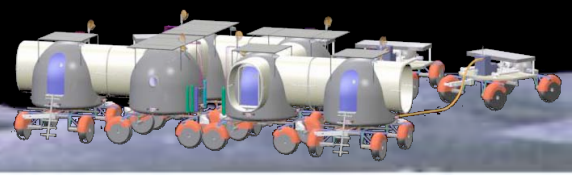
MORPHLAB

Modular Roving Planetary Habitat, Laboratory, and Base

Critical Design Review

April 19, 2004



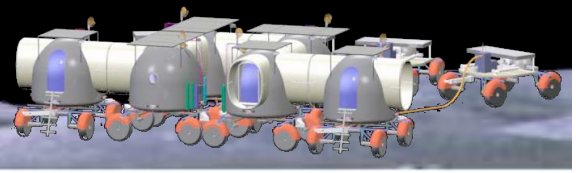
MORPHLAB

Mission Statement

"Returning to the moon is an important step for our space program… The moon is home to abundant resources. Its soil contains raw materials that might be harvested and processed into rocket fuel or breathable air. We can use our time on the moon to develop and test new approaches and technologies and systems that will allow us to function in other, more challenging environments. The moon is a logical step toward further progress and achievement."

~ President George W. Bush

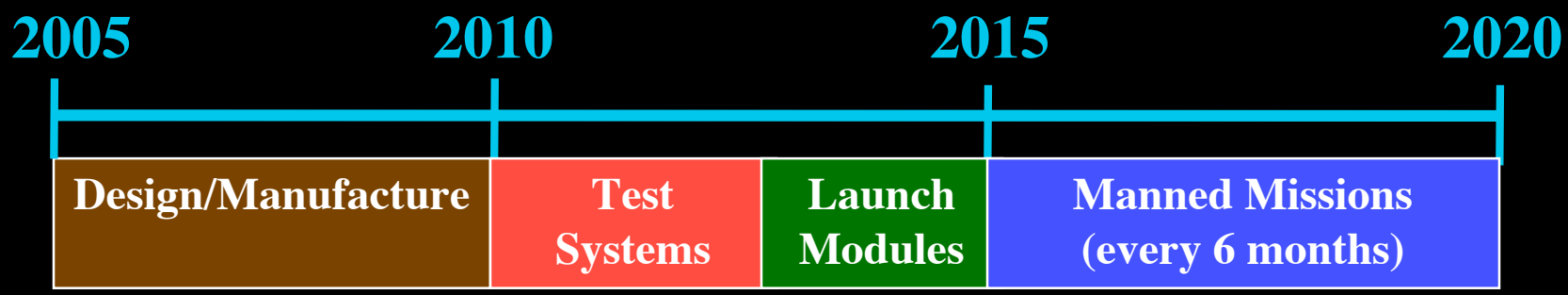
- Restore human exploration to the moon, investigating a large portion of the lunar surface
- Maximize the search for natural lunar resources through a mobile base
- Develop the experience and the required technologies for extended human space travel



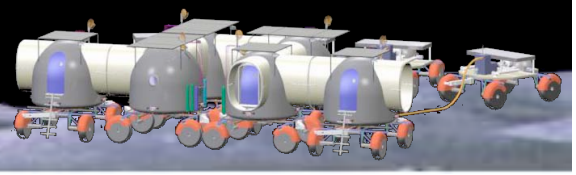
MORPHLAB

Program Overview

Designed to meet externally applied constraints



- Launch small, autonomous, mobile modules with specialized purposes to the moon
- Assemble the modules into a complete base
- Send a crew of 4 to the assembled base to conduct experiments for 3 lunar day-night cycles (months)
- Disassemble base and send modules to next site of interest, up to 1000km away, over an unmanned period of 3 months



MORPHLAB

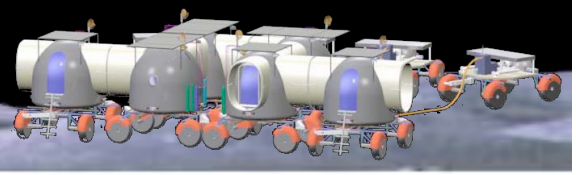
Science Objectives

- Study the effects of the lunar environment on life, especially long duration missions

Radiation	Plant and animal biology
Skeletal system	Nutrition and medical care
Cardiovascular system	Crew dynamics
Muscle development and decay	Human performance and adaptations

- Study the moon and its resources

Volcanic and impact history	Deep lunar composition
Water ice and ore deposits as potential resources	Environmental variations along the surface

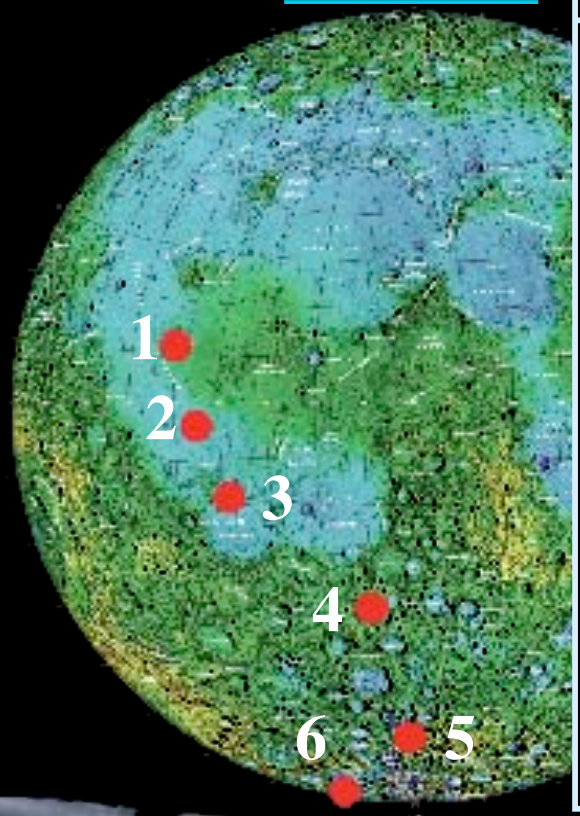


MORPHLAB

Assembly Sites and Selection Criteria

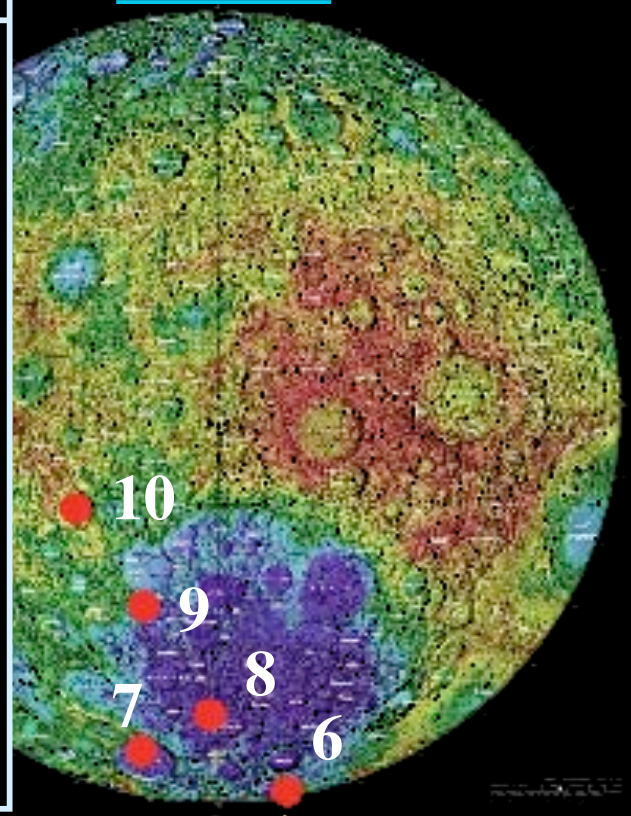
- Approximately 1000 km apart
- Apollo site candidates
- Surveyor landing sites
- Ore deposits and useful elements
- Permanently shadowed regions
- Age and appeal of lunar structures

Near Side

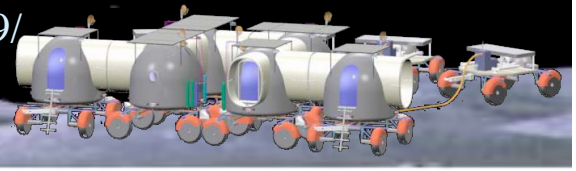


Sites
1) Marius
2) Flamsteed
3) Gassendi
4) Tycho
5) Meretus
6) Drygalski
7) Schrodinger
8) Minnaert
9) Mare Ingenii
10) Gagarin

Far Side



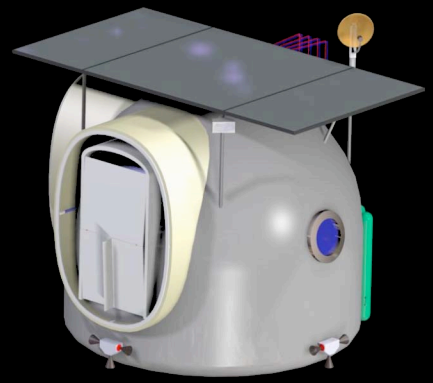
http://geopubs.wr.usgs.gov/i-map/i2769/



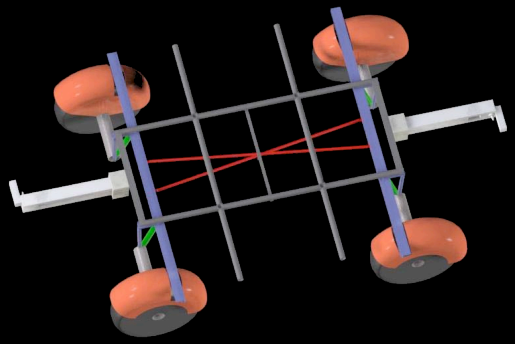
Kevin Eisenhower

MORPHLAB

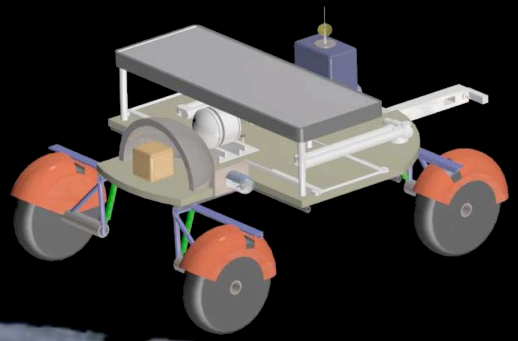
Module Types



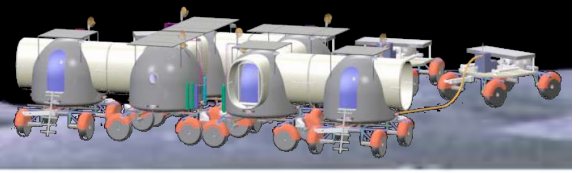
- 6 Habitable Modules
  - Size governed by launch vehicle payload size
  - Need 6 to achieve the necessary floor space and volume to accommodate a crew of 4 for 3 lunar sols



- 6 Chassis with all-wheel drive
  - Provide locomotion for Habitable Modules
  - Equipped with transit connections to link vehicles in the transit phase



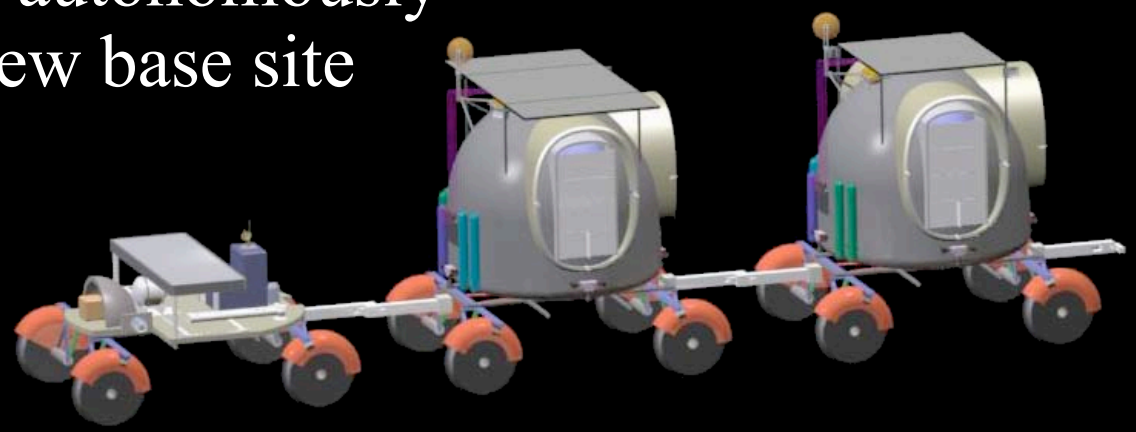
- 4 Power Modules with all-wheel drive
  - Provides AC power to all modules
  - Equipped with navigation computers and leads during transit



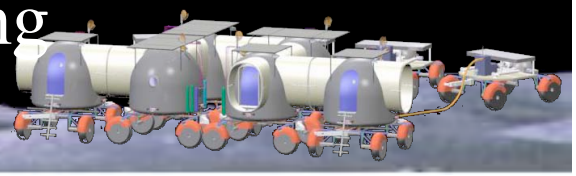
MORPHLAB

Modularity – Transit Phase

- After each manned mission, MORPHLAB will disassemble and travel autonomously to a new base site
- Transit configuration:
  1 Power Module,
  2 Habitable Modules, &
  2 Chassis Modules



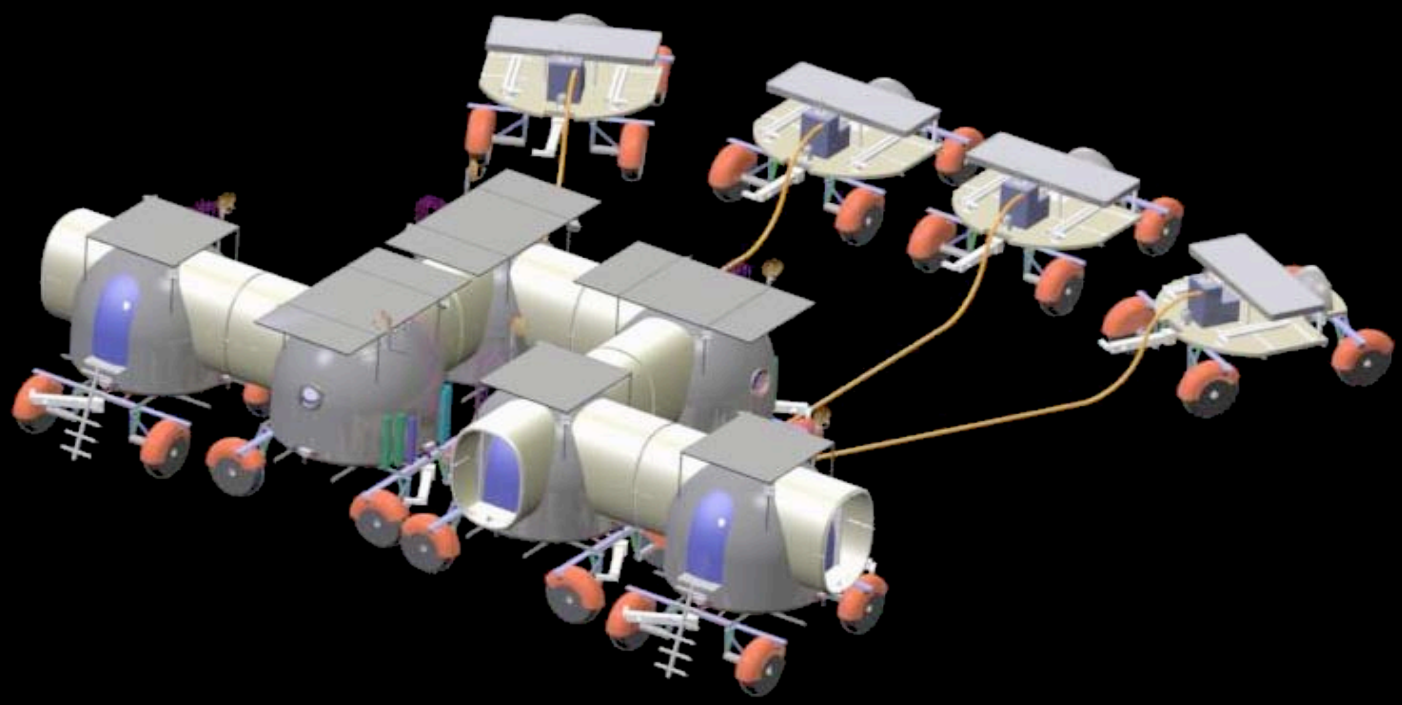
- Enables exploration and analysis of vast areas of the Lunar surface
- Science will be performed by the modules while traveling

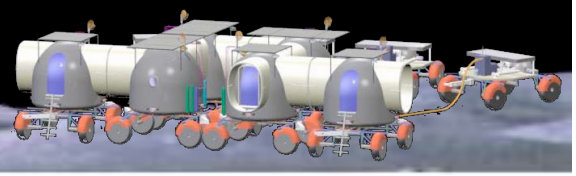


MORPHLAB

Modularity – Manned Base Phase

- Multiple base configurations possible
- Subsystems split between modules

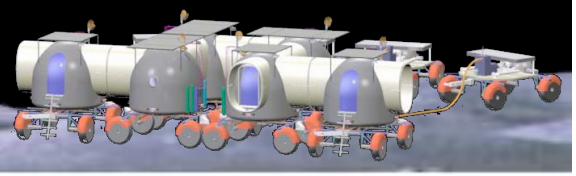




MORPHLAB

Benefits of Modularity

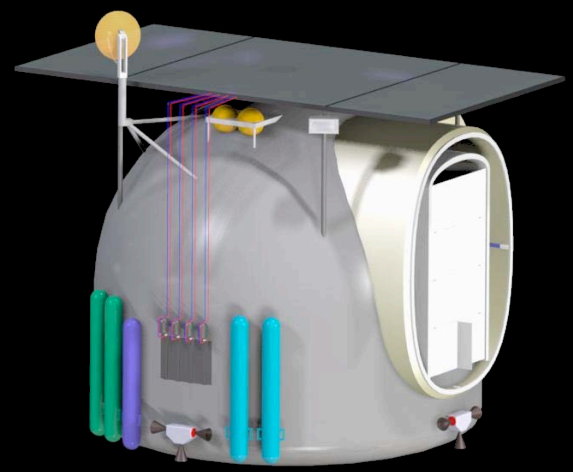
- Modules are less massive than a large-scale structure
  - Can be launched on existing launch vehicles
  - Increased mobility
- Capable of traversing great distances
  - Multiple lunar base locations
  - Science may be performed while modules are in transit
  - Experiments may be subjected to long exposures to the lunar environment
- Feasible program expenditures
  - Allows for cost spreading over the program duration
- Utilizes a cost learning curve



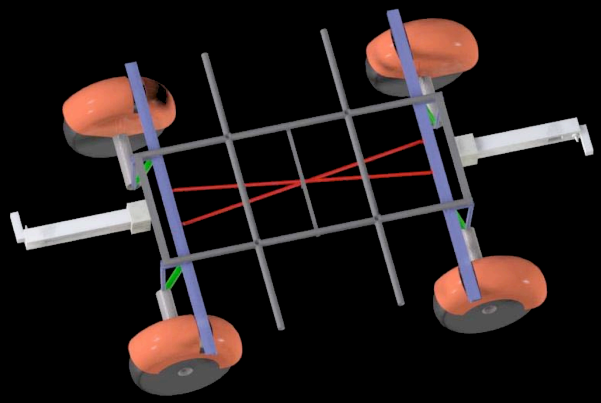
MORPHLAB

Module Details

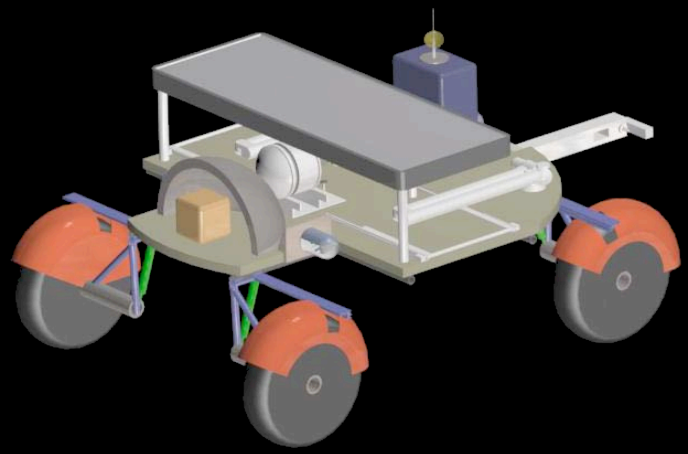
Habitable Module

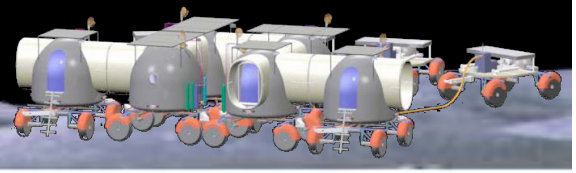


Chassis Module



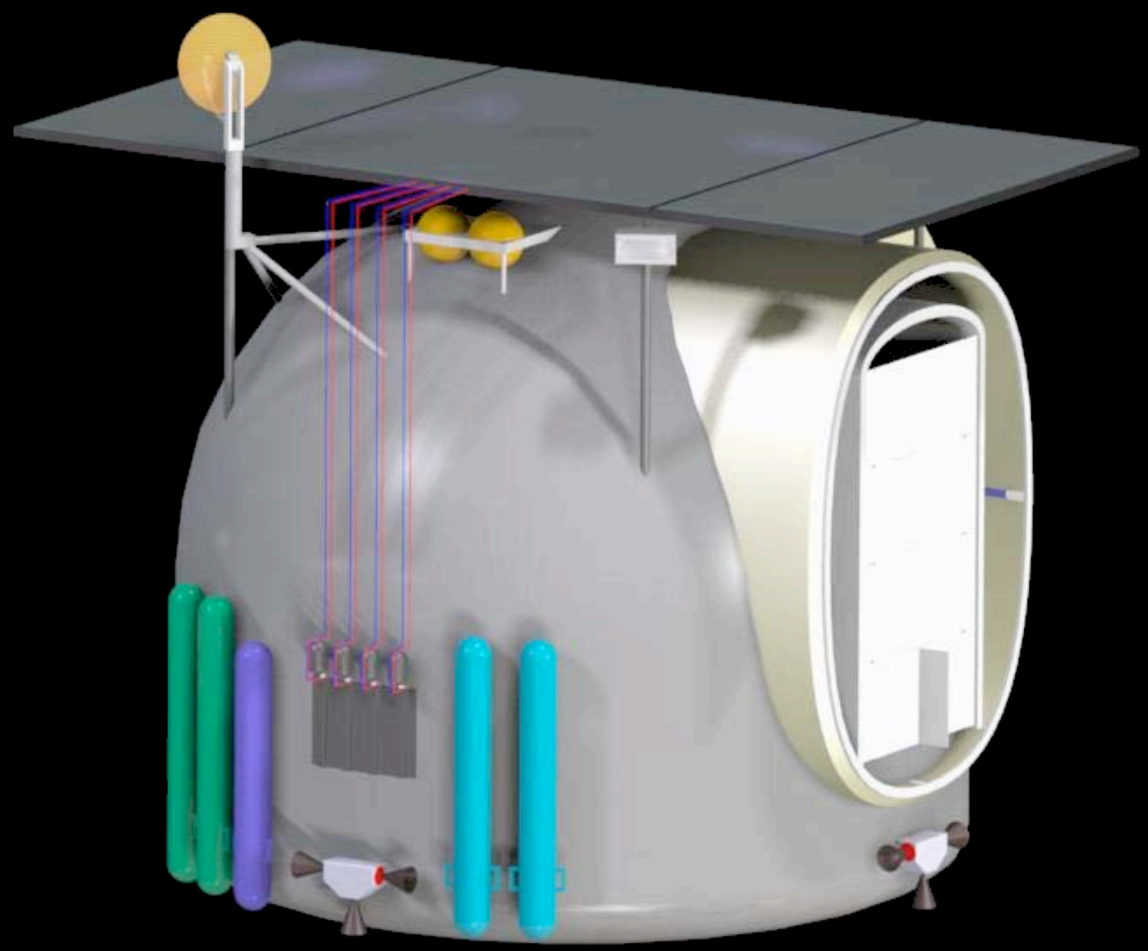
Power Module

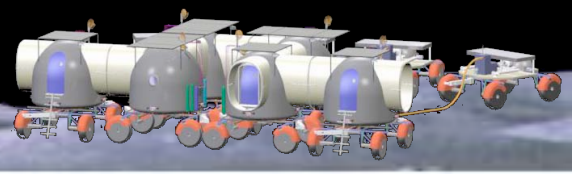




MORPHLAB

Habitable Module





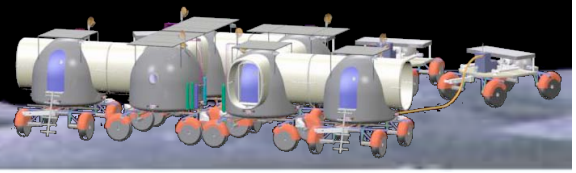
University of Maryland

CDR 04/19/04

MORPHLAB

Habitable Module Overview

- Habitable modules:
  - provide the space where the crew will live and work while not out on EVA
  - two types of modules:
    - Habitable-Living (3 of 6)
    - Habitable-Science (other 3 of 6)
- This breakup
  - allows minimal disruption if the astronauts have different sleeping schedules
  - restricts lunar dust to the EVA areas
- Functions are distributed and redundant so that the failure of any one module will not disrupt normal activities (Level 1 requirements I3, I11)

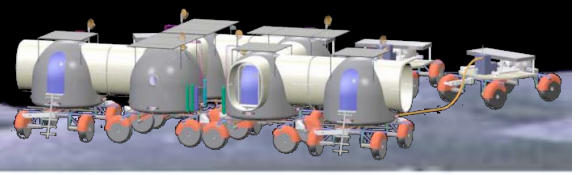


MORPHLAB

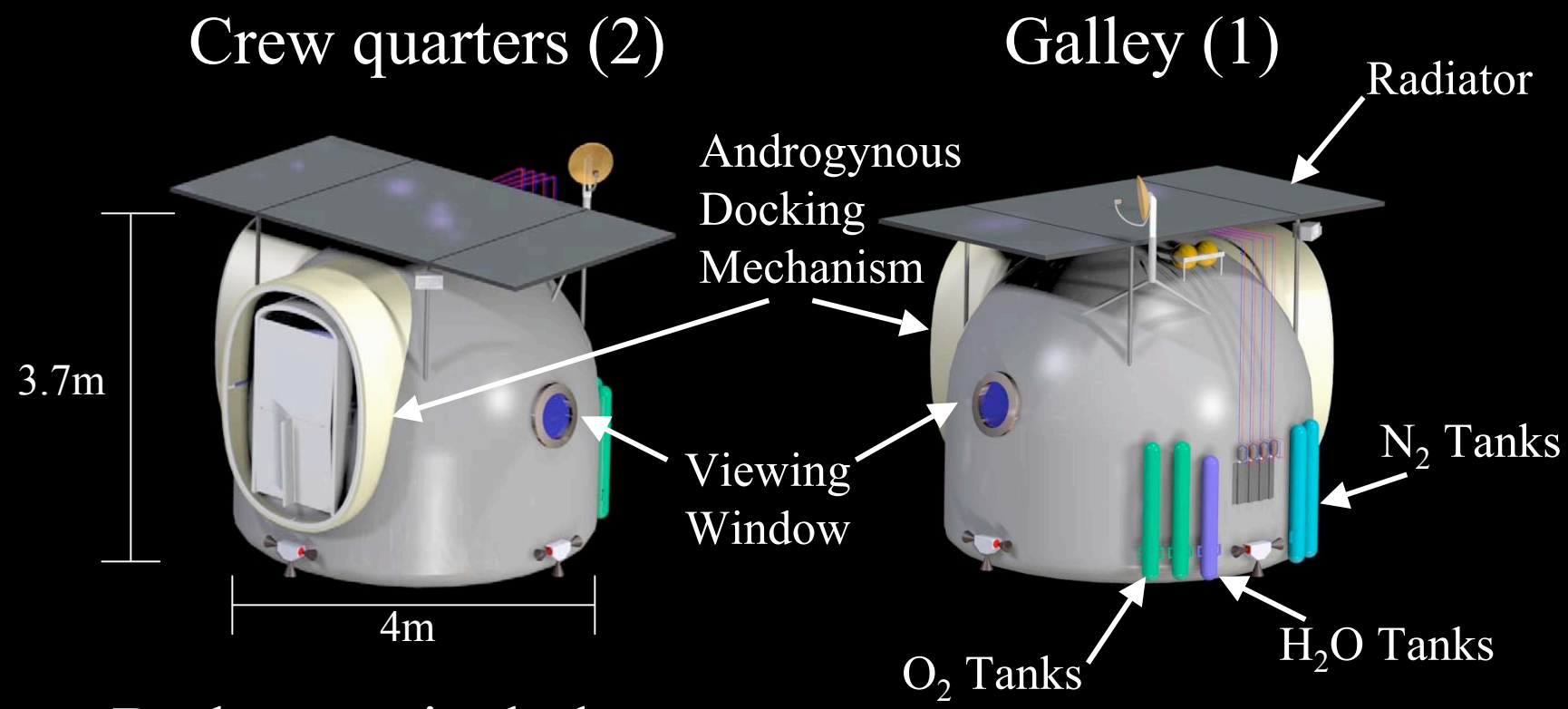
Sizing Requirements

- All crew interfaces are sized to accommodate 95th percentile American males to 5th percentile Japanese females (Level 1 requirements L1, L2)
- The size of the modules is bounded by
  - maximum radius of Delta IV-Heavy payload area – 4.5 m
  - minimum amount of room necessary for four people in the same module – 10.24 m^2
- Habitable modules are 4.0 m in diameter, which gives 12.56 m^2 of floor space per module
  - accounts for wires and pipes behind walls and furnishings
  - leaves enough open space in the modules to move about
  - keeps the module mass reasonable

Cat McGhan &
Jessica Seidel



Habitable-Living Subtypes

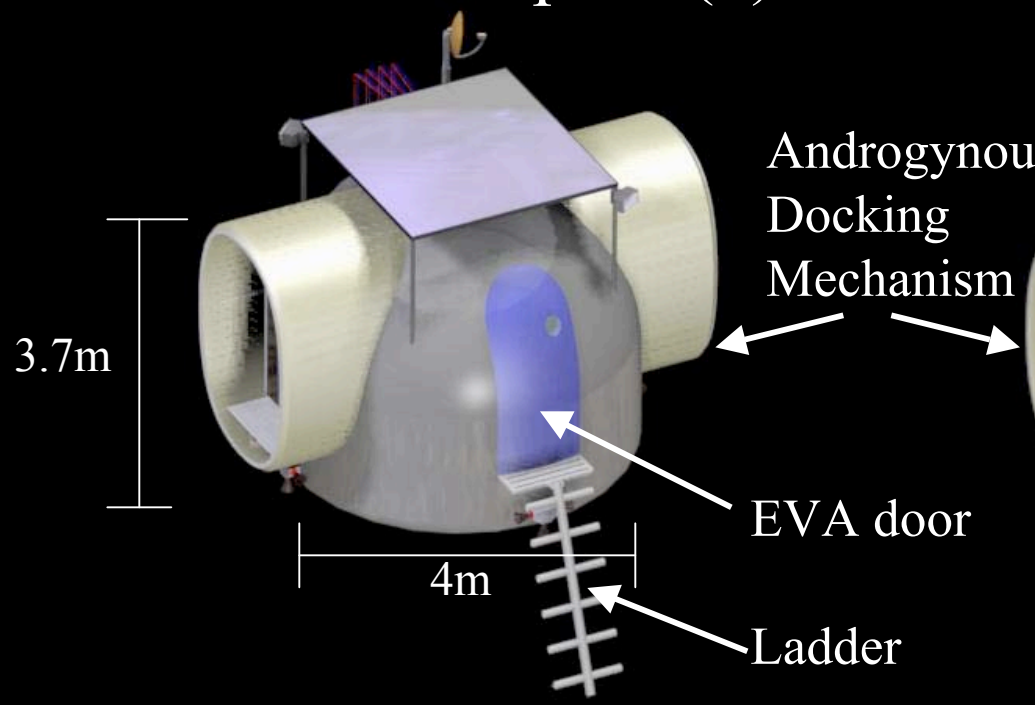


- Both types include
  - Basement level radiation shelter sleeping areas
  - Two hatches, L-shape intersection

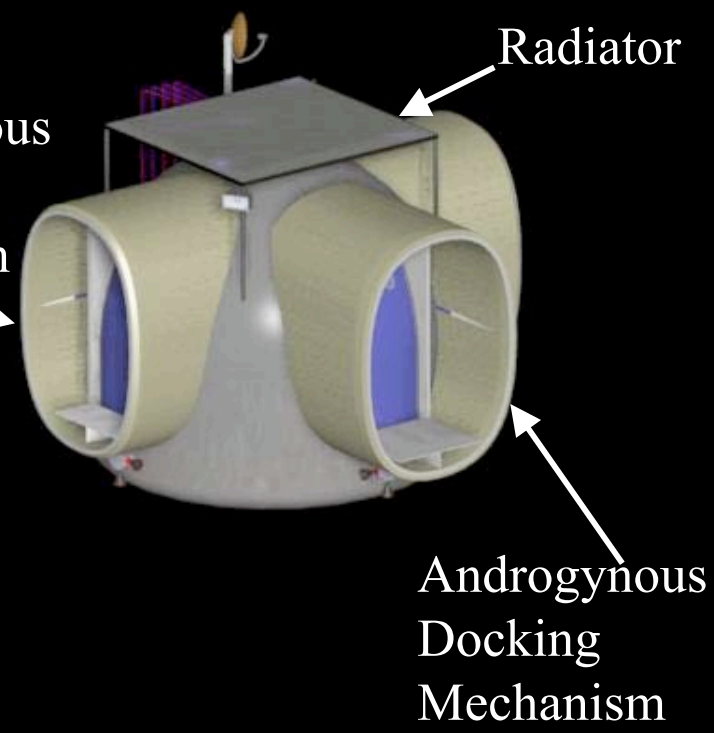
MORPHLAB

Habitable-Science Subtypes

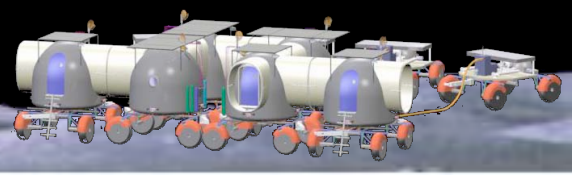
EVA workspace (2)



Experiment area (1)



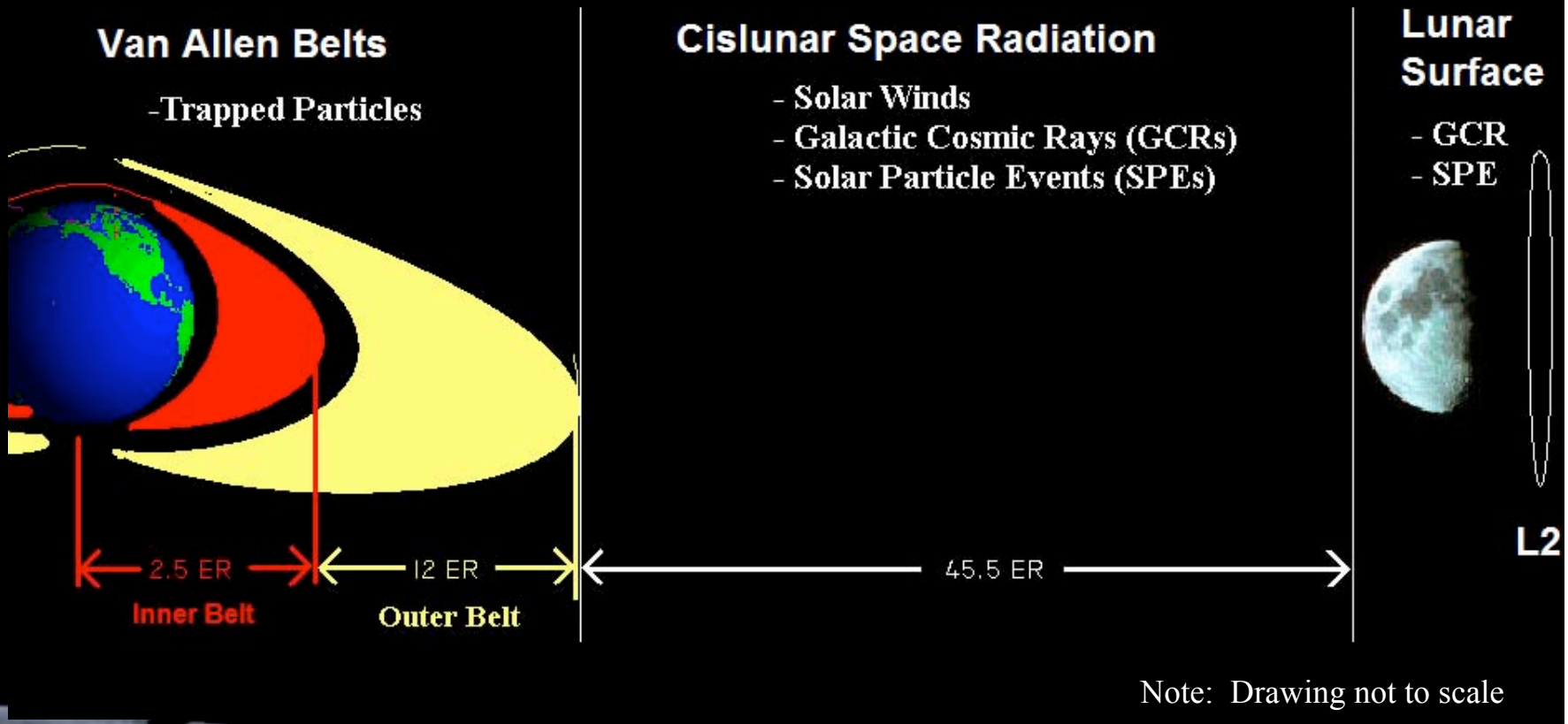
- Both types include
  - Basement level storage compartments
  - Three exits, T-shape intersection



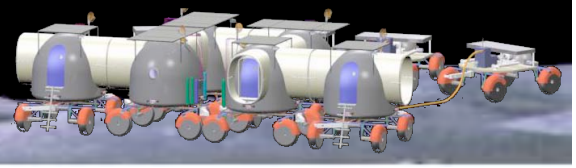
MORPHLAB

Radiation Environment

	Energy Level (MeV)	Flux (p/cm^2-s)	Particles, Time
Van Allen Belts	10^{-1} – 10^{3}	10^{2} – 10^{10}	Trapped p^+, e^-, Short-duration
GCR	10^{2} – 10^{4}, max 10^{11}	10^{-5} – 1, max ~2	85% p^+, 13% He^+, 2% HZE, Near-constant
SPE	10-10^{3}, max ~10^{4}	10^{-3} – 10^{4}, max ~106	96-99% p^+, 1-3 days



Note: Drawing not to scale



University of Maryland
CDR 04/19/04

Cat McGhan, John Albritton

Necessity of Radiation Shielding

Lifetime Limits: BFO dose (blood-forming organs), 5 cm depth				
Sex	Age			
	25	35	45	55
Male	150 rem	250 rem	325 rem	400 rem
Female	100 rem	175 rem	250 rem	300 rem

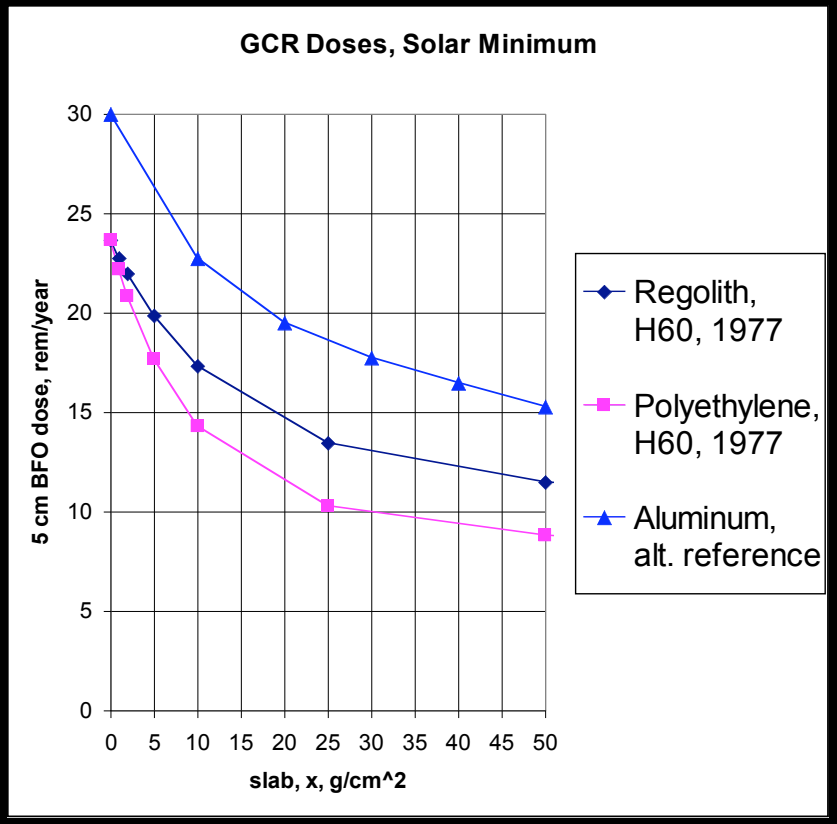
Time interval	BFO dose limits
30 days	**25 rem**
1 year	**50 rem**

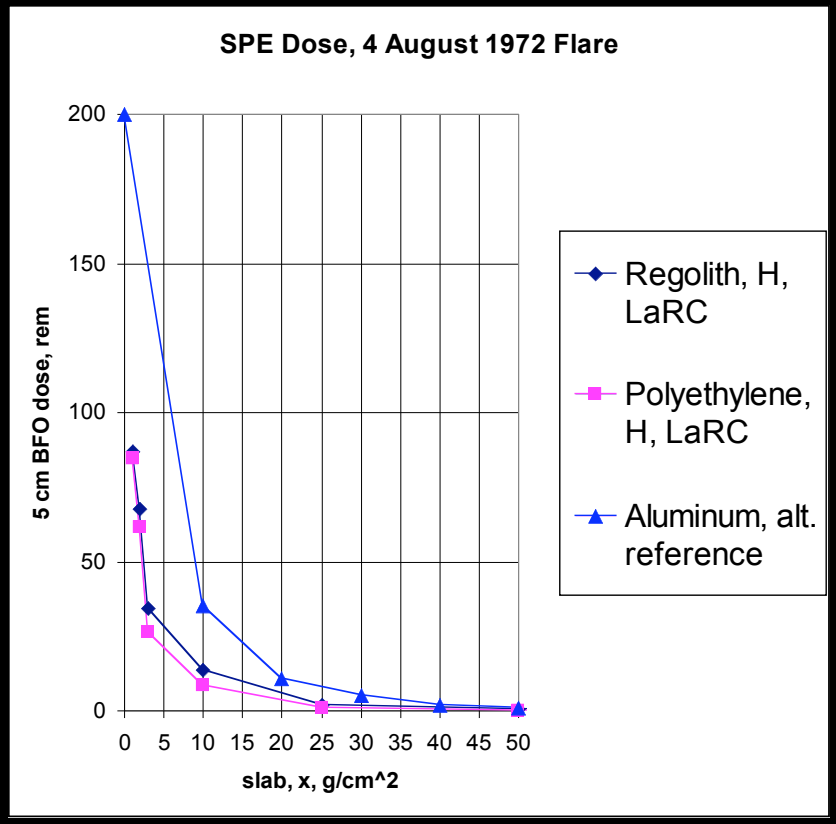
Dose Source	On Lunar Surface
SPE	**200 rem**
GCR	**30 rem/year**

- SPE shielding is necessary
- From the Level 1 requirements (M1, M6, I1, L2, L5, L6, L7), shielding must prevent the radiation dose received from exceeding these levels for the habitable mission length

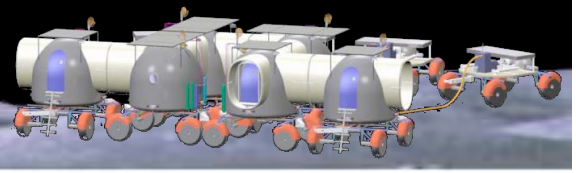
MORPHLAB

Radiation Shielding Comparison





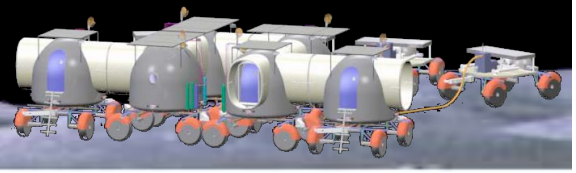
- 5.7cm Polyethylene is used for SPE shielding
- 4mm Aluminum pressure hull helps block GCR



MORPHLAB

Radiation Dose Breakdown

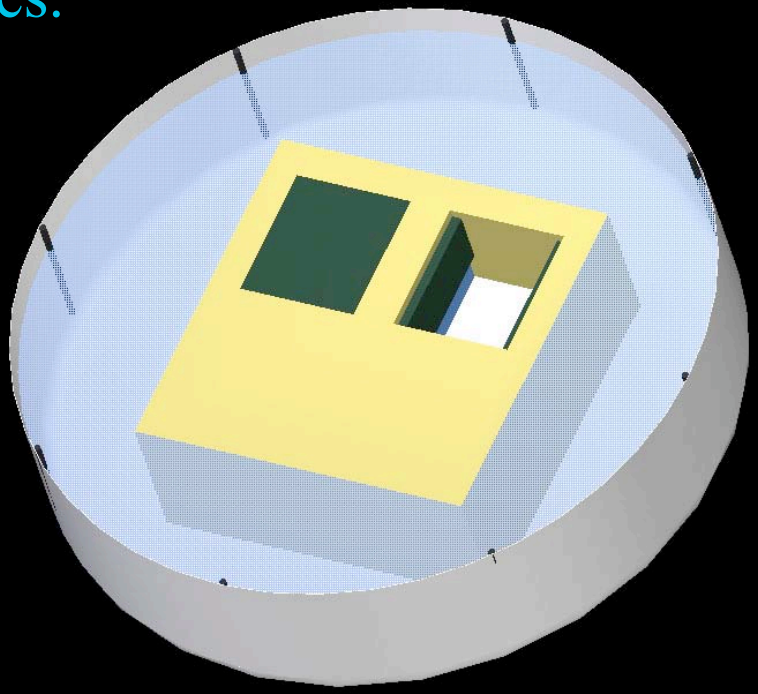
	Period	Total hours	Shielding (g/cm^2)	Total dose (rem)
Van Allen Belts both ways	--	--	--	2
EVAs	84	336	1 Al	1.44
GCR asleep	84	672	5.41 polyethylene	1.33
GCR awake, no EVA	84	1008	1 Al	4.31
DIPS (5 modules)	84	2016	200 kg/per	1.03
GCR asleep	180	1440	5.41 polyethylene	2.85
EVAs	180	~3.5	1 Al	0.01
SPE, August 1972 dosage	180	72	5.41 polyethylene	21.74
GCR awake	180	2805	1 Al	11.99
DIPS (5 modules)	180	4320	200 kg/per	2.2
Total dose 30 days	**24.99 rem**	**Total dose 84+180 days**		**48.91 rem**



MORPHLAB

Radiation Shelter Sleeping Areas

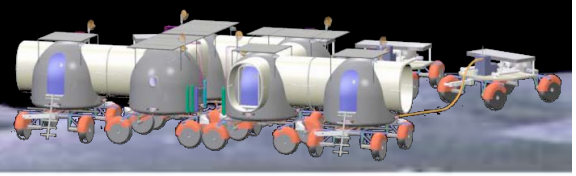
- From the Level 1 requirements and trade studies:
  - Level 2 requirement L6: Radiation shielding capable of suitable protection against a solar flare must be internal to at least three habitable modules.
- Habitable-living basement level
- Split in half by a noise-muffling curtain for privacy
- Dual-purpose
- Emergency exit procedure:
  - Move curtain aside
  - Exit via second door



MORPHLAB

Radiation Shelter Specifics

- Shelter built into basement of Habitable-Living modules
  - Maximizes daytime living floor area
  - Minimizes mass consumption by doubling shelter as sleeping quarters
  - Basement also leaves room for storage and ECLSS systems
- High Density Polyethylene
  - Superior radiation protection per amount of mass compared to other materials
  - 0.057 m thickness based on radiation analysis
  - 568 kg total

