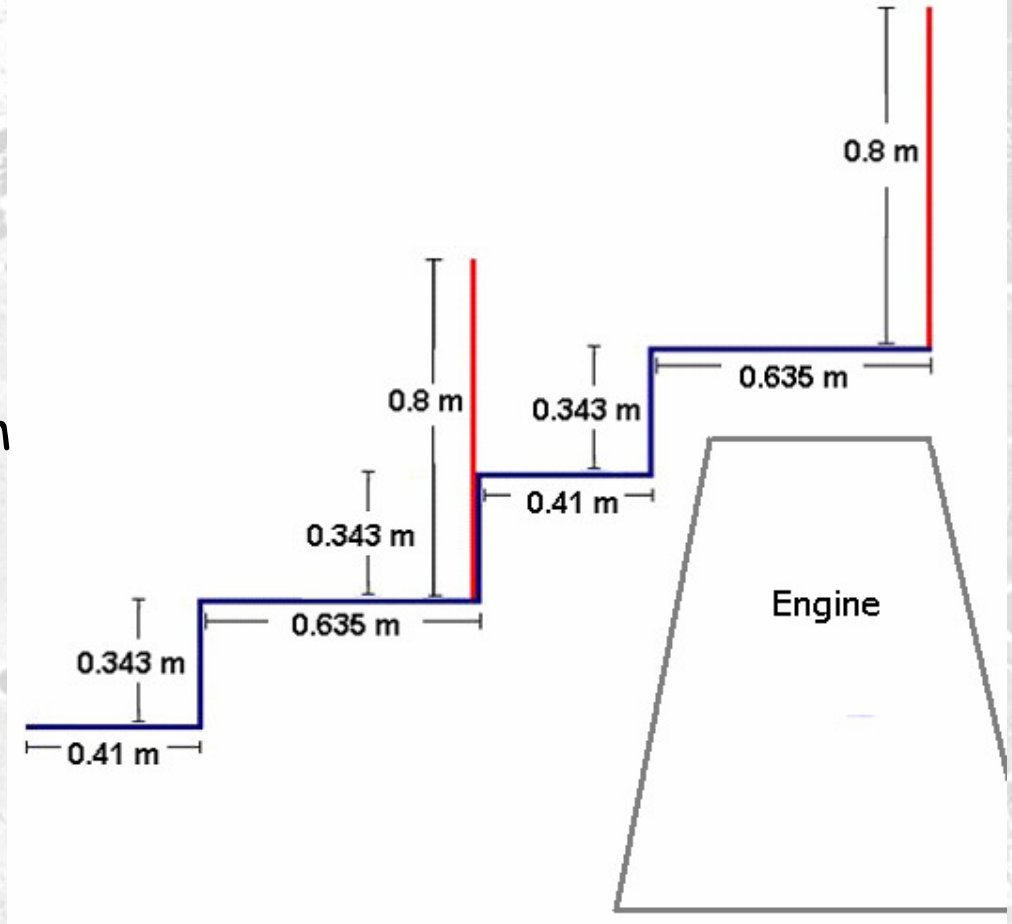


*Ref: Amy Ross, "Lunar Rover Vehicle Mockup Advanced Space Suit Ingress/Egress Test", 2002

Crew Placement: Side View

- Seat height: 0.343 m (13.5")
- Seat depth: 0.635 m (25")
- Foot platform depth: 0.41 m (16")
- PLSS constraint height: 0.8 m (31.5" from seat)

*Ref: Amy Ross, "Lunar Rover Vehicle Mockup Advanced Space Suit Ingress/Egress Test", 2002



Life Support System

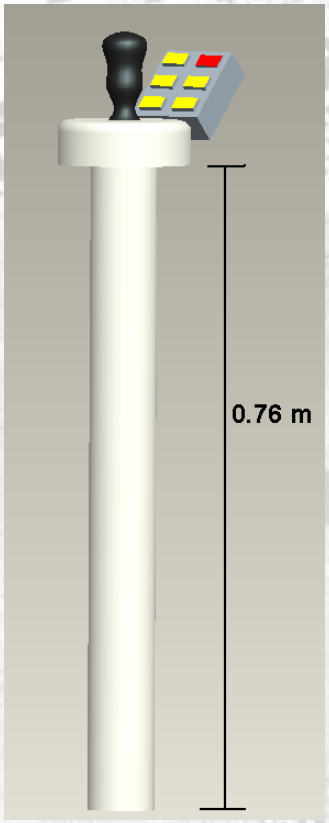
Crew Requirements (per astronaut)