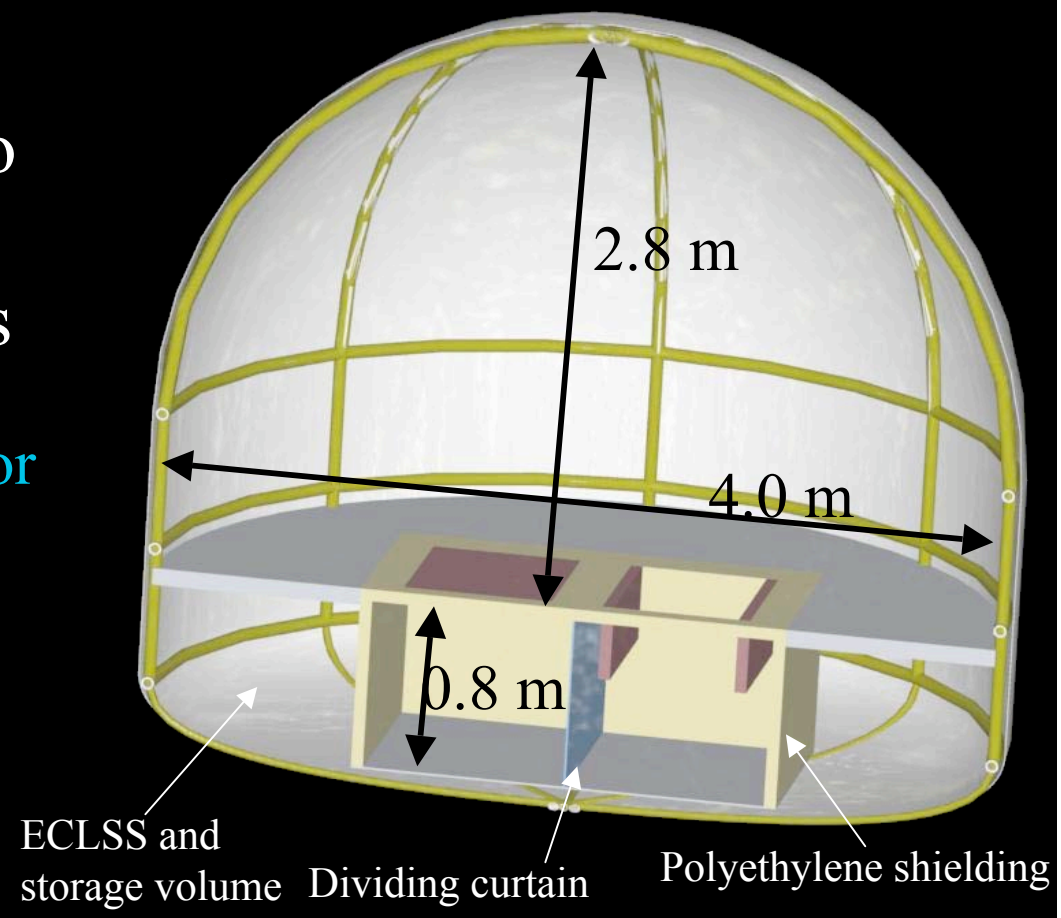


MORPHLAB

Radiation Shelter Specifics

- Can accommodate two people each
- Two doors built into the top
- Internal Dimensions
  - Based on estimated necessary volume for 95th percentile American male to sleep comfortably (derived from L1 requirement)
  - 1.9 m long, 1.95 m wide, 0.8 m tall

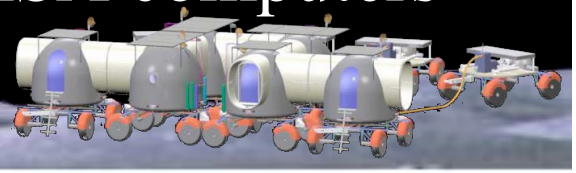
Cutaway Shelter Layout



MORPHLAB

Procedure for Impending SPE

- In the event of an impending SPE:
  - SOHO (SOlar and Heliospheric Observatory) or its successor will give 2-3 days notice of heightened activity
  - The astronauts will be informed by Mission Control and EVAs will be cancelled for the duration
  - Just before the event, SOHO and other Space Weather satellites will give a few hours notice
  - Astronauts will retreat to the shelter for the duration of the event
- The crew will be able to maintain contact with Mission Control via their laptops, and they will have access to whatever libraries and amusements that they can download from the NASA computers



MORPHLAB

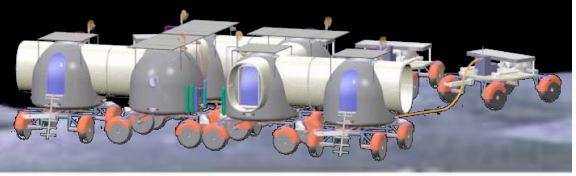
Micrometeoroid Protection

- Micrometeoroids massive enough to cause damage are very rare: probability analysis is necessary
- NASA Human rating requirement: The program shall be designed such that the cumulative probability of safe crew return over the life of the program exceeds 0.99
- We will assume a desired 0.996 Probability of No Penetration (PNP) per mission - same as Apollo requirement

F = cumulative flux (hits/m^2-year)
A = exposed surface area (m^2) = 41.6 m^2
Y = exposure time (year) = 0.75 years

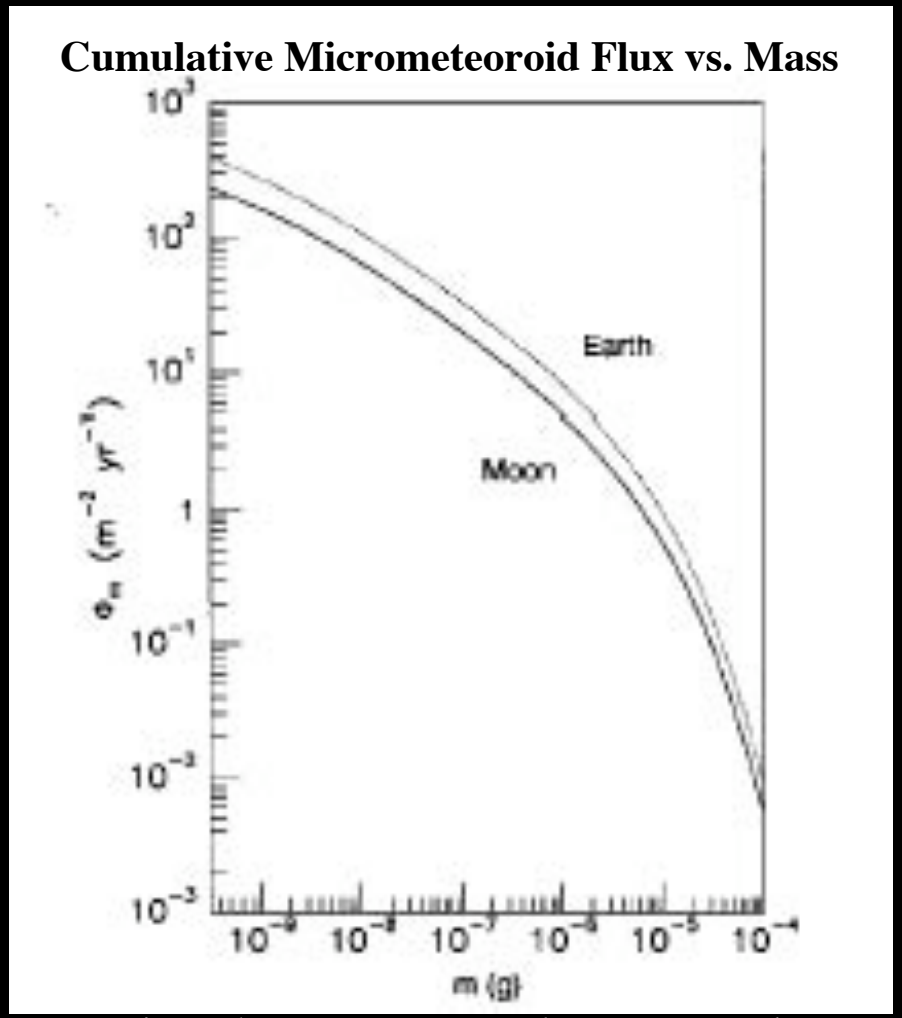
$$F = \frac{-\ln(PNP)}{A * t}$$

- $F = 1.28 \times 10^{-4}$ hits/m^2-year



Micrometeoroid Protection

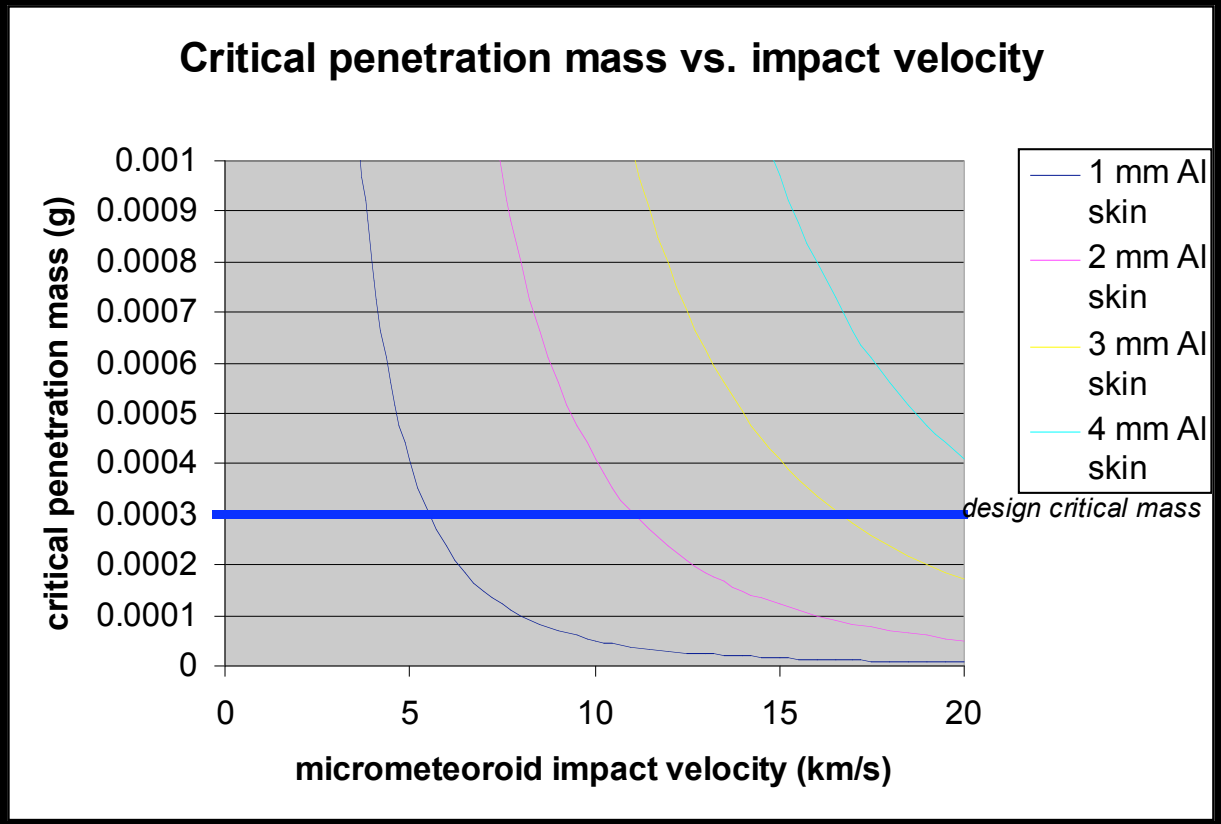
- Micrometeoroid flux of 1.28×10^{-4} hits/m^2-year is off this chart
- Data curve was graphically extended to this flux
- Critical micrometeoroid mass estimated to be 3×10^{-4} grams



[Vanzani, et al. *Micrometeoroid Impacts on the Lunar Surface*. Lunar and Planetary Science XXVIII, 1997.]

MORPHLAB

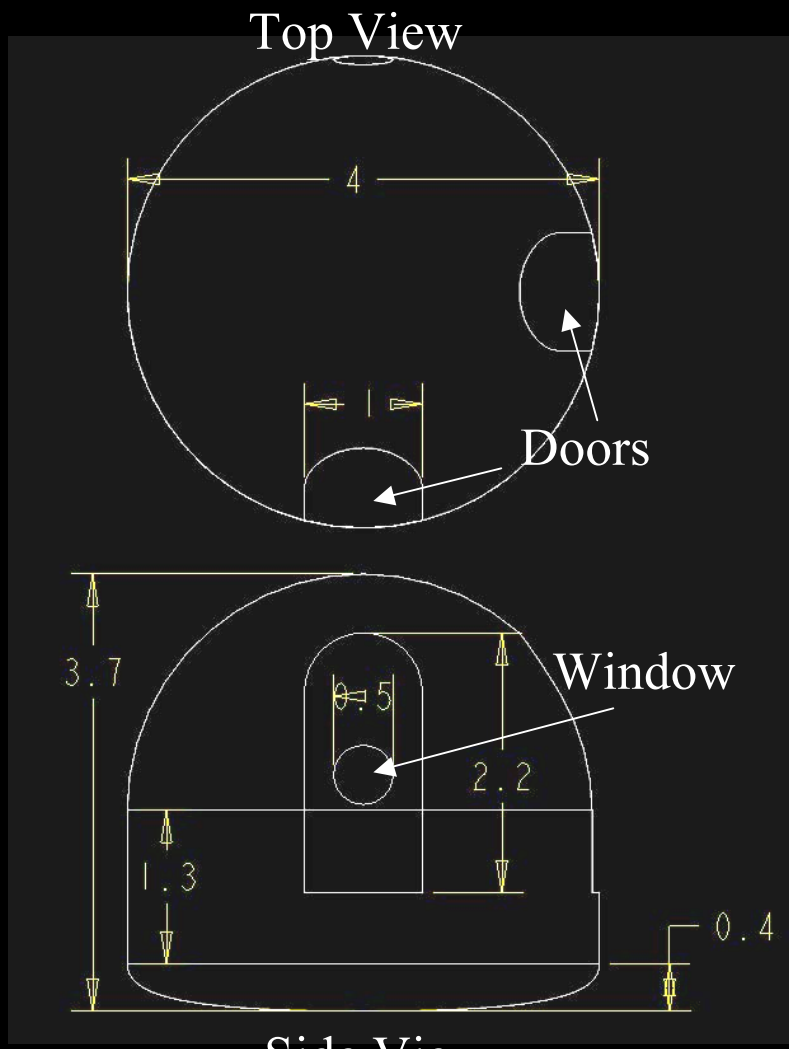
Micrometeoroid Protection

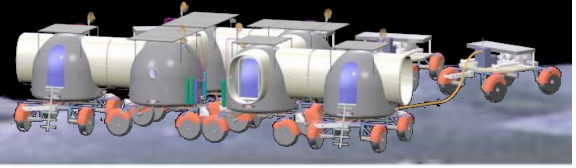


- Data based on heuristic from NASA Preferred Reliability Practices document on micrometeoroid protection (Practice No. PD-EC-1107)
- Assumed .5 mm spacing between MLI and aluminum pressure hull
- 4 mm Al skin chosen based on 13.3 km/s average lunar micrometeoroid velocity

Pressure Hull Design

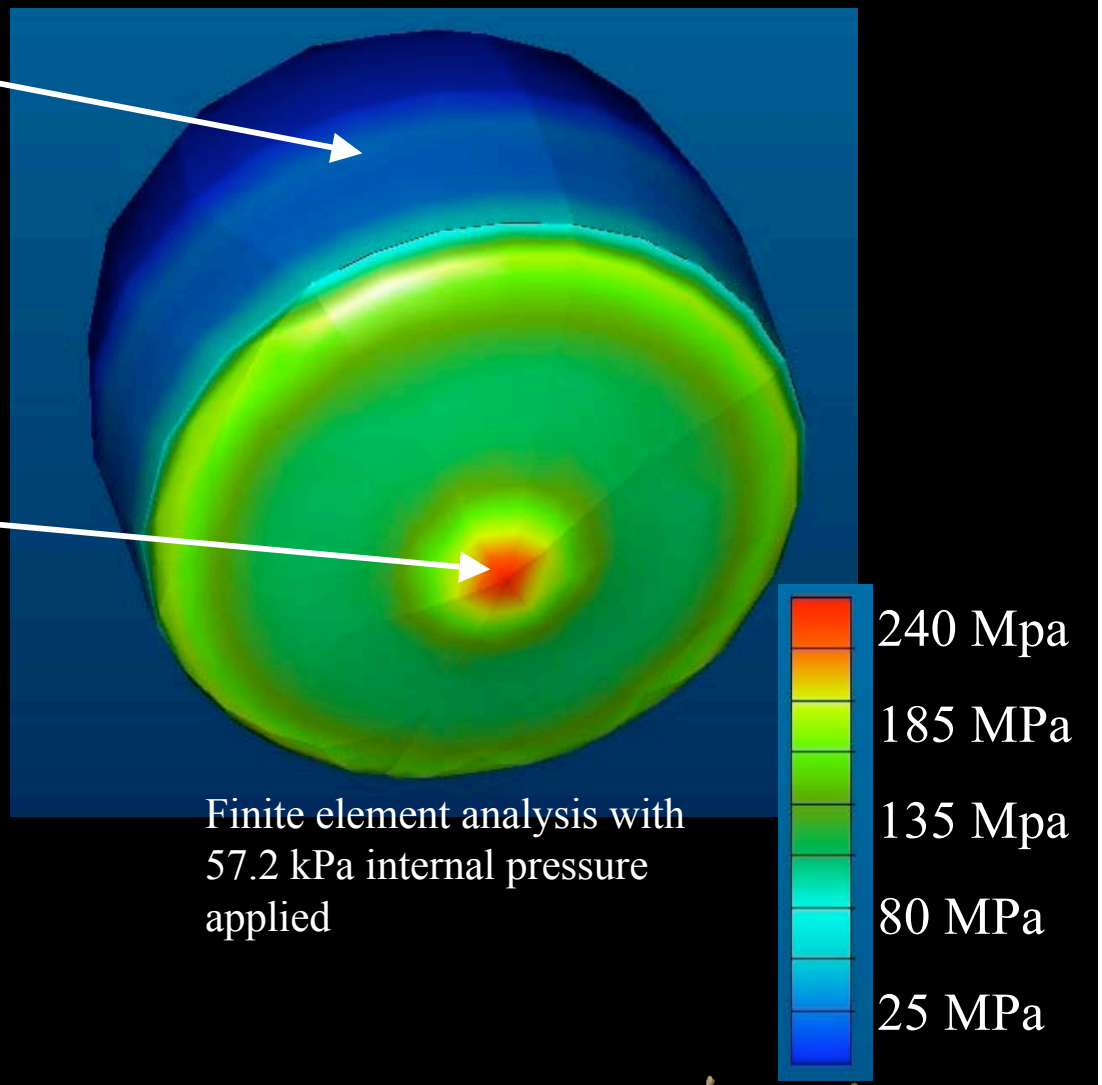
- Requirement S1 states that pressurized tanks must have factor of safety of 3.0
- Rounded shape chosen to minimize stresses due to internal pressure
- Bottom is rounded to minimize pressure stress, but flattened to lay on chassis module correctly





Pressure Hull Analysis

- 4 mm thick Al-2014 pressure hull
  - Stress concentrations around doors and windows are assumed to be handled by their frames
  - 2.8 margin of safety for hoop stress
- 2 mm thick bottom reinforcement
  - Where stresses are above 164 MPA with 4mm thickness
- Design based on FEA is conservative: stringers not included in pressure model

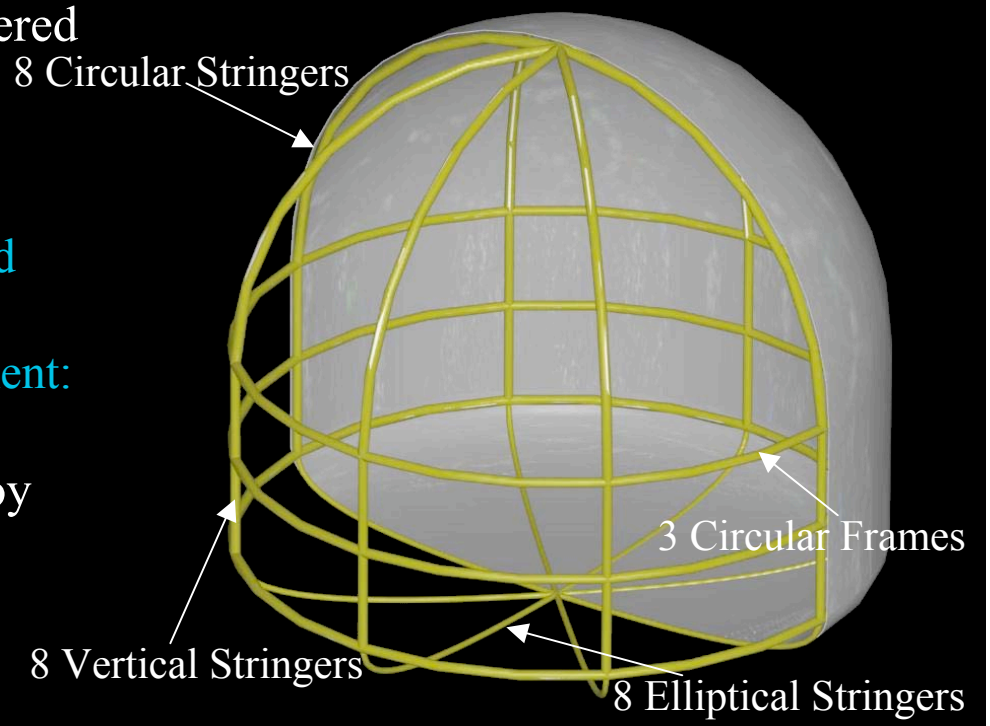


Finite element analysis with 57.2 kPa internal pressure applied

MORPHLAB

Internal Support Structure

- 3 critical loading scenarios considered
  - Launch: 6g's axially, 2.5g's laterally (based on Delta-IV-H payload planner's guide)
  - Landing: 1 lunar g vertically and horizontally, on one leg
  - Hab/Science to Chassis attachment: 4 lunar g's
- All elements made of titanium alloy with hollow circle cross-section
- Primary structure designed for 2.0 factor of safety based on S1 requirement



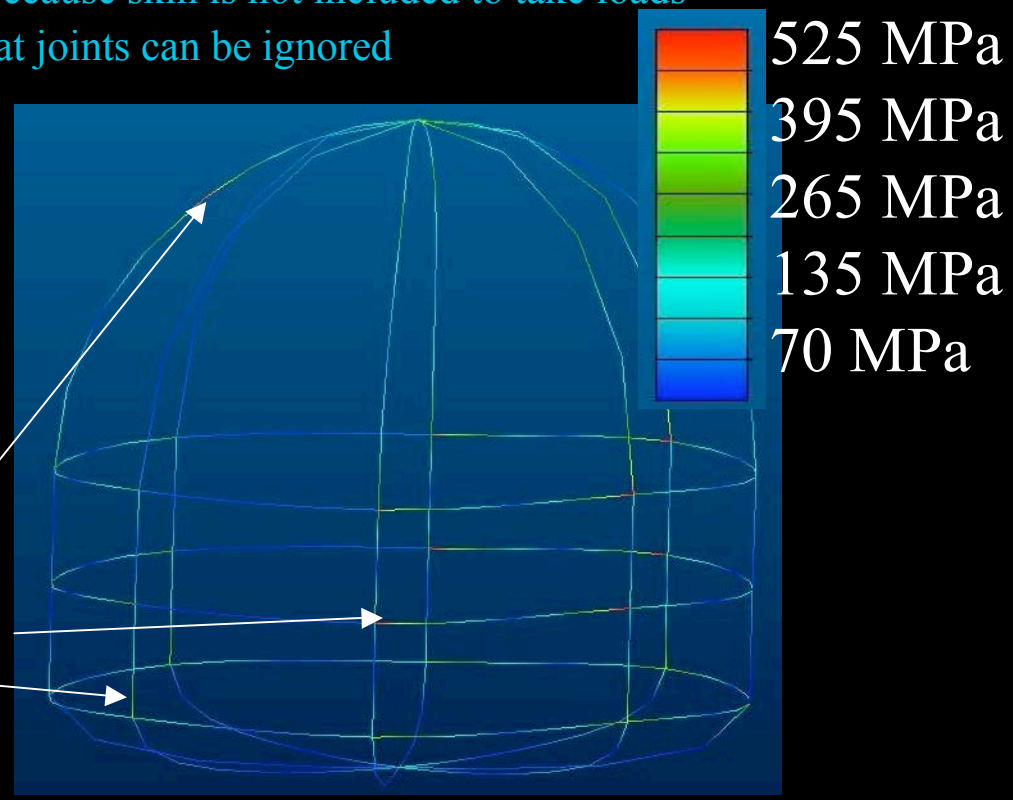
Component	O.D.	I.D.	Mass	Max Design Stress	Margin of Safety	Failure Mode
Vertical Stringers	.030 m	.024 m	49 kg	394 MPa	.40	Compression
Circular Stringers	.033 m	.032 m	24 kg	524 MPa	.052	Bending
Elliptical Stringers	.018 m	.014 m	32 kg	542 MPa	.018	Bending
Circular Frames	.031 m	.026 m	157 kg	524 MPa	.052	Compression

MORPHLAB

Internal Support Structure

- FEM Assumptions
  - Door and window frames that intersect with internal structure will act as the stringers in reality
  - FEM analysis is conservative because skin is not included to take loads
  - Excessive load concentrations at joints can be ignored
- Launch Loading
  - Vertical stringers, circular frames, and upper circular stringers sized based on this scenario
  - Constrained at 4 connection points along bottom frame
  - 3700 kg vehicle mass distributed to structural connection points

Highest stress concentrations

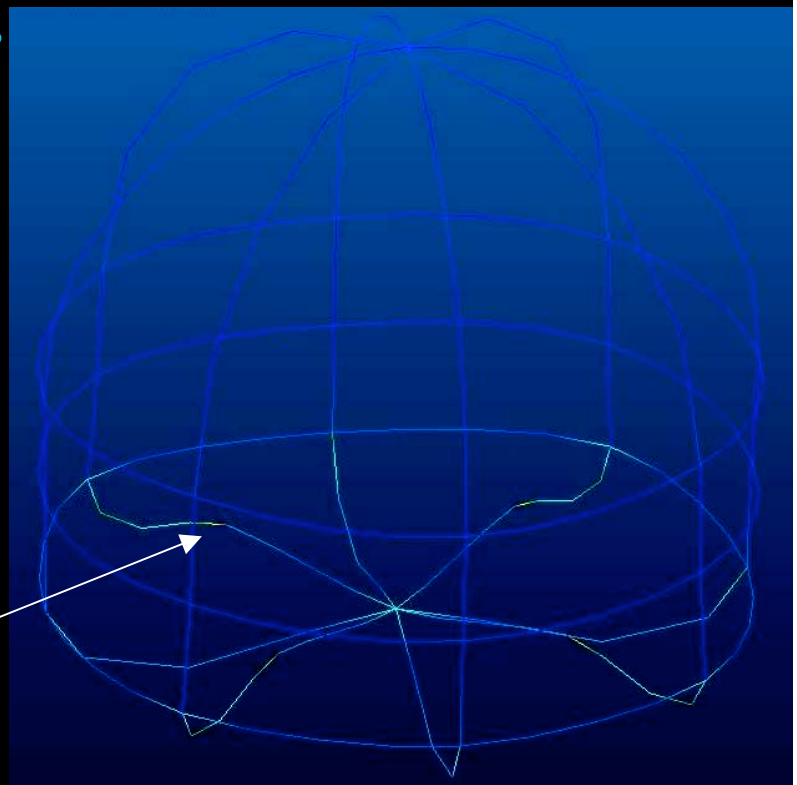


MORPHLAB

Internal Support Structure

- Landing Loading
  - Worst case – landing on one leg
  - Constrained at leg attachment points
  - Max stress: 179 MPa - no internal structural components sized for landing
- Hab to Chassis Attachment
  - .03 m fall onto chassis when landing legs are removed
  - Max stress: 542 MPa in lower elliptical stringers

Attachment Loading FEM



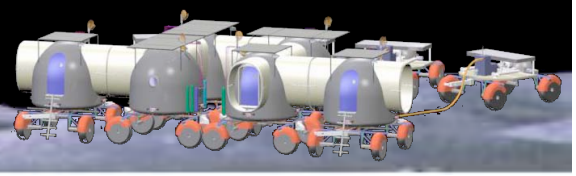
Displacement exaggerated by factor of 15; 3 cm actual displacement

MORPHLAB

Additional Structural Analysis

Component	Material	Max Design Stress (MPa)	Safety Factor	Margin of Safety	Mass (kg)	Failure Mode
Radiator Support Structure	Titanium Alloy	437	2	.26	21.2	Compression
Docking Mechanism Walkway	Aluminum 2014	174	2	.049	93	Bending
Radiation Shelter	Polyethylene	3.2	1.5	3.6	568	Bending
Oxygen Tank	Aluminum 2014	109	3	.003	65	Hoop Stress
Nitrogen Tank	Aluminum 2014	109	3	.003	58	Hoop Stress

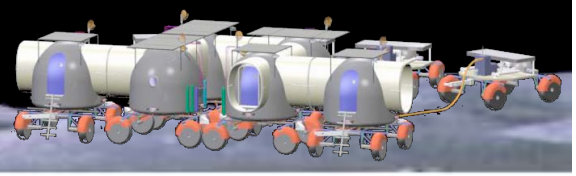
- Safety factors based on S1 requirement
  - 2.0 for primary structures
  - 1.5 for secondary structures
  - 3.0 for pressure vessels



MORPHLAB

Floor Panel Requirements

- Composite sandwich panel used to sustain compressive and bending loads of floor items
- Level 1 requirements
  - S1: Factor of Safety = 2
  - S2: Non-negative MOS (Margin Of Safety) for launch loads (6g Earth)
- Total load of interior items
  - Must sustain launch loads
  - Assumed the load is distributed over entire panel
  - Future iterations will use composite laminate theory for more precise numbers



MORPHLAB

Floor Panel Design

Mass of Interior Items Estimated 876.1 kg

Skin: High Modulus Carbon Fiber-Epoxy
- 37 kg
- 0.13 cm thick

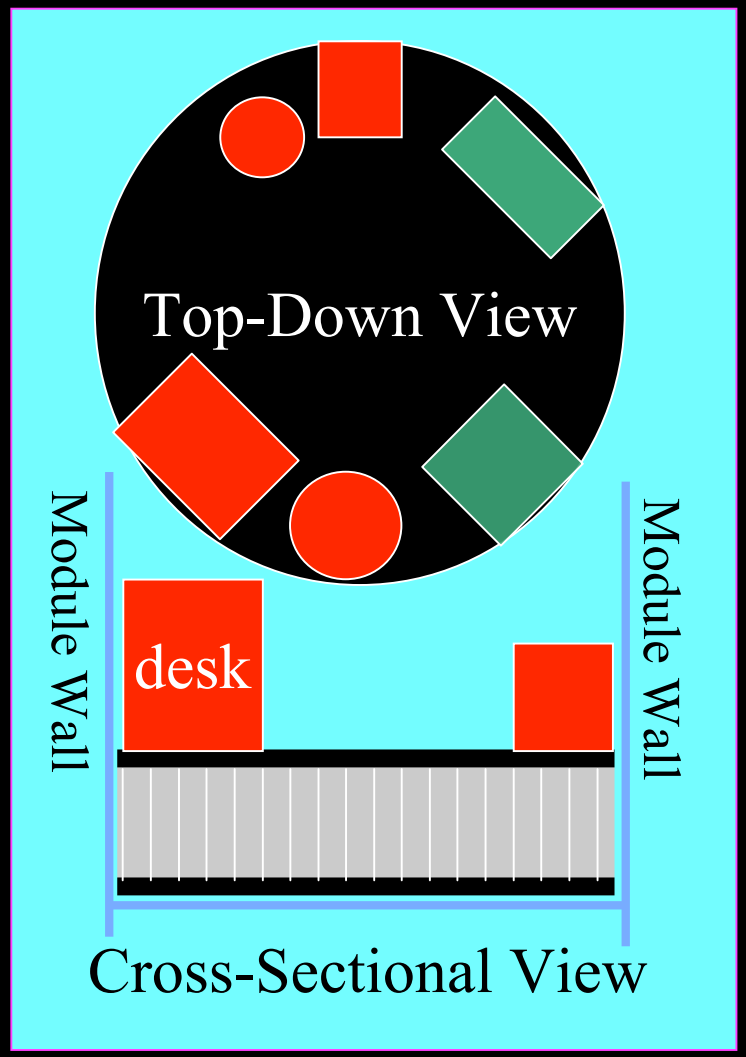
Core: Aluminum 5056 Honeycomb
- 37 kg/m^3
- ¼ in. cell size
- 24 kg
- 7.24 cm thick

Total Panel:

61 kg

7.49 cm thick

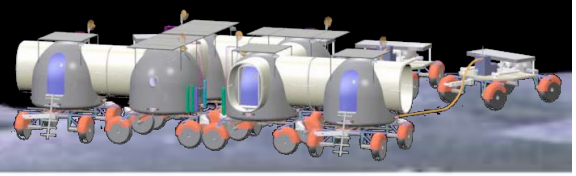
0.98 cm max. deflection



MORPHLAB

Floor Panel Deflection and Failure Modes

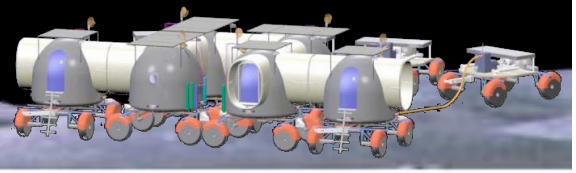
Loading Effect	Effect Induced	Limit	MOS
Maximum Deflection	0.98 cm	0.01 cm	0.02
Local Compressive Stress	11500 Pa	5.20 MPa	451.73
Skin Stress	59.5 MPa	1.24 GPa	19.83
Core Shear Stress	0.168 MPa	1.80 MPa	9.69
Potential Failure Phenomenon	Buckling Stress		
Intra-cell Buckling	20 GPa	1.24 GPa	12.44
Skin Wrinkling	1.33 GPa	1.24 GPa	0.07



MORPHLAB

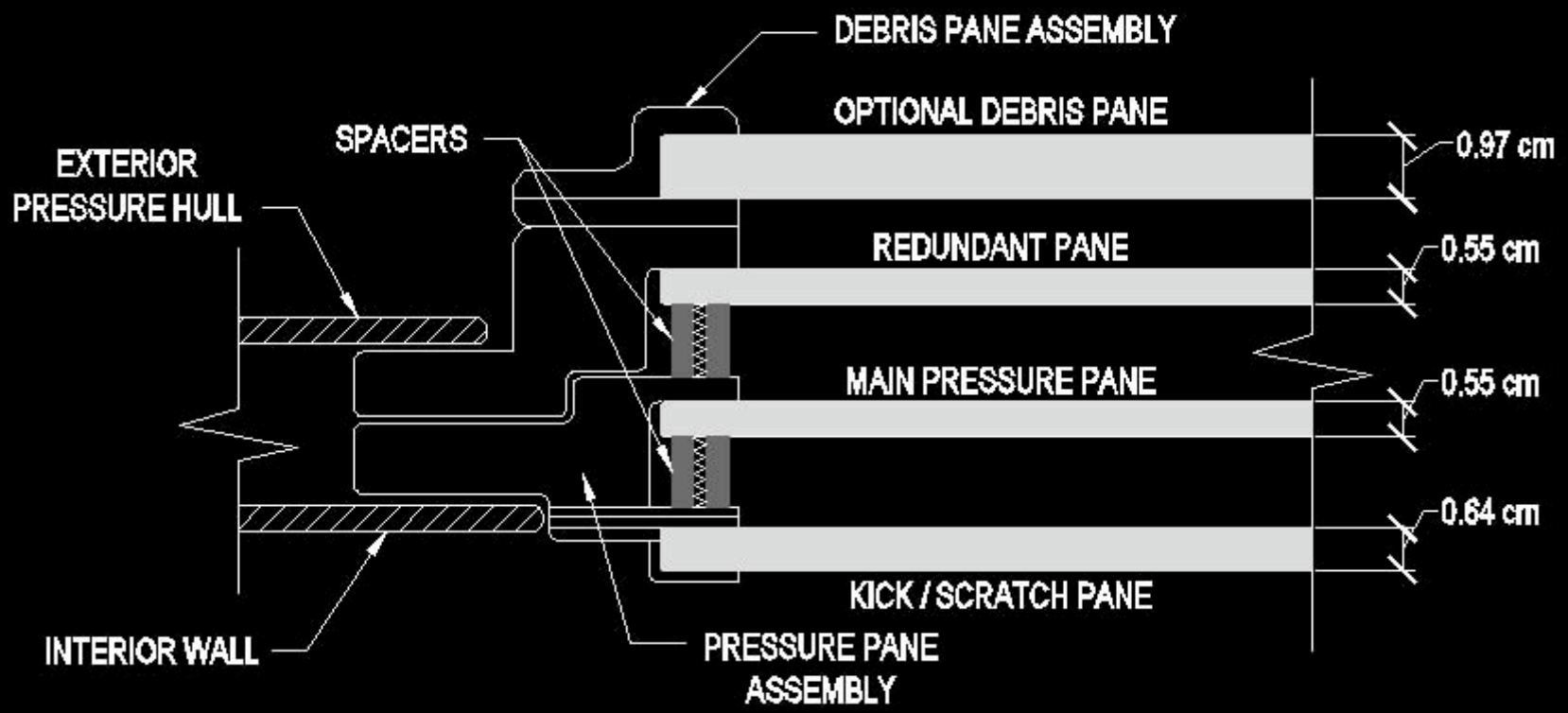
Window Requirements

- Types: Hatch and General Area
- Level 1 Requirements
  - S1: Factor of Safety = 3
  - S2: Nonnegative MOS in bending for launch loads (6g Earth)
  - L2: Adhere to NASA-STD-3000, delimiting the following:
    - minimum window diameters, minimum blunt impact (550N) , height of windows, optical and manufacturing requirements, ionizing radiation protection (GCR), non-ionizing radiation protection (UV), safety precautions
  - L8: Must have emergency alternative access / bailout options
- S2 met by using the window frame to channel launch loads around the window and into a stringer
- L2 is met using a sunshade 4 mm thick of Aluminum 2014. Sun shade also protects crew from earth's magnetic field
- L8 is satisfied using hatches, where a porthole must be present to allow astronauts to see what is on the other side of the hatch



Window Assembly

- Material: Ceradyne Thermo-Sil® Ultra High Strength Fused Silica
  - radio wave, IR, microwave radiation transparent
  - low CTE ($0.5*10^{-6}$/°C)
  - high strength/weight ratio:
    flexural strength ~ 55 MPa
    density ~ 2020 kg/m^3

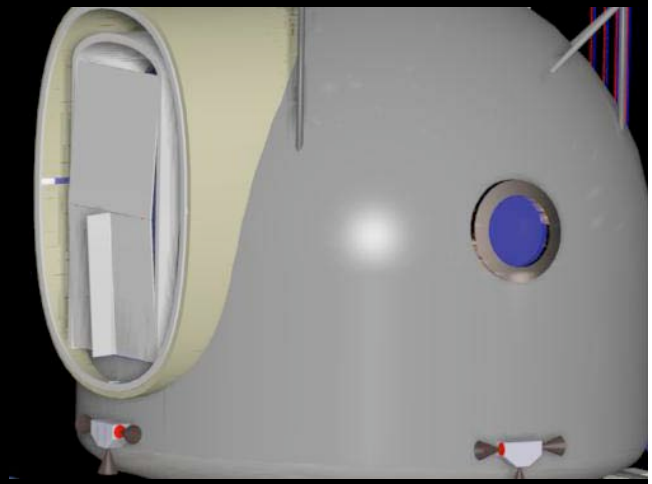


Hatch Window Assembly

MORPHLAB

Window Assembly

- Differences from ISS windows:
  - –Different pressure pane thickness from ISS
  - –MORPHLAB uses 4 mm Aluminum 5056 sunshades over all windows

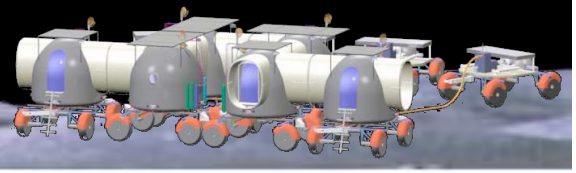


- Similarities to ISS windows:
  - Same debris pane thickness
  - Anti-reflective coating on outer surface of outer window pane
  - Blue-red reflective coating on inner surface of inner window pane to filter out IR and UV
  - Air tight seal between pressure panes

MORPHLAB

Window Panes

Pressure Pane	Hatch	General Area
Diameter (cm)	20.3	50.8
Thickness (cm)	0.547	1.37
MOS	0.0100	0.0100
Mass (kg)	0.559	8.76
Fused Silica Kick Pane		
Thickness (cm)	0.644	0.644
MOS	0.0182	0.0182
Mass (kg)	0.556	3.48
Aluminum Sunshade		
Thickness (cm)	0.400	0.400
Mass (kg)	0.510	3.77
Fused Silica Debris Pane		
Thickness (cm)	0.970	0.970
Mass (kg)	0.835	6.18



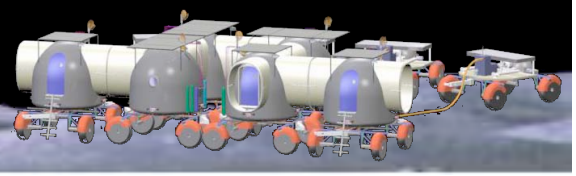
MORPHLAB

Window Masses Per Module

	Habitable-Living	Habitable-Science
Hatch Windows with Pressure Panes, Kick Pane, and Aluminum Sunshade	2	3*
Hatch Windows with Pressure Panes, Kick Pane, Aluminum Sunshade, and Debris Pane	0	1*
General Area Windows with Pressure Panes, Kick Pane, Aluminum Sunshade, and Debris Pane	1	0
Total Window** Weight (kg)	35.3	9.57

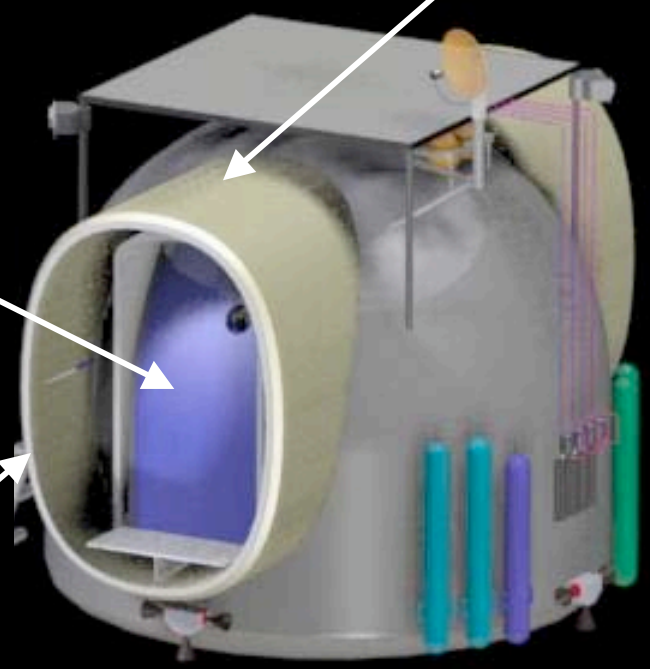
* Walkways protect all hatch windows except outer EVA hatch window; only the outer EVA door's window needs micrometeoroid and lunar dust protection during transit

** Total Window Weight excludes TBD window frames



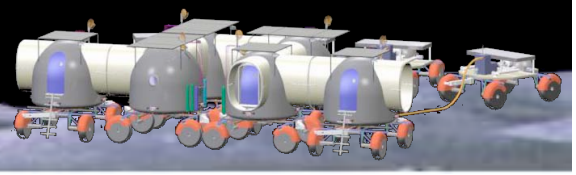
MORPHLAB

Hatches & Docking



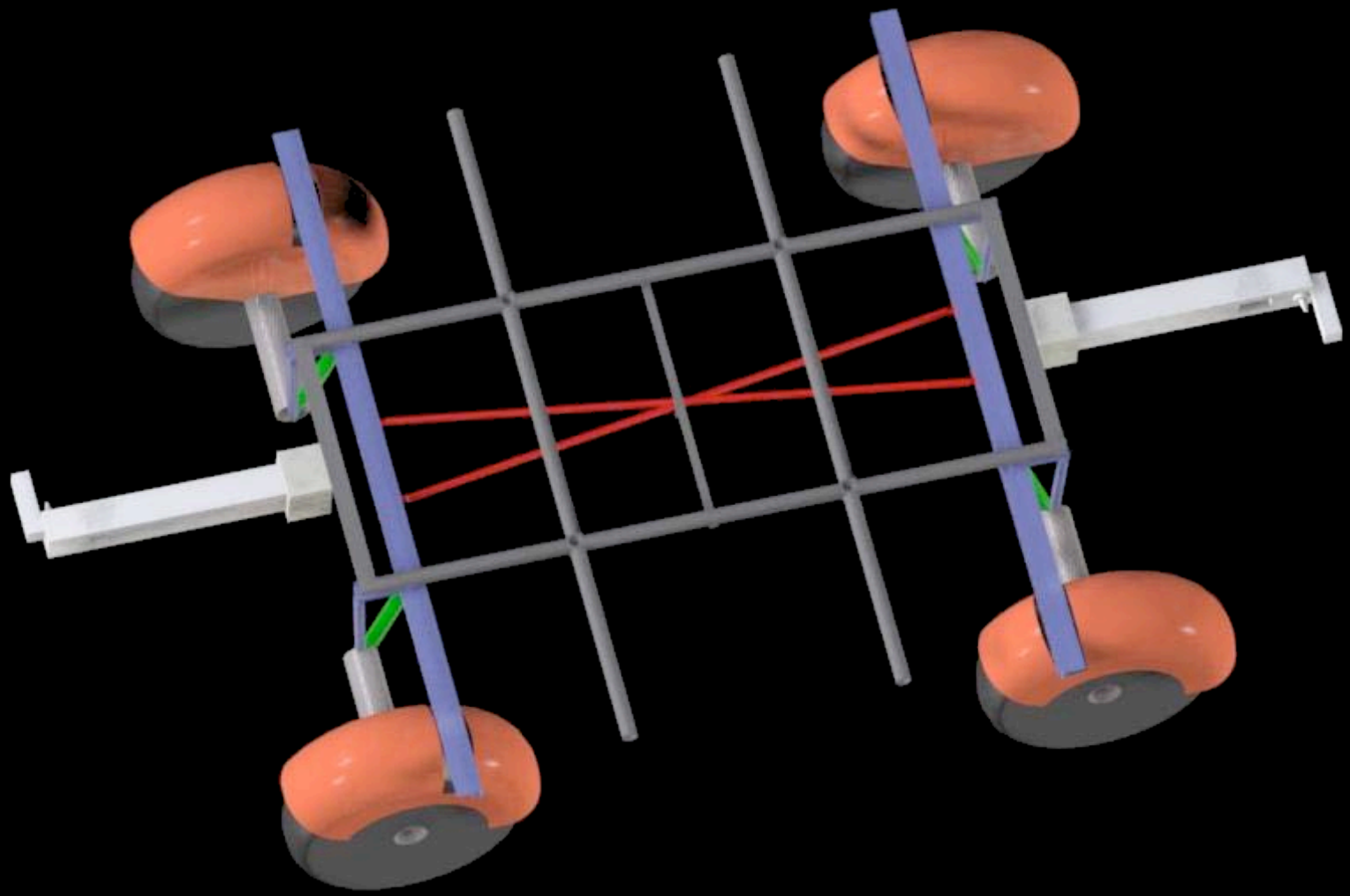
- Provides travel between modules in shirtsleeve environment
- Provides power, water, and air transfer between modules during base phase
- More details forthcoming

Russell Parker, Craig Nickel



MORPHLAB

Chassis Module



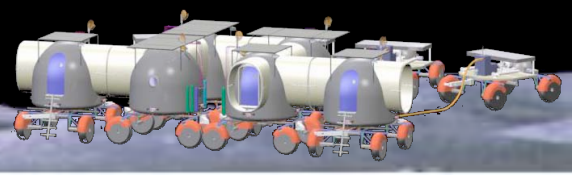
University of Maryland

CDR 04/19/04

MORPHLAB

Chassis Overview

- Single universal chassis for all MORPHLAB applications
  - 4 power modules landed on Moon with chassis permanently attached
  - 6 Chassis Module landed on Lunar Surface
- 4 wheel drive / 4 wheel steering
- Total Mass = 1483kg
- Drive platform for Power Module and Habitable Module
- Utilizes 24 hour battery power source until mated with Power Module
- Capable of supporting 3700kg load during transit and base phase
- Can be directly landed on lunar surface with a payload of 2000kg
- .7m minimum ground clearance and 1.4m diameter wheel to meet Level 1 requirement : capability of traversing a .5m obstacle



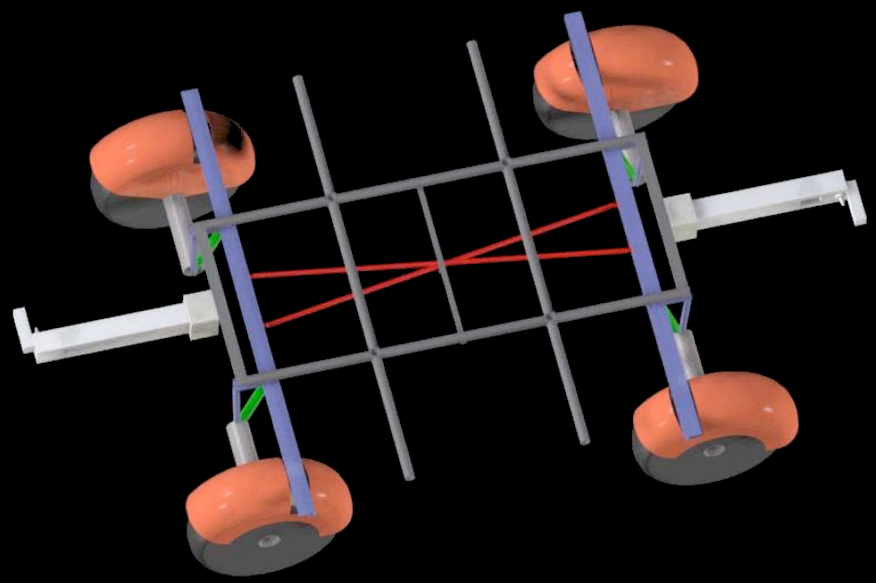
MORPHLAB

Chassis Dimensions

Requirements:

Must be capable of traversing over a .5m boulder

Must fit within 4.5m dynamic envelope of Delta IV-H payload shroud



- Ground clearance = .7m
- Total Height = 1.7m
- Maximum width = 4.16m
- Closed Maximum length = 4.16m
- Open Maximum length = 7.6m

- Max wheelbase = 4.16m
- Max Wheel Stance (width between wheels) = 3.2m
- Total Structural Mass = 305kg
- Materials used include Aluminum 2014 & Titanium Alloy (Ti -10V-2Fe-3AL)

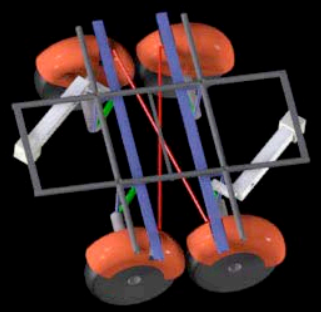
MORPHLAB

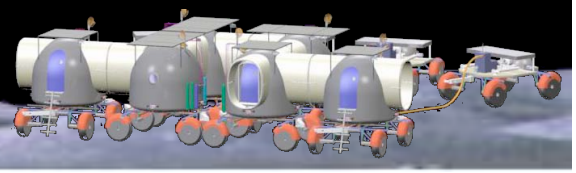
Chassis Expansion

Requirements:

- Must be capable of traversing a 20 deg. cross slope.
- Must be capable of traversing a 30 deg. Direct incline.
- All components of MORPHLAB shall be launched on Atlas V or Delta IV launching systems.
  - Launching on a Delta IV-H results in greatest payload in LEO, therefore, greatest landed mass on lunar surface.
  - To fit on Delta IV-H all components of MORPHLAB must fit inside 4.5m diameter dynamic envelope of a 5m payload shroud.

To meet these requirements the chassis was designed to be in a folded position during transit atop a Delta IV-H and to expand during lunar orbit to a greater wheelbase. The extended wheelbase of 4.16m is necessary to prevent tipping during 30 deg. direct incline.



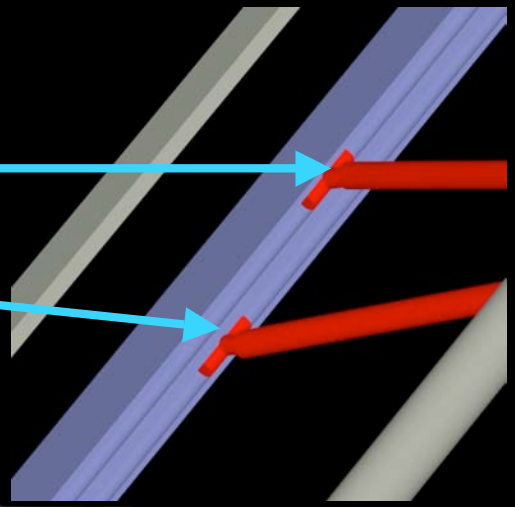


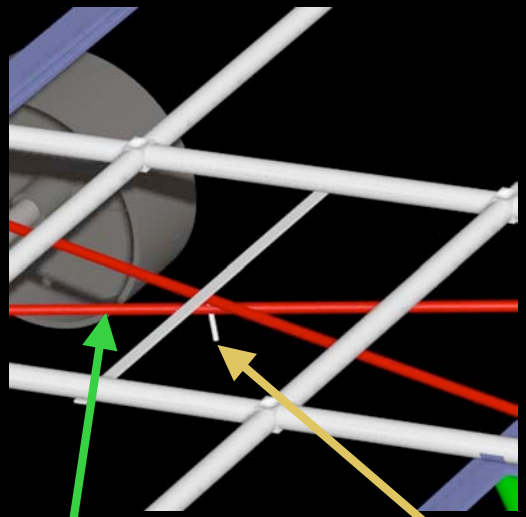
MORPHLAB

Chassis Expansion

- Expansion accomplished by two equal length ‘spreading bars’ rotating about a ‘central pin’ to force two ‘sliding bars’ outward carrying with them the wheels and struts that are attached.
- The spread bars are both driven by a single electric motor with a geared connection to the bars.
- Once in final position the strut assembly is rigidly locked in place at the ends of the upper frame to prevent loads during landing and lunar surface transit to flow through the ‘spreading bars’.
- Expansion mechanism mass = 20kg.

Sliding bar forced outward by 2 cylinders connected to spread bars with ball joints

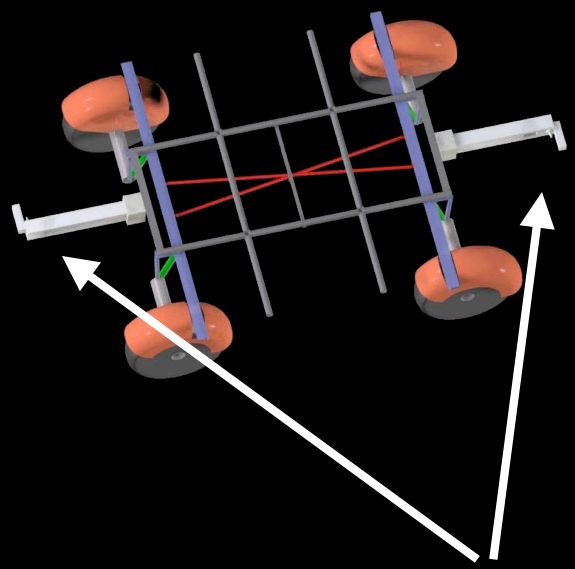


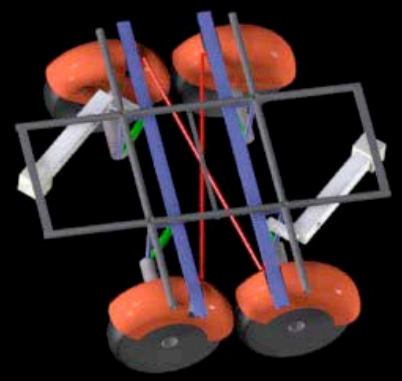


Spread Bars About Central Pin

MORPHLAB

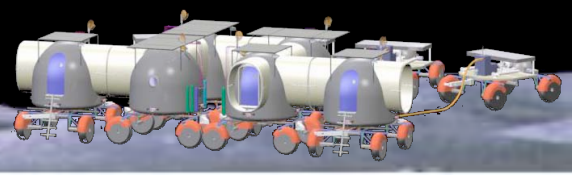
Chassis Components





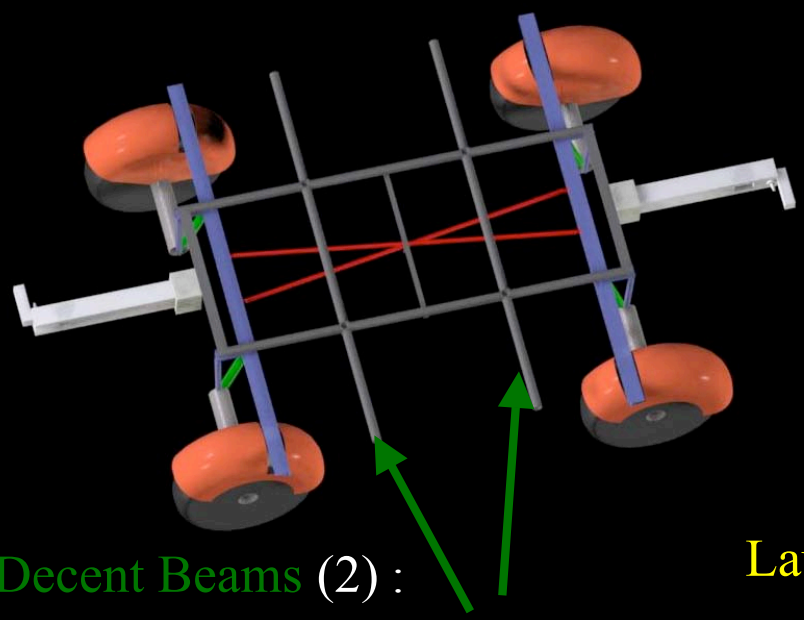
Transit Connections:

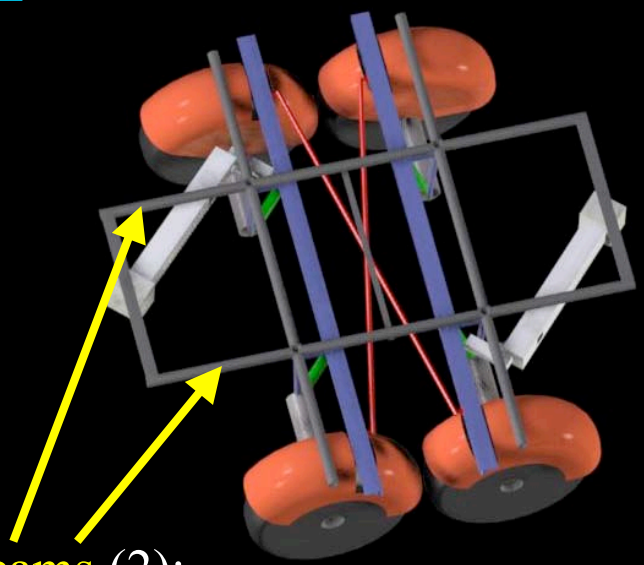
- Connect modules and provide power and data connections during transit configuration
- Initially stowed to fit in Delta IV-H payload



MORPHLAB

Chassis Components





Decent Beams (2) :

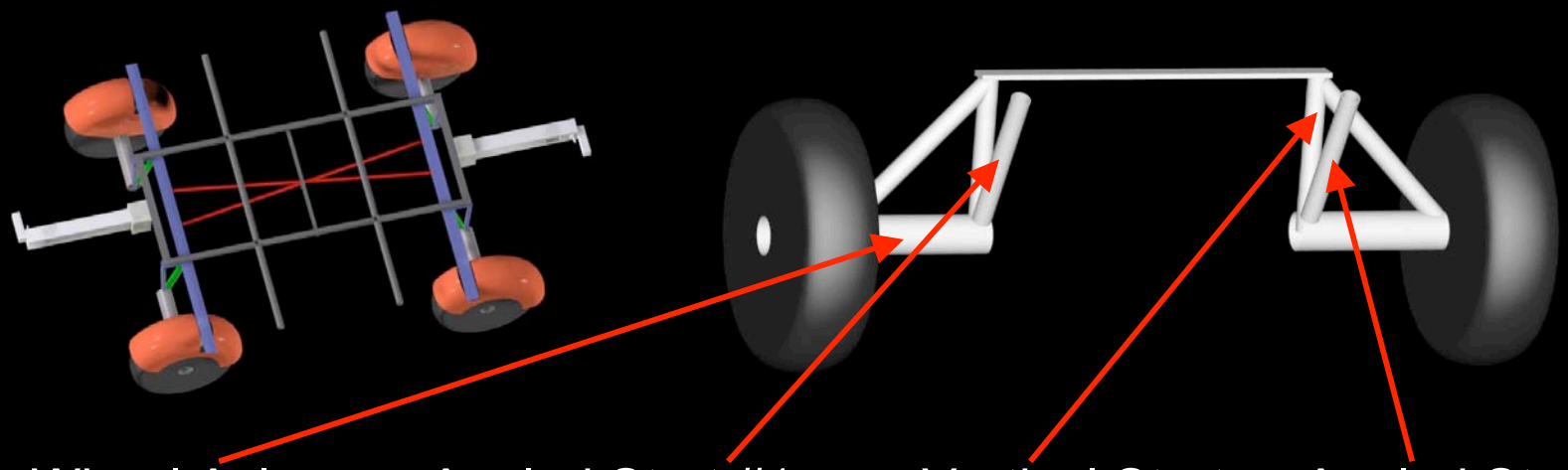
- Aluminum 2014
- Mass of each = 5.8kg
- Critical Load During Lunar Decent each sustaining 3500N Maximum Stress = 81MPa
- Margin of Safety = 1.02
- Failure mode : bending

Launch Beams (2):

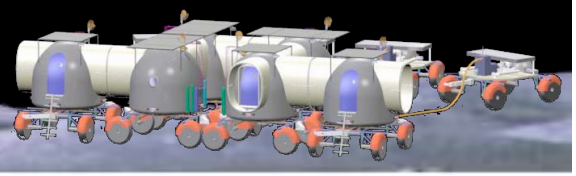
- Titanium Alloy Ti -10V-2Fe-3AL
- Mass of each = 53.7kg
- Critical Load During Delta IV-H main engine cutoff, max axial acceleration = 6g's, max lateral acceleration = 2.5 g's, supports maximum of 3500kg (including chassis)
- Margin of Safety = .23
- Failure mode: bending

MORPHLAB

Chassis Components



- Struts and axles affected by bending moments, compression, and tension.
- Compression, bending, and sheer forces most critical during lunar landing.
- Struts and axles also affected by dynamic loading during lunar transit and static loading during base configuration.
- Components sized to support 3500 kg above chassis during all transit and static cases and to support 3500 kg total for landing loads.
- All components finalized through Finite Element Analysis with ProMechanica.



Chassis Components

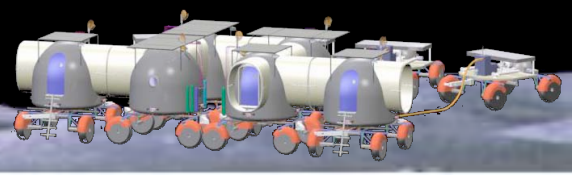
MORPHLAB

Struts and Axles:

Component Name	Material	Max Stress (MPa)	Margin Of Safety	length (m)	Outer Radius (mm)	Inner Radius (mm)	Total mass (kg)
Vertical Strut	Ti Alloy	400	0.38	0.8	0.05	0.045	22.2
Angled strut 1	Ti Alloy	400	0.38	0.9	0.05	0.045	25.0
Angled strut 2	Ti Alloy	400	0.38	1.1	0.05	0.04	57.8
Wheel Axle	Ti Alloy	350	0.58	1.2	0.1	0.098	27.8

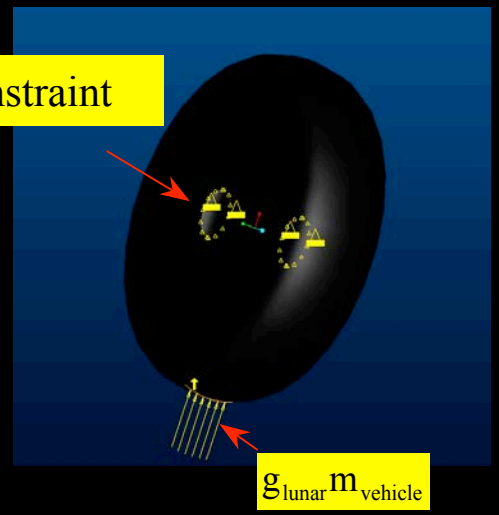
Vertical Strut (4) and **Angled Strut 1** (4) :Critical loading during power module landing on lunar surface directly on wheels; worst case considered as landing directly on one wheel with all force acting in vertical direction. Failure due to combination of compression and bending.

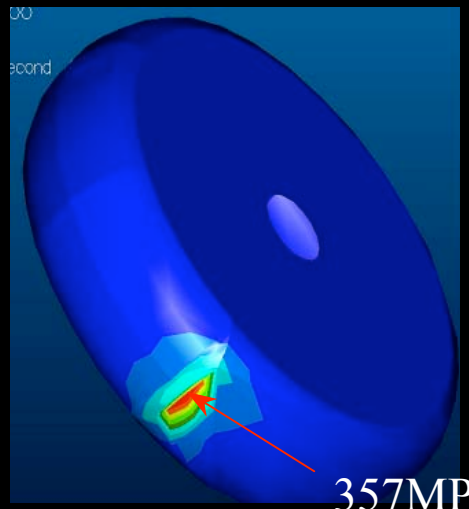
Angled Strut 2 (4) and **Wheel Axle** (4) : Critical loading during power module landing on lunar surface directly on wheels; worst case considered as landing directly on one wheel with all force acting in chassis horizontal direction (first wheel touchdown with chassis perpendicular to lunar surface).

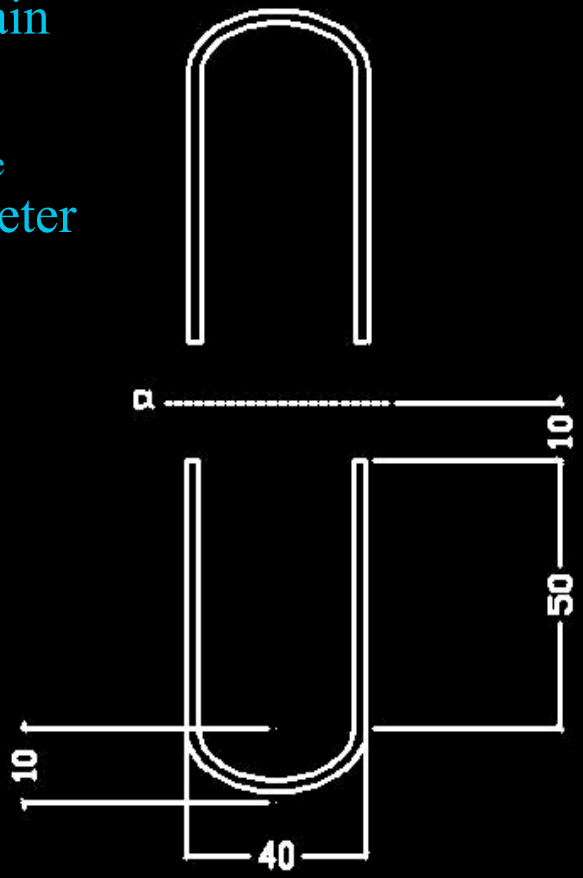


Wheel Design

- Requirement
  - MORPHLAB must overcome 0.5m obstacles.
  - Wheel must support the weight of power module during landing
  - Safety Factor = 2
- Assumptions
  - Axle constrain
  - Load = $g_{lunar} * m_{vehicle}$
  - Wheel diameter = 1.4 m
  - Ti alloy







dimensions: cm

MS = 0.540 Mass = 37.4kg

University of Maryland
CDR 04/19/04

Kevin Mako/Abraham Daiub

MORPHLAB

Motor / Gear

With a 20% margin:

- The wheels need 655.4 N-m torque on the Power module
- The wheels need 810.2 N-m torque on the Hab Life/Science modules
- The chosen motor is the MF0210050 from Emoteq Corporation

Chosen for:

- Decent torque output 305.7 N-m
- Low Mechanical time constant (time to get to 63.2% of max speed)
- Low weight 7.61 kg

- The torque is good, but a gear will need to be used to get the torque for the modules, thus a gear with a gear ratio of 3 to 1 is used

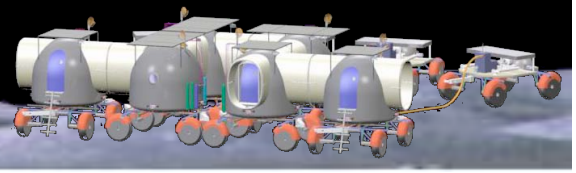
Picture of a MF0210 motor

www.emoteq.com

MORPHLAB

Braking System

- Derived Requirements
  - Stop while moving at maximum speed
    - Stopping distance < linkage bending tolerance
    - Stop full caravan assembly
  - Stopped on maximum slope
    - 30º longitudinal slope
    - One end sitting on 0.5 meter obstacle
- Electrohydraulic Disc Brakes (shuttle)
  - Less torque variation during stop vs. drum brakes
  - Benefits of carbon brakes vs. steel brakes
    - Lighter
    - Resistant to friction
    - Efficient whether hot or cold
    - Absorbs 2-3 times more heat



MORPHLAB

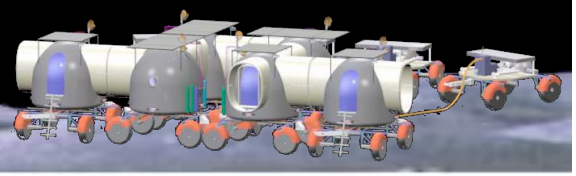
Braking System

Moving at 1 km/hr

Braking Force	236 N
Brake Torque	165 N-m
Stopping Time	0.091 s
Energy Dissipated	358 J
Average Power Dissipated	3920 W

Stopped on Slope

Braking Force	9110 N
Brake Torque	6370 N-m



Chassis / Habitable Interface

MORPHLAB

Requirements:

- Provide rigid connection between Habitable module and Chassis
- Transfer power between Chassis and Habitable module
- Prevent Dust from interfering with power connection

Cylinder Diameter = 5 cm

Cylinder length = 8 cm

Max Compression = 128 MPa

Material = Al 2014

Margin of Safety = .2

Blue cup fixed on 4 locations on bottom of Habitable Module Skin.

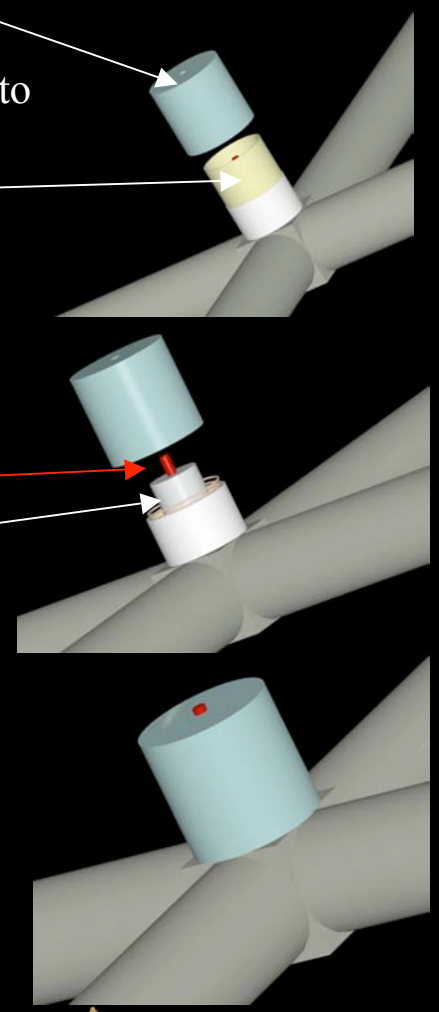
Yellow sleeve spring loaded and designed to prevent dust from collecting on power connection.

Sleeve is driven down inside larger sleeve to expose supporting cylinder and power connection probe

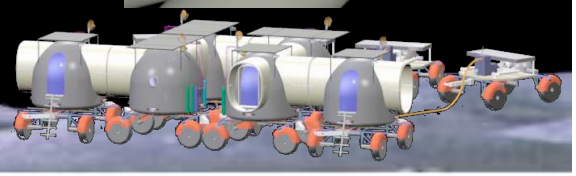
Power connection probe

Supporting cylinder

As Habitable Module descends it automatically aligns itself snuggly on top of supporting cylinder and allows power probe to reach into plug internal to Habitable Module

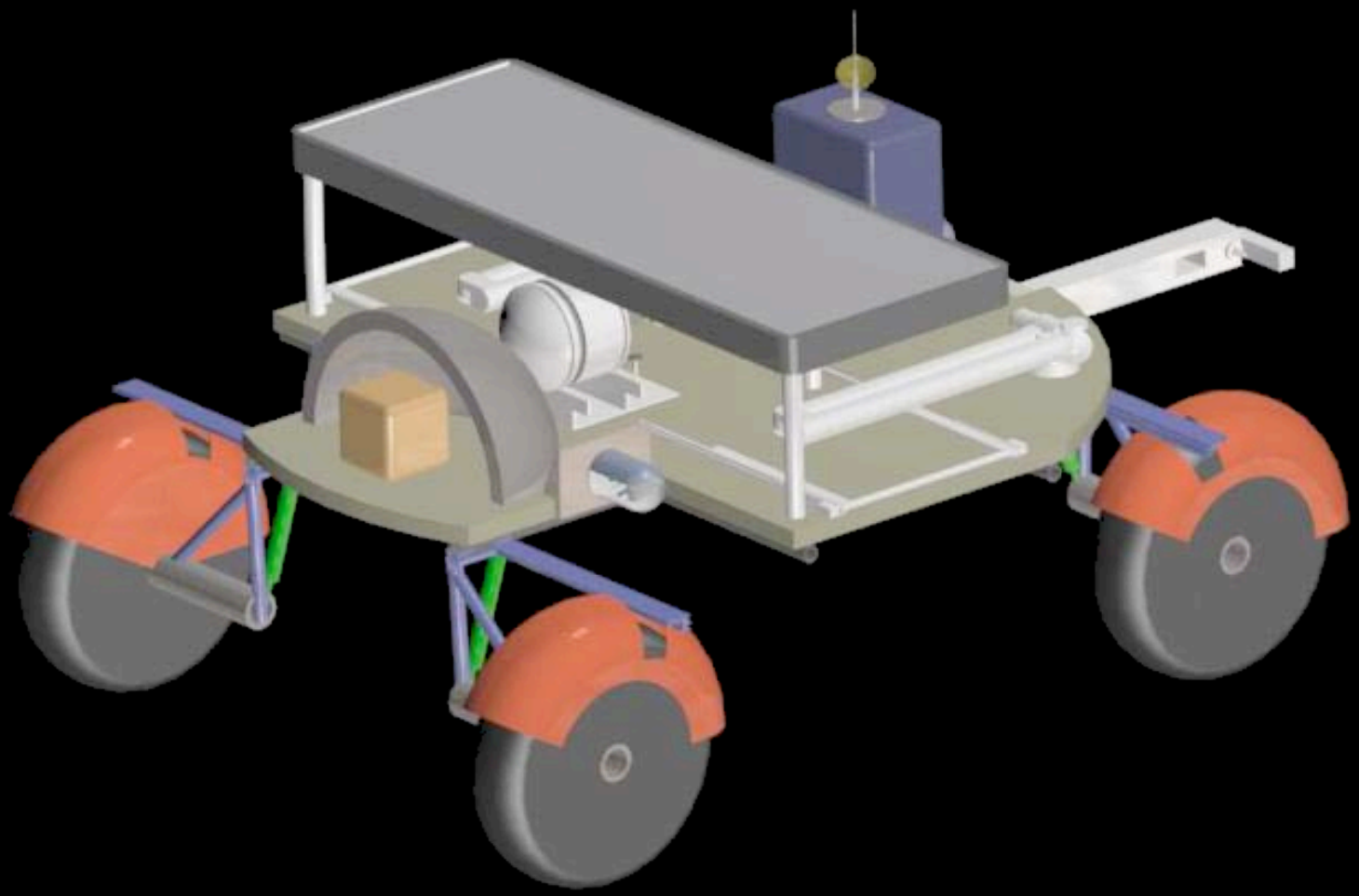


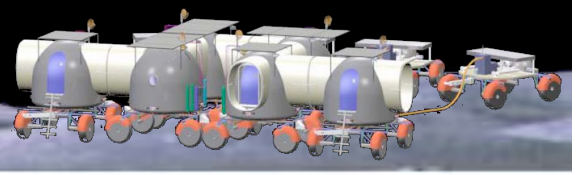
Jason Seabrease &
John Albritton



MORPHLAB

Power Module





University of Maryland

CDR 04/19/04

MORPHLAB

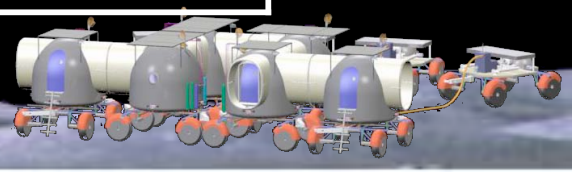
Power Module Overview

Requirements:

- Supports a 5 year mission (M6)
- Capable of producing power during the lunar night (M1)
- Must not impose a health risk to the crew (M1, L7)
- Multiple power sources to accommodate potential module loss (I3, I4)
- Size must not impact MORPHLAB system mobility (M2)
- Additional Factors: low system mass, high reliability

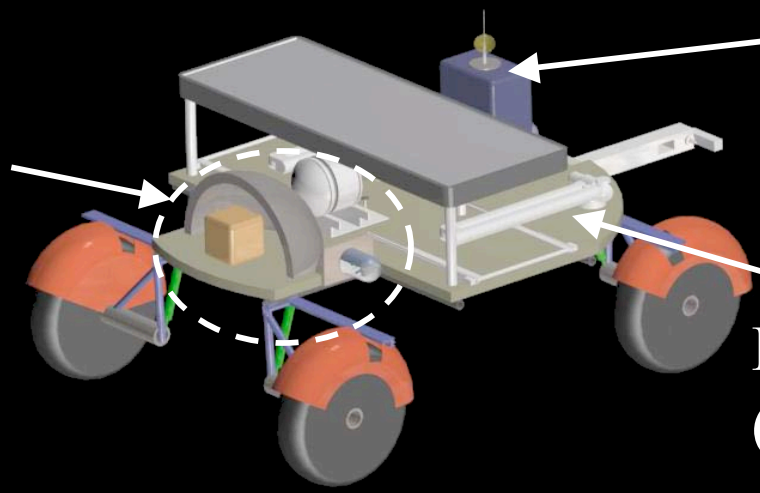
Selected: Dynamic Isotope Power System (DIPS)

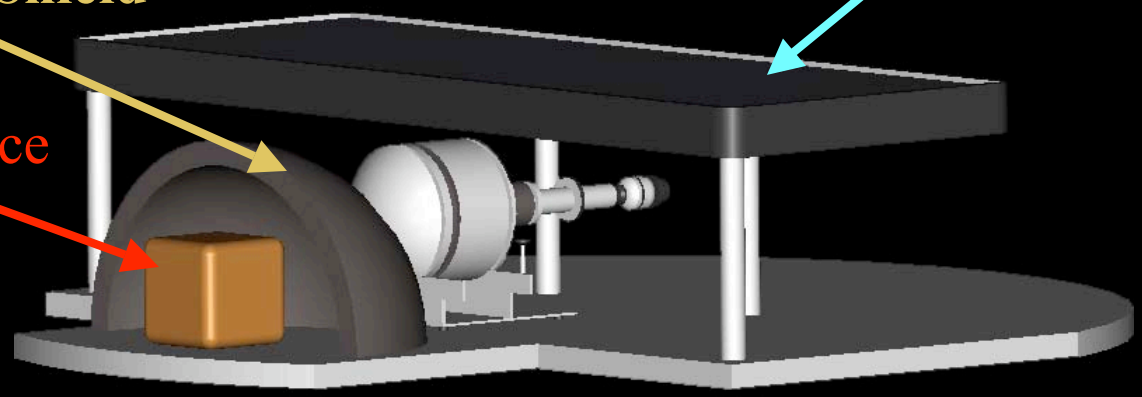
No Single-Point Failure Reliability	.9955
Thermal to Electric Efficiency	26%
Specific Power (with shielding)	12.6 W/kg
Total DIPS Mass (with shielding)	420 kg
Power Output	5.3 kWe
Number of Units	4



MORPHLAB

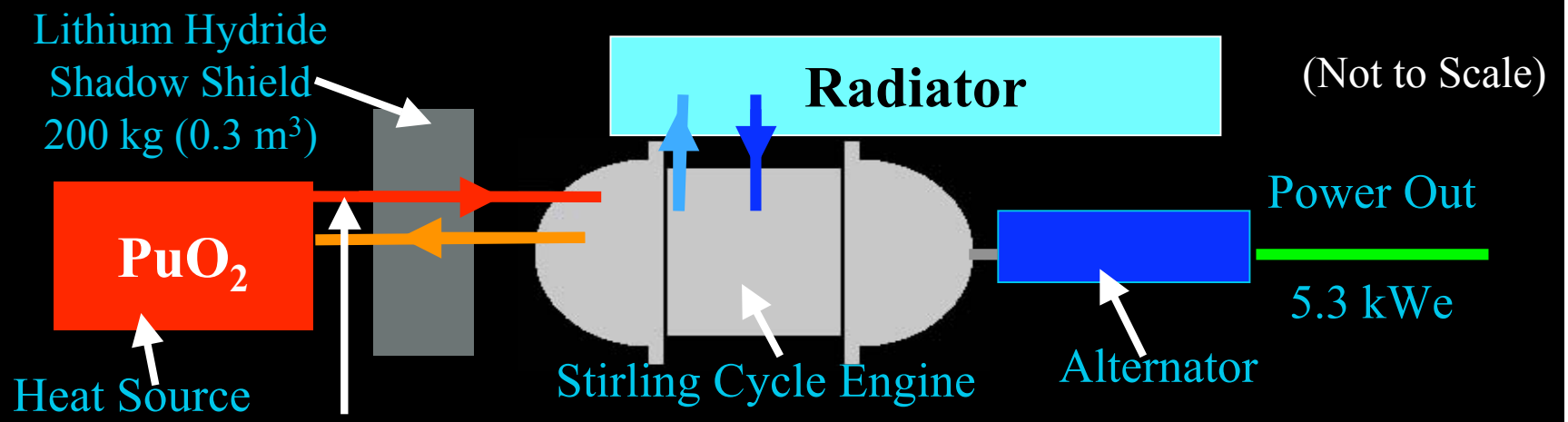
Power Module Components





MORPHLAB

DIPS Details



Heat transfer into engine estimated as 75% efficient

Heat Source:

Half Life	88 years
Mass	95 kg
Thermal Output	20.3 kWt
EOL Thermal Output	19.5 kWt

(EOL: End of Life)

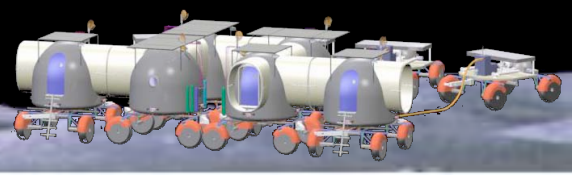
Engine:

Qin	15.3 kWt
Qout	5.5 kWt
Work Out	7.4 kW
T_H	1300 K
T_L	460 K
Carnot Eff.	64.3%
Actual Eff.	48.6%

Alternator:

Efficiency	72%
Power Output	5.3 kWe
EOL Power Output	5.1 kWe

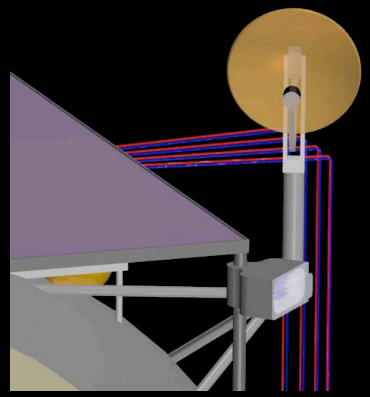
Total System Mass: 420 kg



Joe Cavaluzzi

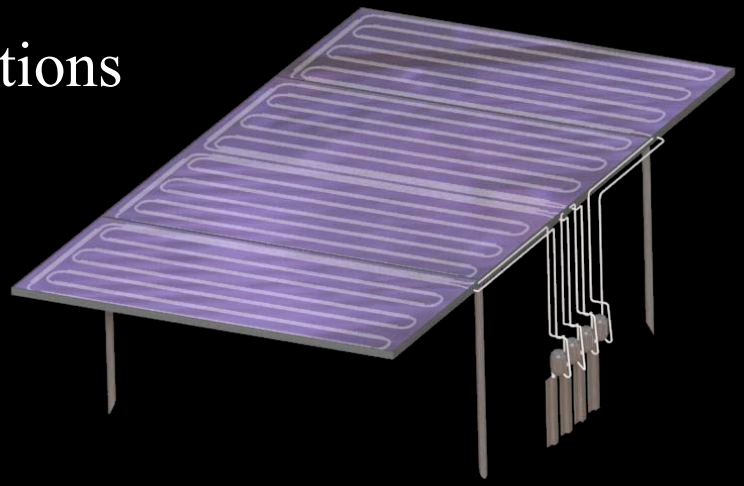
MORPHLAB

Common Sub-Systems

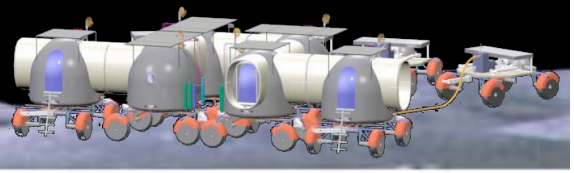


Communications

External Lighting



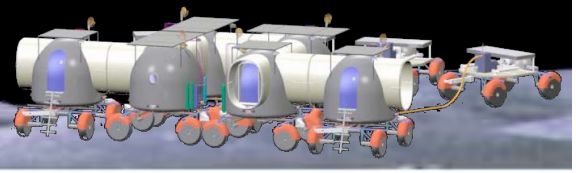
Thermal Control Systems



MORPHLAB

Thermal Control System

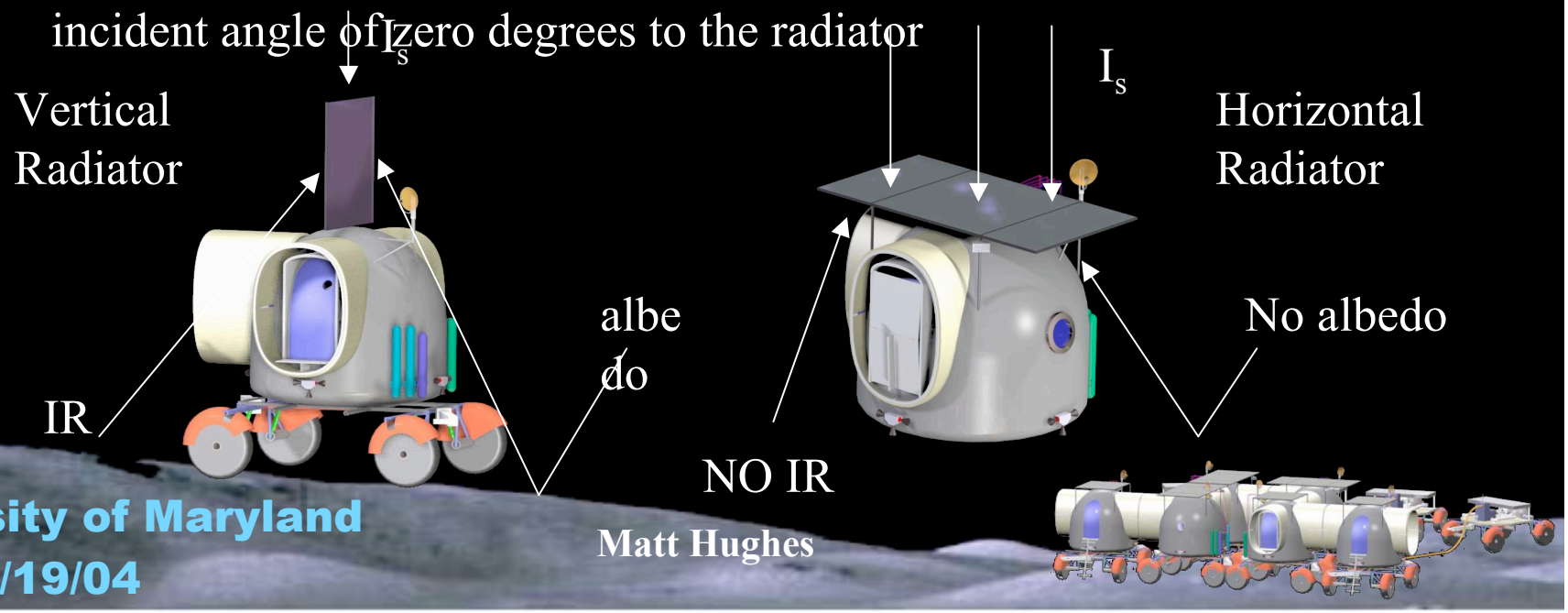
- Modules will be insulated with Multilayer Insulation (MLI)
  - Thin layers of Mylar coated with aluminum separated by a vacuum
  - The Mylar has low-conductivity of .20 W/m*K so it effectively isolates the inner-workings of the module from the harsh lunar environment with fluctuations in temperature from 160K to 380K
  - During the lunar day and night, the assumption is there will be enough layers of MLI (ie. 10) to act adiabatically and therefore keep the ambient inside reference temperature at 298K
  - Moonshine and lunar albedo will not pose a heating problem to the module, even though it will "see" 380K at some points, because of the MLI and its adiabatic assumption
  - Aerogel will be used where heat leakage paths occur (ie. Panel seams, corners) because it insulates well (thermal cond.= .004 W/m*K) and has a density of 10 kg/m^3
  - 10 layers @ .25 mm thickness implies volume of .14 m^3 and with a density of 1420 kg/m^3 gives a mass of 193 kg



MORPHLAB

Radiator

- A vertical radiator atop a module on the lunar surface will "see" solar flux (I_s), moonshine (IR), and lunar albedo (alb) which means the environment temperature would be around 380K at the equator during lunar noon.
- Since the top of the module is 4.5m off the surface, a horizontal radiator will never "see" moonshine or lunar albedo. The only radiation it will "see" is from solar flux, where the worst case would be noon at the equator when the entire radiator is illuminated.
- There will be no solar flux at night or at the poles because of the sun's incident angle of zero degrees to the radiator



MORPHLAB

Radiator Sizing

- Ran thermal equilibrium analysis on horizontal radiator to find out what area was needed to dissipate the allotted heat per module
- Since lunar albedo and moonshine are not considered, the thermal equilibrium equation then becomes:

$$I_s \acute{a} A_s + P_{\text{int}} = \mathring{a} \acute{o} A_R (T^4{}_{rad} - T^4{}_{env}) \qquad (1)$$

α : Absorptivity (.08)

A_s : Projected Area Facing Sun

P_{int} : Internal Heat Dissipated (Q_{in})

T_{rad} : Temperature of Radiator Surface

ε : Emissivity (.92)

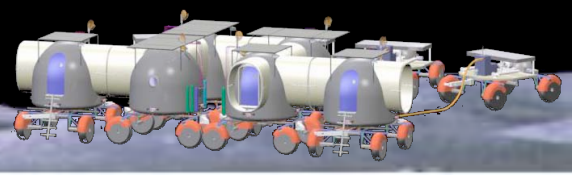
A_R : Total Radiative Area

σ : Stefan-Boltzman Constant (5.67e-8 W/m^2K^4)

T_{env} : Temperature of Environment (4K)

- Took case of sun directly overhead illuminating the whole area of the radiator with all energy needing to be dissipated through radiator. Therefore,

$$A_R = A_s = A$$



MORPHLAB

Radiator Sizing Continued

- Taking the case of Lunar noon at the equator, the optical properties must have a low absorptivity as to minimize solar heating effects and high enough emissivity to radiate internal heat effectively (ie. $\varepsilon = .92$ and $\alpha = .08$)

	Q_{in} (kW)	Rad Area (m^2) ^	Mass (kg)*	Dimensions (m^3) ~
Habitable Living	4.0	13.34	71	5.00 x 2.67 x .04
Habitable Science	2.3	7.67	41	2.77 x 2.77 x .04
Power Module	7	6	32	4.65 x 1.5 x .04

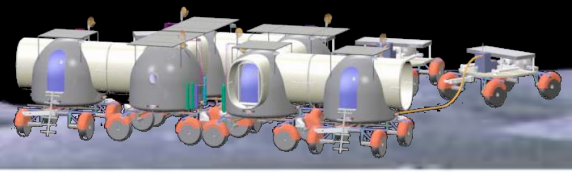
- ^ Assuming $T_{rad} = 298K$, and therefore in thermal equilibrium with inner cabin
- * Assuming 5.3 kg/m^2 for one-sided, horizontal radiators from Lunar Base Handbook
- ~ Assuming .04 m for thickness of typical radiator

MORPHLAB

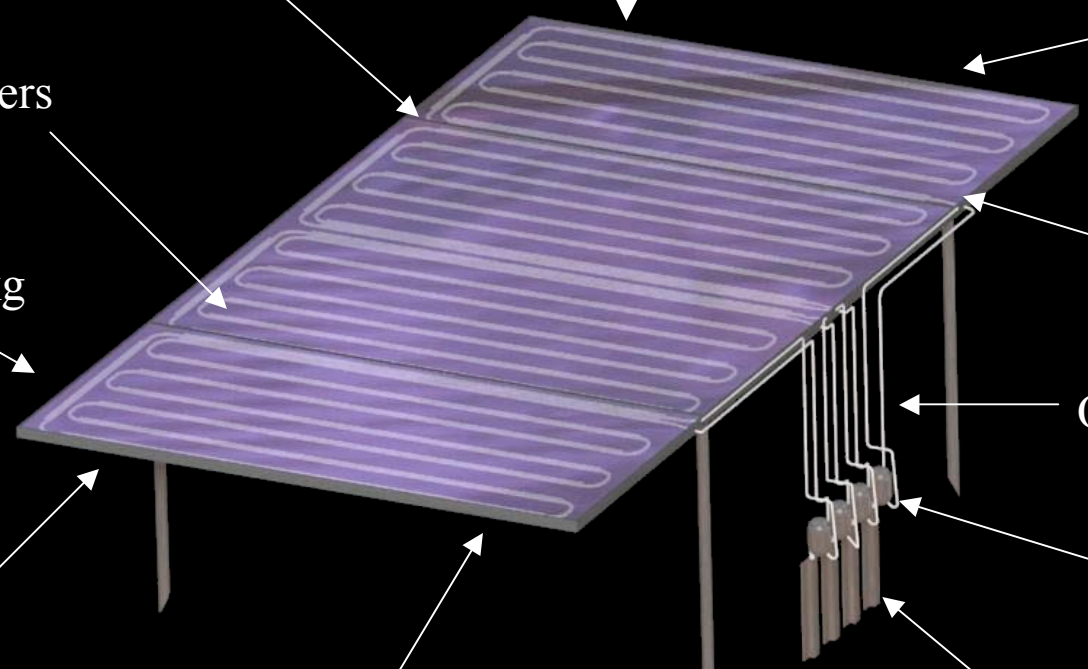
Radiator Mass

	Volume (m^3)	Q_{in} (kW) Low Level	Area (m^2) Low Level	Area (m^2)
Habitable Living	.51	1.3	3.16	10.18
Habitable Science	.29	1.3	3.16	4.51

- Using loop heat pipes (LHP) due to flexibility and fact that they dissipate more heat then conventional heat pipes. A benchmark of 1 loop heat pipe being able to dissipate 1.6kW was used.
- Habitable-Living Module has 4 LHP (two outer: 1350 kW/each, two inner: 650 kW/each to handle lower night loads
- Habitable-Science Module has 4 LHP (two outer: 500 kW/each, two inner: 650 kW/each to handle lower night loads as well



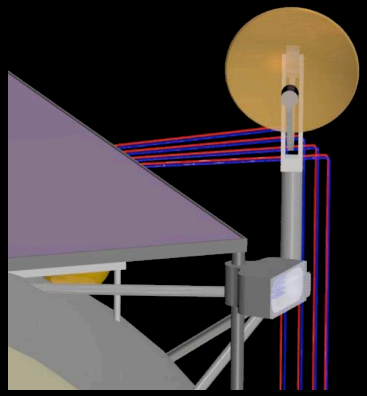
Habitable Living Radiator



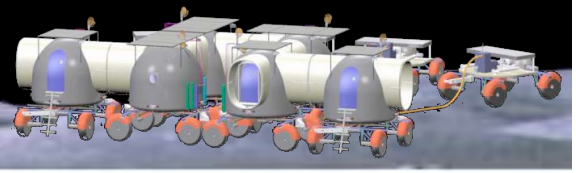
MORPHLAB

Communication Capabilities

- Level 1 Requirements:
  - 10Mbps of bidirectional digital data
  - Two uplink channels HDTV
  - One downlink channel HDTV



- Derived Requirements:
  - EVA communications
    - Module – Rover
      - Main comms. with EVA
      - Send one HDTV to base
    - Module – Astronaut
      - Voice
      - Health monitoring
  - Inter-Module communications
    - Nominally use only wireless
    - Backup physical connection
    - Receive commands during transit
    - Processor/memory sharing during peak usage times