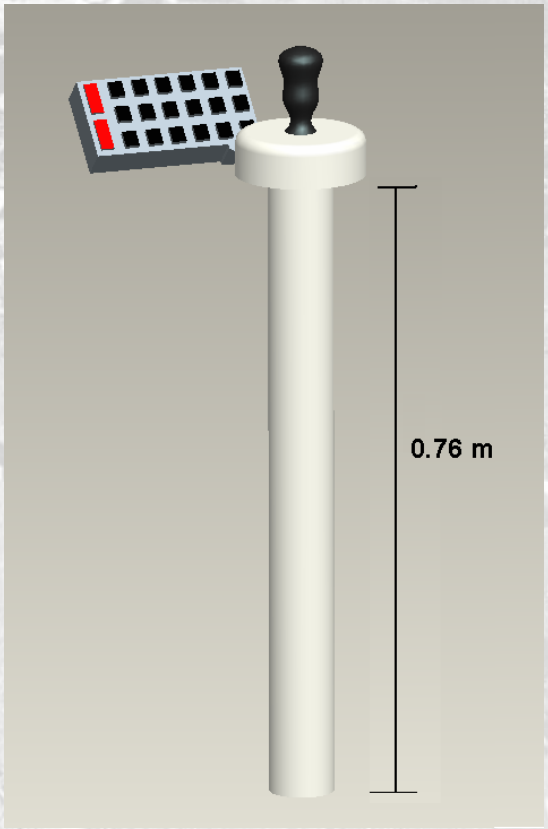
- Breathing oxygen
  - 0.84 kg of O_2 per day
  - Oxygen used from liquid oxygen tanks
- Carbon dioxide scrubbing
  - 1.00 kg of CO_2 per day
  - LiOH scrubber
- Cooling water re-supply
  - 5.22 kg of water for every 8 hours
  - 15.7 kg replacement water needed for 24 hours
- Drinking water re-supply
  - 1.62 kg of drinking water per day
  - 0.2 meter diameter containment sphere
- 120 W power for the suit

Reference: Dr. David Akin ENAE483 Slides, 2008

Control Panels

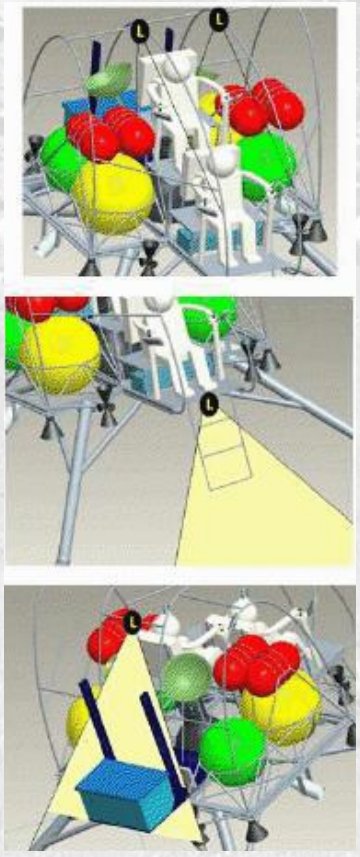
- Controls needed for both astronauts
  - 2 joysticks for manual control
  - Physical warning lights
  - Controller pad for mission critical controls
  - Heads-Up Display (HUD)
  - Voice commands in helmet