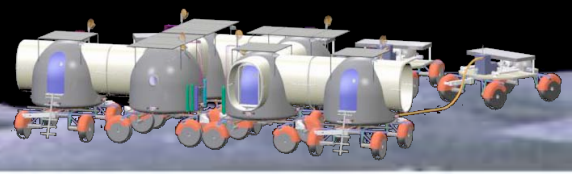


MORPHLAB

Bandwidth Requirements

- HDTV Requirements
  - Uncompressed single channel is 1.5Gbps
  - With MPEG-2 compression single channel is 19.4 Mbps
    - Internationally accepted industry standard
    - Depending on available bandwidth high quality compression up to 80Mbps
  - 4 – 8 standard video channels on single HDTV band
  - Two uplink – 40Mbps
  - One downlink – 20Mbps
- Total Uplink – 50Mbps
- Total Downlink – 30Mbps

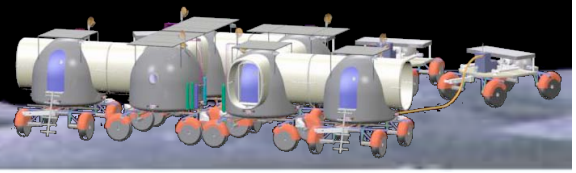
- Lunar Surface
  - Bandwidth determined by
    - Rover – Module
    - EVA/Suit - Module
    - Module – Module
  - Inter-module communications used for computer interaction and communications between crew members
    - <1Mbps for voice comms
    - Remainder used for data transfer and video link
- Total Uplink – 60Mbps
- Total Downlink – 40Mbps



MORPHLAB

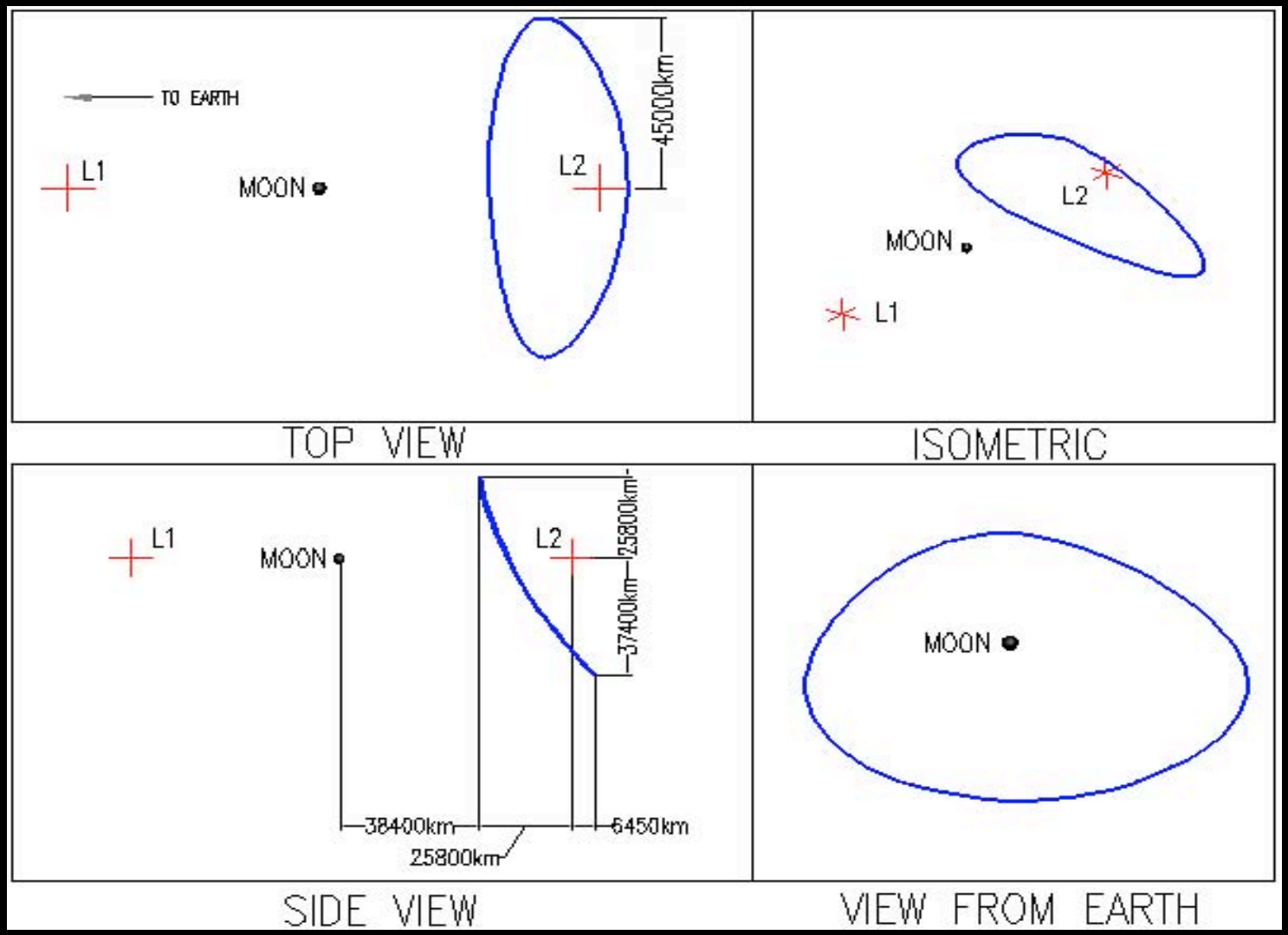
Halo Orbit

- Far side communications will be accomplished through satellites placed in halo orbits about the Earth-Moon L2 point
  - Number of satellites: 4
    - Placed in the same orbit with 90° phase offset
    - Provides two fault tolerance regardless of base or satellite location
  - Orbital parameters
    - Period: ~ 1 year
    - In-plane amplitudes:
      - 32,250 km in line with the Earth-Moon vector
      - 90,000 km normal to the Earth-Moon vector
    - Out-of-plane amplitude: 63,200 km



MORPHLAB

Halo Orbit Diagram

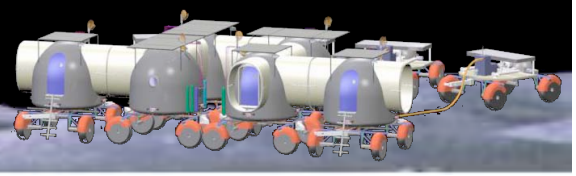


MORPHLAB

Moon – Earth Link Budgets

	Moon NS Hab-Earth	Moon NS Power-Earth	Moon FS Hab-Halo	Moon FS Power-Halo
Diameter	50 cm	10 cm	50 cm	10 cm
Band	Ka	Ka	Ka	Ka
Transmit Bit Rate	50 Mbps	10 Mbps	50 Mbps	10 Mbps
Receive Bit Rate	30 Mbps	10 Mbps	30 Mbps	10 Mbps
Output Power	1.2 W	4.0 W	4.0 W	11.4 W
Link Margin	3.0 dB	3.0 dB	3.0 dB	3.0 dB

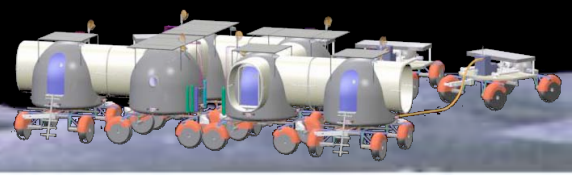
NS – Near Side Module FS – Far Side Hab – Habitable



MORPHLAB

Lunar Surface Link Budgets

	Module-Module 20km range	Rover-Module 20km range	EVA Suit-Module 10km range	Total Module Budget
Diameter	Omni-antenna	Omni-antenna	Omni-antenna	Omni-antenna
Band	UHF	UHF	UHF	UHF
Transmit Bit Rate	30 Mbps	30 Mbps	<1 Mbps	60 Mbps
Receive Bit Rate	30 Mbps	10 Mbps	<1 Mbps	40 Mbps
Output Power	N/A	18.2W (Rover only)	1 W	37.5 W
Link Margin	3.0 dB	3.0 dB	3.0 dB	3.0 dB



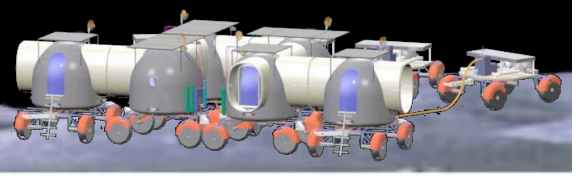
MORPHLAB

Radiation-Hardened Computers

- Level 1 Requirements
  - Shall be capable of reaching a TRL of 6 by the technology cut-off date of Jan. 1, 2010
    - TRL 6: System/subsystem model or prototype demonstration in a relevant environment (ground or space)
- Looked at 7 different radiation hardened (Rad-Hard) computers for trends

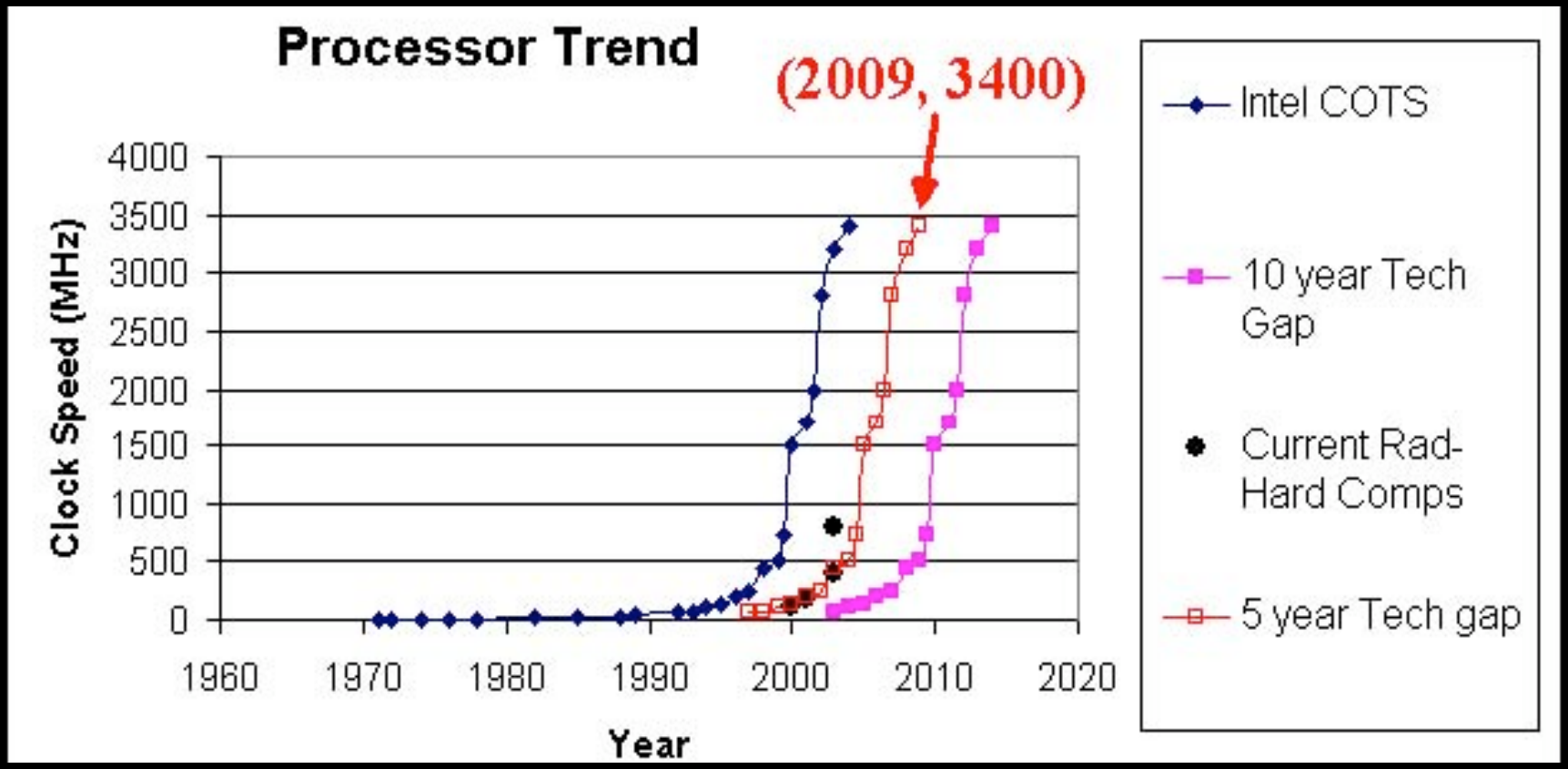
  - MASS - SCS750 - RHPPC
  - RAD750 - RHPCM - RAD6000
- Compared Rad-Hard vs. Commercial Off the Shelf (COTS) to identify technology gaps and trends:

  - Processor Speed -Bus Speed -Power Consumption



MORPHLAB

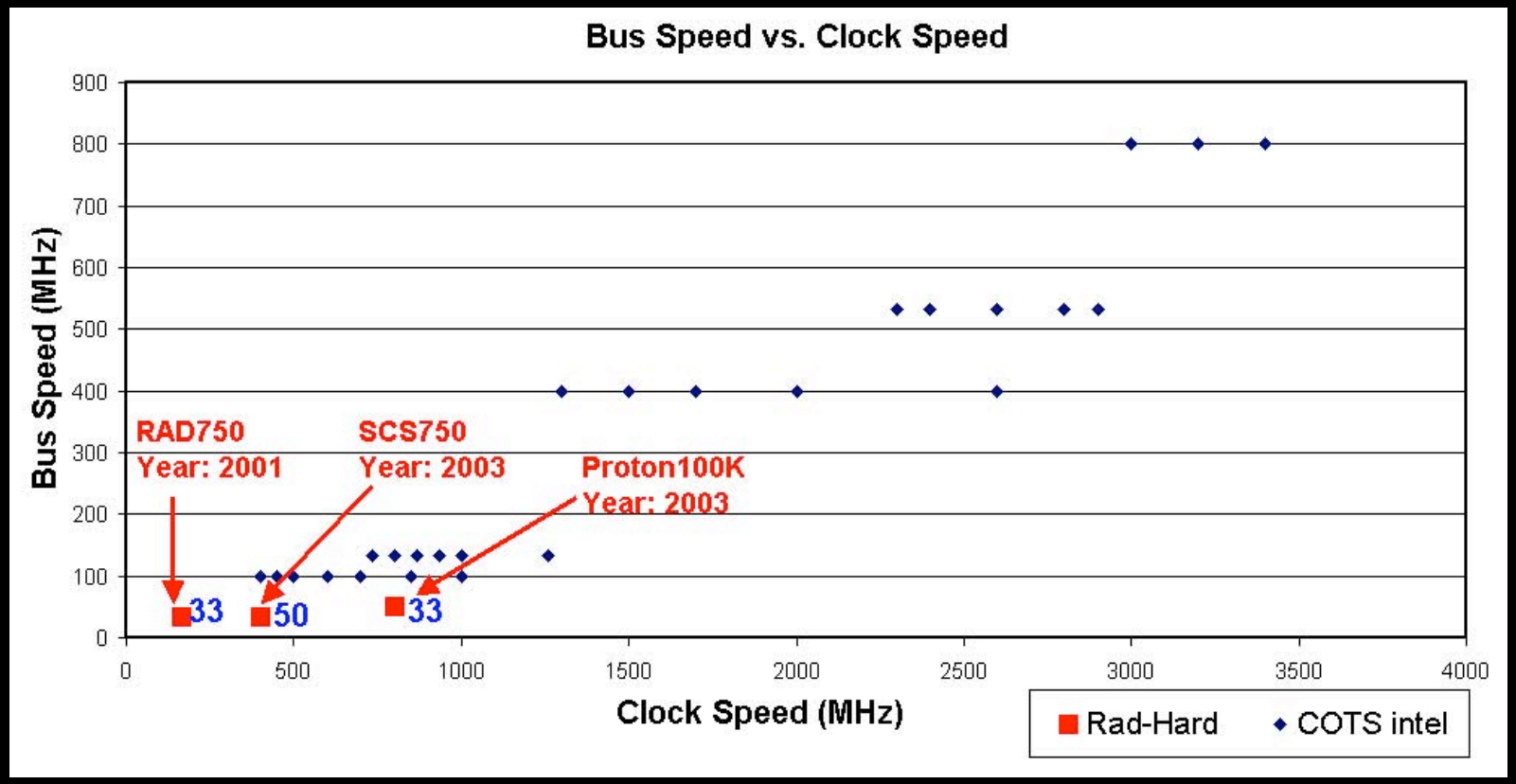
COTS vs Rad-Hard: Clock Speed



- Trends suggest a 5 year technology gap in clock speed between COTS and Rad-Hard
- By 2010 Rad-Hard Processor speed of 3400 MHz

MORPHLAB

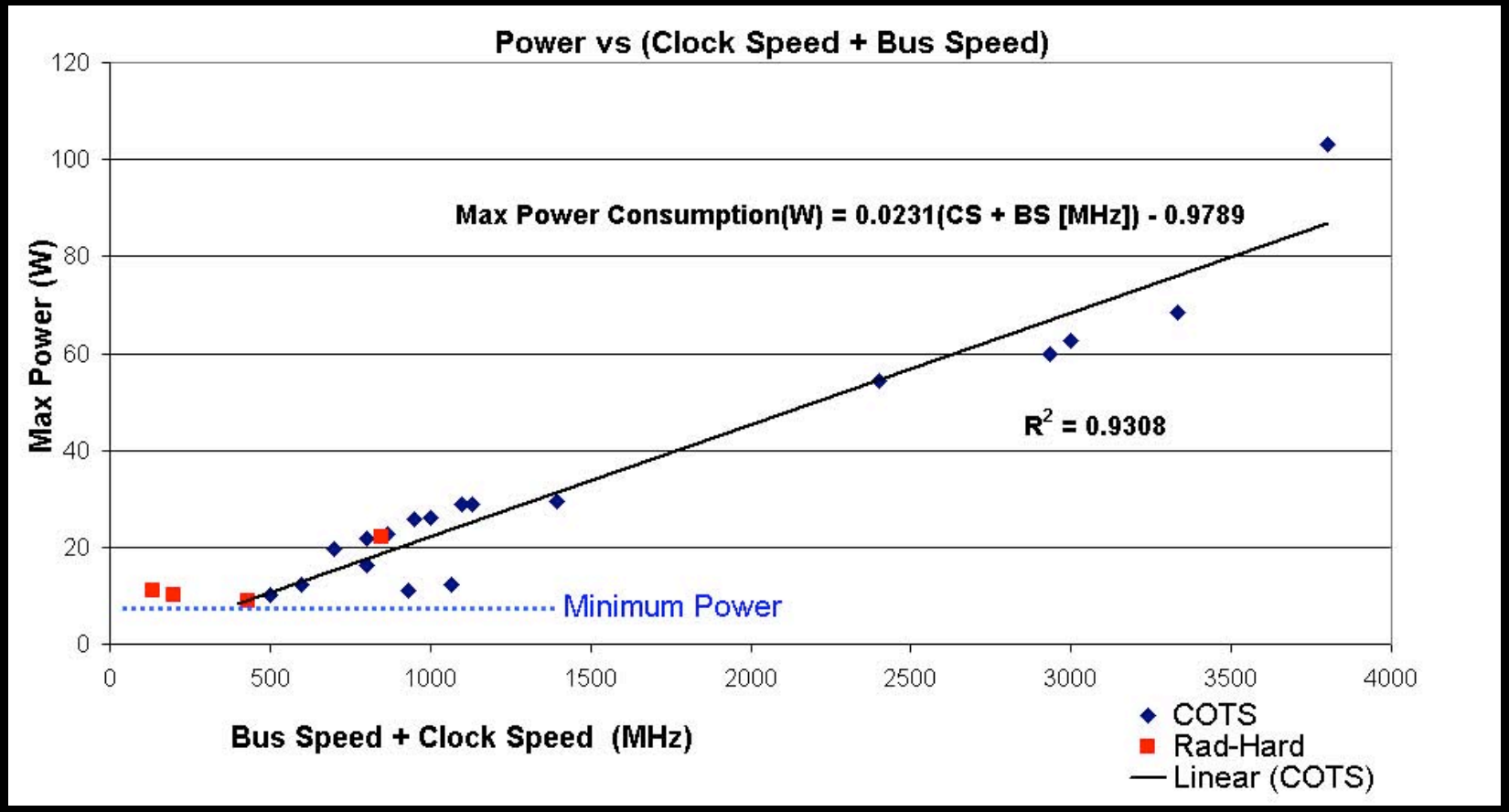
COTS vs Rad-Hard: Bus Speed



- Bus speed is positively related to clock speed for COTS
- No correlation or trend could be established for Rad-Hard in 2010

MORPHLAB

COTS vs Rad-Hard: Max Power



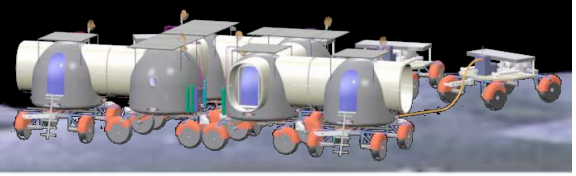
- Used COTS to establish a heuristic
- Rad-Hard plotted against heuristic as verification

MORPHLAB

Rad-Hard Computer Mass

Rad-Hard Computers	MHz	Power	Mass
MASS	N/A	11 W	< 1 kg
RAD6000	25	7.5	0.849
RHPPC	100	11 W	1kg
RHPCM(p)	120	11W	1kg
RAD750	166	10W	.549 kg
RAD750***	200	10W	1kg
Proton100K	400	7-9 W	N/A
SCS750*	800	8-22 W	< 1.5kg

- As technology increases, performance increases, but also hardware is smaller and lighter, thus mass is relatively constant.
- We adopted a mass estimation above the current heaviest and highest performing Rad-Hard computer of 1.5 kg.



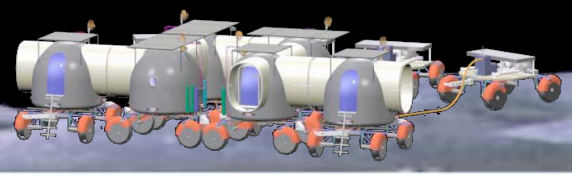
MORPHLAB

Rad-Hard Computer

- Conclusion: By 2010:

Clock-Bus Speed	Power	Mass	SDRAM
3400-50 MHz	96 W	1.5 kg	256 MB

- Other Features:
  - Single Event Latchup immune
  - Single Event Upset rate 1E-6 upsets/day
  - Direct Memory Access Bus 1GB/s for data storage
  - Selectable processor speed and power consumption
- Open Items: Look into ThinkPad 760X, ThinkPad 755C, AP-101S

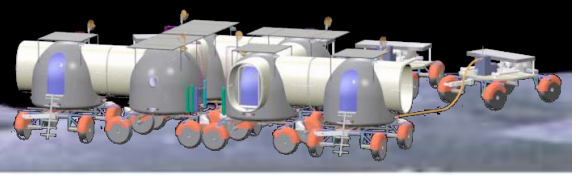


MORPHLAB

Dual Computer Interface

Module	# of Computers	Landing	Base	Transit	Storage
Power	2	5	1	5	Non-volatile memory card
Habitable Science	2 (1)	3	1-5	2	Solid state recorder
Habitable Living	1	3	3-4	2	Solid state recorder
Chassis	1	3	1	3	Non-volatile memory card

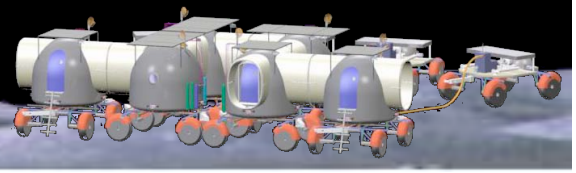
1 – Minimum processing power – sensor monitoring, basic communications
3 – Medium processing power – GUI interfaces, full communications, calculations
5 – High processing power – High rate data intake and analysis, autonomous tasks



MORPHLAB

Multi-Processor Issues

- Each module will be equipped with up to two computer systems that utilizes three CPUs each
  - Two of three processors used during healthy mode
  - Third processor monitors heartbeat of other two and takes control in the event of CPU failure
- Measures must be taken to ensure correct handling of all tasks
  - Tasks must have locks to ensure only one processor attempts it at a time
  - Local memory to perform current task
  - Shared memory to provide information to other processors about state of completed tasks
  - Memory backups for recovery on separate CPU/computer

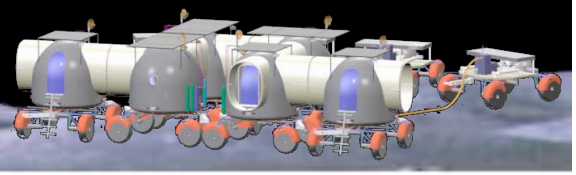


MORPHLAB

CPU Monitoring

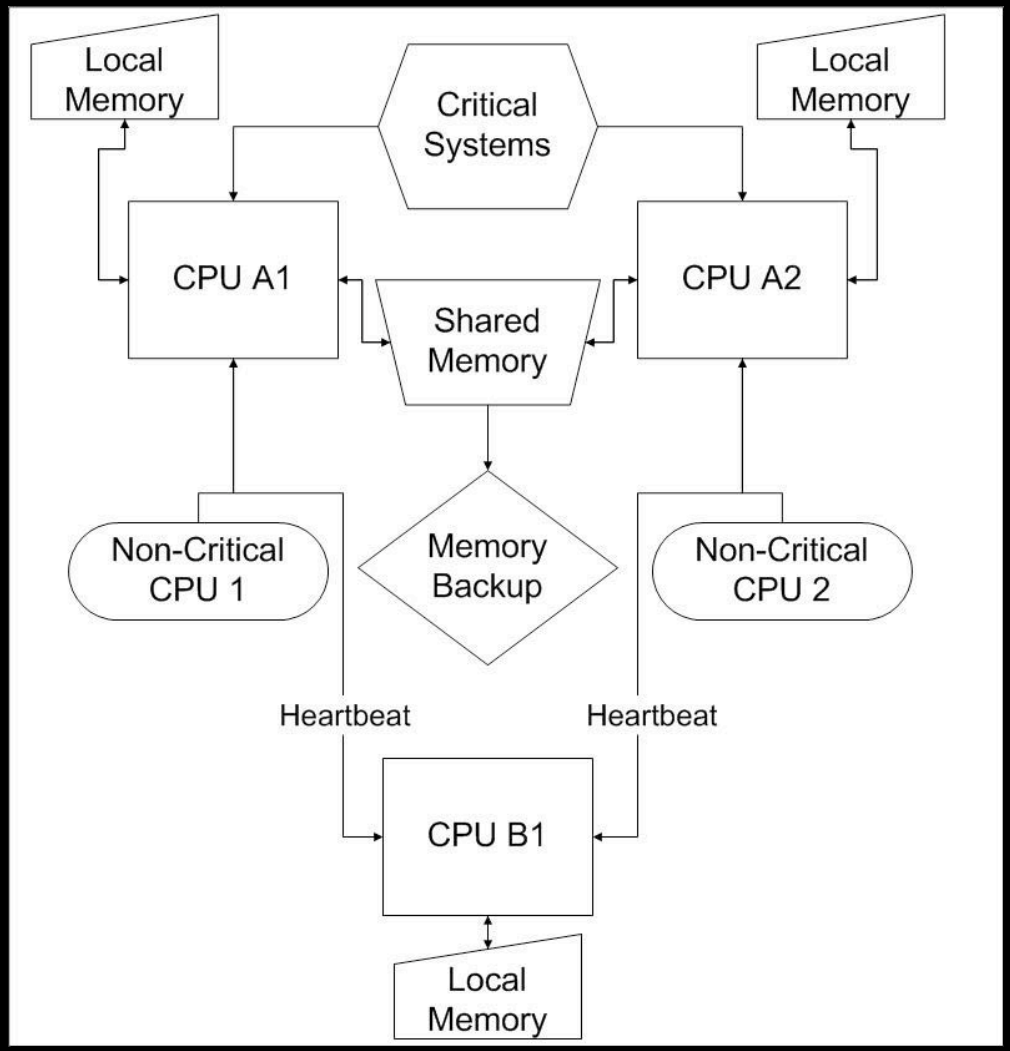
Each set of computers will need to be monitored on both a hardware and software level:

- Hardware monitoring
  - Voltages throughout system
  - Memory parity checking
  - CPU temperature
  - Clock/timer input sync
- Software monitoring
  - Unexpected results trigger diagnostics
  - Checksum calculation verification on memory contents
  - Extra diagnostics run during idle periods
  - All functions return status codes
  - Timeouts on all loops
  - Event logging



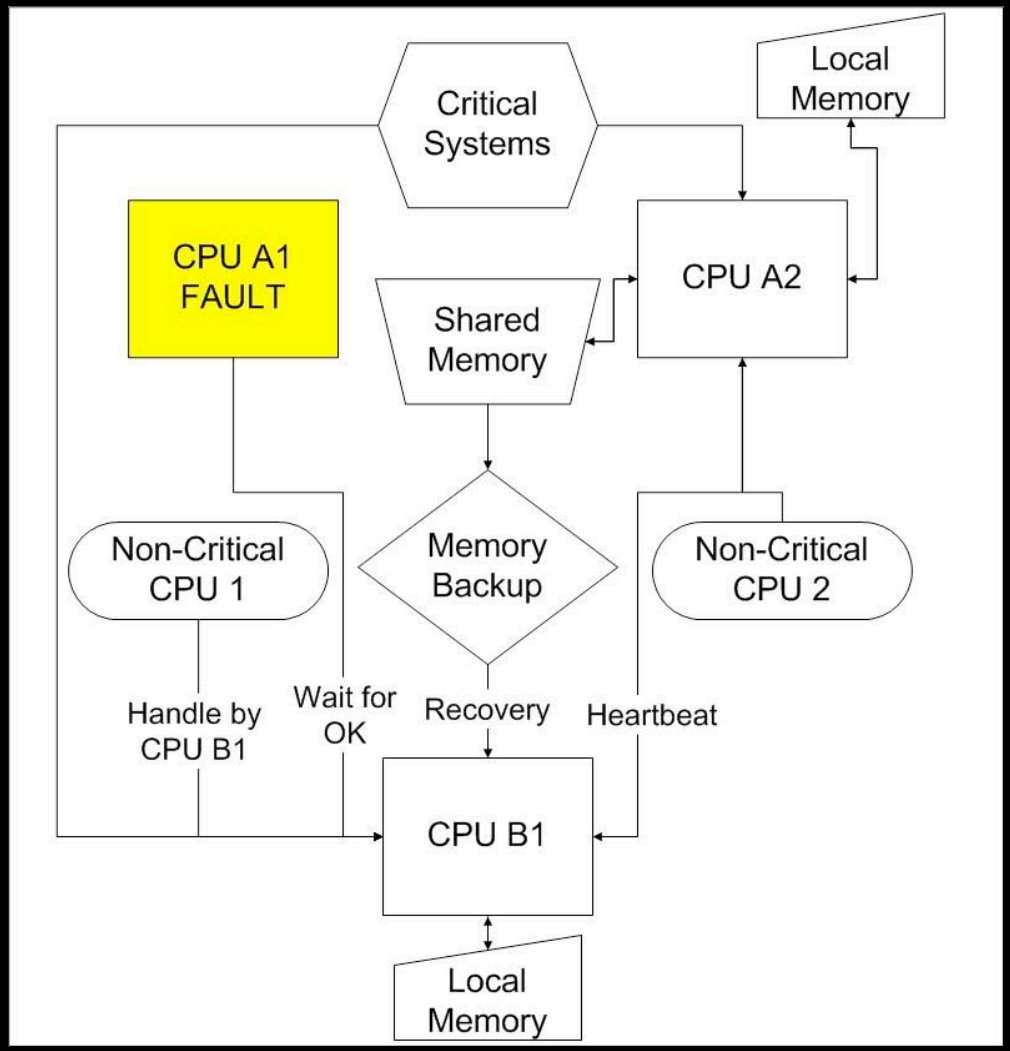
MORPHLAB

Computer System Fault Path



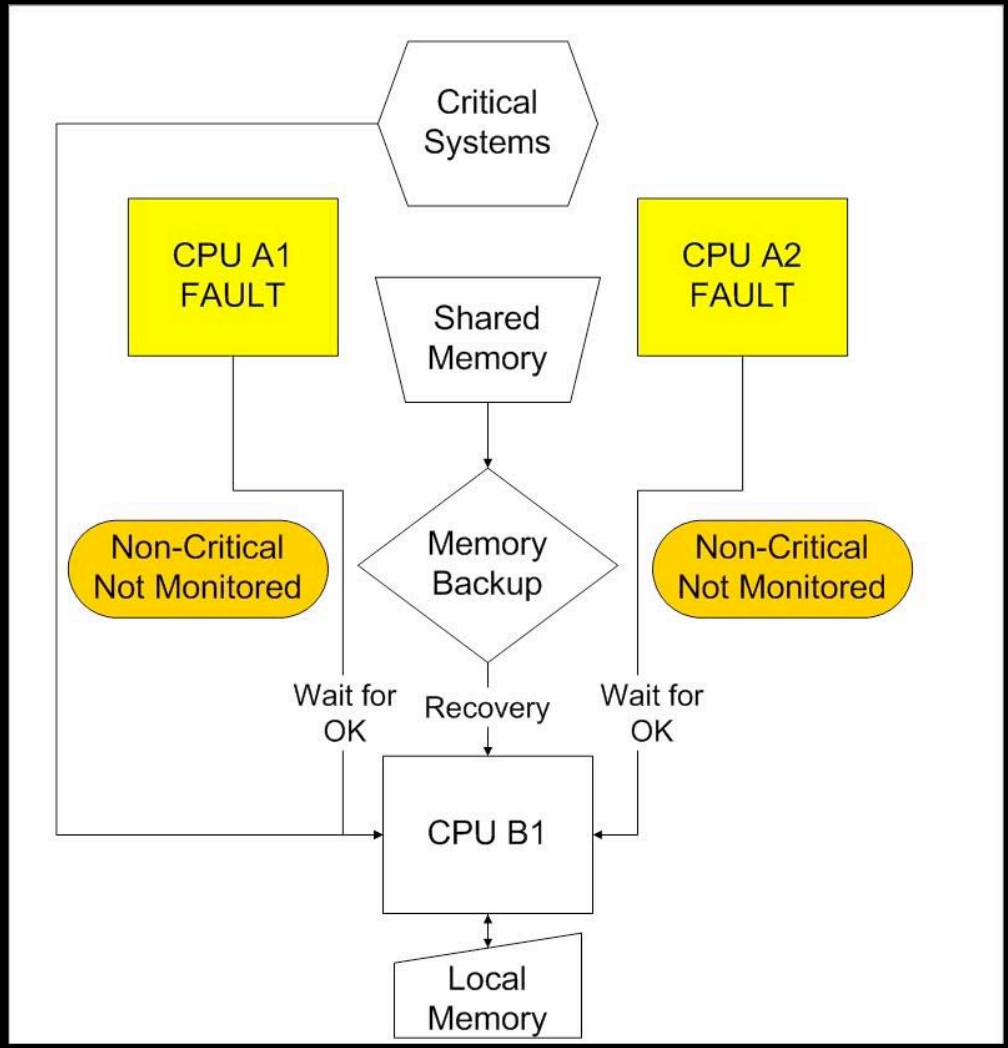
MORPHLAB

One CPU Failure…



MORPHLAB

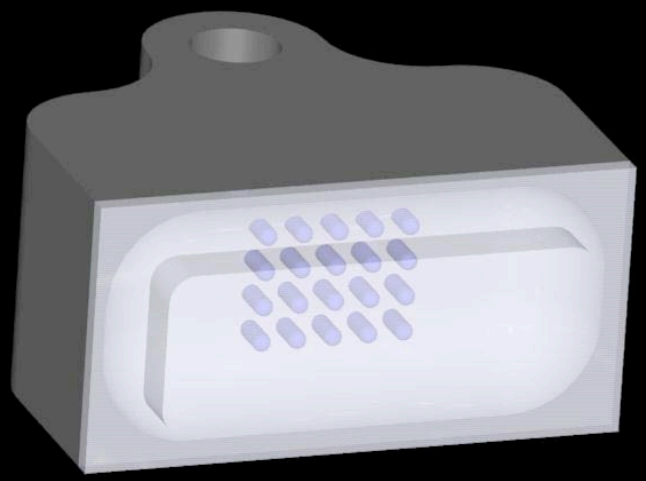
Two CPU Failures…



MORPHLAB

External Lights

- Made from super bright LED's (light emitting diodes)
- LED's will be bundled into a "headlight" configuration consisting of 19 individual diodes
- The resulting bundle will be 3-4 times brighter than a standard headlight, with at least as much range (~.15 km)



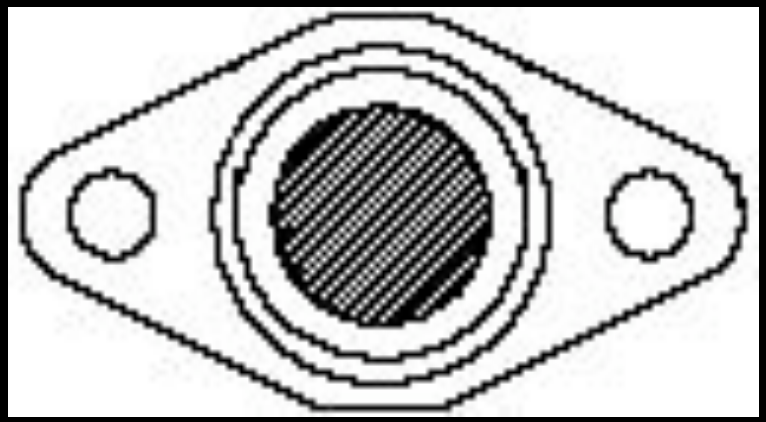
Close up of light

MORPHLAB

External Lights

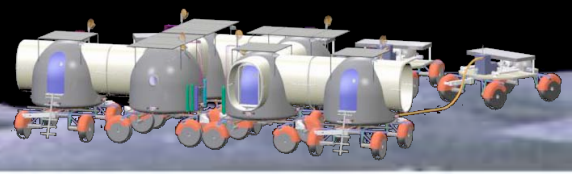
- LED used LEDW47-66-60-120 by Laser Optronix
- Each LED produces 13 candles of light
- Each LED weighs .037 kg which makes each bundle weighs .71 kg
- Each LED needs 4.56 W of power
- Lights will be used during travel phases for far side and night traversing

LED



31.5 mm

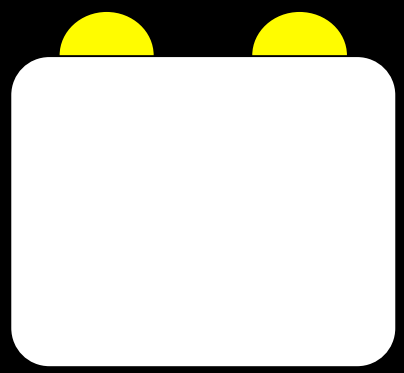
- Lights will be used during base phase for perimeter lighting for safety



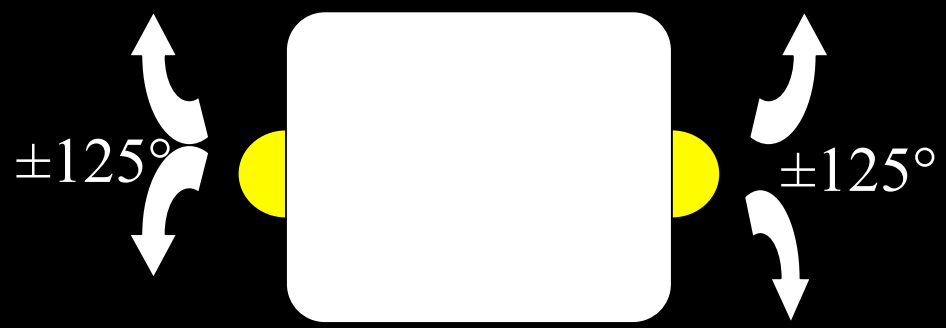
External Lights

Two types of lights made from the bundles

Non-movable



Limited Movement lights

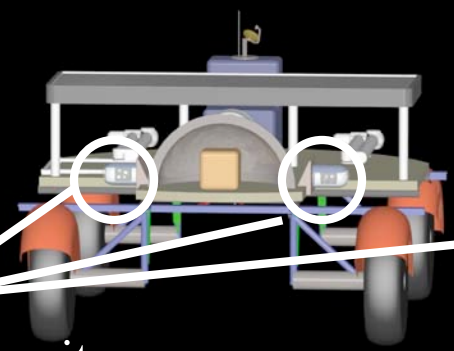


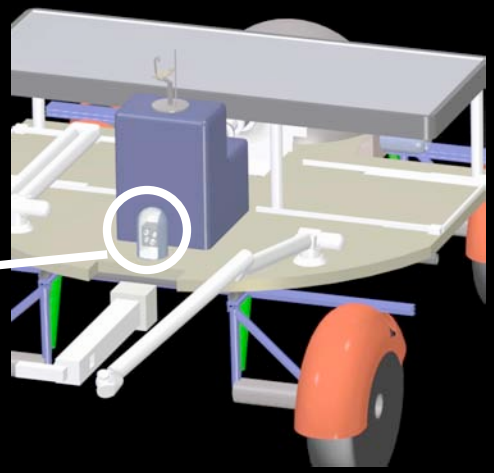
Limited Movement can also pitch up and down 35°

MORPHLAB

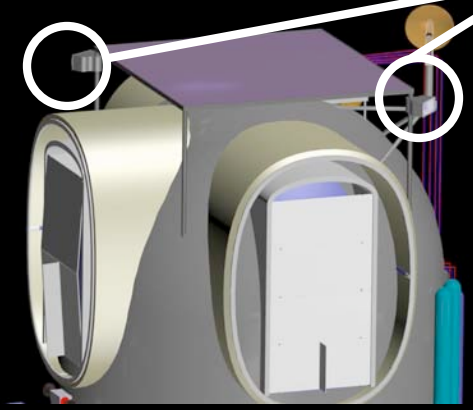
External Light Placement

Power module:
3 lights integrated with sensor suite





Power lights mounted with lidar suites



Lights mounted on Hab modules

Habitable module:
2 limited movement lights mounted on opposite sides

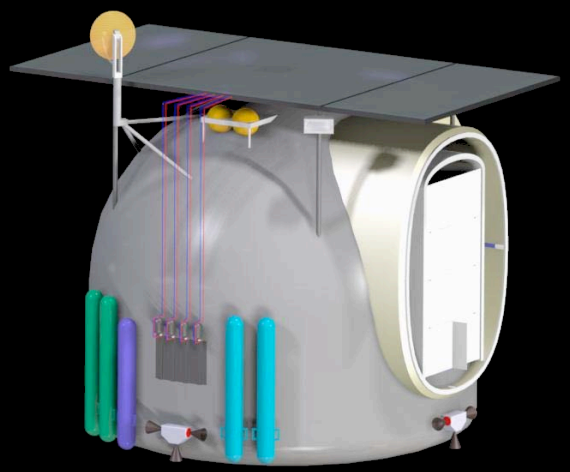
Robonaut on wheels: (not pictured)
1 mounted light

Rover (not pictured):
1 light mounted on a rotating mount

MORPHLAB

Module Mass Breakdown

Science Specialized:



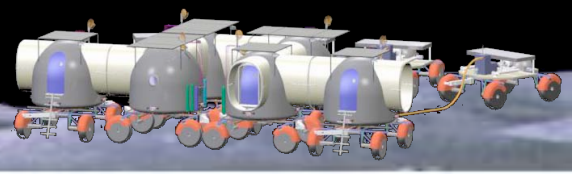
Habitable Modules

Living / Life Support	600 kg
Avionics	100 kg
Structural	1410 kg
Descent / Landing	180 kg
Power Systems	120 kg
Science Instruments	500 kg
Total	2910 kg
Margin	20%

Living Specialized:

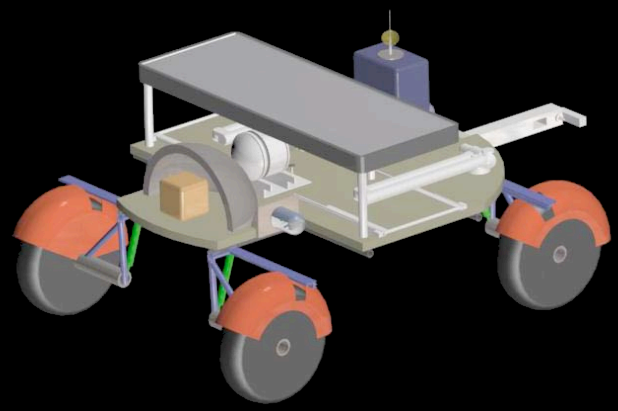
Living / Life Support	760 kg
Avionics	100 kg
Structural	1950 kg
Descent / Landing	180 kg
Power Systems	120 kg
Total	3100 kg
Margin	15%

Kevin Eisenhower, Daniel Senai & Luke Twarek



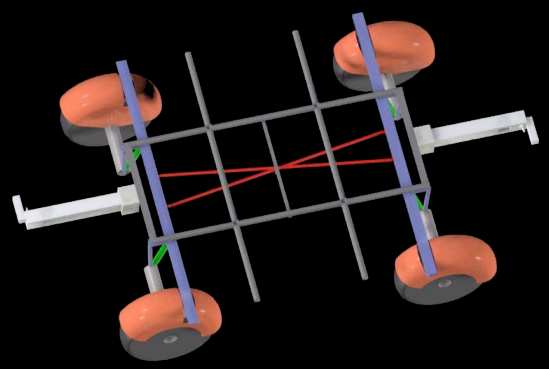
MORPHLAB

Module Mass Breakdown



Power Module

Avionics	200 kg
Structural	750 kg
Drive System	650 kg
Power Systems	240 kg
2 Robotic Arms	150 kg
Total	1980 kg
Margin	46%

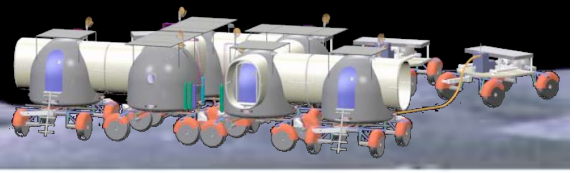


Chassis Module

Avionics	100 kg
Structural	650 kg
Transit Connections	200 kg
Drive System	650 kg
Power Systems	90 kg
Total	1480 kg
Margin	60%

University of Maryland
CDR 04/19/04

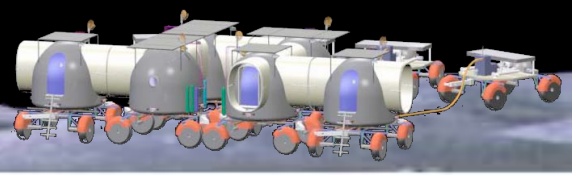
Kevin Eisenhower, Daniel Senai & Luke Twarek



MORPHLAB

Power Distribution

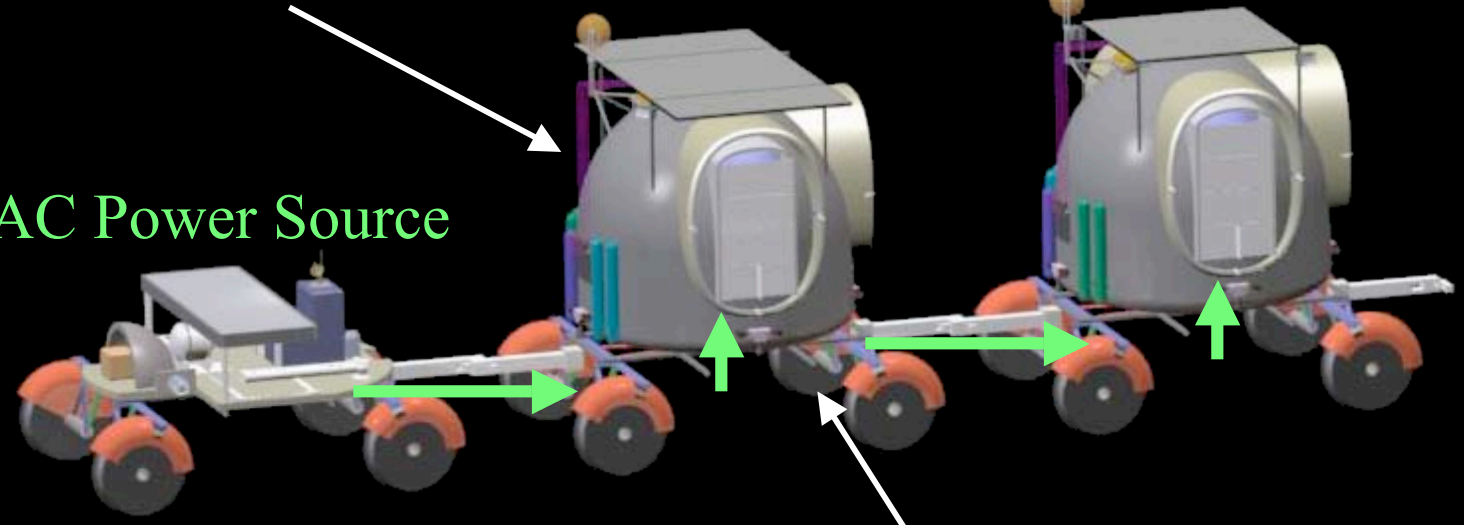
- Combination of AC and DC power
  - AC enables multiple base configurations while reducing switchgear
  - DC reduces development costs for electrical components by utilizing already developed components
  - Exact voltages and frequencies are still being determined to minimize power losses and reduce arcing potential