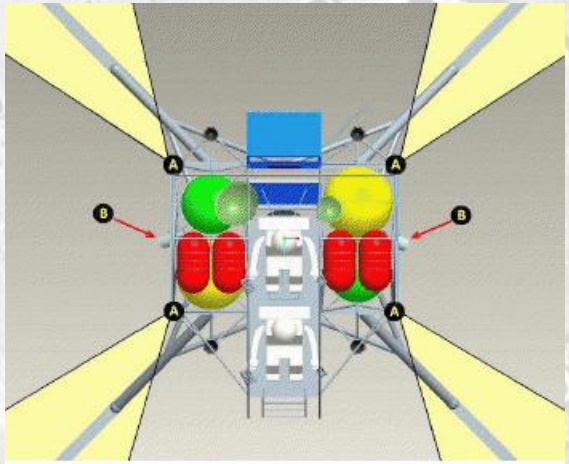




Lighting

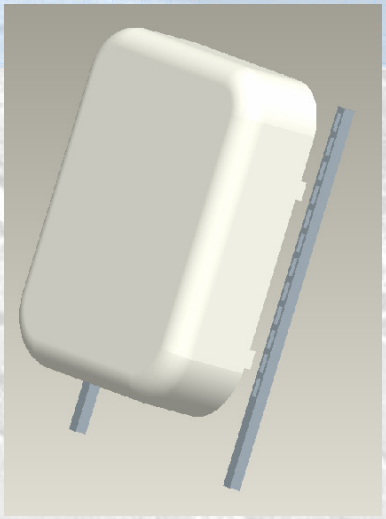
- Four 20 W halogen lamps illuminate:
  - Crew flight control area
  - Crew ingress/egress area
  - Cargo elevator
- Four 50 W halogen lamps illuminate the surrounding area

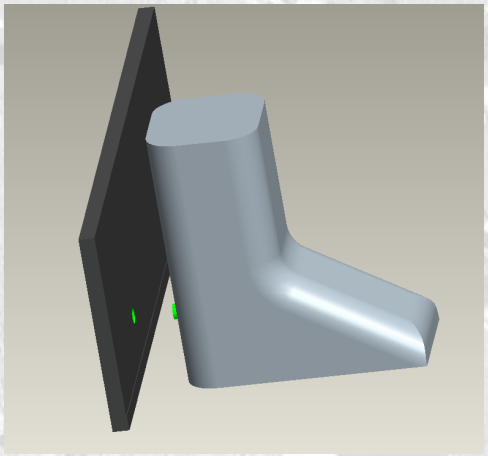




Restraints

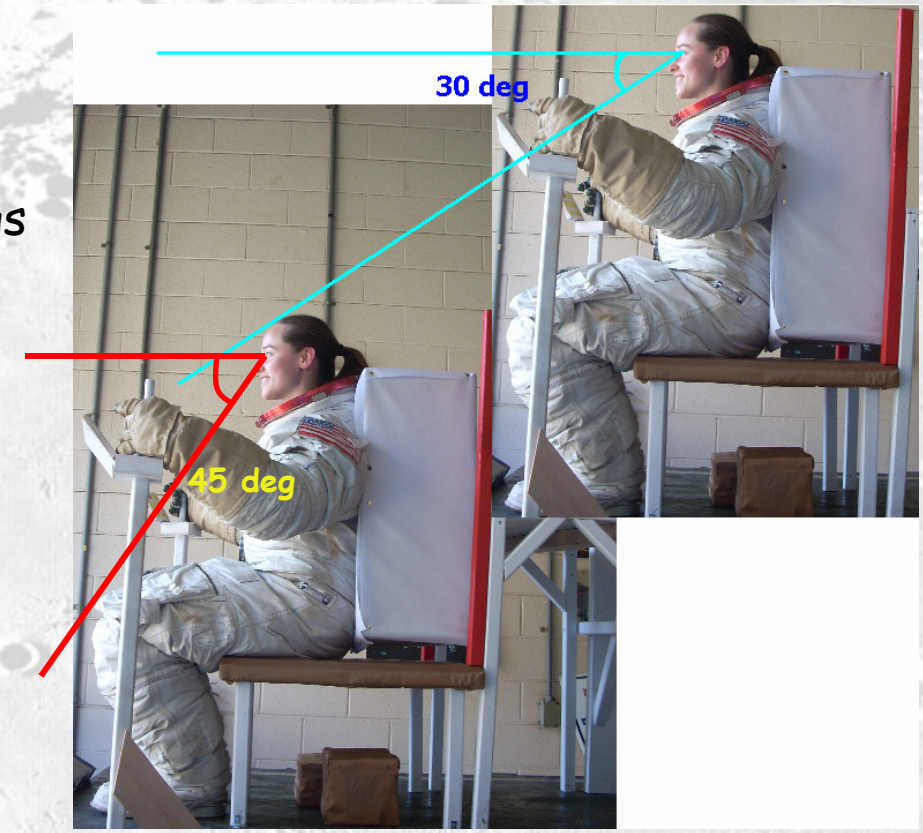
- PLSS secures onto repeating latch pattern on restraining bar at multiple points
- Release switch placed within easy reach
- To avoid damage to forward crew member's PLSS the aft crew member's boots must be restrained against kicking upward
- Boots can be restrained at the heel





Sightlines

- Alshain piloted by fore crew member
  - Limiting factor of vision is legs at 45°
- Contingency: Piloted by aft crew member
  - Possible limiting factors
    - Lower body obstruction: 45°
    - Forward crew member: approx. 30°



Hardware

- Testing crew systems including crew interfaces and accommodations
  - Board vehicle and occupy the aft of the crew station
  - Occupy the lower of the forward stations
  - Egress vehicle
- Apollo era suit
- Results:
  - Roll cage supplies handholds necessary to facilitate ingress/egress

Contingency

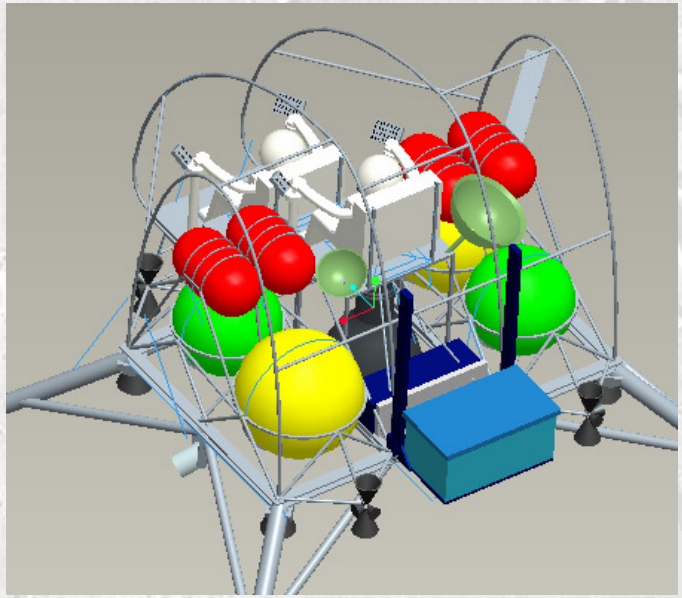
- Incapacitated astronaut scenario:
  - Use an astronaut dummy to test loading and securing an incapacitated astronaut into the craft.
  - Testing:
    - Load dummy onto designated area in cargo lift equipped with PLSS restraint bars
    - Load a second incapacitated astronaut into the aft crew position
  - Results:
    - Additional mechanism required for incapacitated crew loading