Power Connections & Distribution

MORPHLAB

Habitable Modules:
- AC/DC Rectifier
- Rechargeable Battery

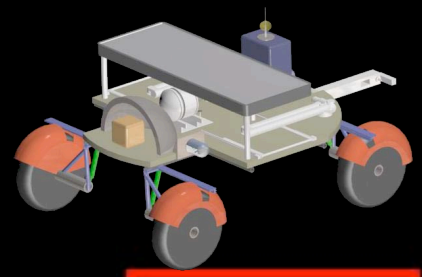


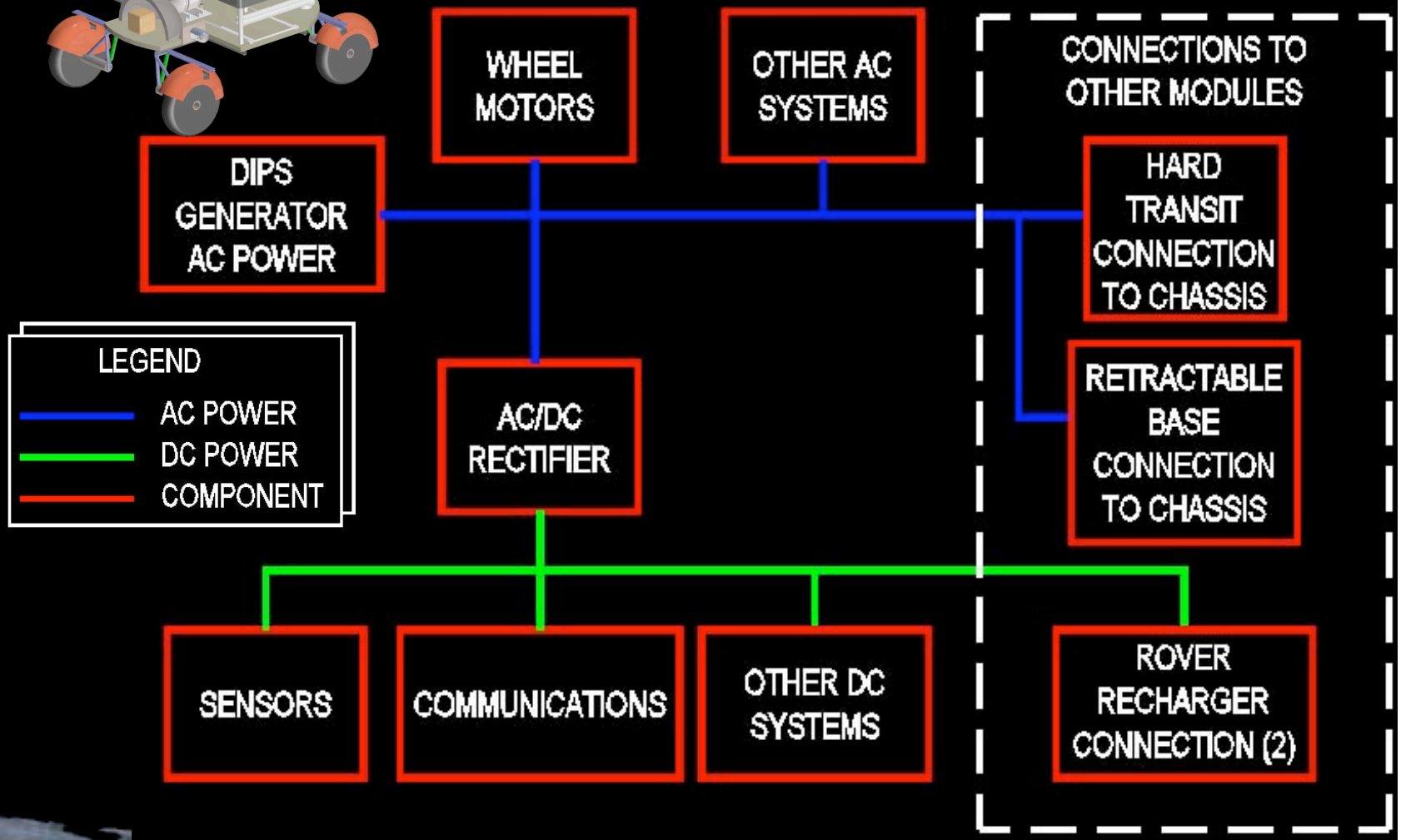
Power Modules:
- DIPS
- AC/DC Rectifier

Chassis Modules:
- AC/DC Rectifier
- Rechargeable Battery

MORPHLAB

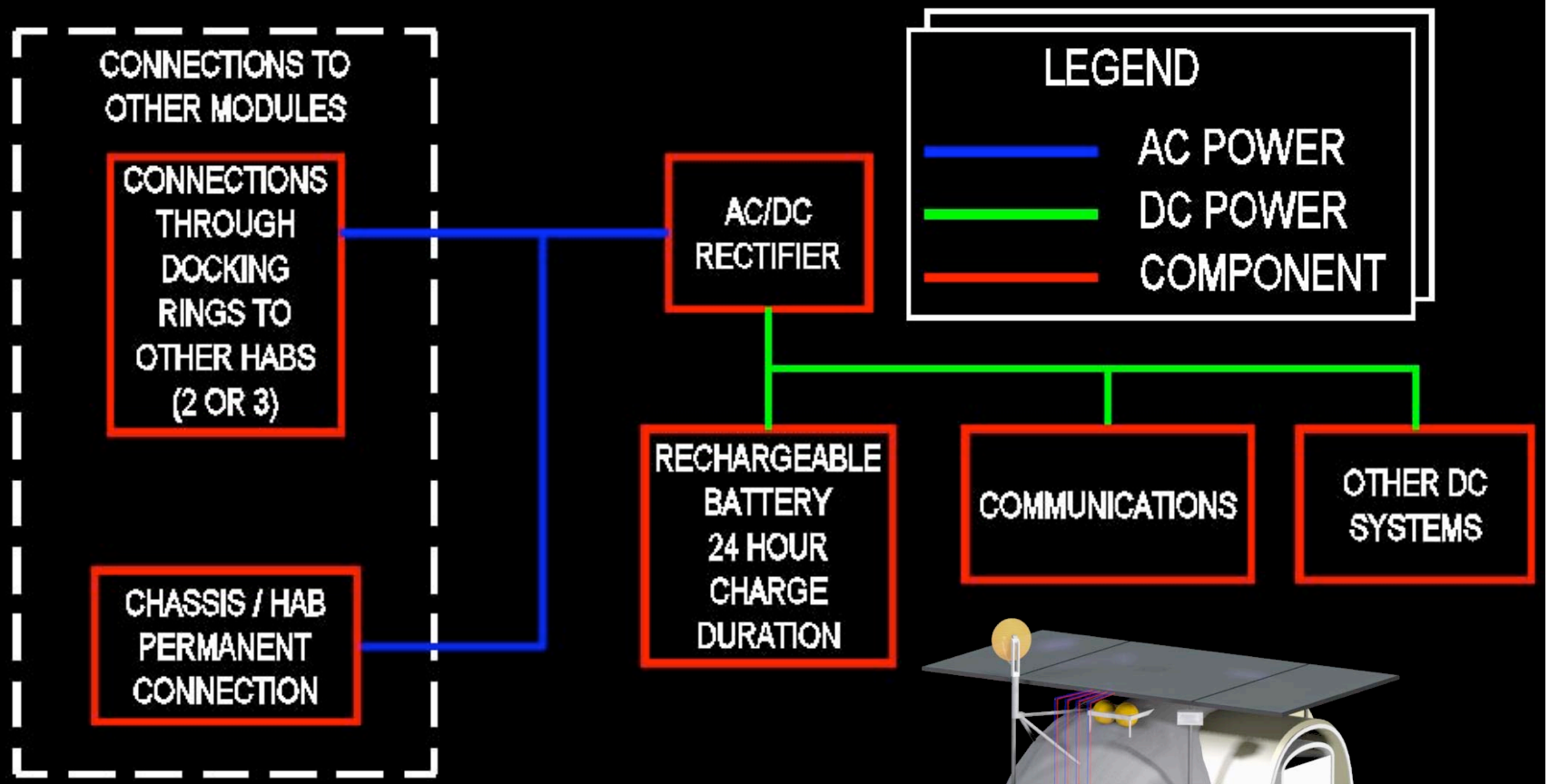
Power Module Power Layout

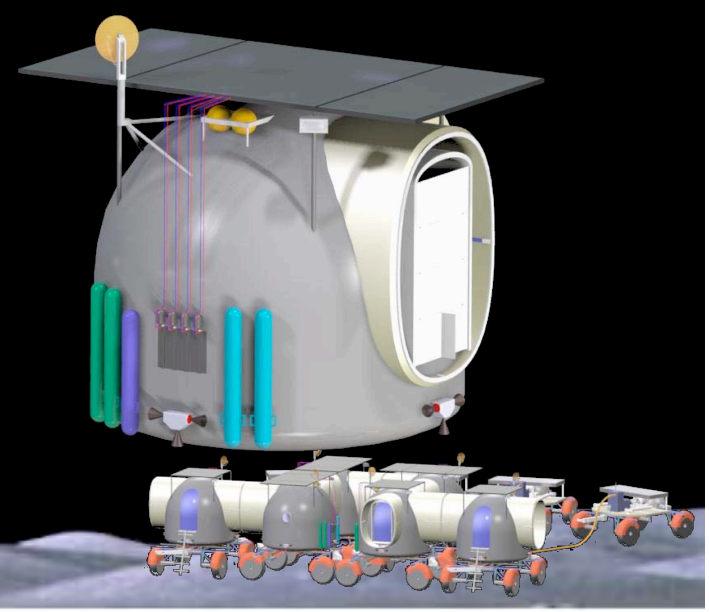




MORPHLAB

Habitable Module Power Layout

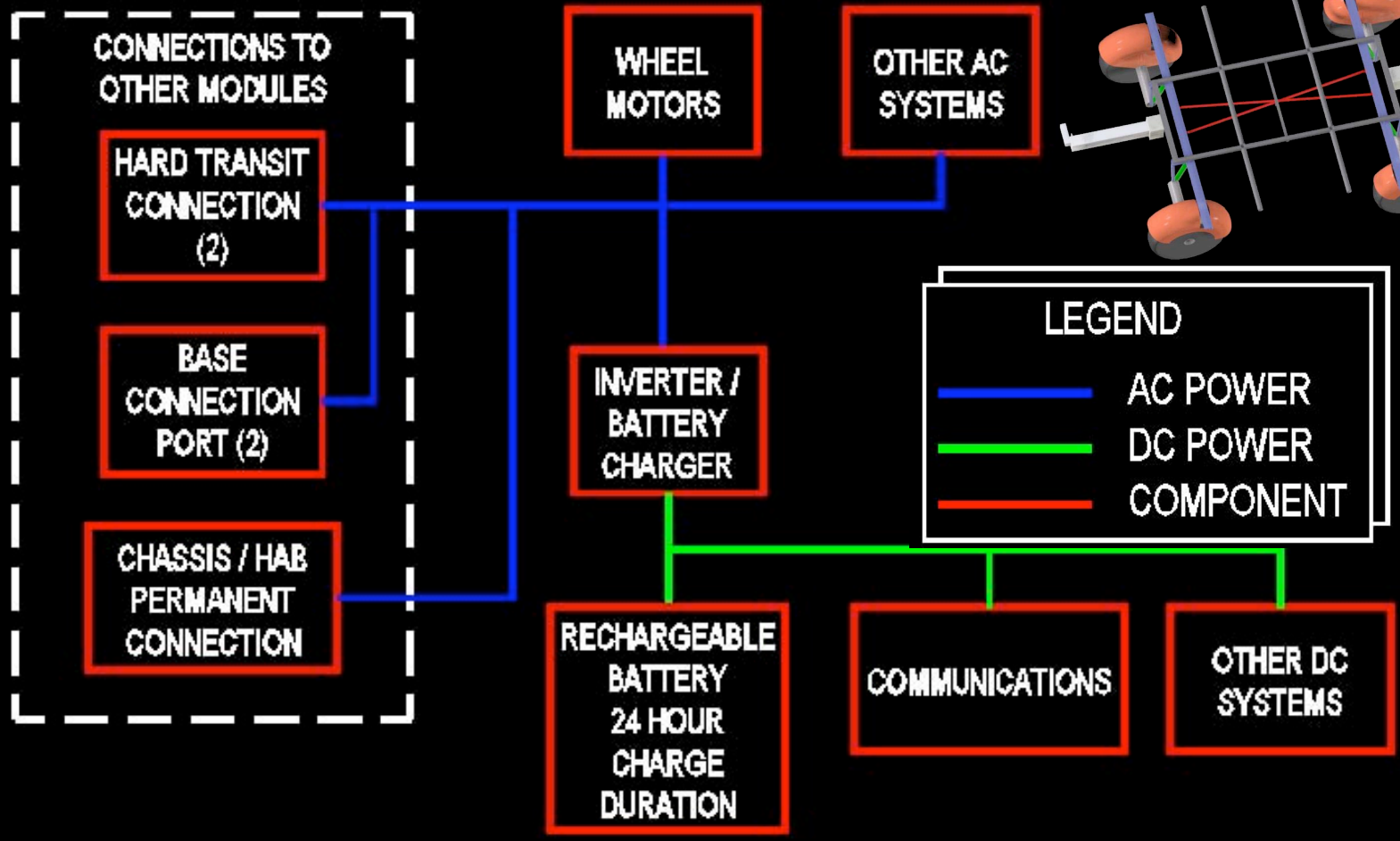




David Pullen

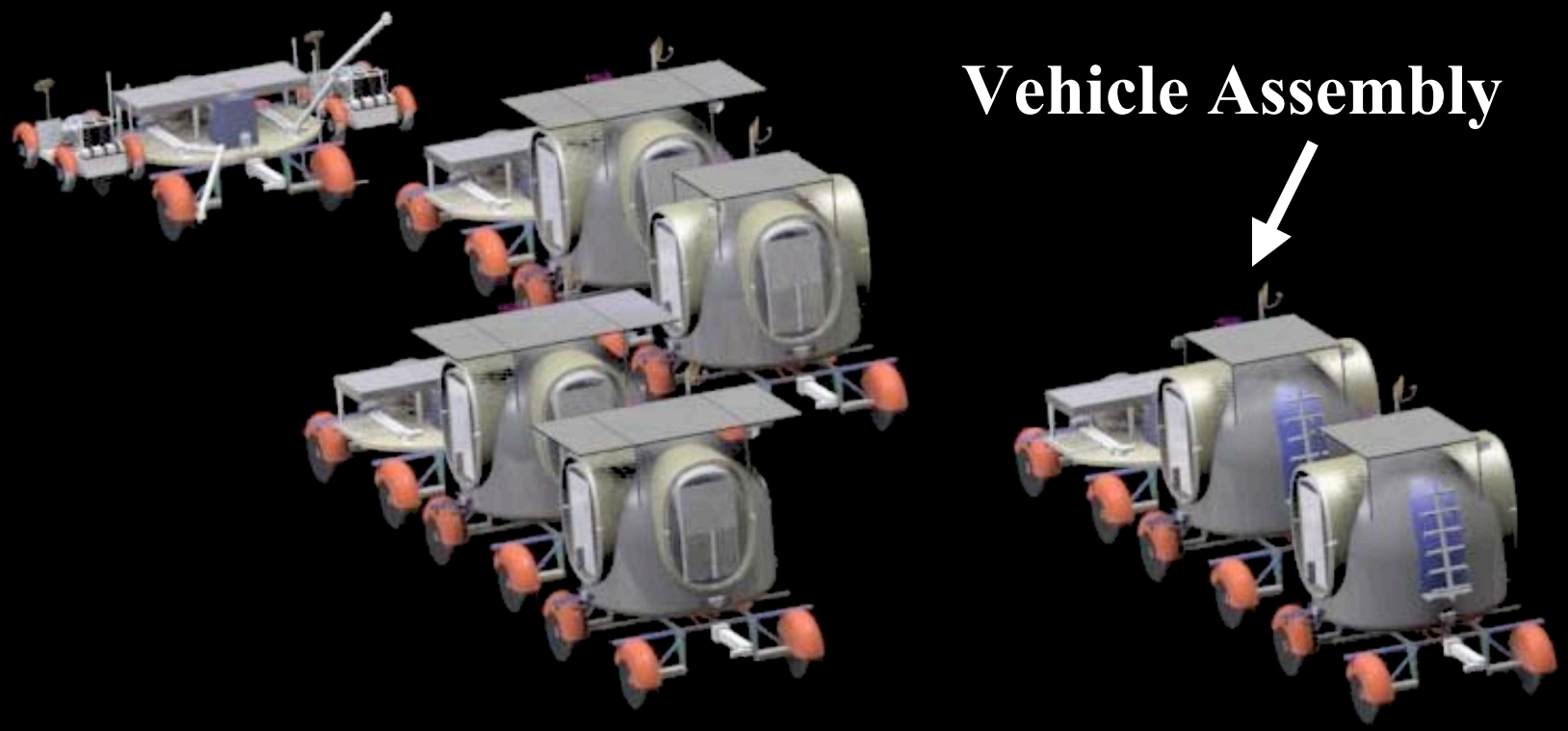
MORPHLAB

Chassis Module Power Layout



MORPHLAB

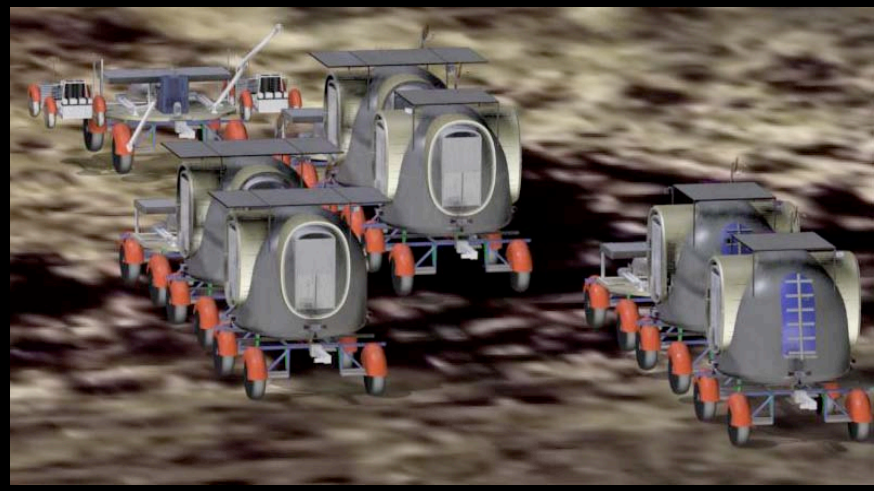
Unmanned Transit Phase

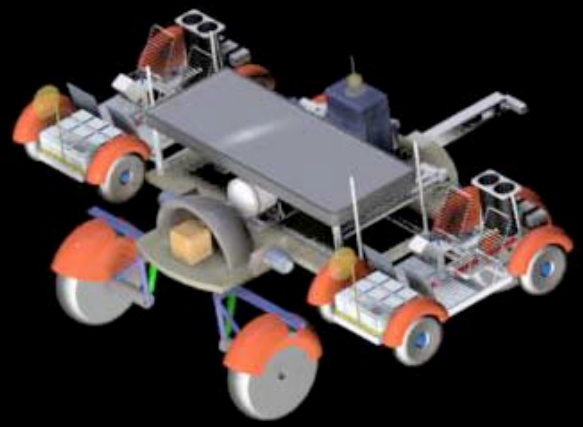


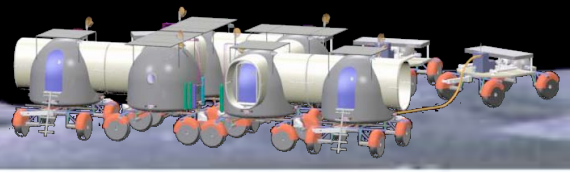
MORPHLAB

Transit Phase Overview

- After each manned mission, MORPHLAB will disassemble and travel autonomously to a new base site
- Enables the exploration and analysis of vast areas of the Lunar surface
- Science will be performed by the modules while traveling



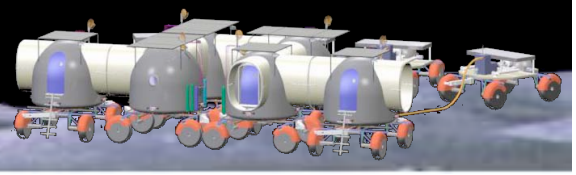




MORPHLAB

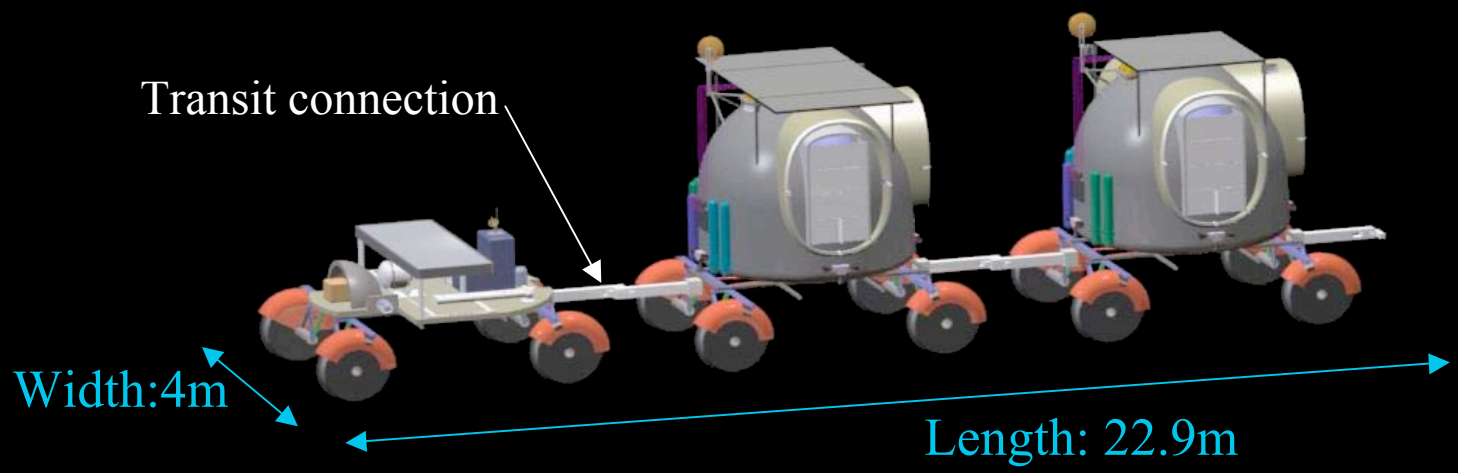
Transit Phase Topics

- Transit assembly layouts
- Mapping satellites
- Position determination & obstacle avoidance
- Transit power budgets
- Transit connections
- Steering
- Module control scenarios & failure modes
- Science performed in transit

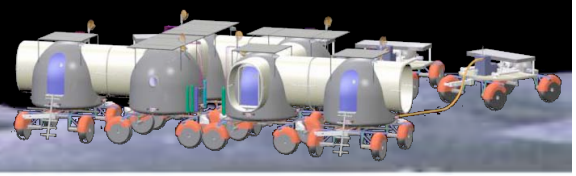


MORPHLAB

Vehicle Assembly



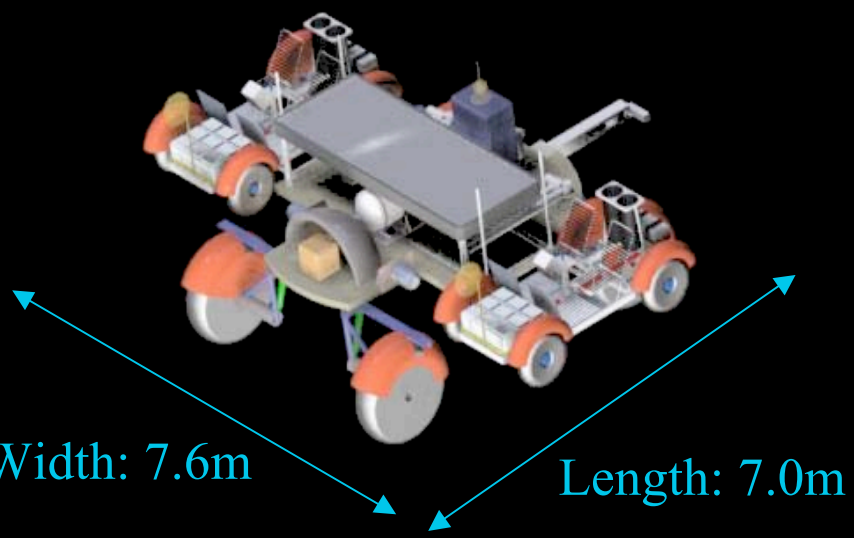
- 3 Vehicle Assemblies:
  - Each vehicle assembly consists of a power module and two habitable – chassis assemblies
  - The modules are joined through transit connections on the chassis
  - Power and data are transferred through the transit connections



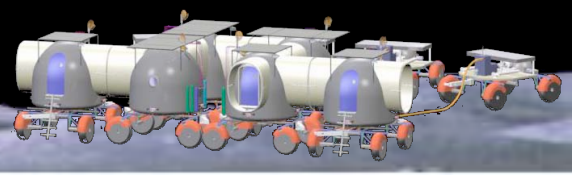
MORPHLAB

Vehicle Assembly

- Vehicle assemblies can take different paths to the next base site, expanding the area covered for scientific exploration



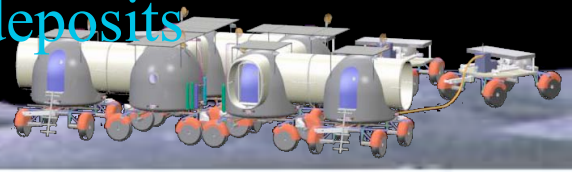
- 1 power module is dedicated to carry two lunar modules



MORPHLAB

Mapping Satellite

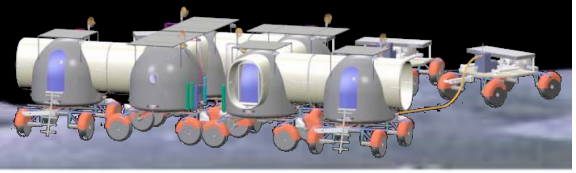
- Current lunar topographical information
  - Clementine LIDAR mapping mission
    - Resolution
      - Vertical: 40 m
      - Horizontal: 100 m
    - Cross-track measurement spacing: 40 km
    - In-track measurement spacing: 1 – 2 km
    - Coverage limited to ± 60° latitude
- Photography
  - Lunar Orbiters
    - Photographed 95% of the surface
    - Resolution up to .3 m
- Derived requirements
  - Courses must be plotted prior to departure
  - Polar regions need to be analyzed for topography and water ice deposits



MORPHLAB

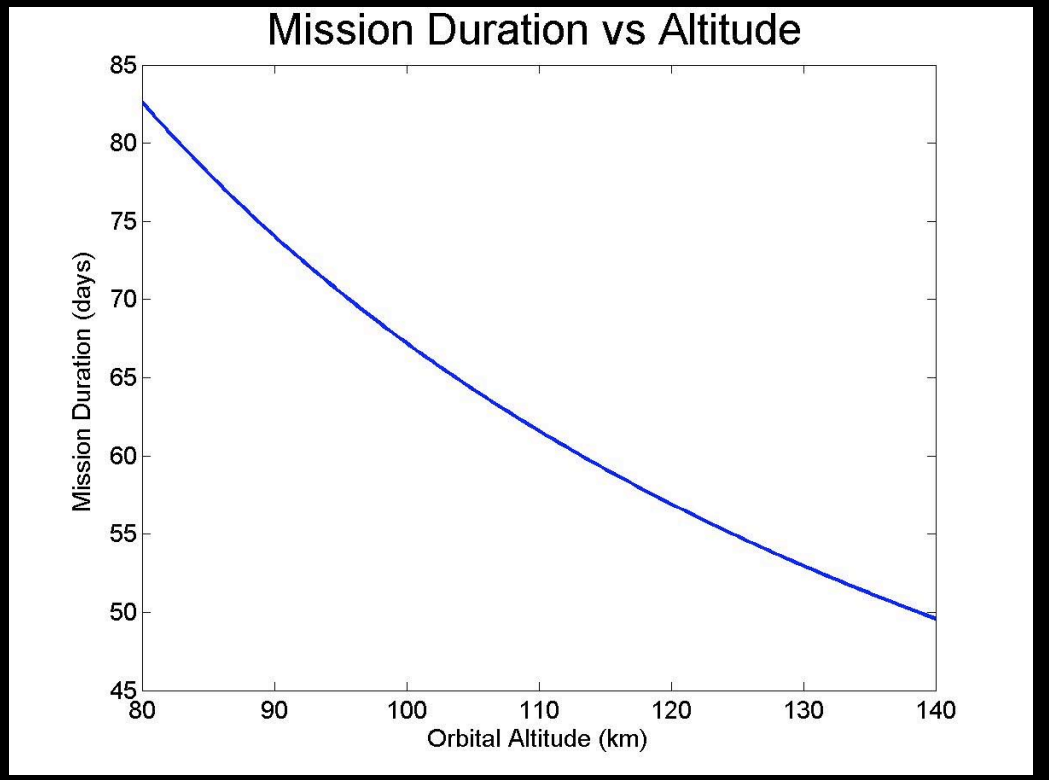
Mapping Satellite

- Specifications derived from Mars Global Surveyor (MGS)
  - MGS Narrow Angle Camera
    - Resolution: 1.4 m/pixel
    - Field of view (FOV) up to 2.9 km X 25.2 km
  - MGS LIDAR
    - Resolution
      - Vertical: 2 m
      - Horizontal: 160 m
    - 10 Hz sample rate
- Assumptions
  - Mission duration: 60 days
  - Circular Orbit
  - Tech capabilities scaled by 2x compared to MGS
  - Photographs
    - Taken on light side only
    - Resolution and FOV scaled linearly vs. altitude
  - LIDAR ranging
    - Taken on both sides
    - No across-track measurements



Mapping Mission Analysis

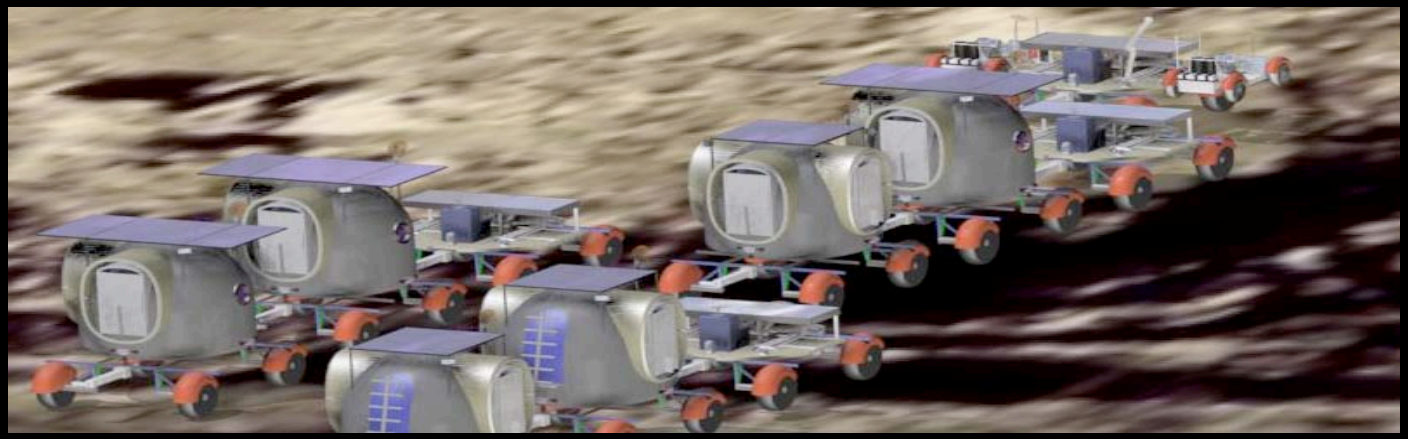
- Nominal mission duration: 60 days
- Altitude: 115 km
- Camera specs
  - Resolution: 20 cm
  - Field of View: 1.5km X 15 km
- LIDAR specs
  - 20 Hz sample rate
  - Measurements:
    - In-track: 76m
    - Cross-track: 15 km

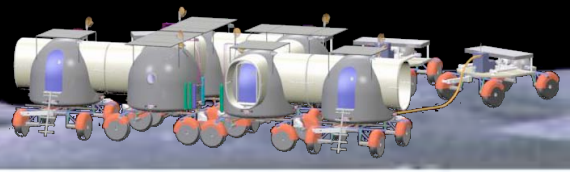


MORPHLAB

Position Determination

- **MORPHLAB must be capable of determining its position and attitude during its entire mission duration**
  - This will be accomplished with:
    - Inertial mass units (IMU)
    - Star trackers
    - Communications with other modules and Earth

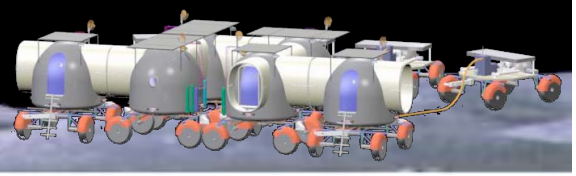




MORPHLAB

Position Determination

- Currently, IMUs and star trackers are used in many space applications for position and attitude determination
  - Current specifications will be sufficient to meet requirements
  - Specific systems used in MORPHLAB will be determined closer to the technology cutoff date
- Design constraints
  - Low Mass
  - High Reliability

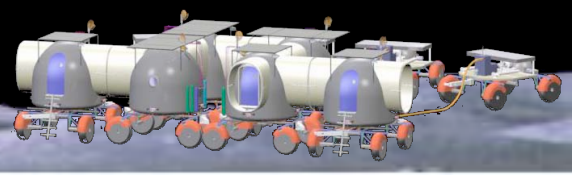


MORPHLAB

Position Determination

Current IMU specifications

- Source: Ball Aerospace
- Mass: 1.4 kg
- Power requirement: 6 W
- Gyro
  - Range: +/- 200 deg/sec
  - Bias: +/- 1 deg/hr
- Accelerometer
  - Range: +/- 12 g's
  - Bias: +/- 0.3 mg's
  - Clock: 10MHz
  - Activation time: 5 sec

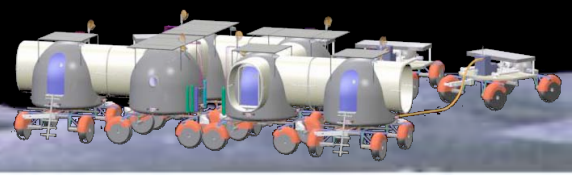


MORPHLAB

Position Determination

Current star tracker specifications

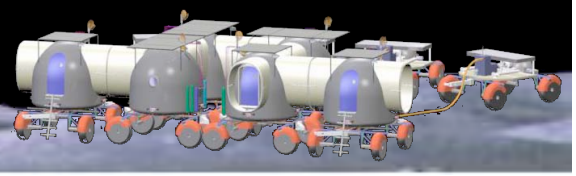
- Source: Ball Aerospace
- Mass: 2.5 kg
- Power requirements: 9W
- Angular accuracy: 40 arc sec
- Update rate: 10 Hz
- Field of view: 20° x 20°
- Catalog Size: 6000 stars



MORPHLAB

Obstacle Avoidance

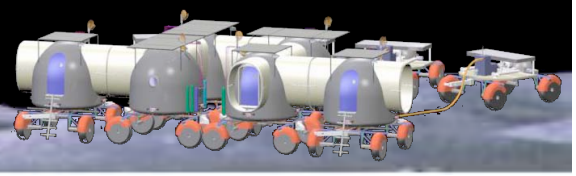
- Level 1 requirements
  - MORPHLAB must be capable of traversing obstacles smaller than 0.5 m
  - MORPHLAB must be capable of traversing slopes up to 20° cross-slope or 30° direct slope
- Derived requirements
  - Sensors must be capable of resolving a 0.5 m obstacle at a distance of no less than 7 m away
  - Transits must be plotted prior to departure to ensure paths are free of large obstacles or slopes over the entire route



MORPHLAB

Obstacle Avoidance

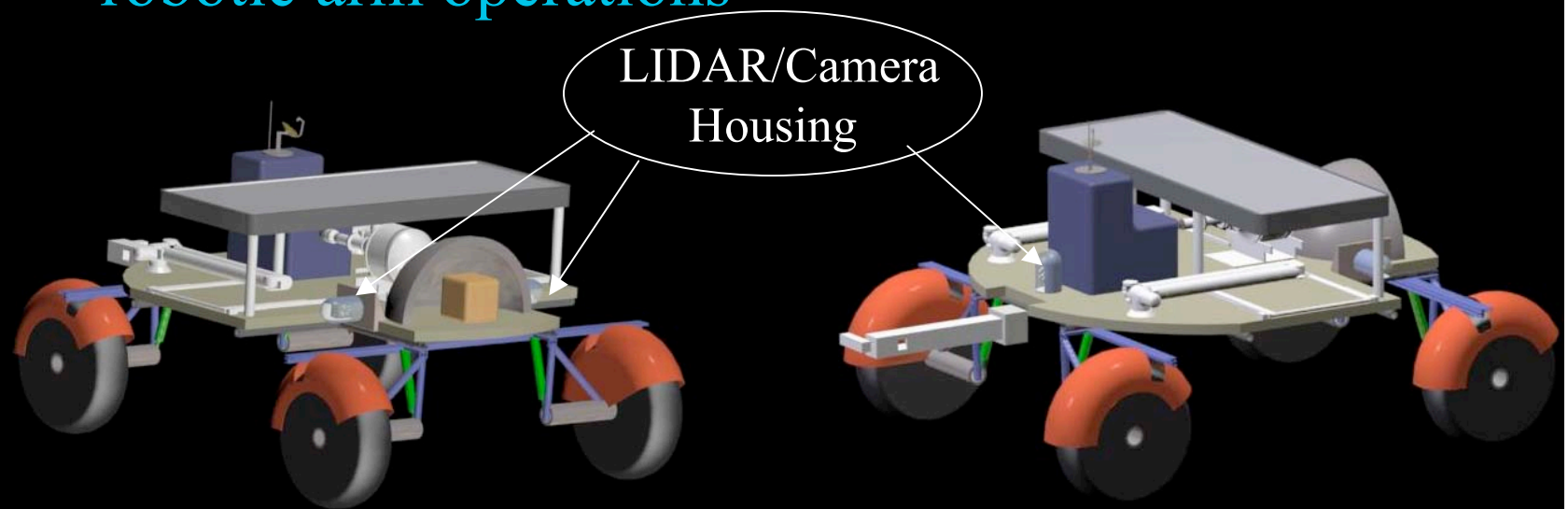
- Rough course will be determined from Earth by analyzing mapping satellite data prior to mission start
- Small obstacles will be located and avoided in real-time using on-board sensor suites
  - Power module sensor systems
    - Laser imaging radar (LIDAR) – resolves obstacles regardless of lighting
    - Video cameras – provide visual images for teleoperation / supervisory control
  - All other modules will be controlled by the power modules via communications links



MORPHLAB

Obstacle Avoidance

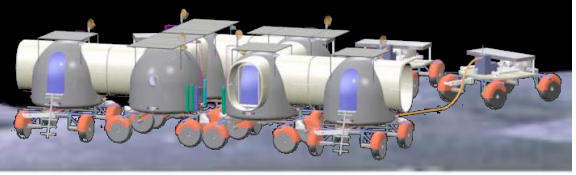
- Power modules will have 3 complete sensor suites
  - Mounted on gimbals in rotating assemblies
    - Azimuth range of vision: 360°
    - Elevation range of vision: 180°
  - One sensor is located in the rear, dedicated to robotic arm operations



MORPHLAB

Obstacle Avoidance

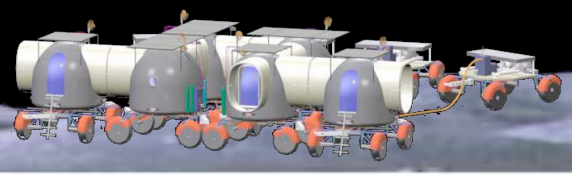
- Current LIDAR specifications
  - Mass: 3.6 kg x 3 = 10.8 kg
  - Power requirement: 16 W x 3 = 48 W
  - Pulse duration: 8 ns
  - Measurement rate: 12 kHz
  - Distance range: 0 – 250 m
  - Accuracy: +/- 6 mm
  - Acquisition time: 2 sec
- Current video camera specifications
  - Mass: 0.3 kg x 3 = 0.9 kg
  - Power requirements: 3 W x 3 = 9 W
  - Image: 1024 x 1024 pixels



MORPHLAB

Obstacle Avoidance

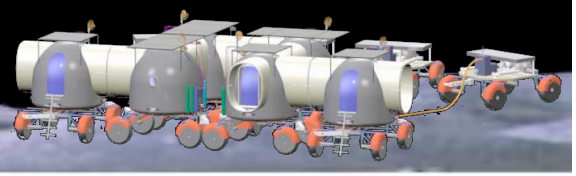
- The following conditions must be known or monitored:
  - Situational awareness
    - State of own vehicle
      - Current speed / acceleration
      - Position on surface
      - Adherence to planned route
      - Reaction time of human or computer in control
    - State / model of nearby objects / environment
      - Location and classification of object
      - Patterns of transit hindering objects and lighting distortions
  - Processing and algorithms
    - What situation are we in?
    - How likely is a collision?
    - How dangerous is the situation?
    - Is an action needed?



MORPHLAB

Obstacle Avoidance

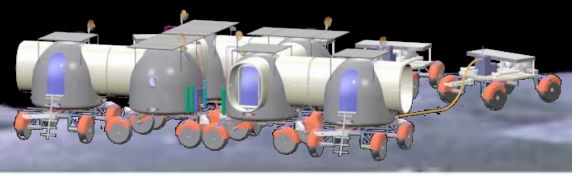
- System response
  - Human or on-board computer senses a transit hindering obstacle via sensor systems
  - Collision warnings
    - Audio and visual warning alert user of a likely collision
    - Vehicle comes to a stop
  - Collision avoidance
    - Steering and speed of vehicle altered to avoid obstacle



MORPHLAB

Operational Requirements

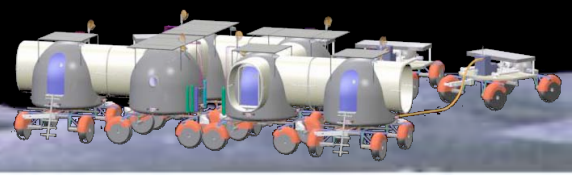
- **Level 1 requirements:**
  - Systems onboard MORPHLAB shall be capable of operating in any of the following control modes for any or all of the nominal mission segments:
    - On-board direct human control
    - Teleoperation
    - Supervisory control
    - On-board autonomous control
- **Derived requirements**
  - A human operator shall be able to take over the control of the vehicle from Earth and teleoperate if a critical situation arises (e.g. less than 0.01m from an approaching boulder larger than 0.5 m in height)
  - If an obstacle is observed, but the planned trajectory does not avoid the obstacle, supervisory control shall be implemented to avoid obstacle.