Radiation

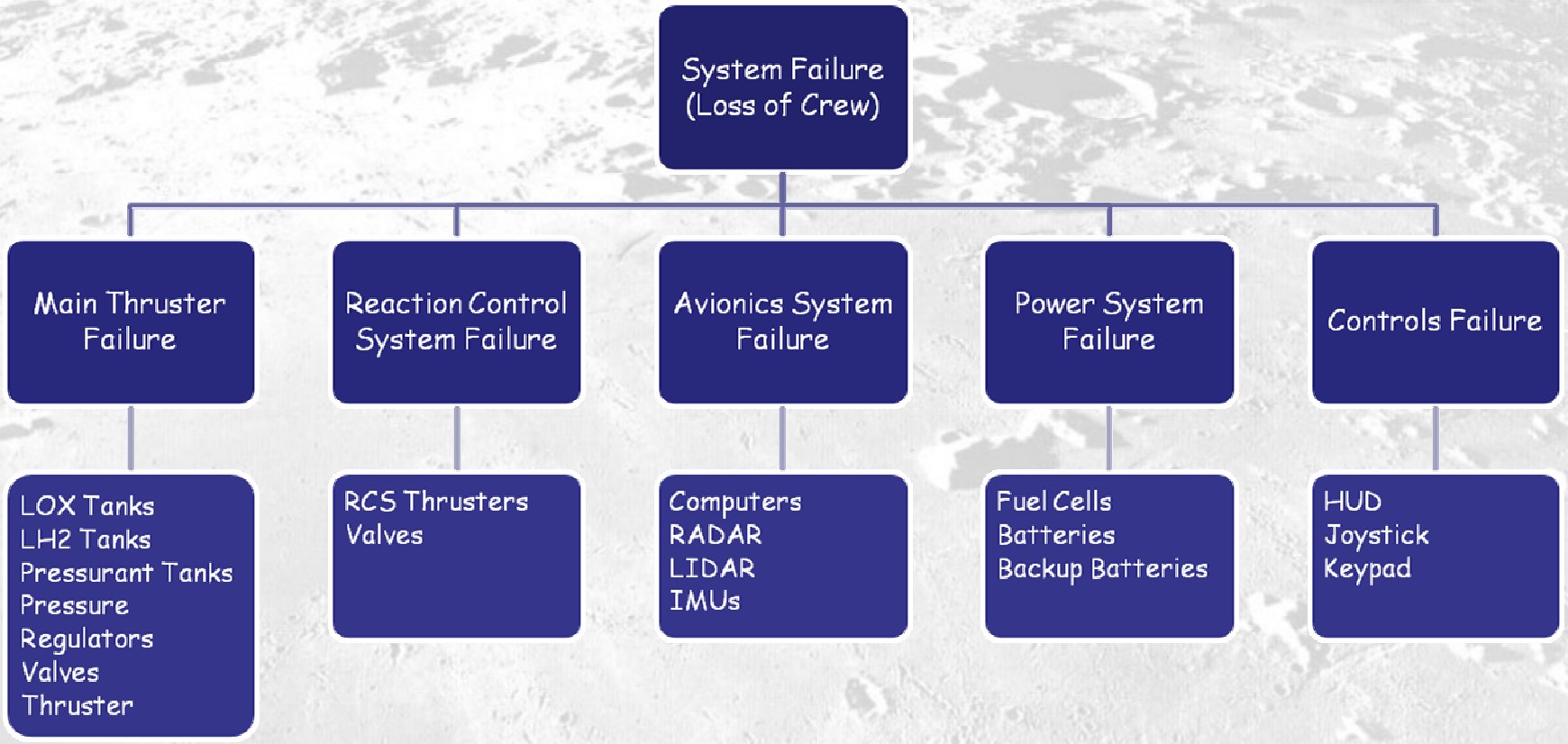
- Large SPE typically occur approx. 1-2 times per solar cycle (11 yrs)
  *Ref: Spaceflight Radiation Health Program at JSC
- Probability of large SPE in 24 hours: 5.1×10^{-4}
- Mission reliability: 99.2%
  - Probability of mission failure: 0.8% = 0.008
- Probability of failure and SPE:
  $5.1*10^{-4} *0.008 = 4 \times 10^{-6}$
- Flights in program lifetime: 250
- Probability of failure and SPE during program lifetime:
  $1-(1-4*10^{-6})^{250} = 1 \times 10^{-3}$ **(1 in 1000)**

Payload Bay

- Payload bay size dictated by contingency requirement to carry an incapacitated astronaut
  - 170 kg mass (95th percentile male wearing PLSS)
  - Capable dimensions of 1.49x0.86x1m (volume of 1.28m^3)
- Used a database of 103 previous NASA payloads
  - Alshain can carry several of these on each mission



Fault Tree Structure



Final Results

- A Monte Carlo simulation shows:
  - Total system reliability: 99.6% (18 failures out of 10000)
  - NASA will require 99.9%

Weak Points	System Failures Caused
RCS Thrusters	27.37%
Pressure Regulators	26.89%
Valves	26.77%

- These are component areas of research to increase reliability

Critical TRLs

- The following technologies require additional research and testing to be used in conjunction with Alshain:
  - Composite cryogenic tanks (LOX, LH_2) – TRL 3
  - PEM Fuel Cells – TRL 6
  - HUD – TRL 4
  - Radio frequency gauging – TRL 4
  - ALHAT – TRL <6
  - Copper Beryllium Spring – TRL 3

Mass Budget

Component	Estimate	Margin	Budgeted
LOX Tanks	19	5.7	24.7
LH2 Tanks	26	7.8	33.8
Pressure Tanks	168	50.4	218.4
Engine/RCS	185	55.5	240.5
Power/Wiring/Thermal	60	18	78
Crew Interfaces/Support	54	16.2	70.2
Lighting/Crew Shielding	47	14.1	61.1
Landing Gear	87	26.1	113.1
Structure	101	30.3	131.3
Avionics	122	36.6	158.6
Reserve		260.7	
Total Inert Mass	869		**1129.7**

Costing Analysis

AMCM

- Mission Type:
  Spacecraft Lunar Rover
- NR Development (2008$):
  - 623 ($M)
- Recurring Production:
  - 219 ($M)
- Total Cost:
  - 842 ($M)

SVLCM

- Type:
  Manned Spacecraft
- NR Development (2008$):
  - 1093 ($M)
- Recurring Production:
  - 129 ($M)
- Total Cost:
  - 1222 ($M)

*www.westegg.com/inflation

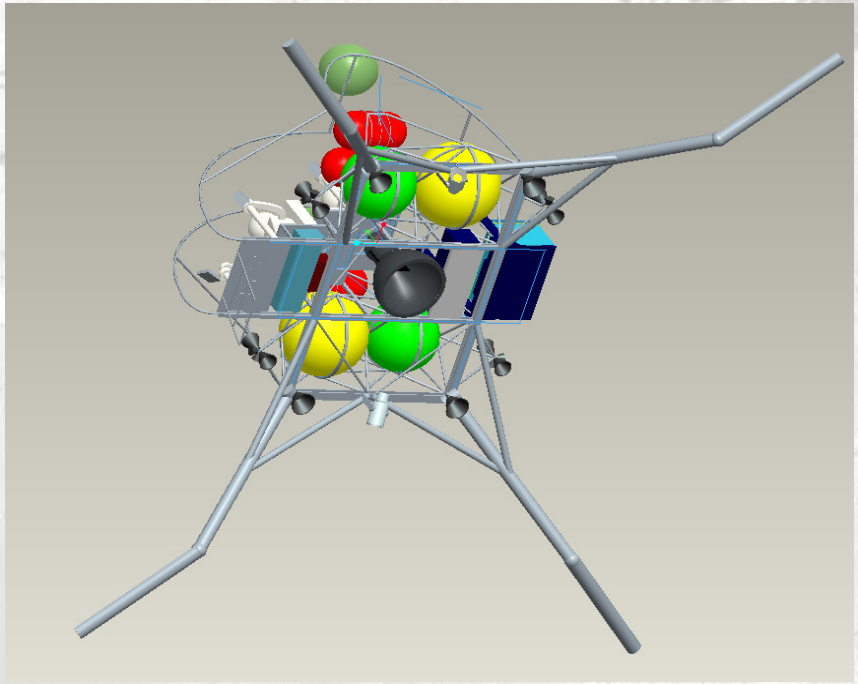
Outreach

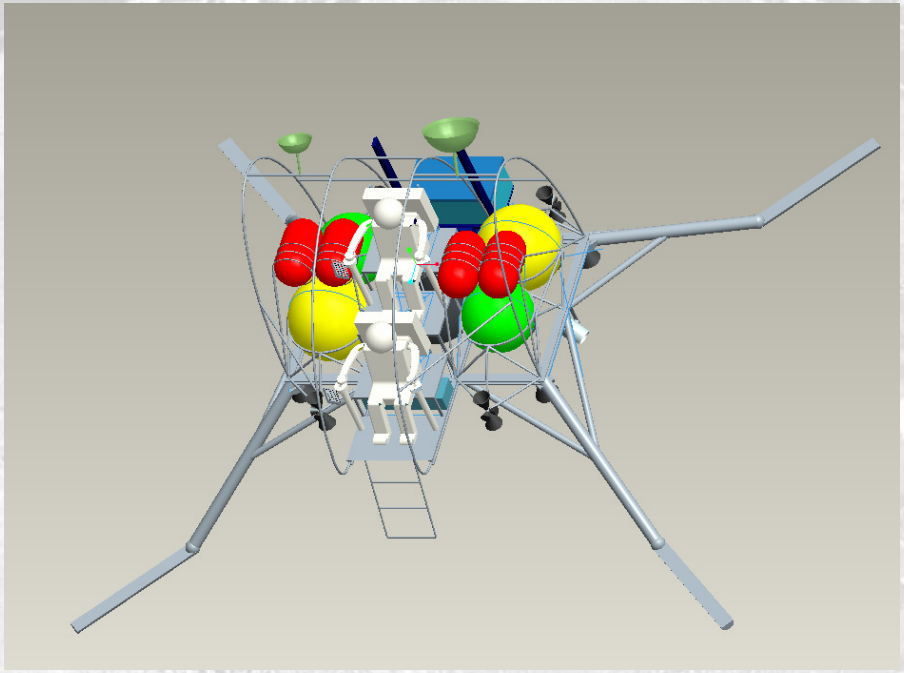
- Events
  - Local science fairs
  - Maryland Engineering Challenges in Baltimore, MD
  - Open houses for prospective engineering students
  - Presentation of mock-up at annual Maryland Day celebration
  - Total of 198 hours with 100% participation

Conclusions

- Benefits of the Alshain Lunar Flying Vehicle
  - Capabilities are above and beyond those of a rover
  - Allows scientists to reach previously inaccessible lunar regions
  - Interfaces with Constellation architecture and goals

Questions?