MORPHLAB

Teleoperation and Supervisory Control

- Some situations may arise that will force MORPHLAB out of autonomous control and into either supervisory or teleoperational control
- Supervisory – operation via preprogrammed sequence of events from Earth followed by the execution of these commands by MORPHLAB
  - Shall be implemented if MORPHLAB detects a potential problem that cannot currently be avoided via autonomous control
  - Reliant on accuracy of on-board computers
- Teleoperation – operation of MORPHLAB from Earth
  - Shall be implemented if MORPHLAB senses an unavoidable object
  - Ground user shall take over control, navigate around object, and return MORPHLAB to autonomous control
  - Reliant on accuracy of navigational equipment
- Teleoperation and supervisory control modeled from previous Earth, Mars and Lunar exploration missions: Dante II, NOMAD, Sojourner, Lunakhod

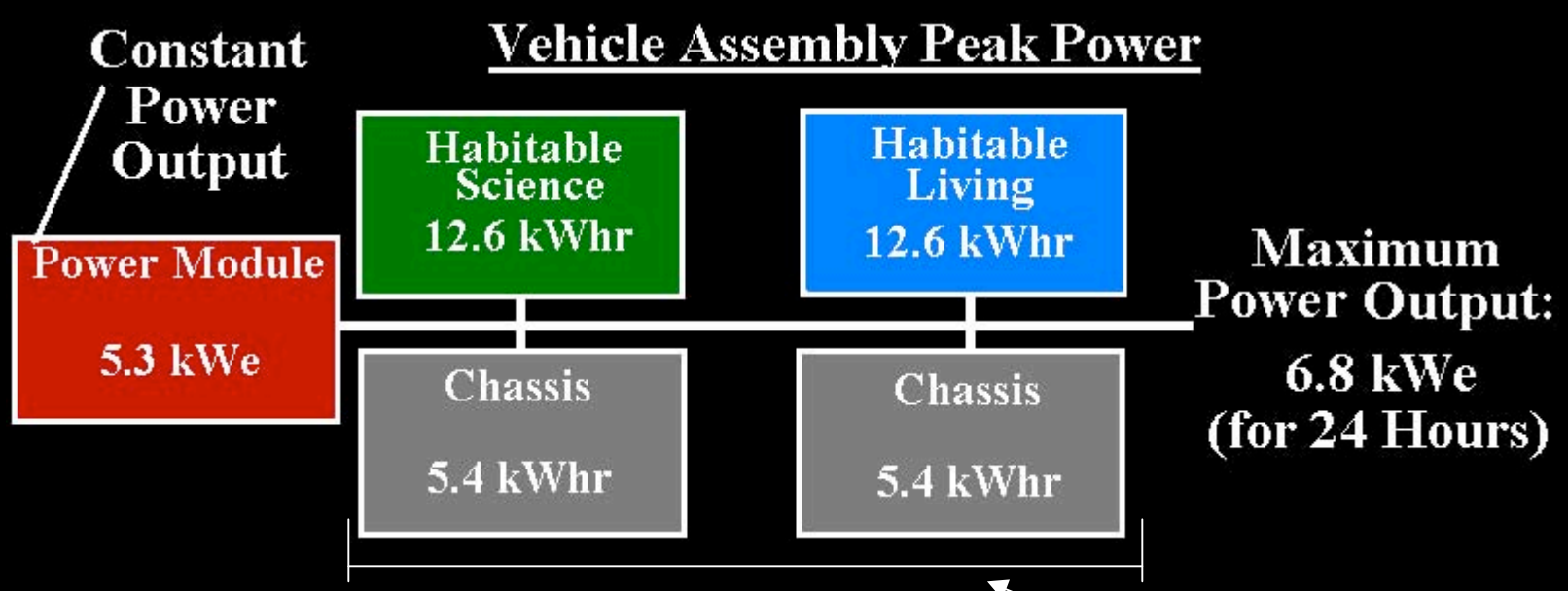


Transit Peak Power System

Li-Ion Battery Banks:

•Sized to provide 24 hours of standby power to an unmated module

•Under high system loads when modules are linked, battery resources can be pooled to meet peak power needs



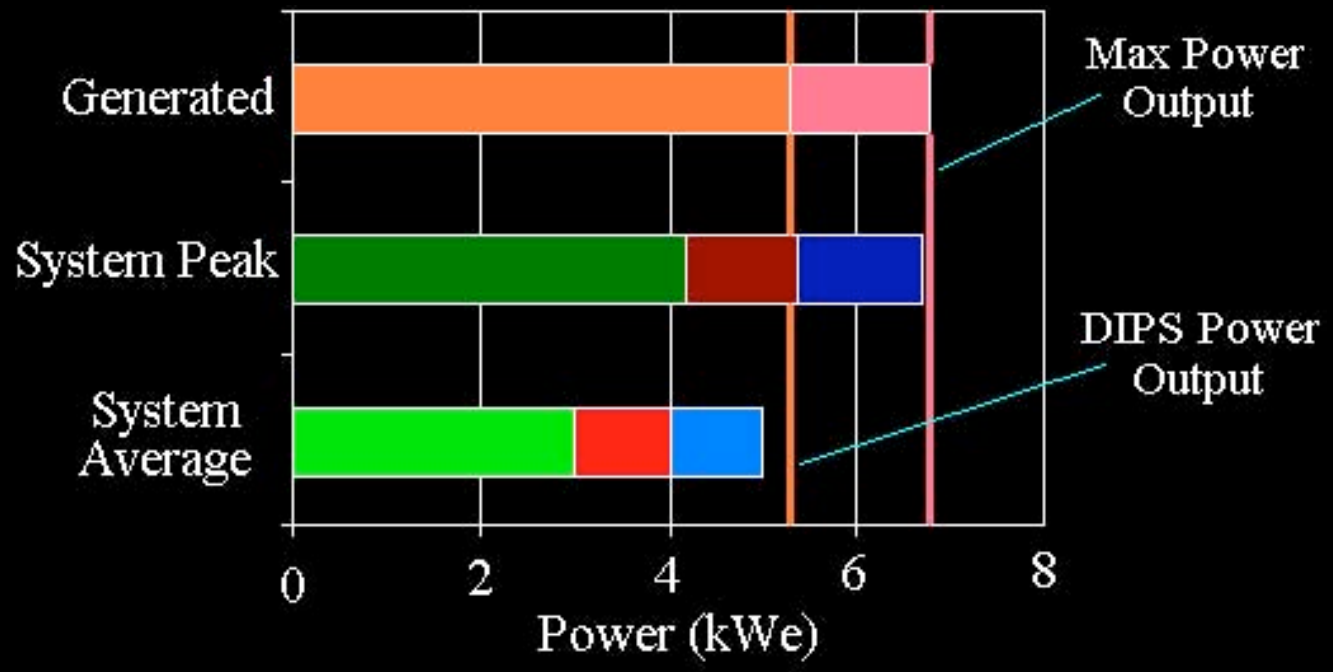
Habitable Module: 101 kg Li-Ion Bank

Chassis: 44 kg Li-Ion Bank

Short Term Power

MORPHLAB

Vehicle Assembly Power Budget



Generated Power

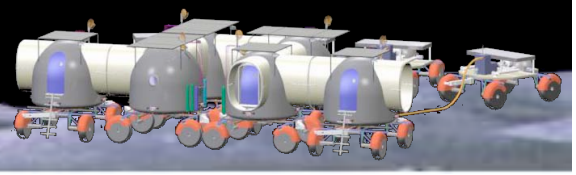
DIPS	5.3 kWe
Battery	1.5 kWe
Total	**6.8 kWe**

Vehicle Assembly System Average

Locomotion	3 kWe
Thermal Control	1 kWe
Avionics	1 kWe
Total	**5 kWe**

Vehicle Assembly System Peak

Locomotion	4.2 kWe
Thermal Control	1.2 kWe
Avionics	1.3 kWe
Total	**6.7 kWe**



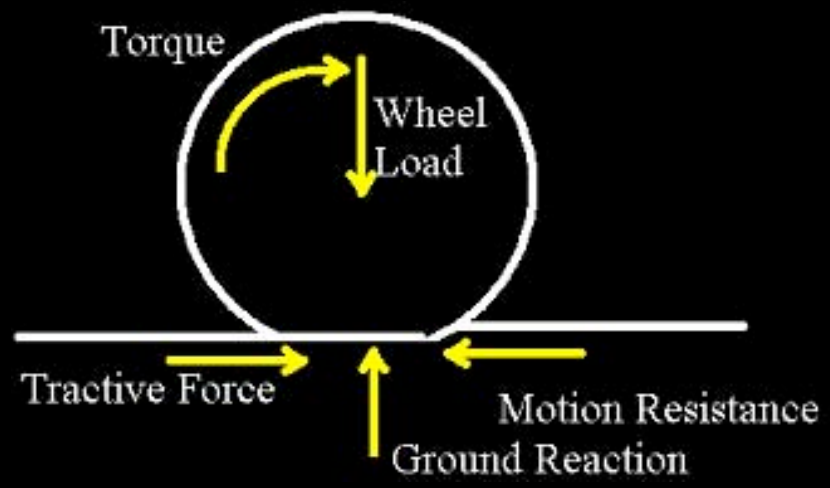
MORPHLAB

Locomotion Resistive Forces

- Soil Compaction Resistance R_c = func.(wheel width, soil properties, wheel sinkage)
- Bulldozing Resistance R_b = func.(wheel width, soil properties, terrain slope)
- Rolling Resistance R_r = func.(soil properties, wheel loading)
- Gravitational Resistance R_g = func.(wheel loading, terrain slope)

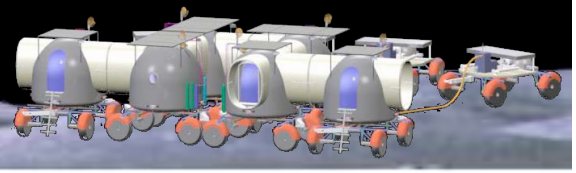
Forward Motion:

Tractive Force > Motion Resistance



Assumptions:

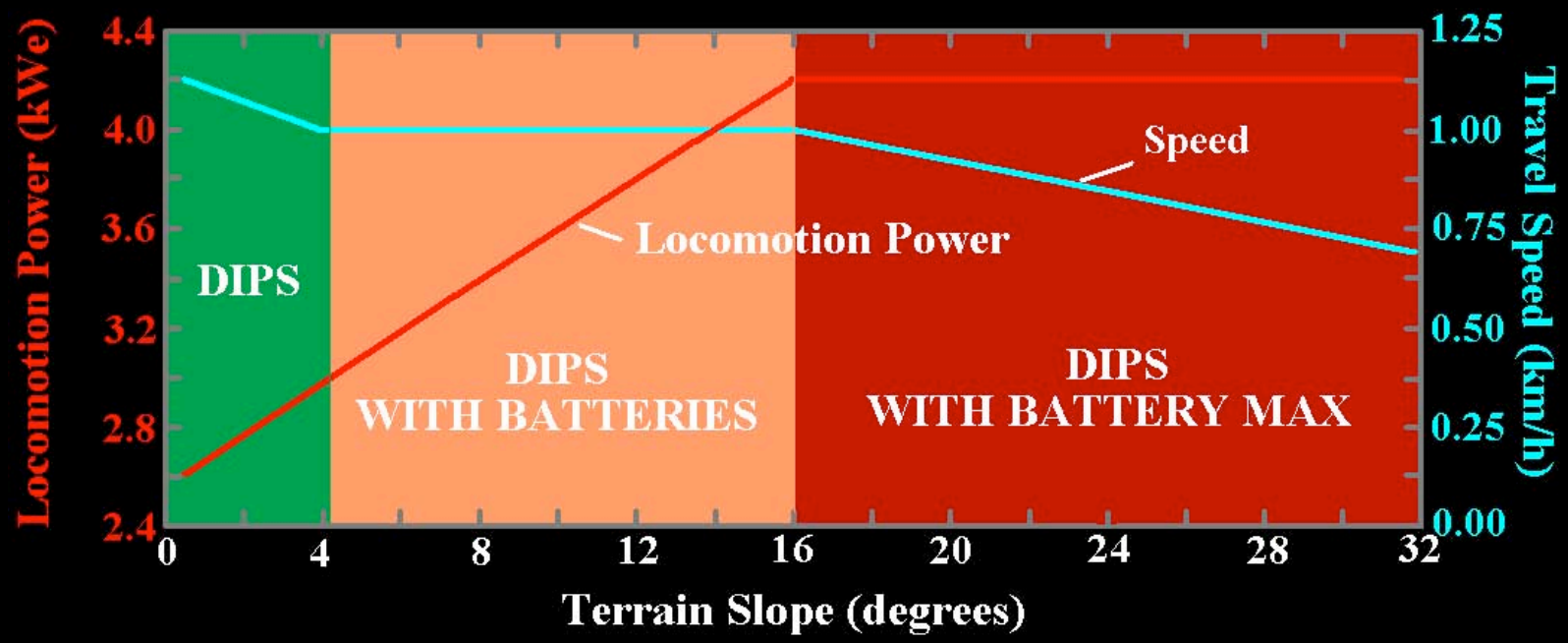
- Maximum chassis wheel load = 1962 N
- Maximum power module wheel load = 1430 N
- Terrain slope will not exceed 30 degrees
- Rolling friction is estimated as 0.2 (comparable to firm sand)



MORPHLAB

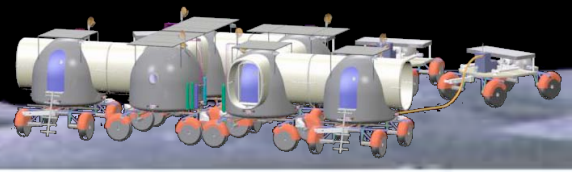
Transit Power Usage

Component	Max Power/Wheel	Max Motion Power (4 wheels)
Chassis	375 W	1.5 kWe
Power Module	300 W	1.2 kWe
Vehicle Assembly	-	4.2 kWe



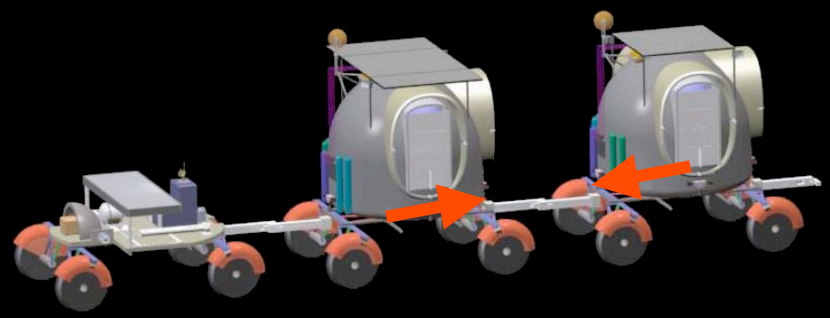
<u>0º - 16 º slope</u> :
Transit Speed 1.2 - 1 km/h

<u>16 º - 30 º slope</u> :
Transit Speed 1 - 0.7 km/h

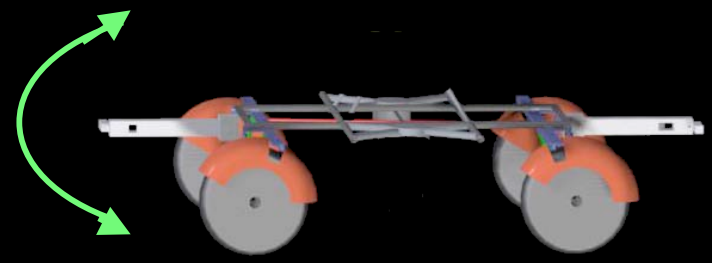


MORPHLAB

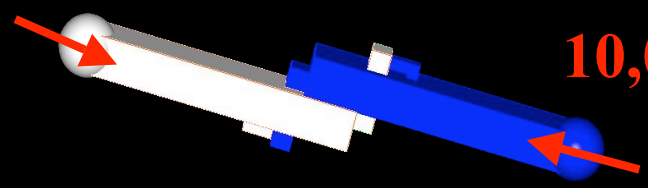
Transit Connection



Ball joint rotates
± 30° up/down

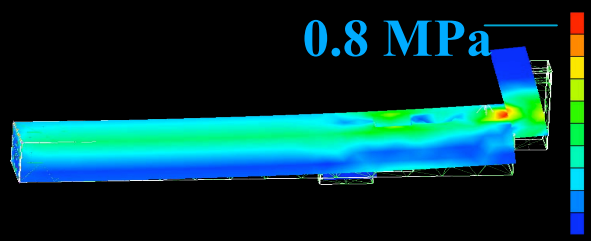


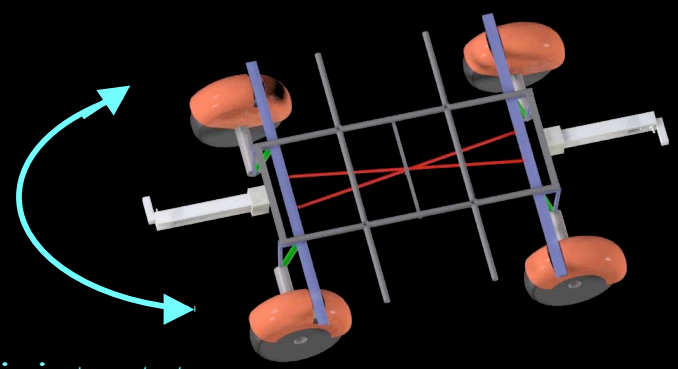
10,000N



10,000N

0.8 MPa





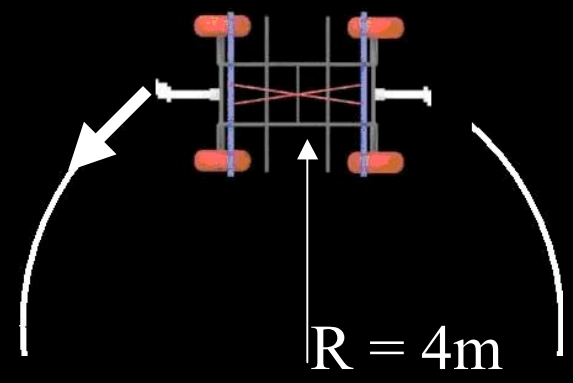
Ball joint rotates
± 45° left/right

Kevin Eisenhower

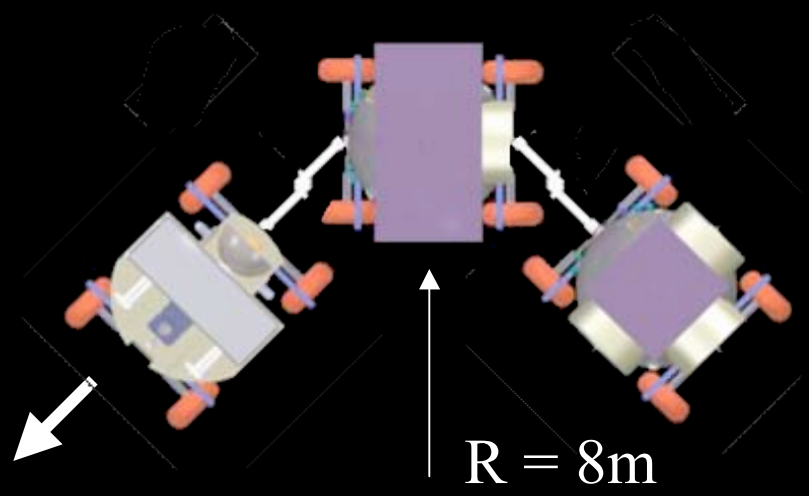
MORPHLAB

Turning Capabilities

- True Double-Ackerman Design:
  - Back Wheel/Front Wheel turn angle ratio of 1
- Turning radius for single module:
  - Wheelbase Length: 4.2m.
  - Wheelbase Width: 3.3m.
  - Wheel turn Angle: 30 deg.
  - **TURN RADIUS = 4m**



- Turn radius for single vehicle assembly:
  - Total vehicle length: 20m.
  - Total vehicle width: 3.3m.
  - Wheel turn Angle: 30 deg.
  - **TURN RADIUS = 8m**

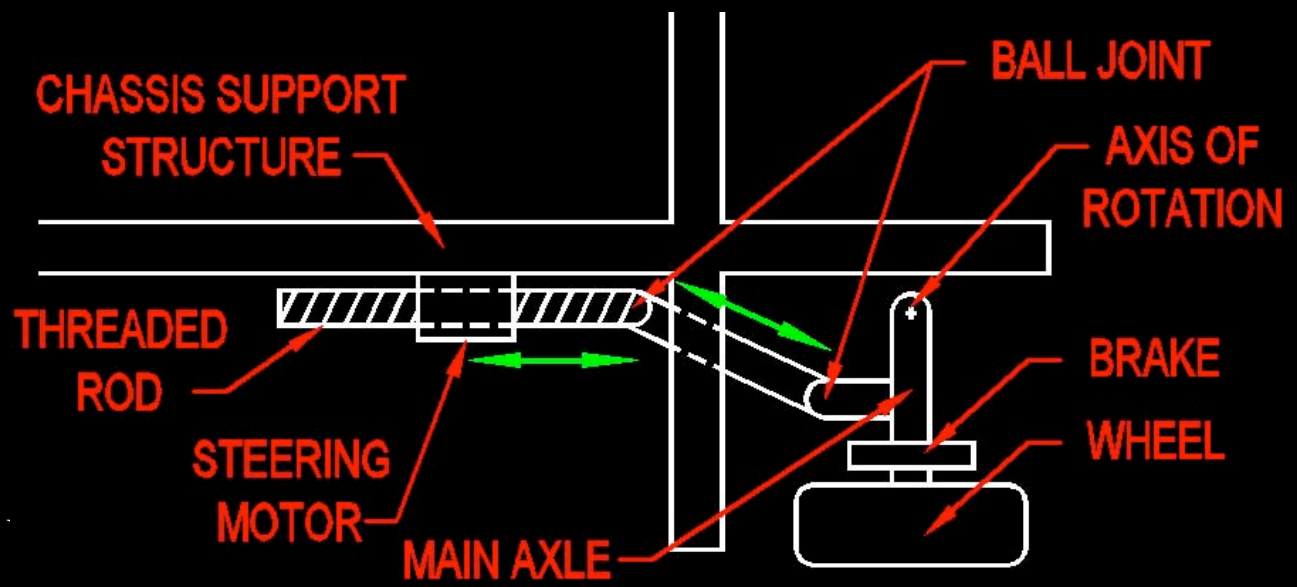


Note: Figures not to scale

MORPHLAB

Steering Mechanism

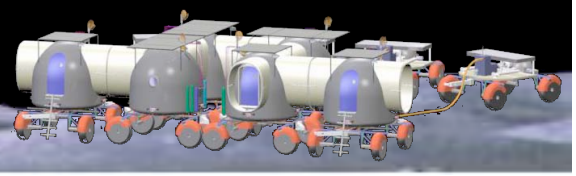
- Modified rack-and-pinion system
- Four-wheel steering with independent motors
- Allows modules to rotate with no translation
- Lunar dust effect on steering is a major concern



Top

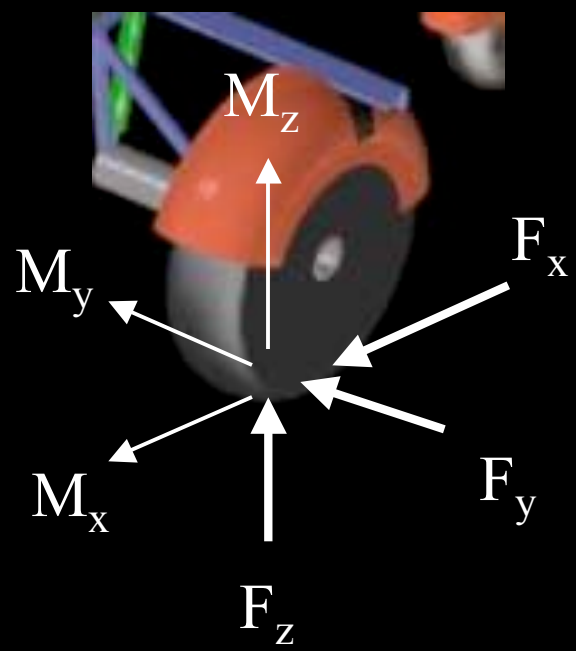
Note: Figure not drawn to scale

Abe Daiub, Daniel Senai



MORPHLAB

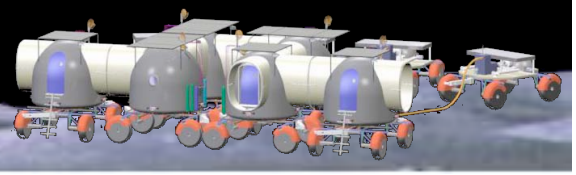
Steering Mechanism



* Assumed slow motion

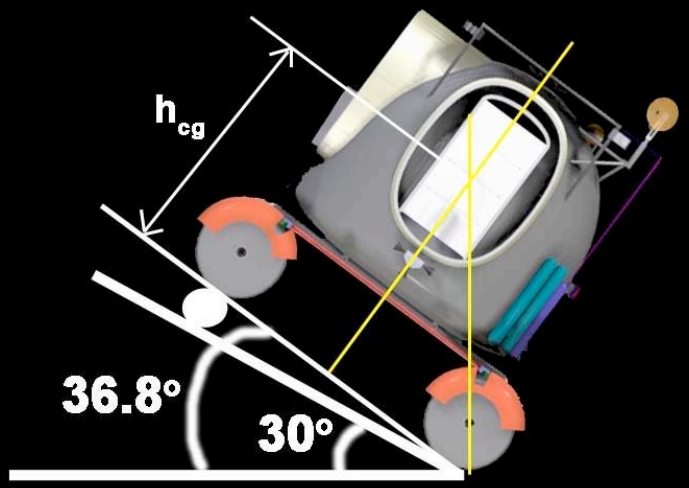
Torque due to:	(N-m)
Vertical Force (F_z)	-48
Lateral Force (F_y)	0*
Tractive Force (F_x)	50
Aligning Torque	30
Rolling Resistance Torque	0
Overturning Torque	0
Net Torque feedback to Steering System	**20**

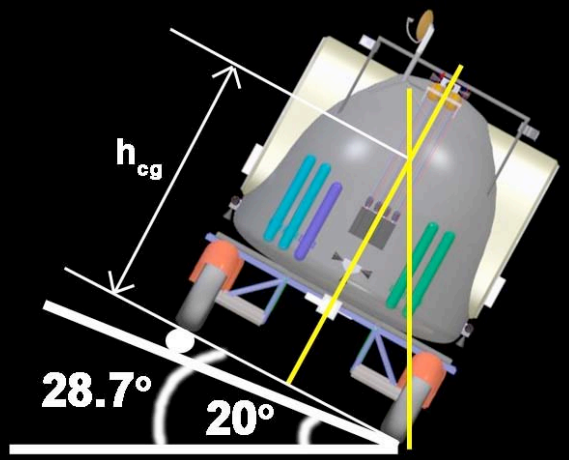
Abe Daiub, Daniel Senai



MORPHLAB

Slope Traversal





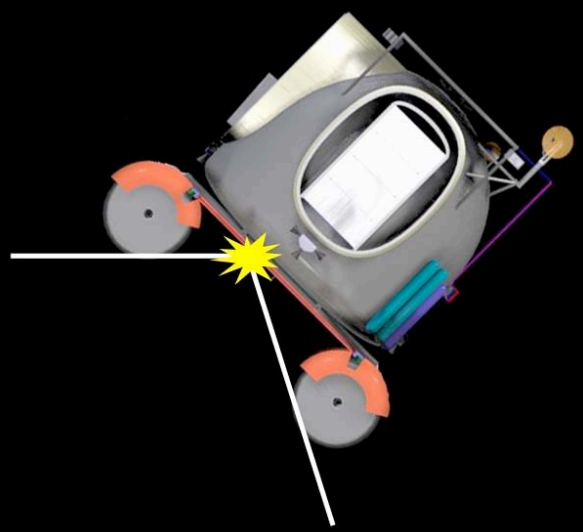
- Level 1 Requirements
  - 30 degree direct slope
  - 20 degree cross slope
  - 0.5 meter obstacle

- Max direct angle: 36.8º
- Max cross angle: 28.7º
- Max C.G.: 2.80 m

MORPHLAB

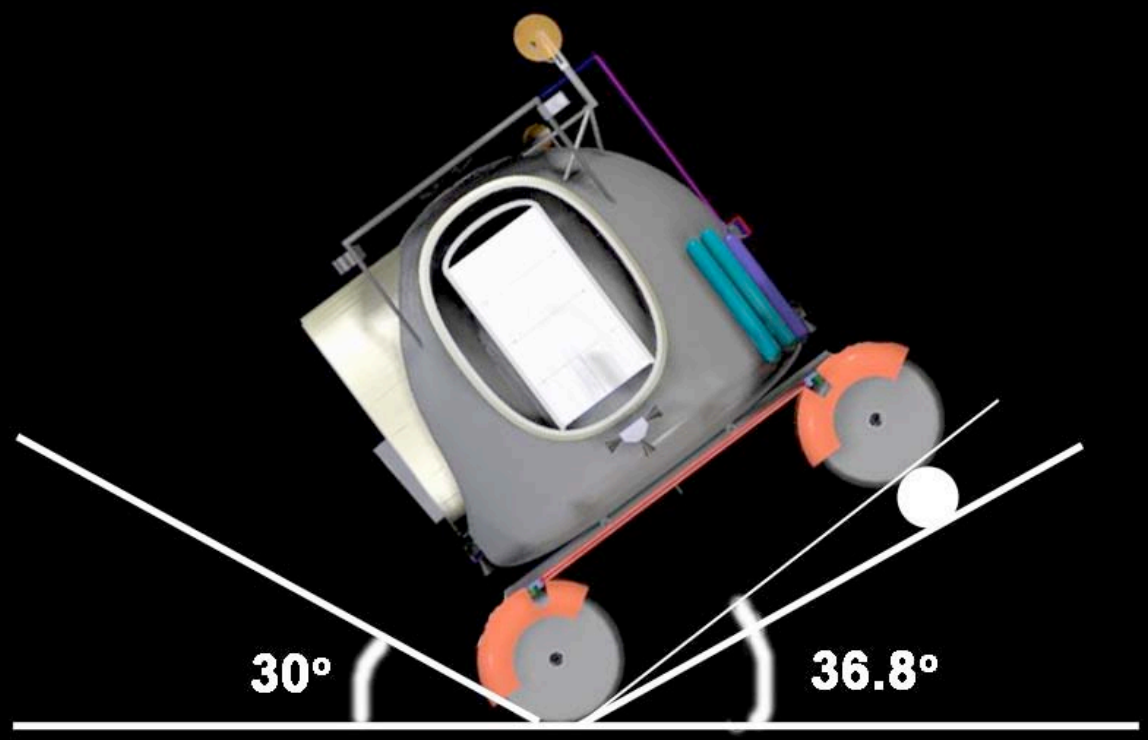
Hang-Up Failure

- Vehicle ground clearance: 1.35 m
- Clearance Requirements
  - 30º direct slope
    - 0.542 m (up-slope to flat)
    - 1.10 m (up-slope to down-slope)
  - 20º cross slope
    - 0.2845 m (up-slope to flat)
    - 0.562 m (up-slope to down-slope)



MORPHLAB

Nose-In Failure

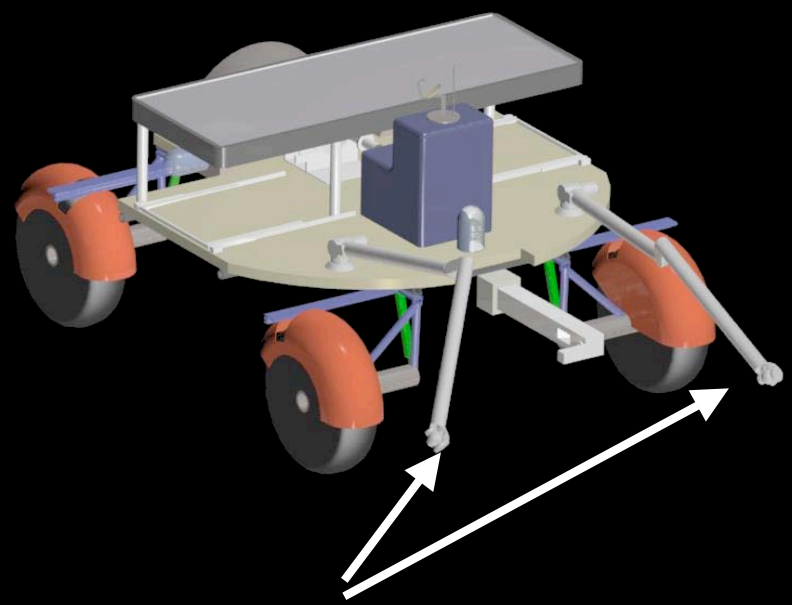


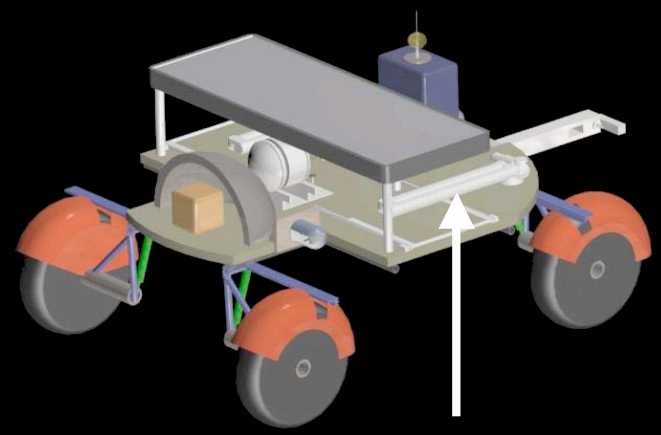
Vehicle overhang from wheel base < wheel radius

Nose-In Failure is not a concern

MORPHLAB

Science in Transit

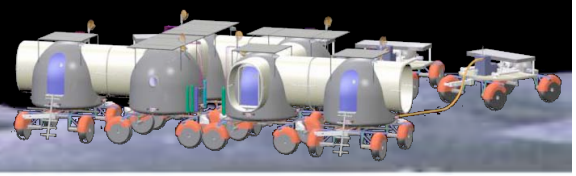




Arms stowed

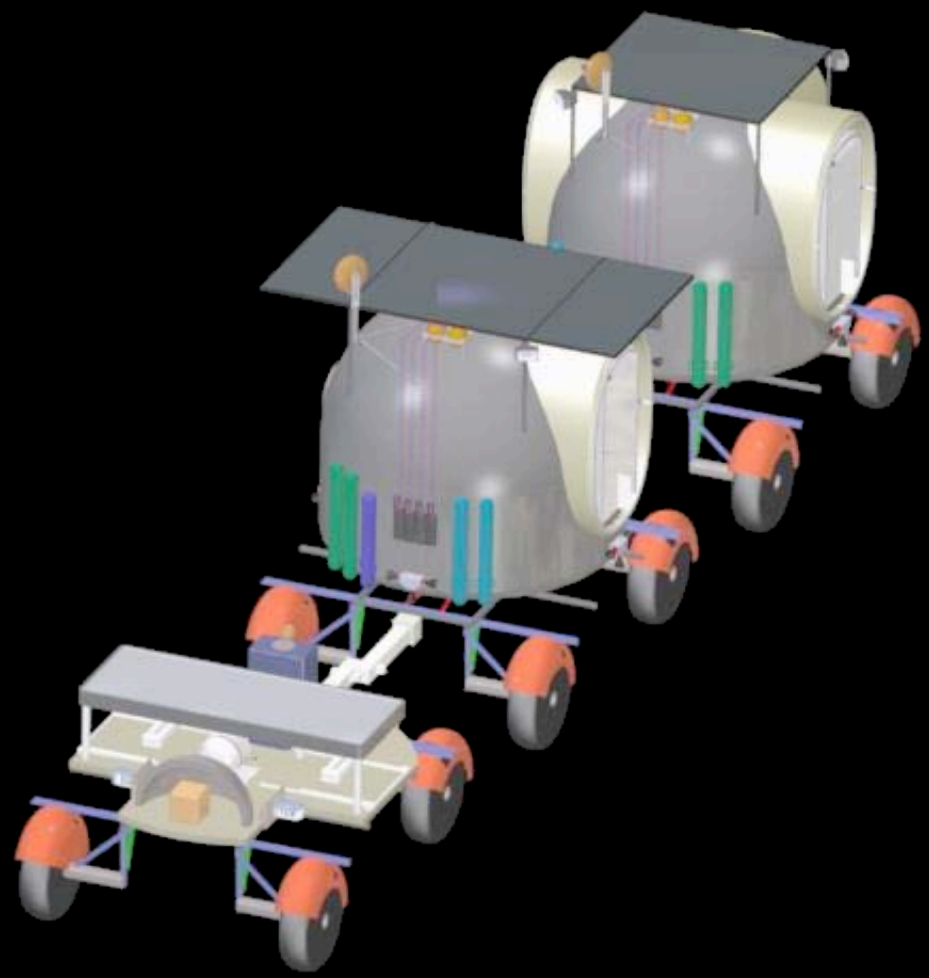
2 robotic arms on each power module:

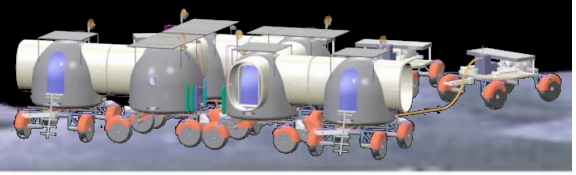
- Capable of collecting and storing soil samples
- Equipped with soil analyzing instruments
- Vehicle assemblies may travel separate to sample more of the surface
- More details forthcoming



MORPHLAB

Intermission

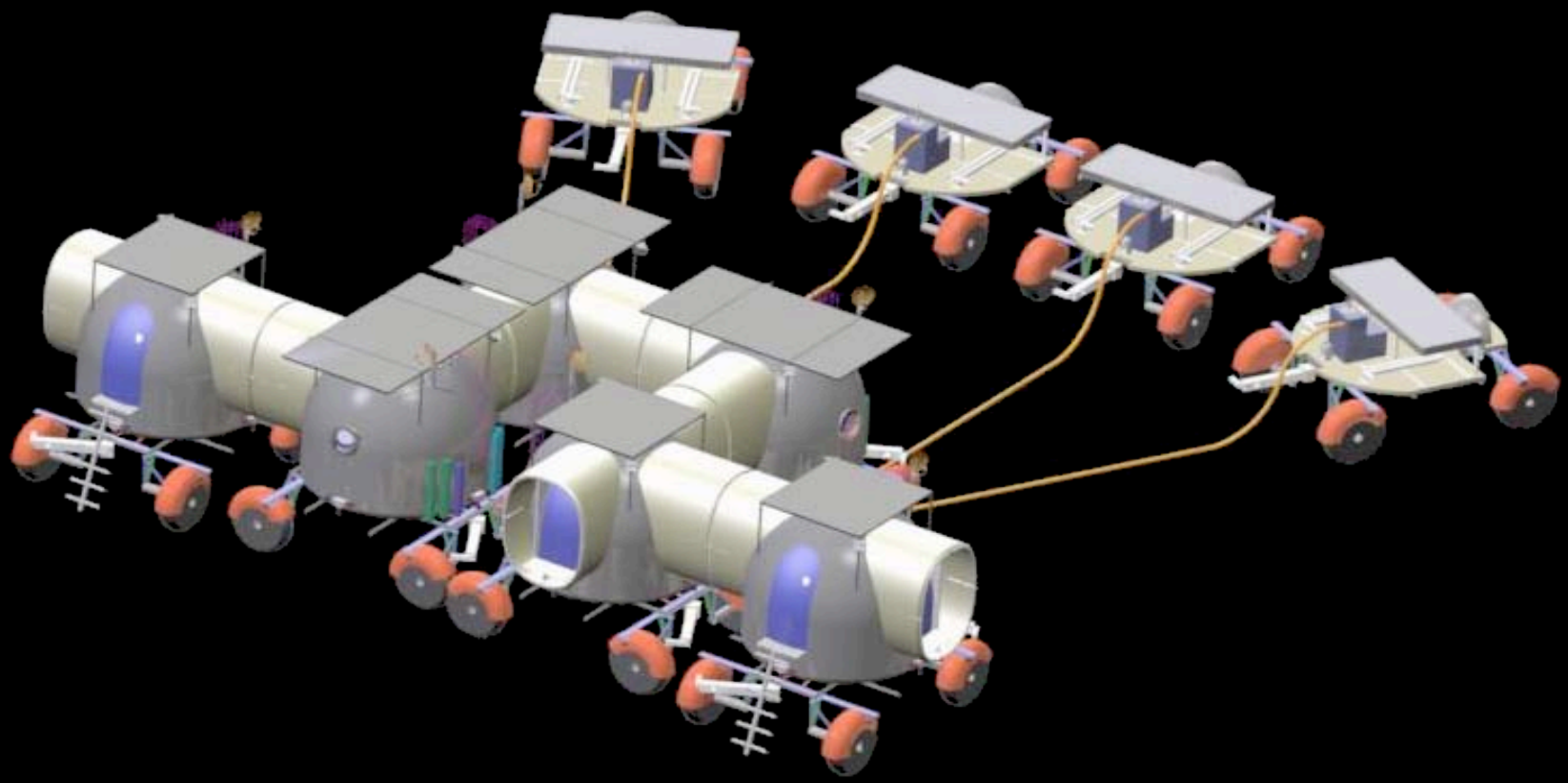


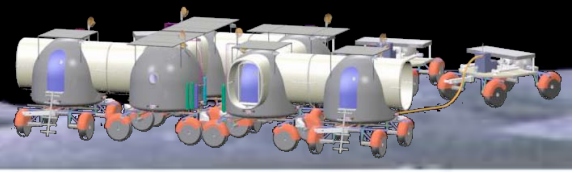


University of Maryland
CDR 04/19/04

MORPHLAB

Manned Base Assembly Phase





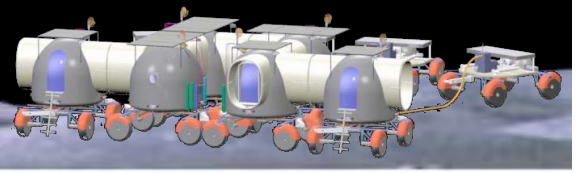
University of Maryland

CDR 04/19/04

MORPHLAB

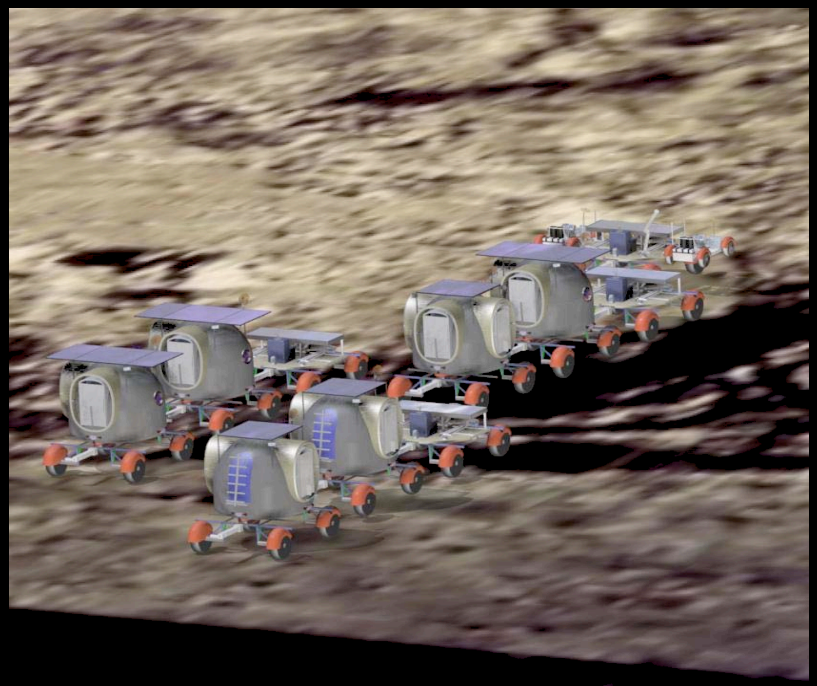
Base Phase Topics

- Science in base assembly
- Docking Mechanism
- Base power budget
- Crew Systems & ECLSS
- Logistics Module
- Interior layout
- Extra vehicular activity
- Lunar roving vehicle

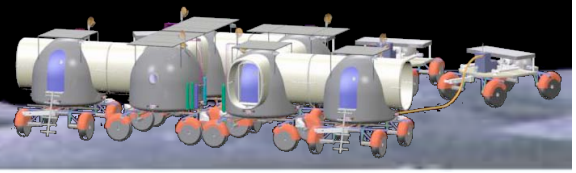


MORPHLAB

Base Assembly Site



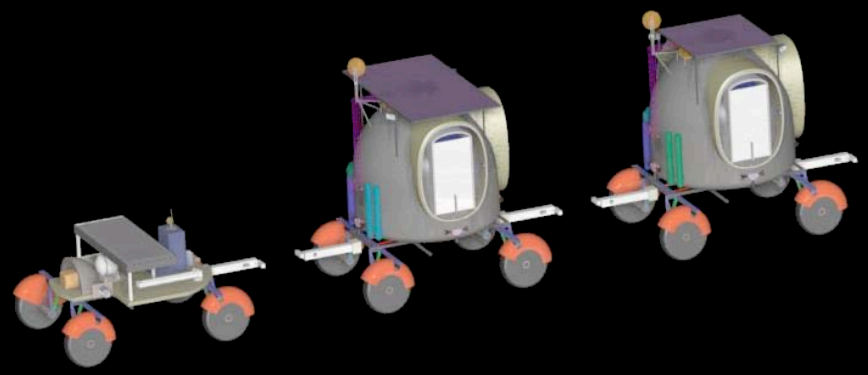
- Crew support equipment is supplied by a logistic depot, landed near the desired assembly site
- The specific base location and configuration will be determined when MORPHLAB arrives
- Assembly will be within 10km of logistic depot
- Astronauts land within 100m of the assembled base
- Tele-operated lunar rovers pick up landed astronauts



MORPHLAB

Base Assembly Overview

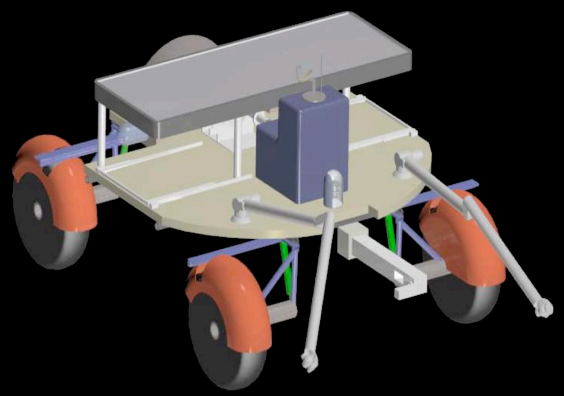
- Transit connections disconnect and modules reconfigure into a base
- While reconfiguring, batteries supply power to the habitable and chassis modules
- Once the modules are positioned correctly, the docking mechanisms extend and connect

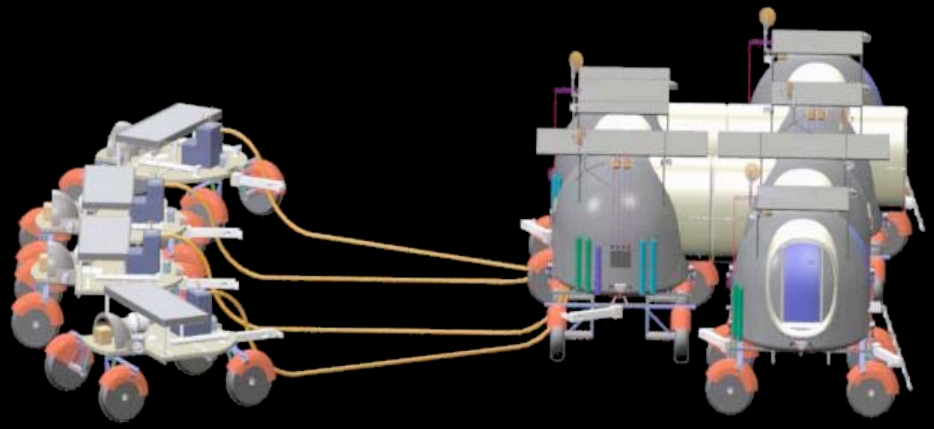


MORPHLAB

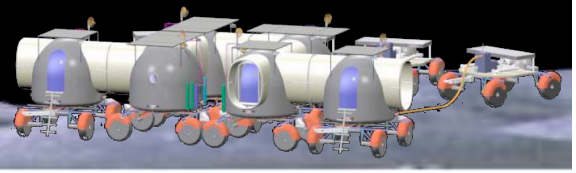
Base Assembly Overview

- Power modules connect power cords to the chassis modules with the robotic arms
- Power modules are driven 10m away from the base assembly to reduce radiation exposure to the crew from the DIPS





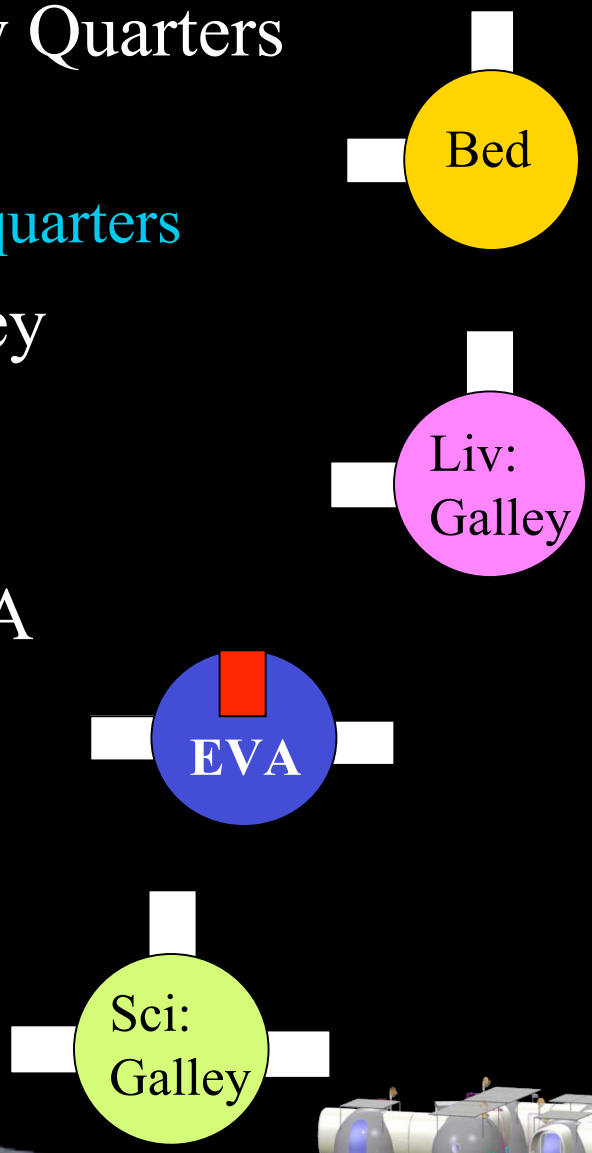
- The modules are pressurized and computers are initialized to prepare for the arrival of the astronauts



MORPHLAB

Module Overview

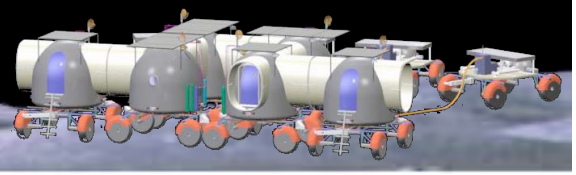
- 2 Habitable-Living: Crew Quarters
  - 2 docking hatches
  - Primary used as sleeping quarters
- 1 Habitable-Living: Galley
  - 2 docking hatches
  - Primary used as a galley
- 2 Habitable-Science: EVA
  - 1 EVA Airlock
  - 2 docking hatches
- 1 Habitable-Science
  - 3 docking hatches



MORPHLAB

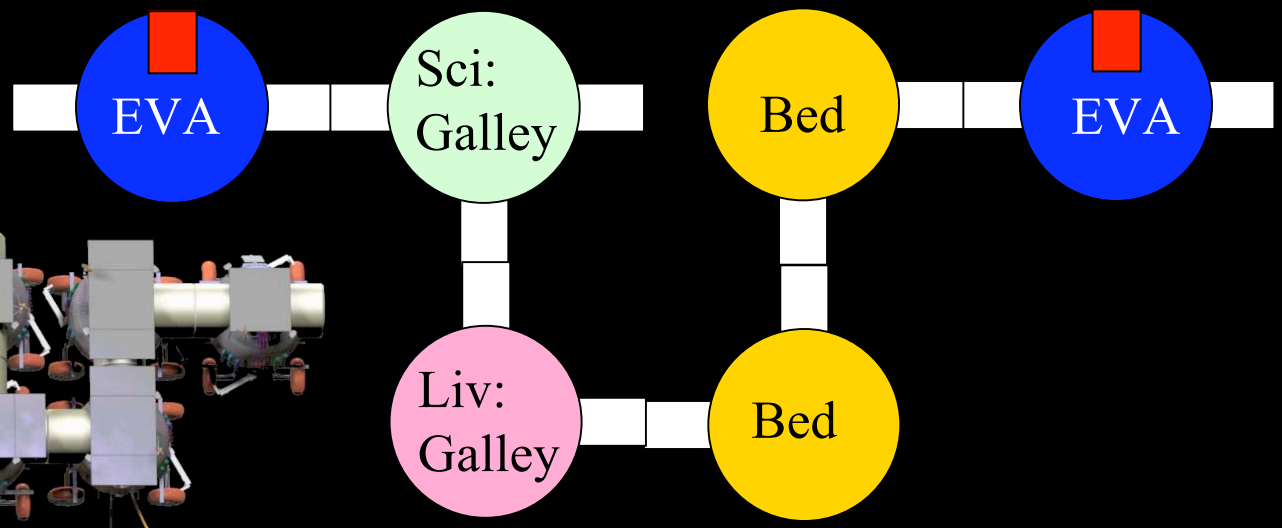
Optimum Base Assembly

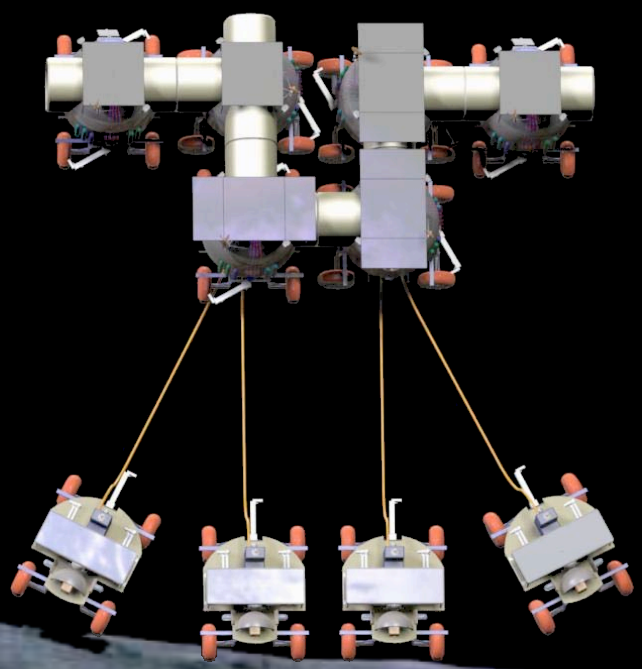
- Base Assembly Requirement
  - At least one habitable-science module is needed to provide all habitable-living modules with complete life support
  - Each module should have two routes to reach EVA airlocks for an emergency evacuation
    - Level 1 requirement L8 : System shall provide for emergency alternative access and EVA "bailout" options
- Consideration for base assembly
  - Base assembly should be comfort for living and working on missions for astronauts