RASC-AL
Project Alshain: University of Maryland – June 2nd 2009

List of Nearby Craters

- Cabeus
- Faustini
  - Cold trap
  - High concentration of hydrogen
- Shoemaker
  - Cold trap
  - High concentration of hydrogen
- De Gerlache

Cabeus
- Location: 84.9° S, 35.5° W
- Diameter: 98 km
- Depth: 5.71 km

Faustini
- Location: 87.3° S, 77.0° E
- Diameter: 39 km
- Depth: *Unknown*

Shoemaker
- Location: 88.1° S, 44.9° E
- Diameter: 50.9 km
- Depth: *Unknown*

De Gerlache
- Location: 88.5° S, 87.1° W
- Diameter: 32.4 km
- Depth: *Unknown*

Westfall, John E. 2000. *Atlas of the Lunar Terminator*. Cambridge Univ. Press.

Shackleton

- Base site lies on crater rim
- Lunar rotational axis lies within interior
  - Crater is in perpetual darkness
- Interior believed to contain hydrogen deposits (possibly water)
- Relatively young compared to nearby craters

- Location:
  89.9° S, 0.0° E
- Diameter:
  19 km
- Depth:
  2 km

Nearby Craters

- Other craters near the lunar south pole also of interest
- Many are larger and older than Shackleton
- Some contain "cold traps"
  - Temperature permanently below 100 Kelvin
  - Any water molecules are trapped within
- Depths are not accurately measured
  - Estimates shown were catalogued by ALPO's Dr. John Westfall
  - The estimates are of unknown certainty

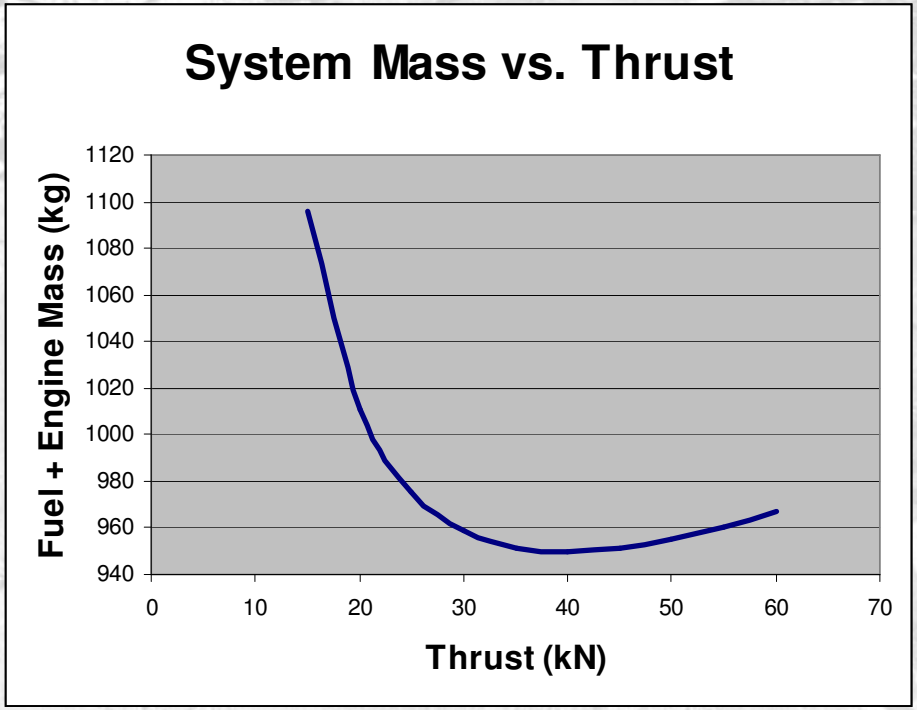
Reaction Control System

- Six degrees of freedom control
- Resist maximum C.G. shift of 0.16 m
- Back up to main thruster
  - Powered landing if engine check fails
  - Higher g-load allowable (contingency)
- Thrusters placed to protect astronauts from exhaust plumes
- 2 fault tolerant