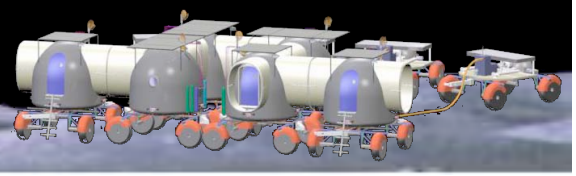


Base Assembly Configuration

- Primary Base Assembly

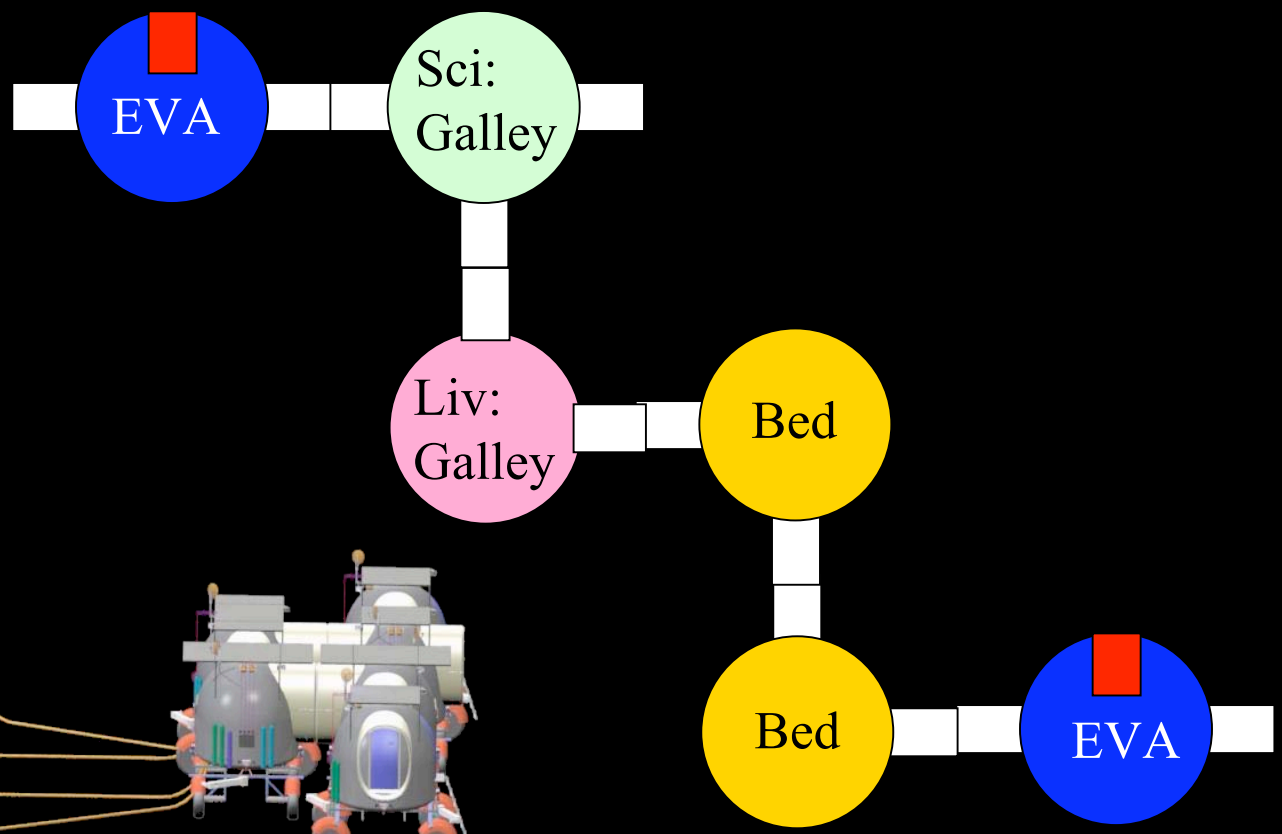


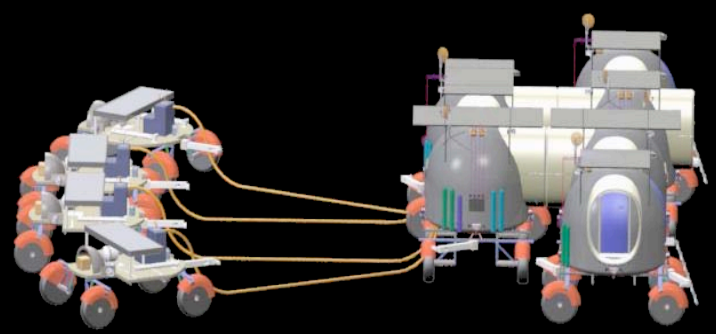


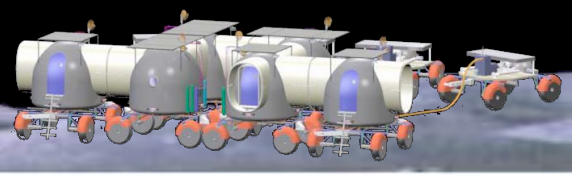


Base Assembly Configuration

- Optional Base Configuration







MORPHLAB

Assembly Site Selection Criteria

Level 1 Science Goals:

- Volcanic and impact history
- Deep lunar composition
- Environmental variations along the surface
- Water ice and ore deposits as potential resources

- Apollo landing site candidates
- Volcanic lava "tunnels" (rilles)
- Permanently shadowed regions → ice
- Age of lunar structures
- Highland material
- Approximately 1000 km apart

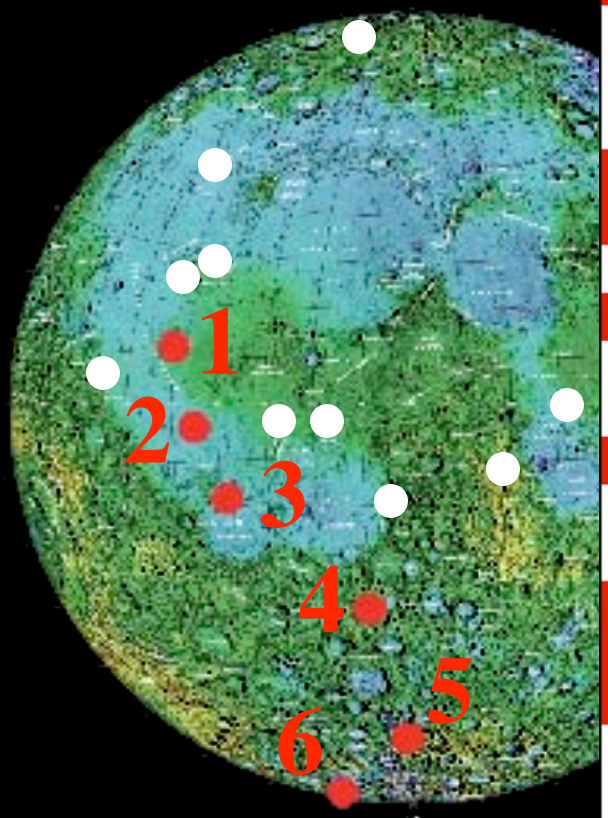
- Ore deposits and useful elements:
  - Helium
  - Nitrogen
  - Oxygen
  - Carbon
  - Silicon → Solar cell production
  - Thorium → KREEP* materials

* Potassium, Rare Earth Elements, Phosphorus

MORPHLAB

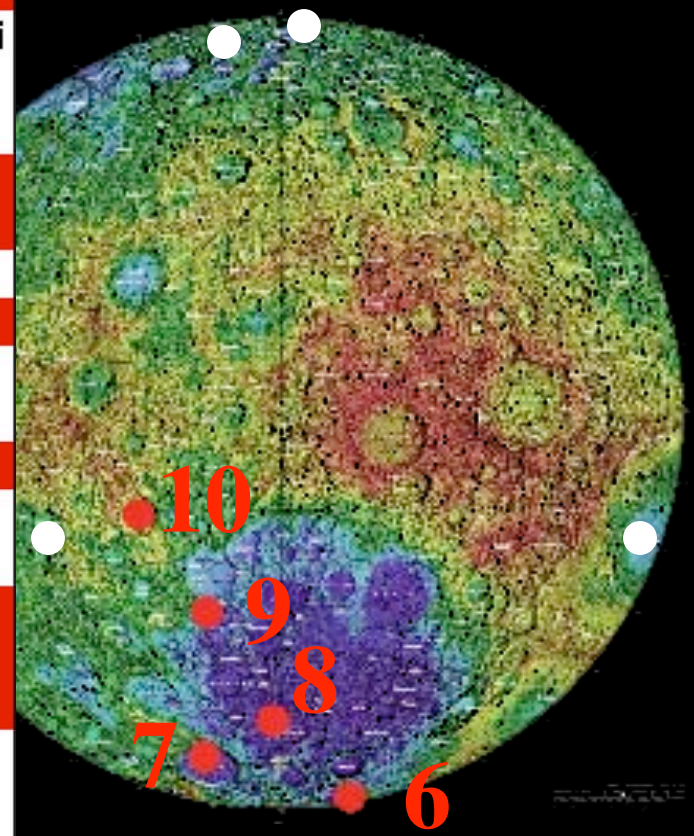
Assembly Site Selection

Near Side



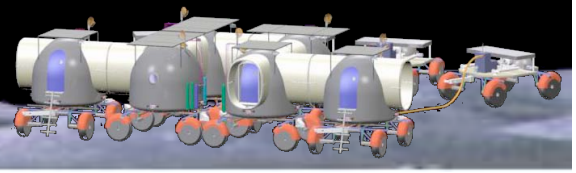
1	Drygalski
2	Moretus
3	Rozhdestvenski
4	Nansen
5	Hermite
6	Schrodinger
7	Gassendi
8	Rima Bode II
9	Tycho
10	Rima Prinz I
11	Tsiolkovsky
12	Minnaert
13	Aristarchus
14	Alphonsus
15	Mare Ingenii
16	Marius
17	Flamsteed P
18	Mons Rumker
19	Lichtenberg
20	Censorinus
21	Mare Orientale
22	Apollo 13 site
23	Apollo 14 site
24	Gagarin
25	Copernicus

Far Side



http://geopubs.wr.usgs.gov/i-map/i2769/

* Site rankings done by trade study of goals, site criteria, and feasibility

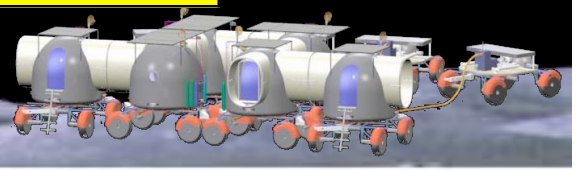


MORPHLAB

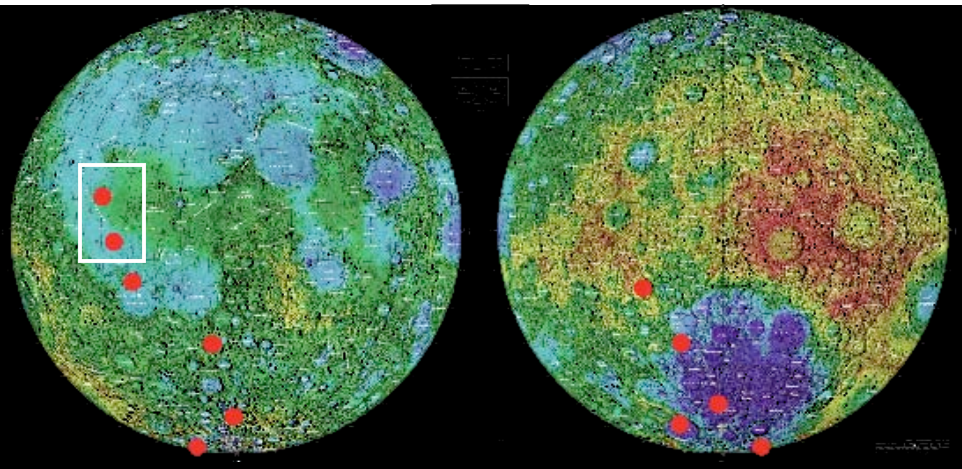
Assembly Site Distances

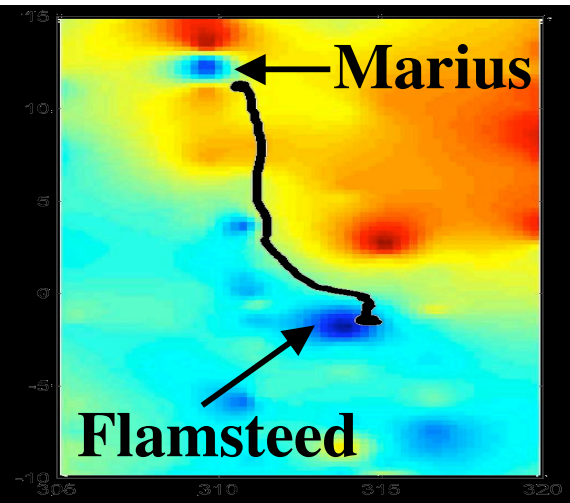
Assembly Site	Straight line distance between (km)	Estimated driving distance (km) (+ 30%)
1) Marius Hills	515	670
2) Flamsteed Crater P	479	623
3) Gassendi Crater	966	1256
4) Tycho Crater	911	1184
5) Moretus Crater	553	719
6) Drygalski Crater	212	276
go through South Pole	546	710
7) Schrodinger Crater	562	731
8) Minnaert Crater	822	1069
9) Mare Ingenii	539	701
10) Gagarin Crater		

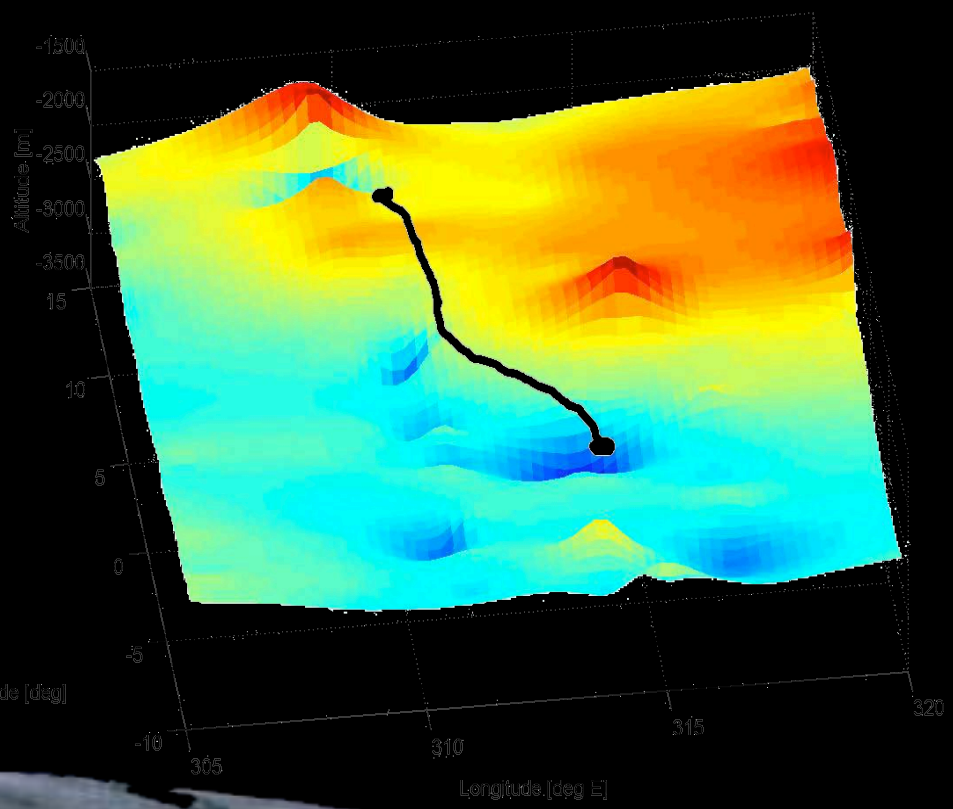
Largest distance



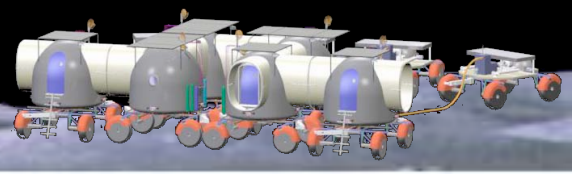
MORPHLAB



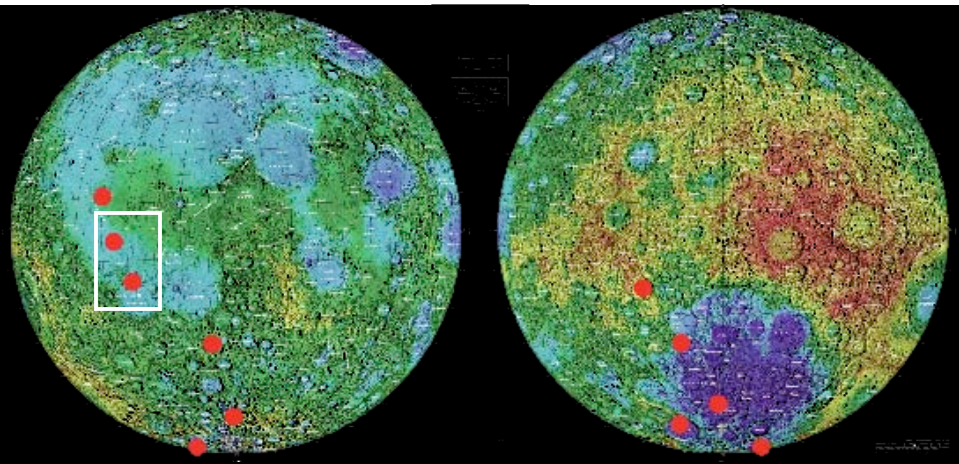


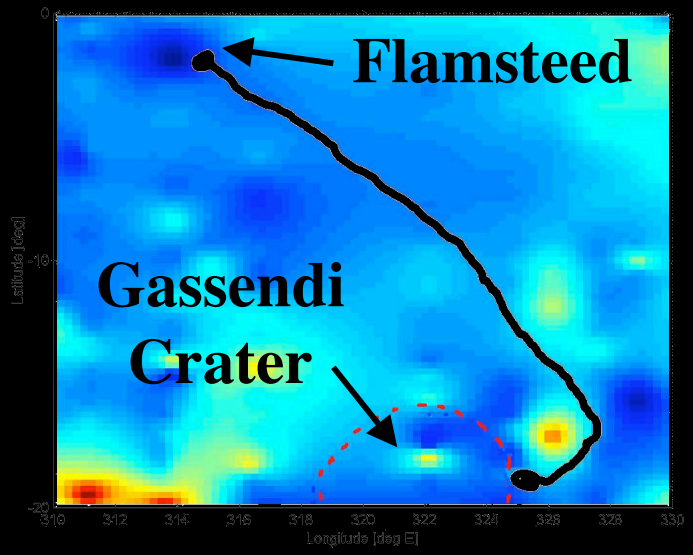


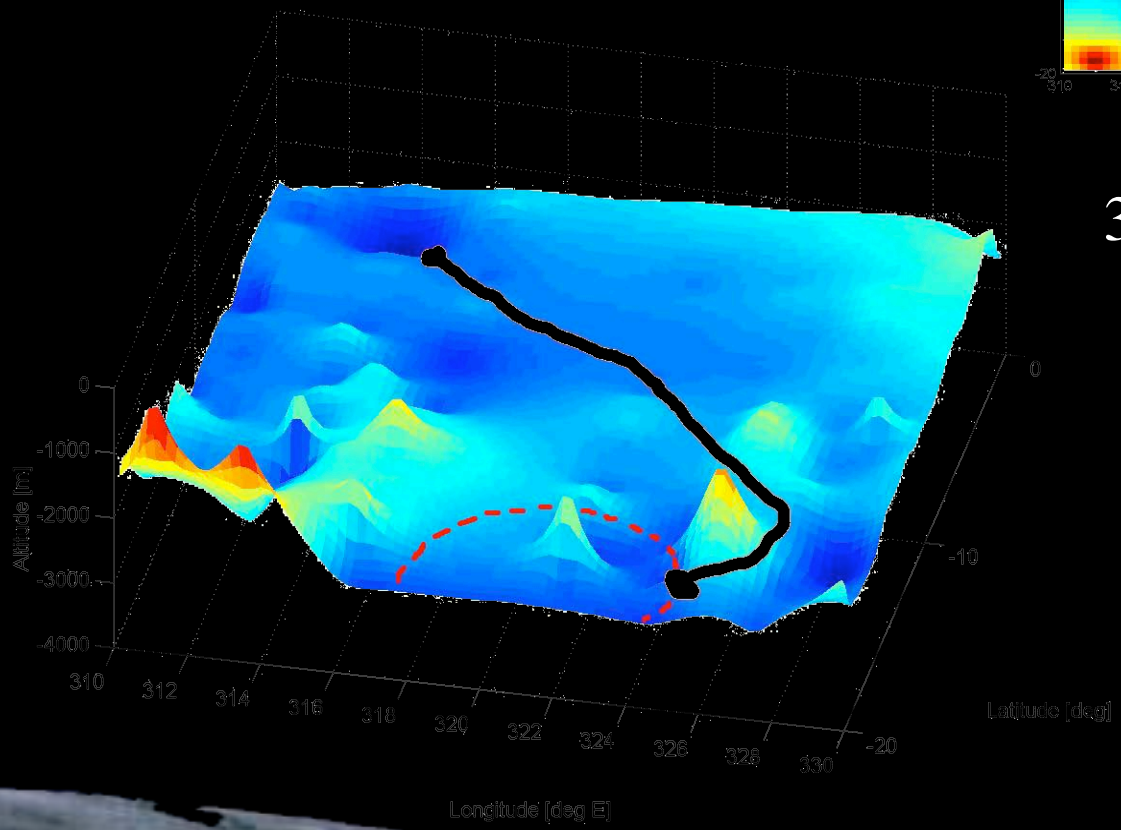
1) Marius Hills (51W, 11N)
   - Steep volcanic hills
   - Large amounts of silica
   - Rilles nearby could be collapsed lava tunnels
2) Flamsteed Crater P (43W, 4S)
   - 1m thick regolith infers that it is young
   - Surveyor 1 landing site



MORPHLAB

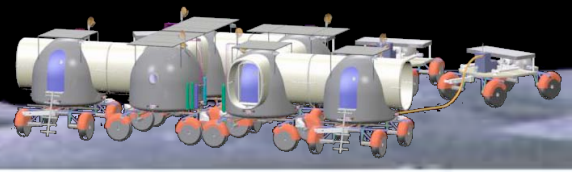




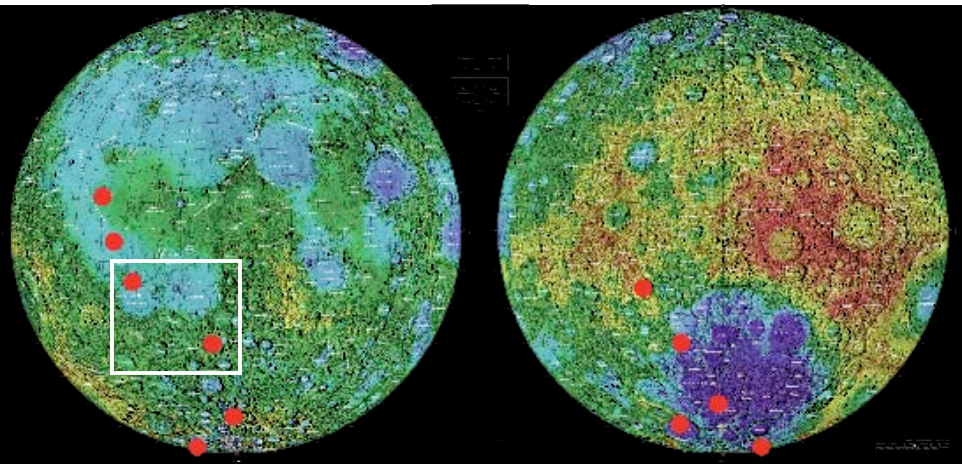


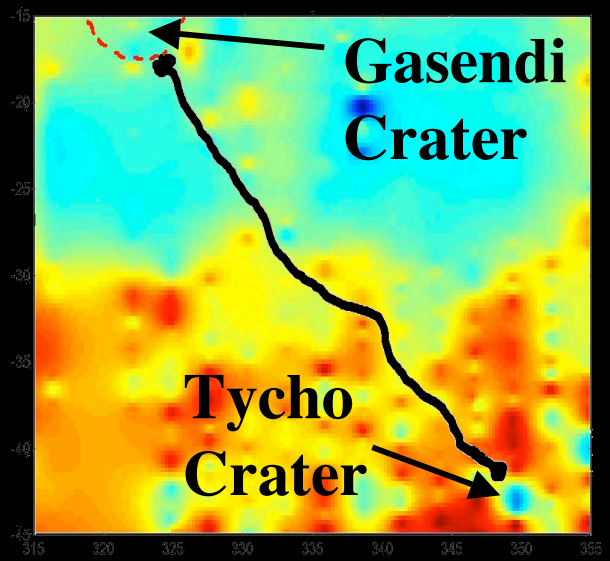
3) Gassendi Crater (38W, 19S)

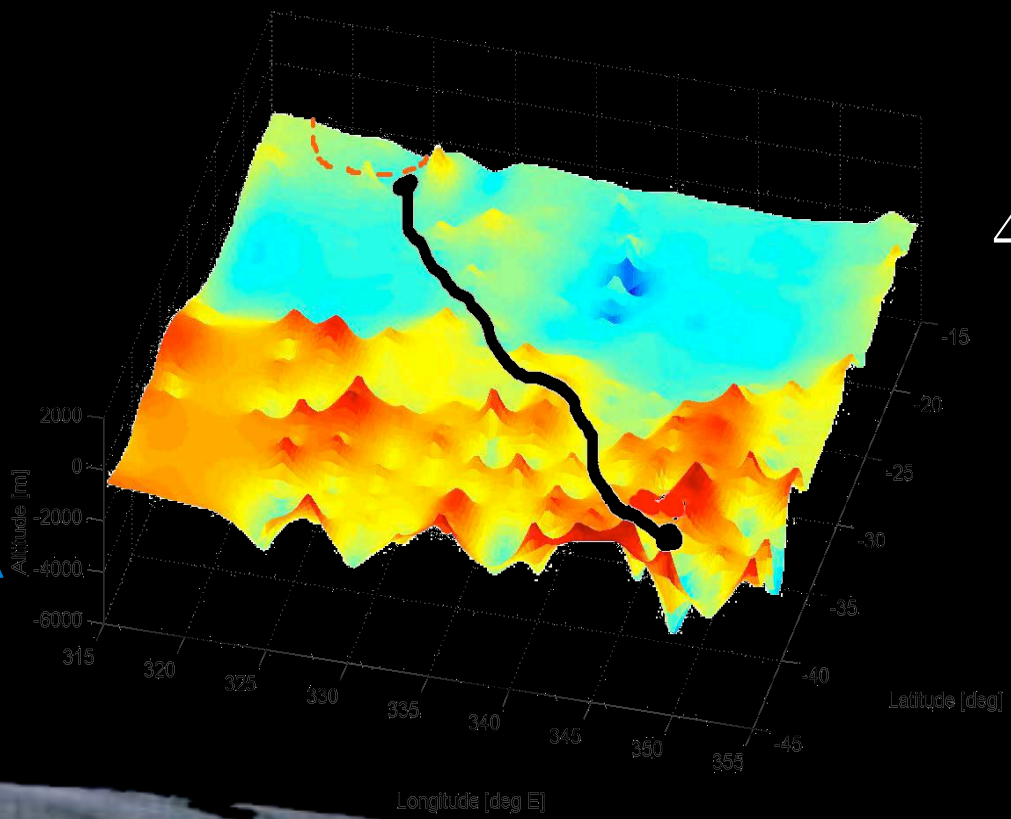
- Contains ancient highland rocks
- Lunar transient phenomenon observations
- Most likely candidate for Apollo 18



MORPHLAB

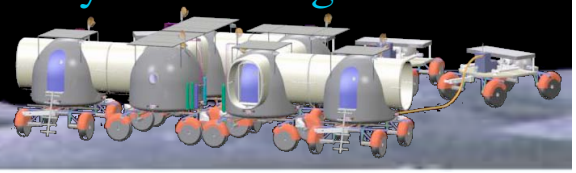




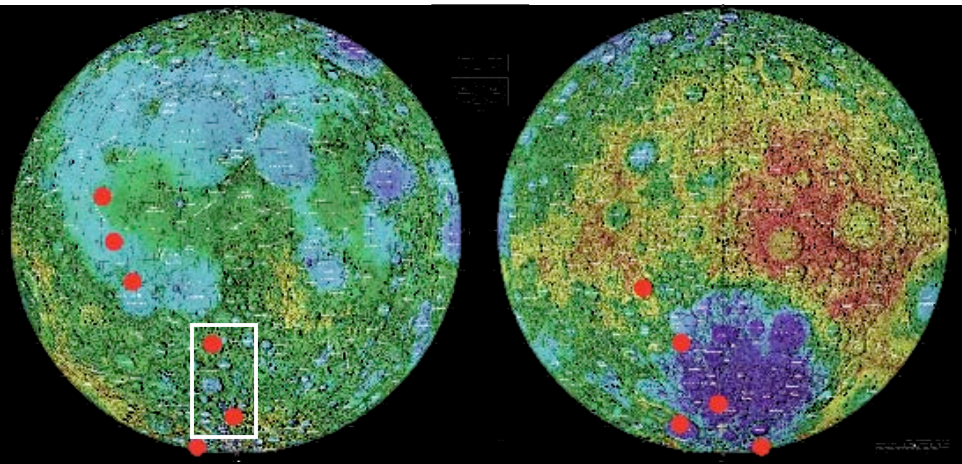


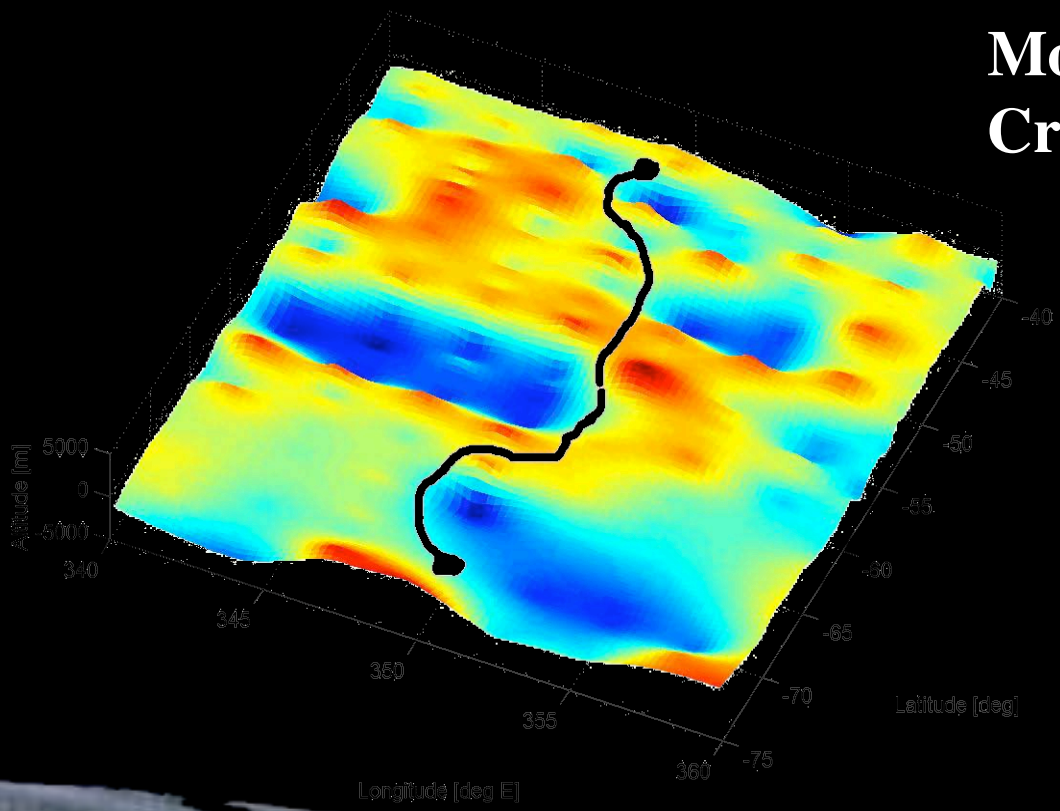
4) Tycho Crater (12W, 42S)

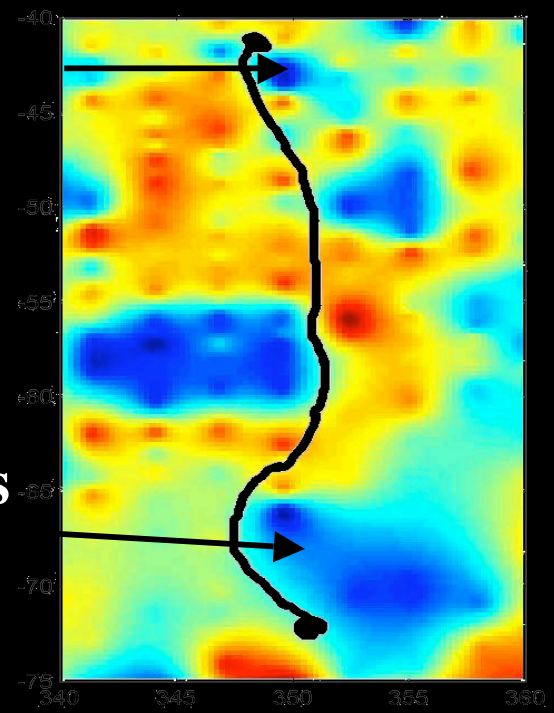
- Rare materials
- Lunar transient phenomenon observations
- Crater still has rays infers that it is young
- Youngest known crater by current knowledge
- Surveyor 7 landing site



MORPHLAB



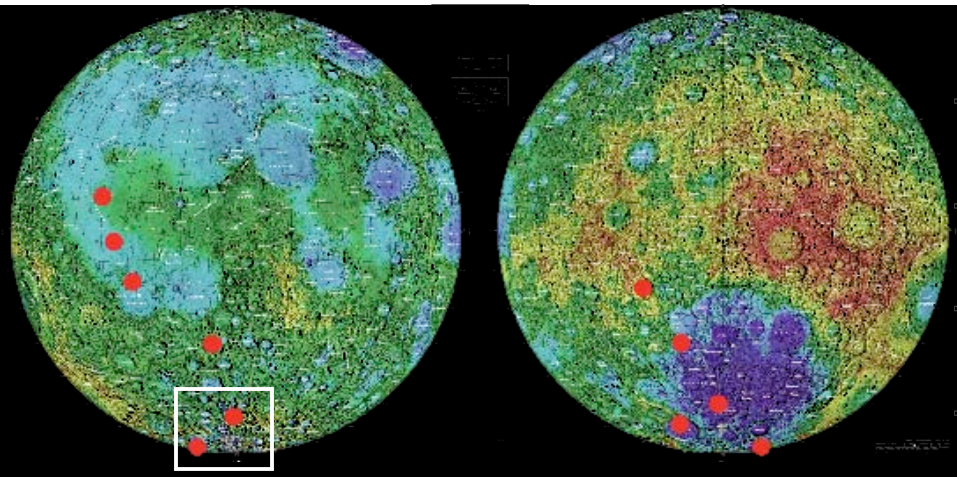


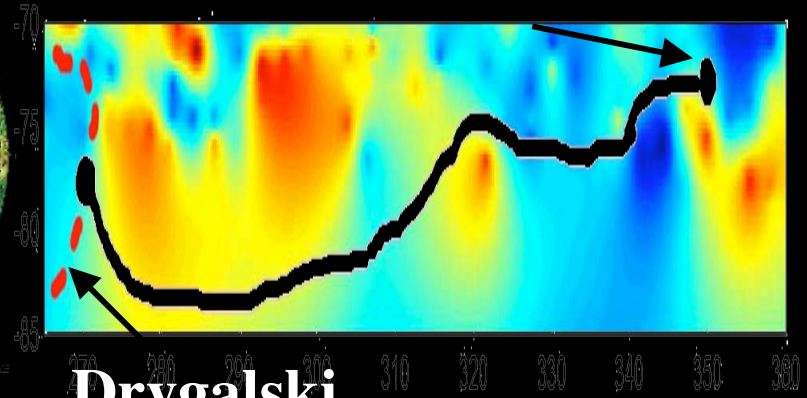


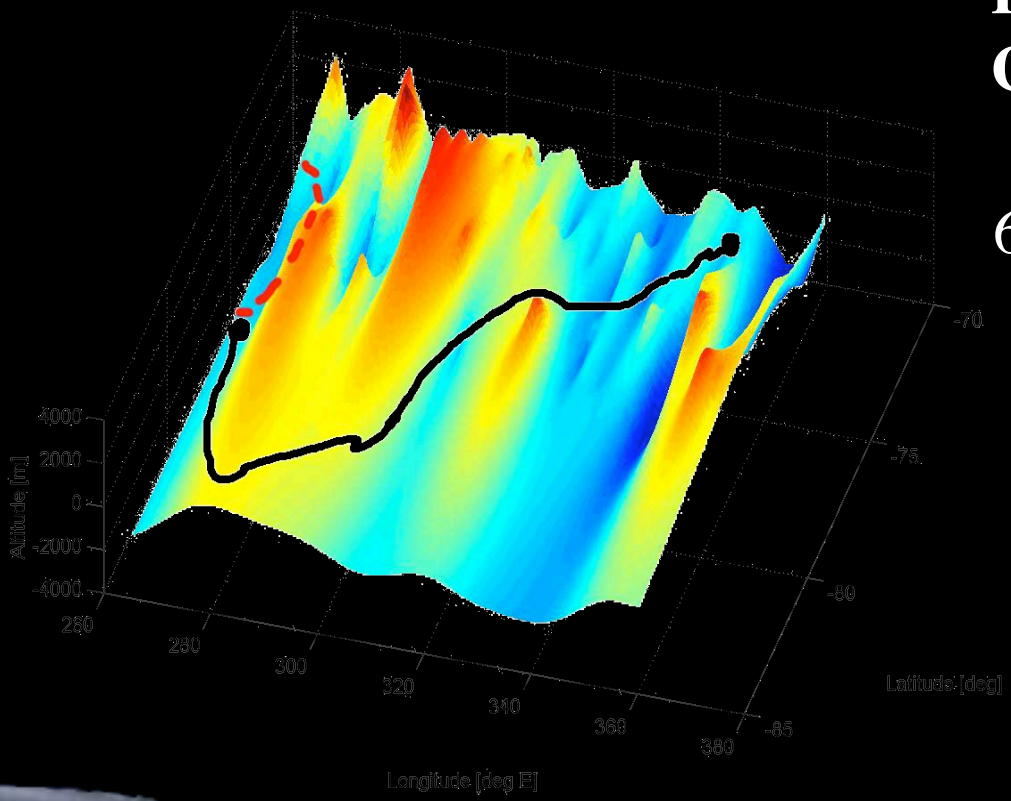
5) Moretus Crater (9W, 72S)

- Possibility of ice in permanently shadowed craters

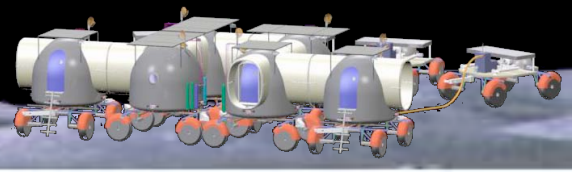
MORPHLAB



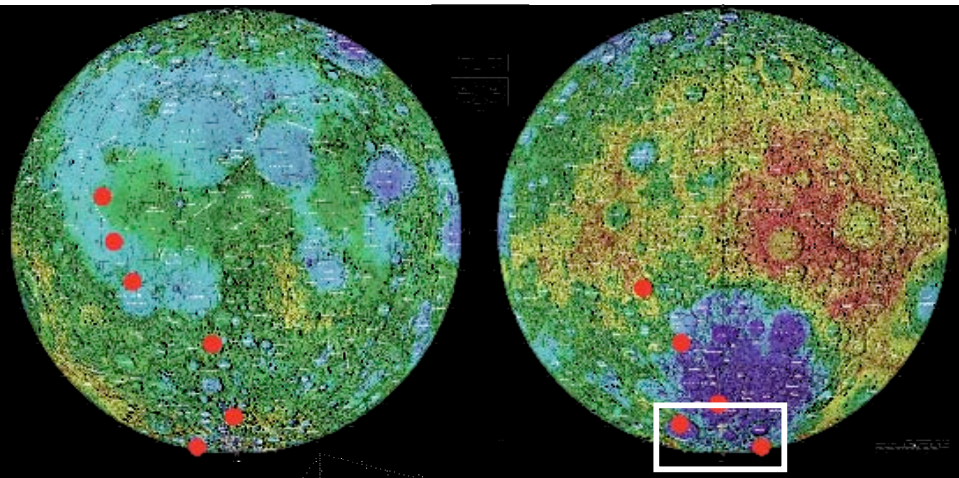


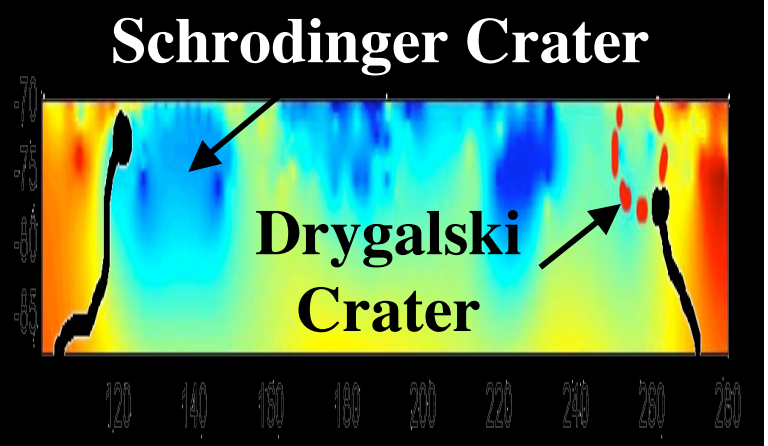


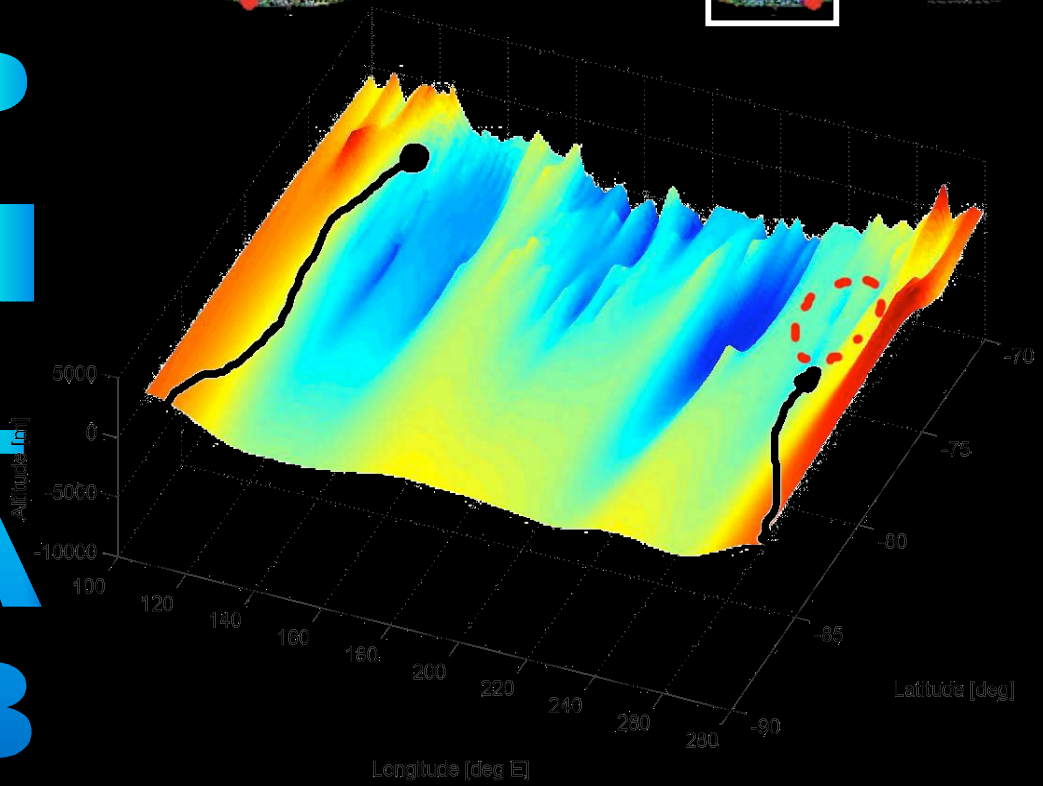
6) Drygalski Crater (83S, 90W)
- Possibility of ice in permanently shadowed craters
- Areas of constant sunlight nearby (Malapert Mountains)



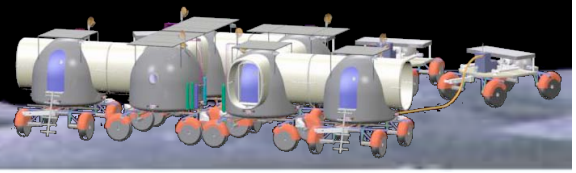
MORPHLAB



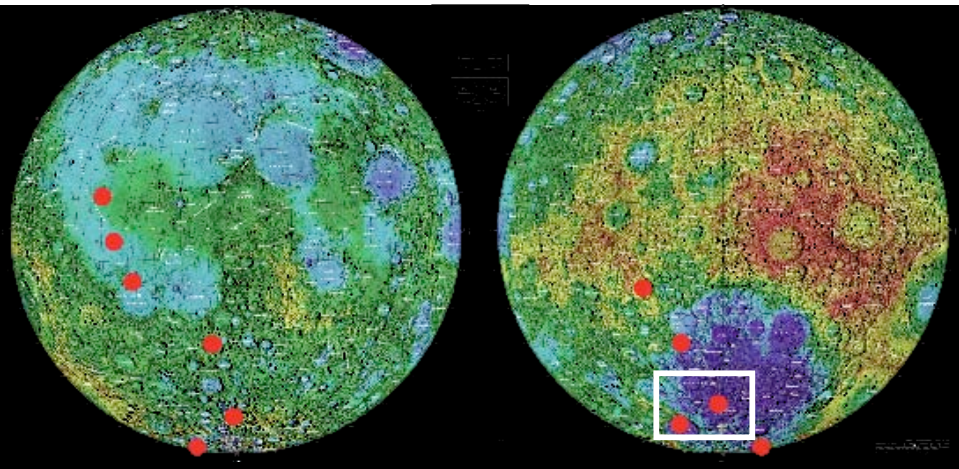


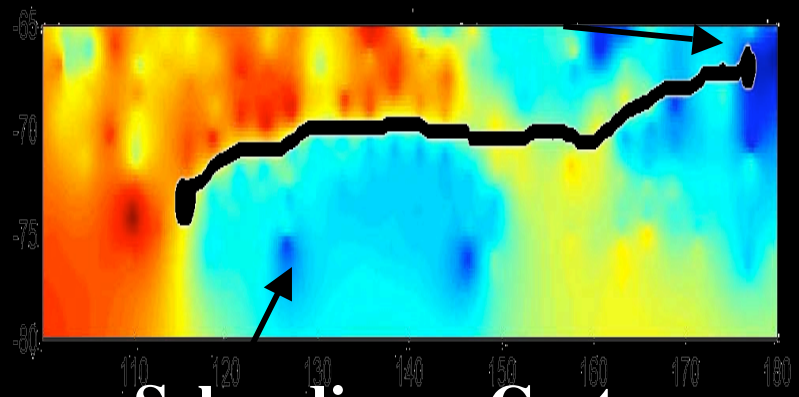


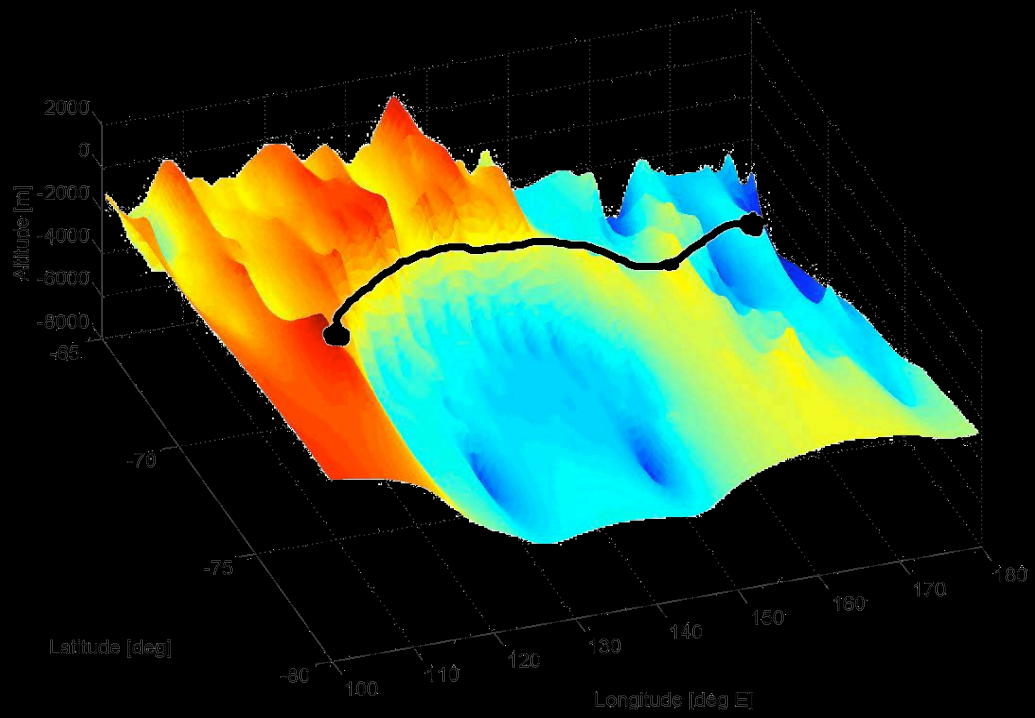
7) Schrodinger Crater (72S, 134W)
- Contains recent volcanic ejecta
- Second youngest impact basin