Main Engine Design

- Required thrust
  - Maximum allowable:
    - Approx. 49 kN (full tanks)
    - Approx. 31 kN (empty tanks)
  - Minimize effect of gravity drag:

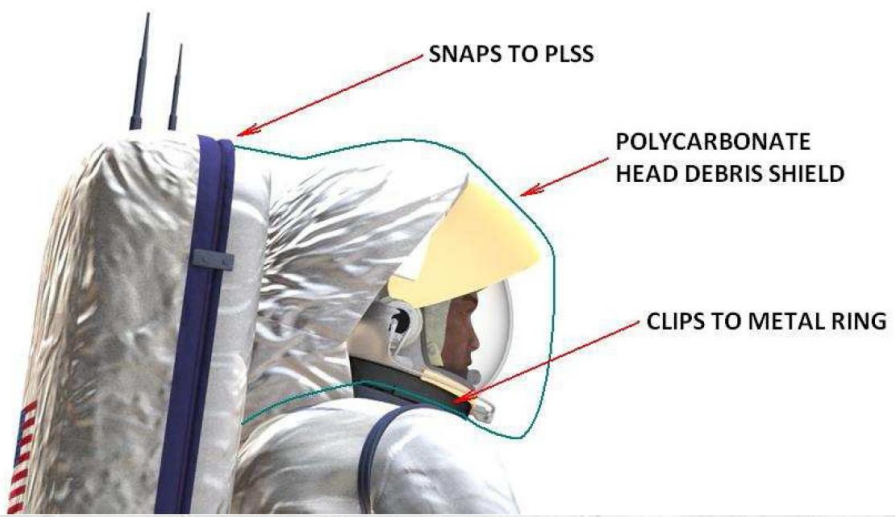
$$\Delta v = -I_{sp} g_e \ln\left(\frac{m_f}{m_i}\right) - \frac{g_m I_{sp} g_e}{T}\left(m_i - m_f\right)$$

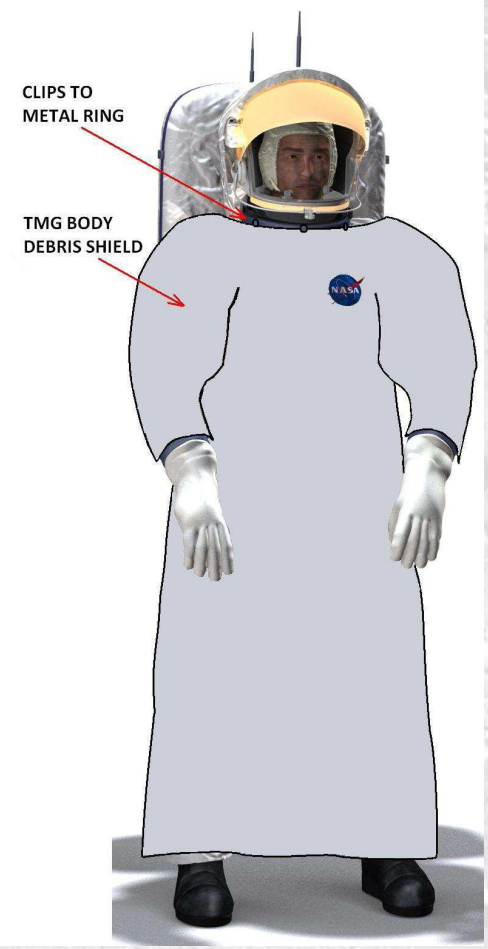


  - Minimize system mass
    - Sum of fuel and engine mass is minimized at 40 kN

Debris Shielding

- Clear plastic shields around head
- Shielding required for protection from space/moon debris during takeoff, flight, and landing





Contingency Power

Equipment	Number of Units	24-hour (W)
WLAN	1	50
Flight Computers	1	25
S/Ka Band Transceivers &Antennae	1	50
Interface Box	1	25
Status Monitoring Instrument	1	20
Vehicle Lighting	2	40
Life Support	1	250
Total Power		**460**
With 30% Margin		**600**