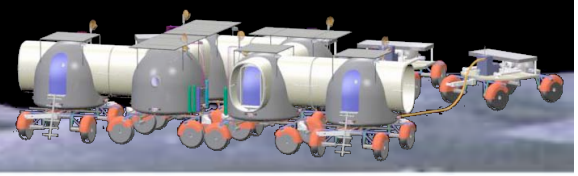
MORPHLAB



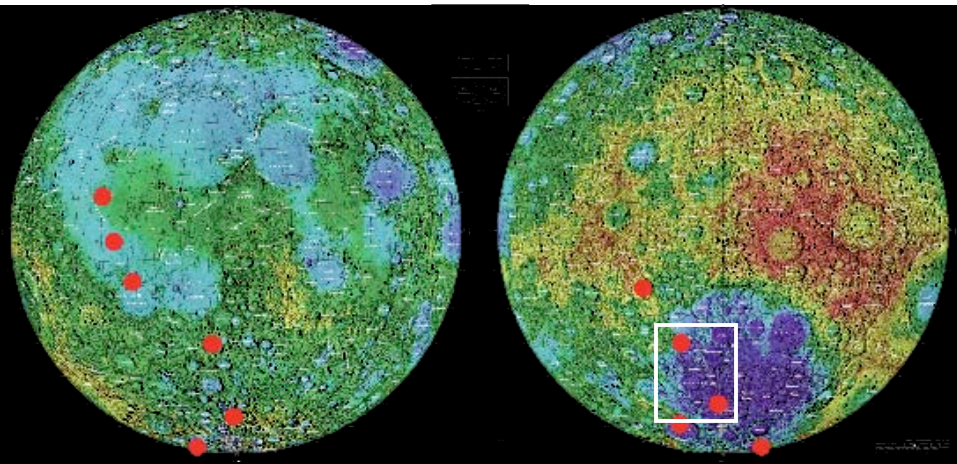


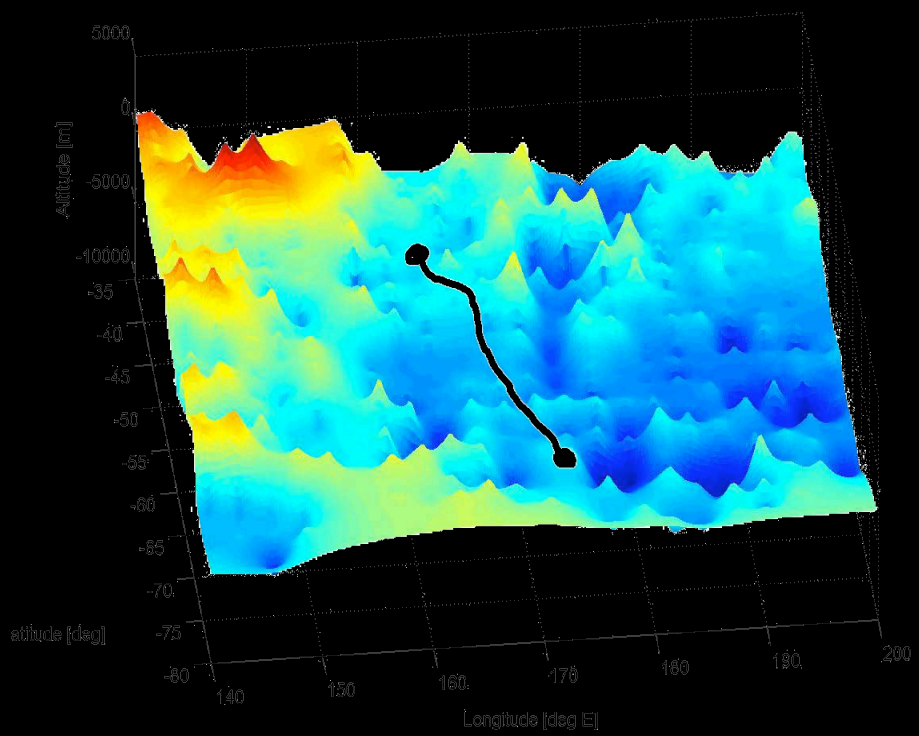


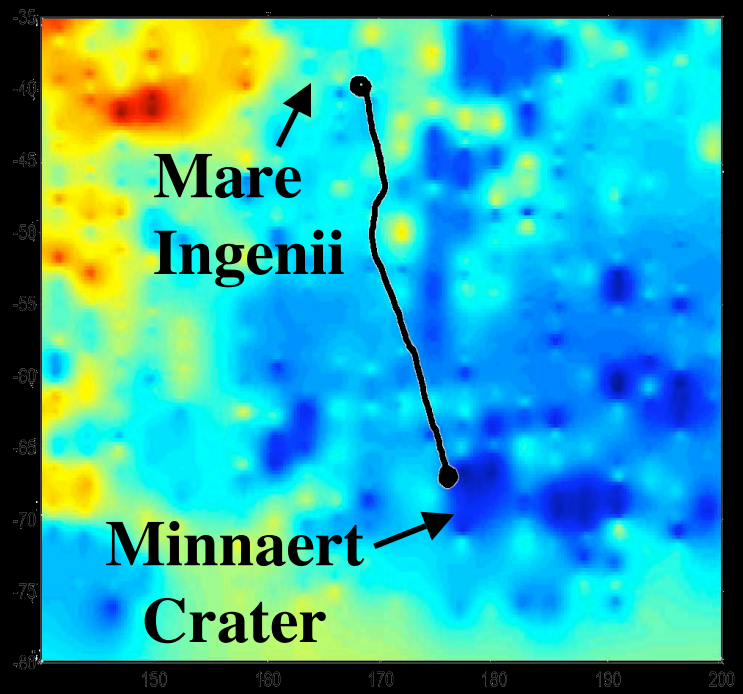
8) Minnaert Crater (67S, 171W)
- Strongest possibility of investigating lunar mantle
- Located within Aitken Basin



MORPHLAB

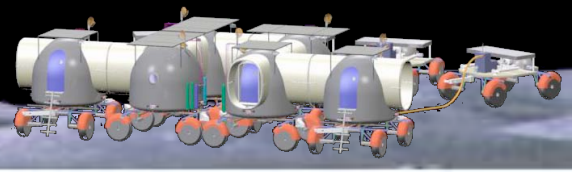




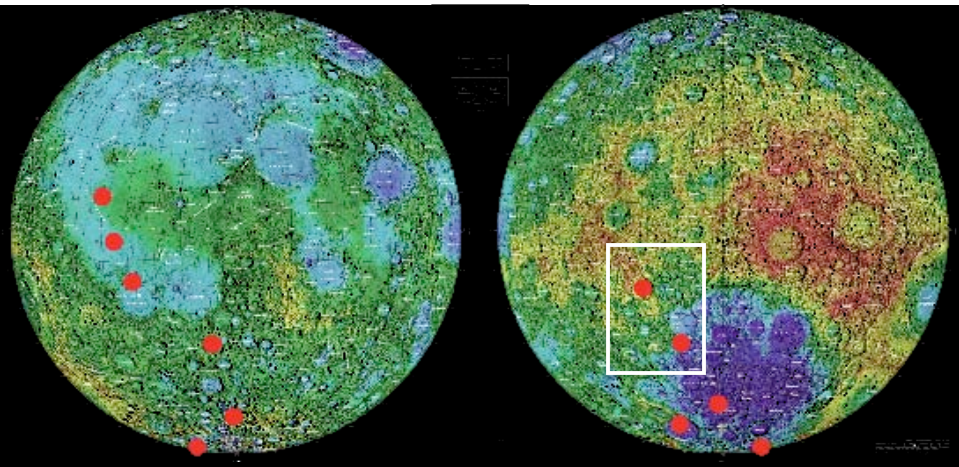


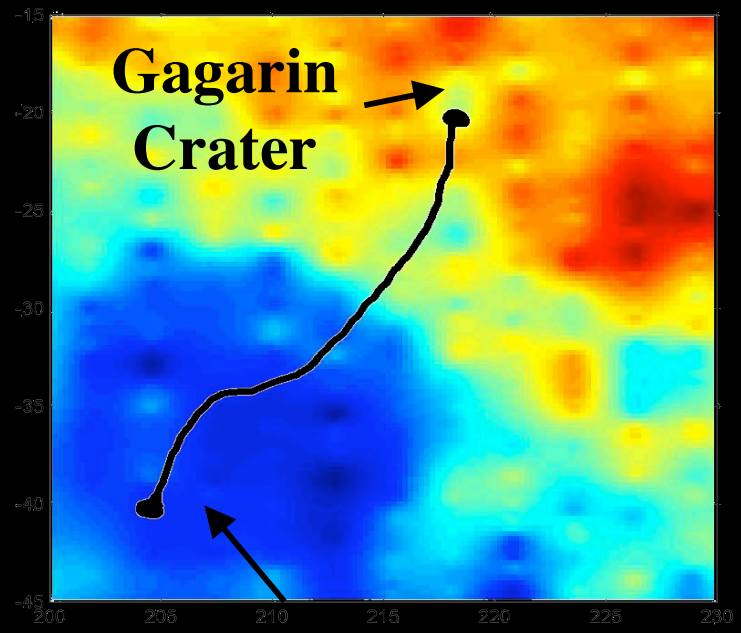
9) Mare Ingenii (40S, 167W)

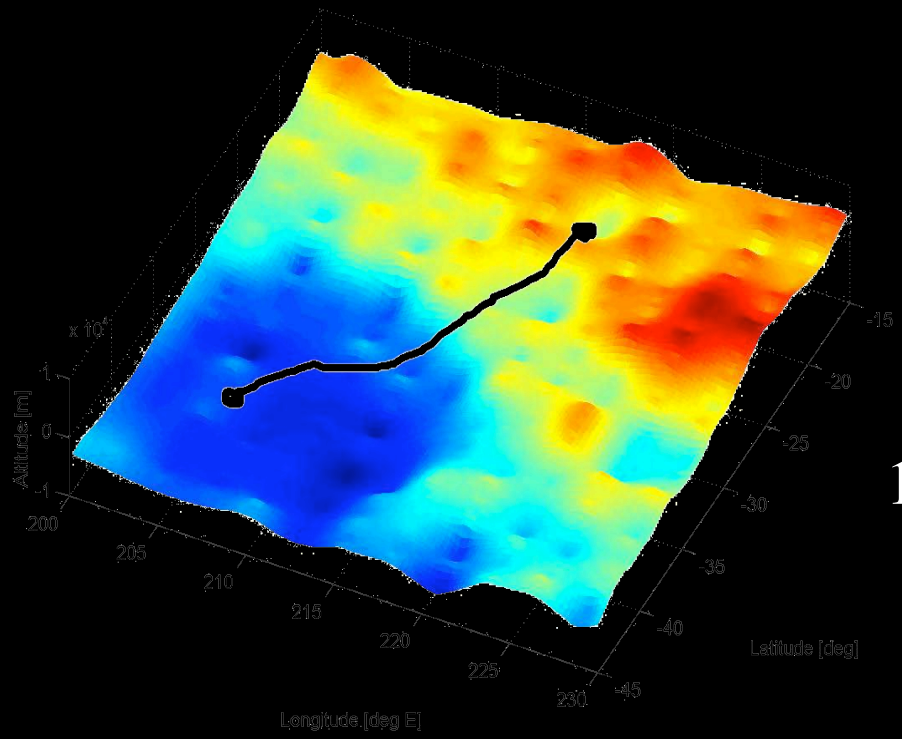
- High concentration of thorium
- Possibility of investigating lunar mantle
- Located within Aitken basin



MORPHLAB

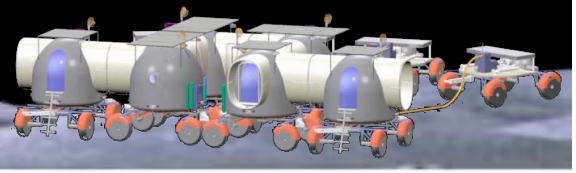






10) Gagarin Crater
(29S, 150W)

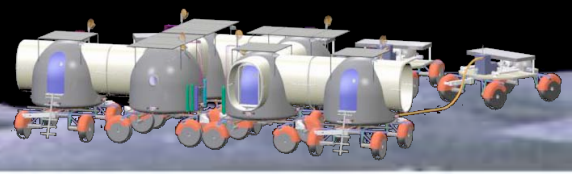
- Contains ancient highland rock



MORPHLAB

Geological Science Instruments

Level 1	Level 2	Level 3
Potential water ice Ore deposits as potential resources	Mineral analysis	• Mini Thermal Emission spectrometer • X-ray / Gamma-ray spectrometer • Mossbauer spectrometer • Integrated Dust/Soil Experiment mass spectrometer
Deep lunar composition	Seismic instruments	• Passive Seismic Experiment Package • Active Seismic Profiling Experiment
Lunar volcanic and impact history	Soil collection	Robotic arms • Scoop • Hammer • Rake • Tongs • Electric drill
Lunar dust and environmental changes	Surveyor instrument retrieval	
	Dust detecting instruments	Lunar Dust Detector



MORPHLAB

Soil Sample Collection

Apollo Soil Collection Details

Apollo	total rock mass (kg)	# of rocks	largest rock returned (kg)	mission hours	EVA hours
11	21.6	68	5.6	195.5	2.25
12	34.3	69	2.4	31.5	7.5
14	42.3	150	9.0	33.5	9.5
15	77.3	370	9.7	67	18.5
16	95.7	731	11.7	71	20.25
17	110.5	741	3.6	75	22

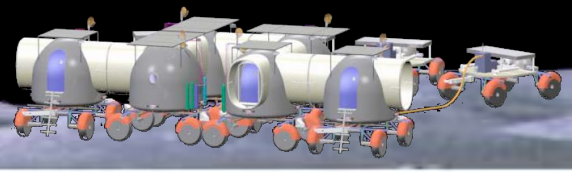
Apollo	avg EVA hours / mission hours	average rock mass / EVA hour	average rock # / EVA hour
11	0.012	9.6	30.2
12	0.238	4.6	9.2
14	0.284	4.5	15.8
15	0.276	4.2	20.0
16	0.285	4.7	36.1
17	0.293	5.0	33.7
average	0.275	4.6	23.0

Apollo 11 discarded

Assumption:
Collect at 1/4th the rate of Apollo (larger stay times, and more time spent traveling in the rover)

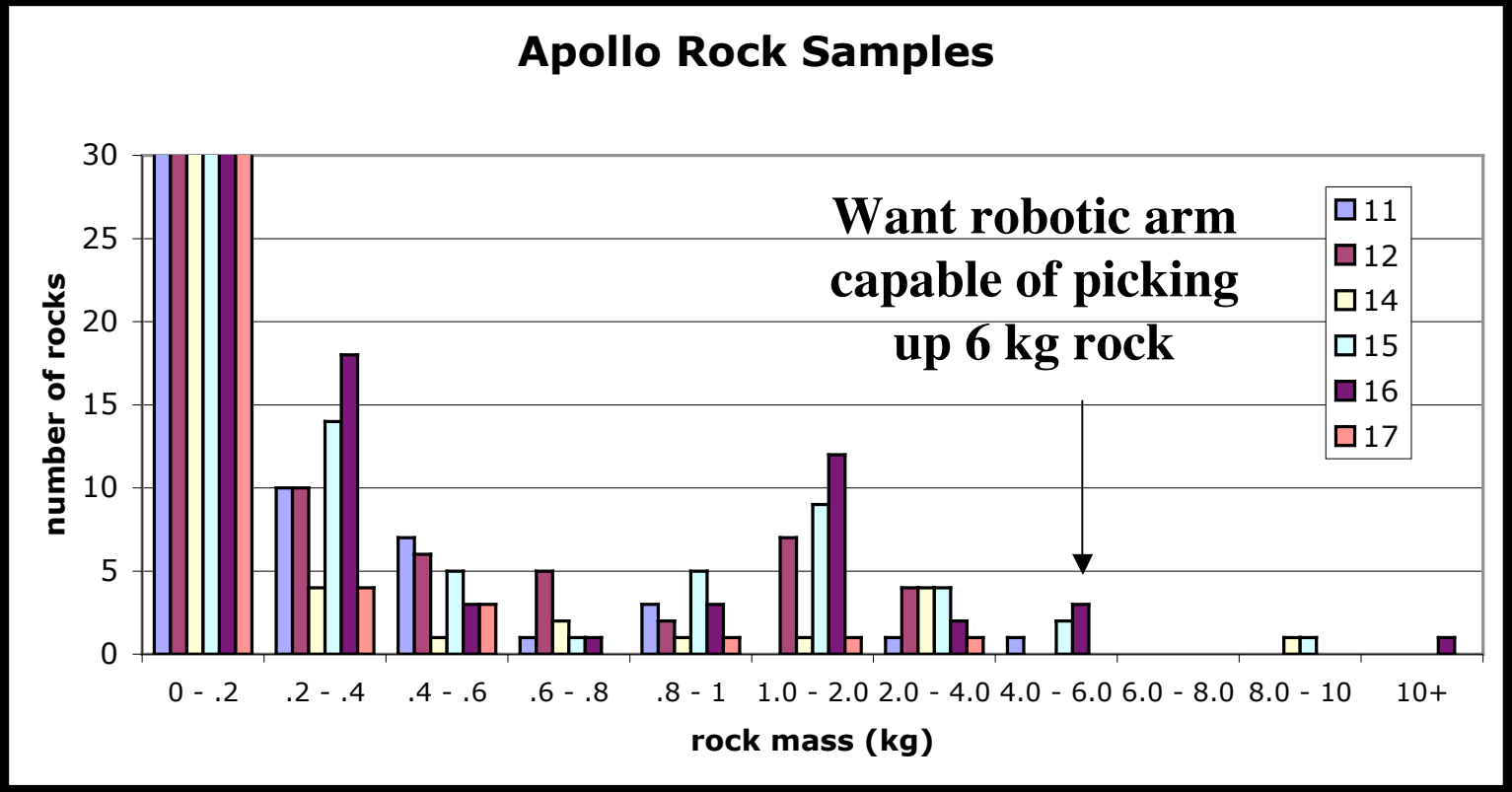
MORPHLAB manned mission: 2160 hours (3 months)

→ **Total collected rock mass: 600 kg**



MORPHLAB

Soil Sample Collection

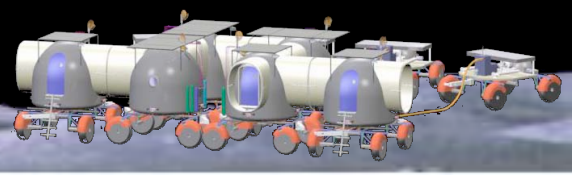


Keep rocks for 7 days → 46 EVA hours (28% mission hours)

→ 50 kg of rocks collected

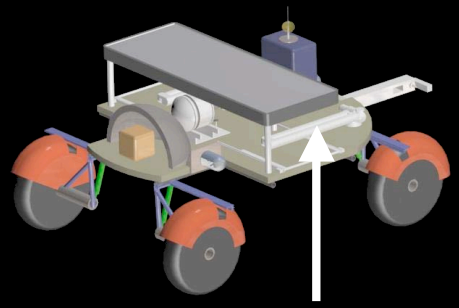
+ 300 kg of rocks returned each mission (50% total collected)

= 350 kg total rock storage mass



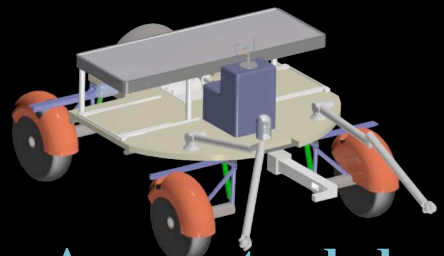
MORPHLAB

Robotic Arm Capabilities

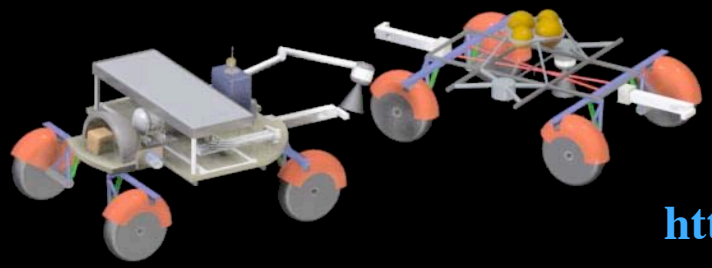


Arms stowed

- Pick up and store soil samples
- Soil inspection
- External module inspection / maintenance
- Removal of descent engines
- Plugging in power cords



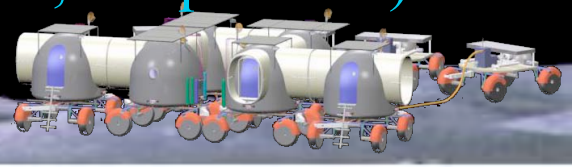
Arms extended



http://ranger.ssl.umd.edu

	mass (kg)	reach (m)	lift at extension (N)	min. temp. (deg C)	max temp. (deg C)
Ranger Arm	77	1.35	133	-40	150
Requirements:		2	59	-173	127
			6 kg rock	moon	

- Different end effectors for each operation
- Modifications necessary (1m extensions, temperature)

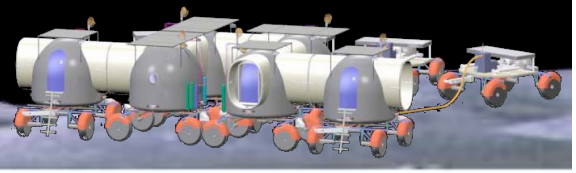


MORPHLAB

Life Sciences: Level 1 and 2

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle development/ decay
- Cardiovascular system
- Nutrition and medical care
- Long term radiation exposure
- Plant biology in the lunar environment

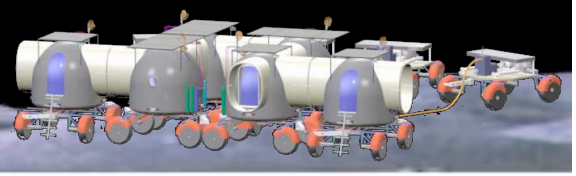
- Questionnaires
- Foot/Ground Reaction System
- Ultrasound
- Gas Analyzer System for Metabolic Analysis Physiology (GASMAP)
- Ambulatory Data Acquisition System
- Portable Clinical Blood Analyzer (PCBA)
- EVARM system
- Advanced Astroculture™ Chamber



MORPHLAB

Life Sciences: Level 2

- Most of these systems have been used on the ISS. The reason for repetitions are:
  - Different gravitational environment
  - Find trends from mission to mission
  - Find a relationship between the Earth's gravity, the Moon's gravity, and microgravity; then educated predictions for other planetary gravities can be made
  - Enhance technology for medical care on Earth and future planetary bases

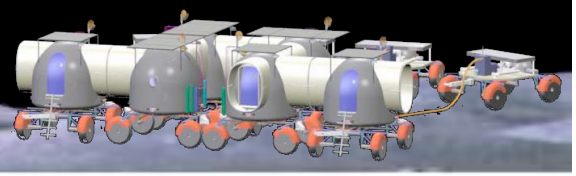


MORPHLAB

Racks

- Each science module will have one science rack
- These racks contain the instruments needed to perform various experiments
- The rack method makes it easy to change experiments & instruments from mission to mission

- Rack 1
  - PCBA (Portable Clinical Blood Analyzer)
  - The PCBA Cartridge Kit
  - PCBA Control Kit
  - EVARM system
- Rack 2
  - The Advanced Astroculture
  - Foot Ground Interface - Flight Cal Unit
  - Total Force - Foot Ground Interface
  - Lower Extremity Monitoring Suit
  - Ambulatory Data Acquisition System
- Rack 3
  - Ultrasound
  - GASMAP /calibration module



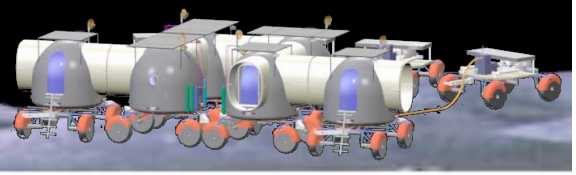
Life Sciences: Level 2

MORPHLAB

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- Nutrition & medical care
- Radiation
- Plant biology

Questionnaires

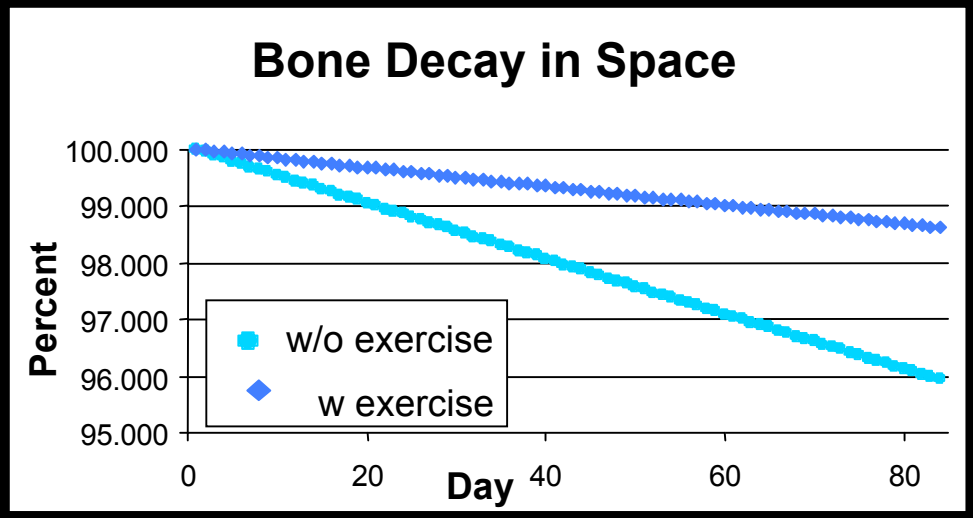
- "The objective of this study is to measure the impact of cultural and language background on space missions and to characterize changes over time in a number of important interpersonal factors, such as tension, cohesion, leadership role, and the relationship between space crews and monitoring personnel on Earth" (http://lsda.jsc.nasa.gov)
- Questionnaires are submitted via computer back to Earth

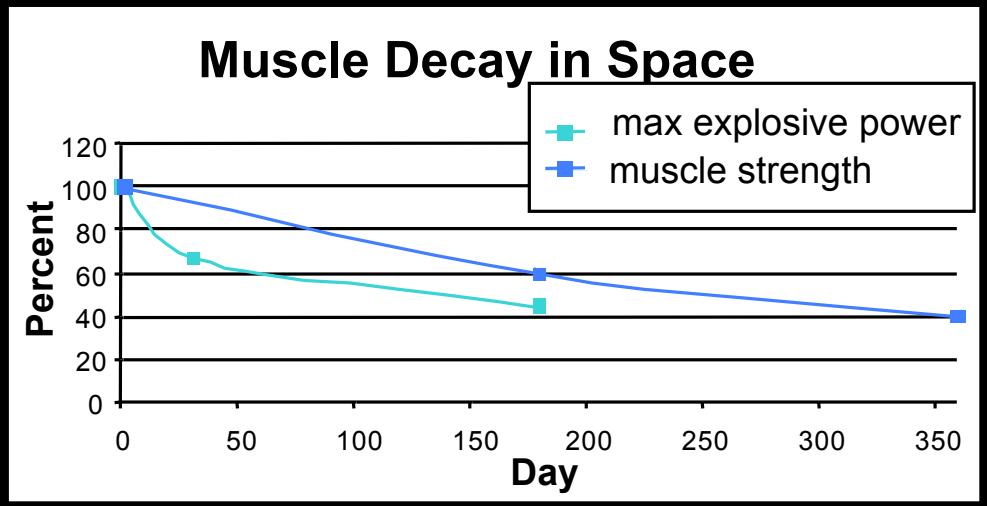


MORPHLAB

Life Sciences: Level 2

- Bones have a steady decay, even with exercise.
- Muscle strength decreases significantly
- In lunar gravity, these number are not expected to be as drastic, but bone and muscle decay still need to be studied





MORPHLAB

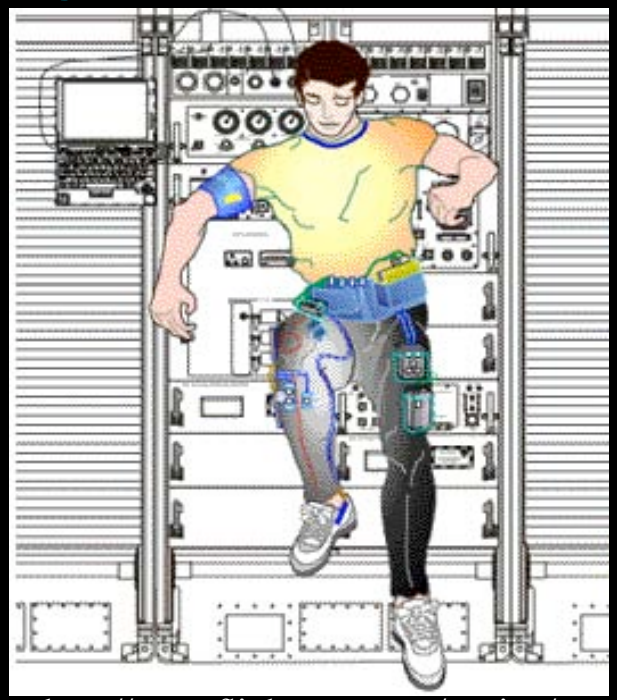
Life Sciences: Level 2

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- Nutrition & medical care
- Radiation
- Plant biology

Foot/Ground Reaction System

- Lower Extremity Monitoring Suit
- Total Force – Foot Ground Interface
- Foot Ground Interface – Flight Calibration Unit

- Measures the forces your legs and feet experience through a normal work day



http://spaceflight.nasa.gov/station/science/experiments/fact_foot.html

- Mass: 46 kg

Life Sciences: Level 2

MORPHLAB

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- Nutrition & medical care
- Radiation
- Plant biology

Ultrasound

- 3D capability & real time 2D
- Respiratory Trace Display
- Total Mass: 86 kg

- **Applications**:
  - Echocardiography
  - Abdominal (deep organ)
  - Vascular, muscle, tendon, trans-cranial ultrasound

http://hrf.jsc.nasa.gov/ultrasound.htm

MORPHLAB

Life Sciences: Level 2

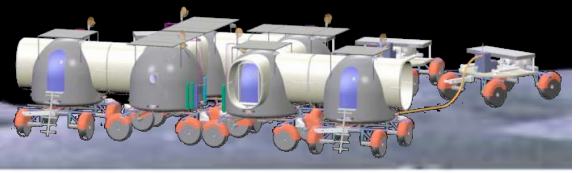
- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- **Nutrition & medical care**
- Radiation
- Plant biology

Gas Analyzer System for Metabolic Analysis Physiology (GASMAP)

- Study effects of reduced gravity on the musculoskeletal aspects of breathing during rest, heavy exercise, and deep breathing

http://hrf.jsc.nasa.gov/gasmappics.htm

- Measures volume, temp, frequency, pressure of inhaled & exhaled air
- To be used during exercise
- Total Mass: 244 kg



MORPHLAB

Life Sciences: Level 2

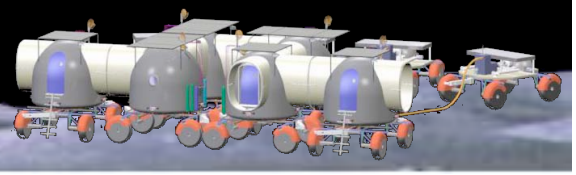
- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- **Nutrition & medical care**
- Radiation
- Plant biology

Portable Clinical Blood Analyzer (PCBA)

- Study red blood cell mass and production.

- Mass PCBA: 0.54 kg
- Mass Cartridge Kit: 0.27 kg

http://www.amedical.com/istat.html



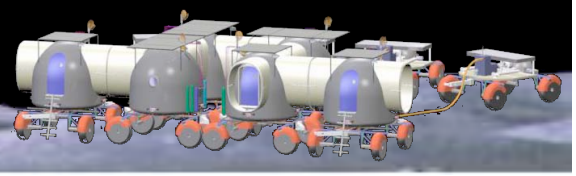
MORPHLAB

Life Sciences: Level 2

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- **Nutrition & medical care**
- Radiation
- Plant biology

Ambulatory Data Acquisition System

- Provides convenient data acquisition and storage of data collected by physiological sensors (such as FOOT). It will measure core body temperature, blood pressure, respiration and other physiological responses.



MORPHLAB

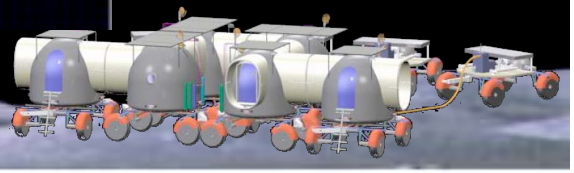
Life Sciences: Level 2

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- Nutrition & medical care
- Radiation
- Plant biology

EVARM System

- Records radiation over different parts of the body during an EVA
- Mounted inside the EVA suit
- Worn on the head, torso and leg

http://resources.yesican.yorku.ca/trek/radiation/final/index_EVARMS.html



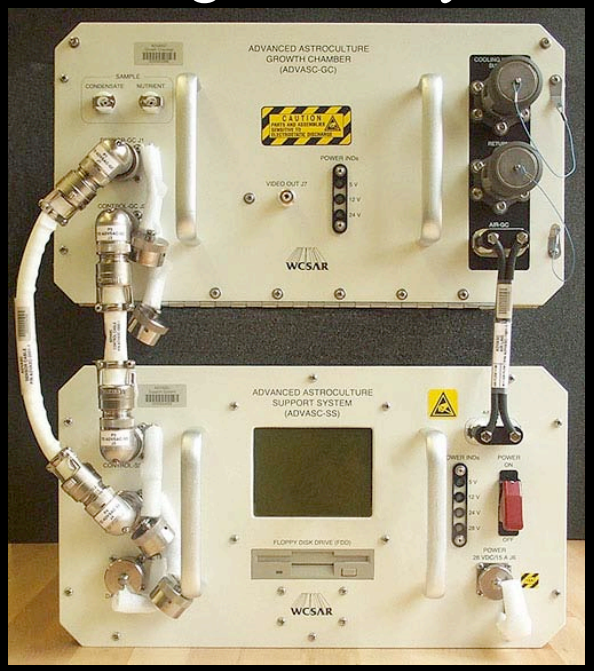
MORPHLAB

Life Sciences: Level 2

- Crew dynamics
- Human performance, adaptations
- Skeletal system
- Muscle decay
- Cardiovascular system
- Nutrition & medical care
- Radiation
- Plant biology

Advanced Astroculture™ (ADVASC)

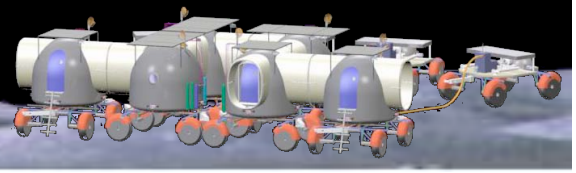
- Autonomous & continuous care for the plant for an average 180 days.



http://wcsar.engr.wisc.edu/advasc.html

- The top box contains the computer, electronics & other support systems
- The bottom box contains the controlled plant growth chamber and ancillary subsystems
- Growing Space
  - Shoot area: 486 cm^2
  - Shoot height: 34.5 cm
  - Root area: 486 cm
  - Root height: 5 cm

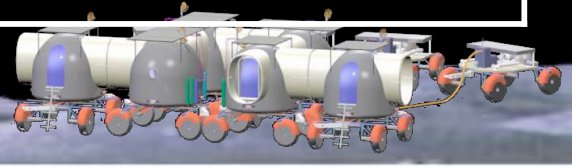
•Mass: 4.4 kg



MORPHLAB

Summary of Instruments

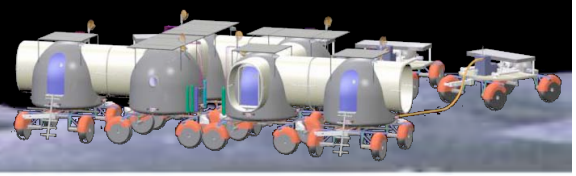
Instrument	Mass: kg	Power
FOOT	46 kg	Batteries included 1.5 V dc
Ultrasound	86 kg	Peak 1004 W
(GASMAP)	244 kg	Peak 270 W
(PCBA)	.81 kg	Two 9 volt batteries
EVARM system	-	-
Questionnaires	-	-
Astroculture™ Chamber	46.7	Peak 300 W
Ambulatory Data Acquisition System	2.31	AA batteries
Totals	426 kg	1574W



MORPHLAB

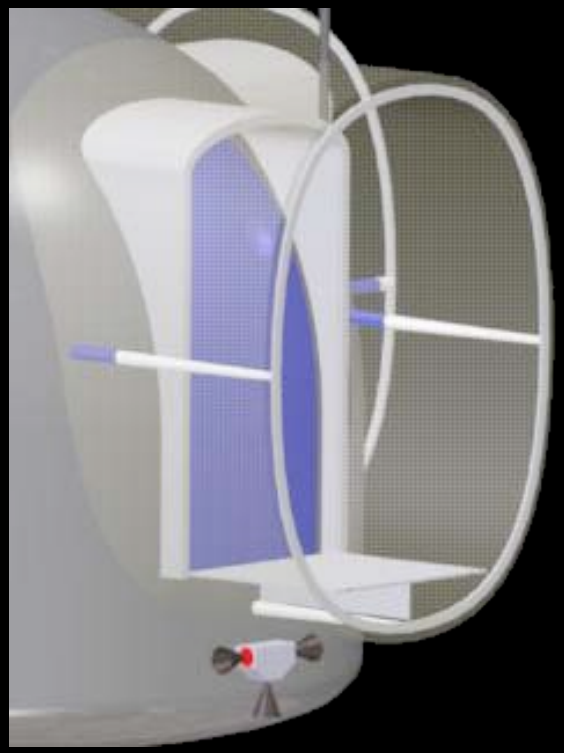
Habitat to Habitat Connections

- To fulfill requirement M5, that all nominal movement between modules be accomplished in shirtsleeve conditions, some form of pressurized mating tunnel is required.
- Space limitations in the launcher payload shroud dictated that this system be retractable.
- Mass limitations on the habitat modules dictated that this system be as light as possible.
- Concerns over tipping while in transit dictated that this system needed to be able to deploy and retract before and after each crewed mission segment.



MORPHLAB

Paramount Tunnel Tradeoffs

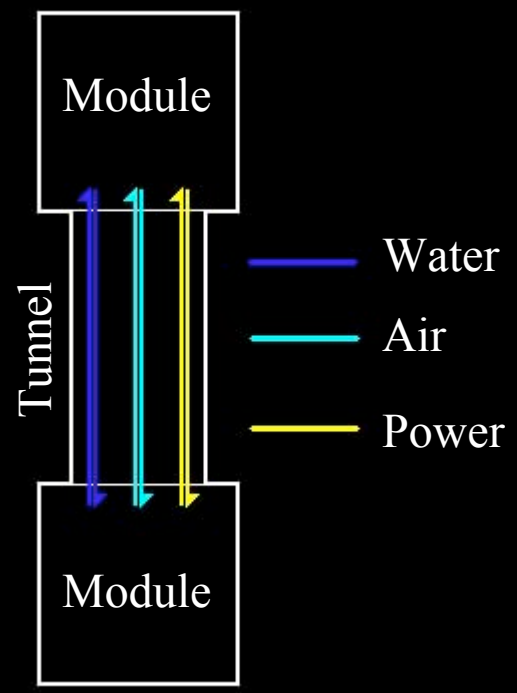


- Metallic vs. Composite
- Male/Female mating vs. Androgynous mating
- Layered pressure bladder vs. Abrasion cover
- Active terminal mating vs. Passive terminal mating
- Passive latch connection vs. Active bolt connection
- Doors: normally open vs. normally closed

MORPHLAB

Additional Tunnel Concerns

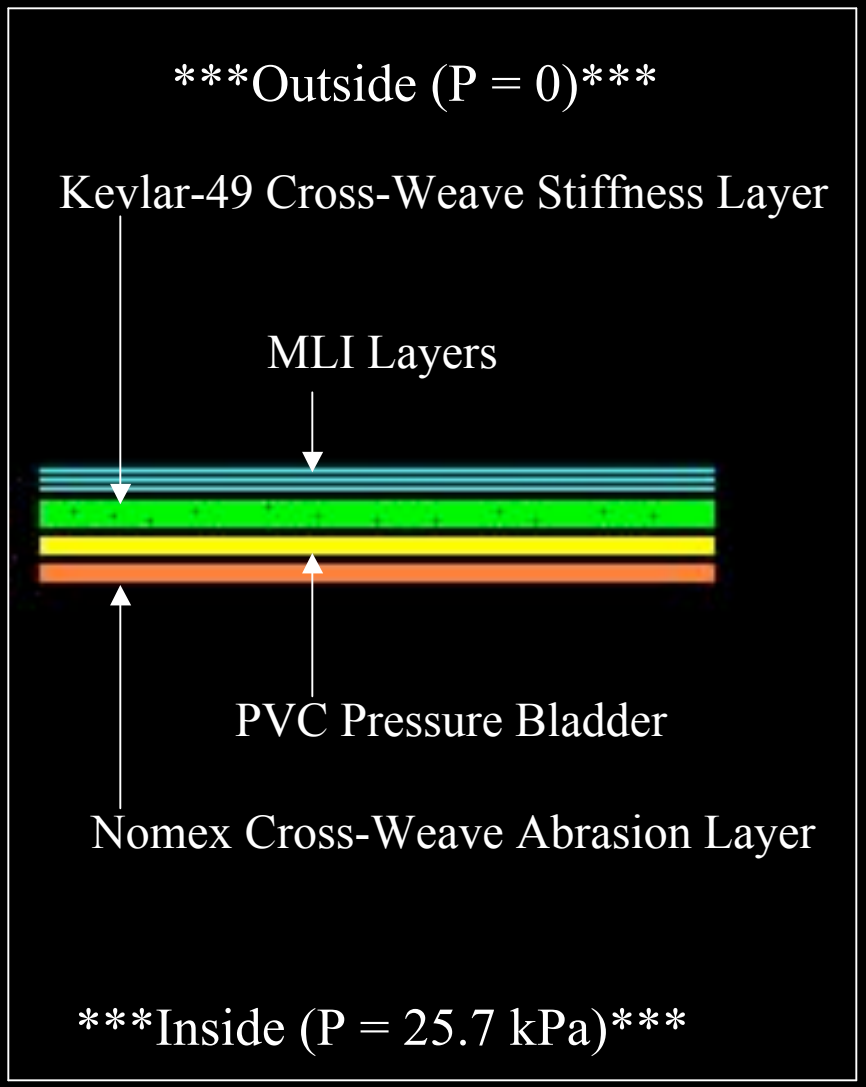
- To modularize the air and water purification systems
  - Airflow must be allowed between habitable sections
  - Piping for water transport would need to exist between habitable modules
- Power delivery between modules could not be accomplished using the mechanical chassis linkages during Base Assembly Phase
  - Cables for power transfer would need to exist between habitable modules



MORPHLAB

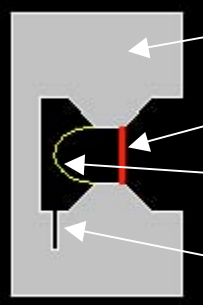
Extendable Tunnel

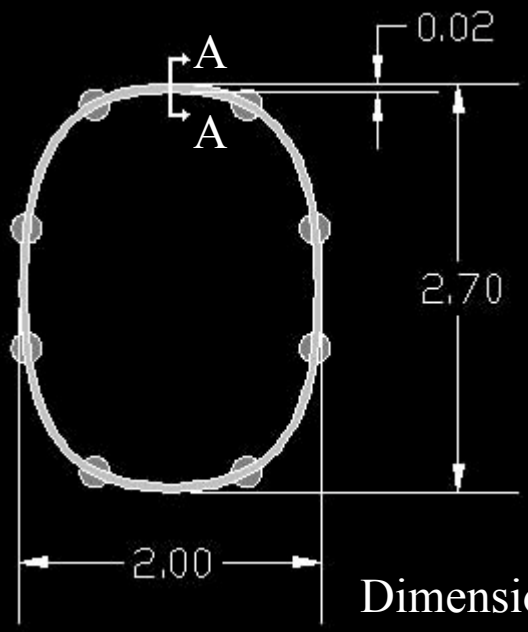
- Foldable composite (Kevlar-49) was chosen over a telescoping metal tube.
  - Mass savings of 8x
  - Lighter extension mechanism than a large telescoping structure
  - Less likely to puncture pressure bladder
- Layers will be held together at the ends by clamped aluminum hoops.
- Two lengths: 1 m and 0.5 m
- Mass of 1 m tunnel: 10 kg
- Mass of 0.5 m tunnel: 6 kg



Mating Ring

- Androgynous mating system chosen over male/female system to maximize possible base configurations.
- Tunnel connected to mating ring via clamping mechanism with self-sealing o-rings to ensure pressure seal.
- Power and water piping connections located in ring
  - Hard dock seals piping
  - Piping runs inside or parallel to extension mechanism
- Total mass of mating ring: 80 kg



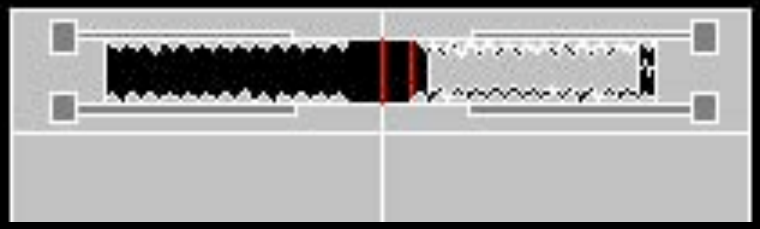


Dimensions in meters

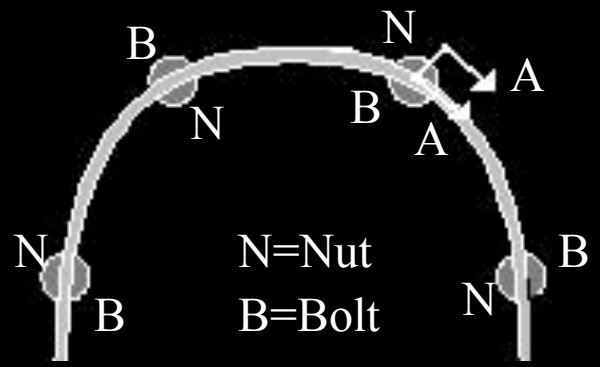
MORPHLAB

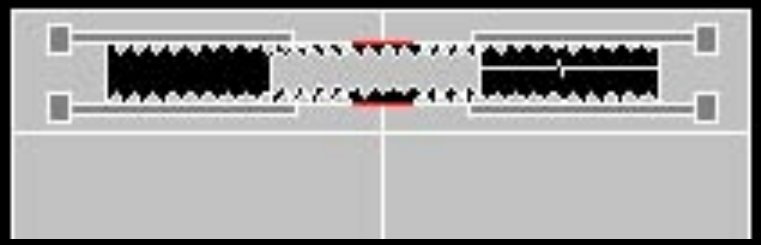
Hard Dock

- Antisymmetric nut/bolt configuration provides androgynous interface.
- Inner and outer hard connection points.
- 16 connections needed to ensure both two-fault tolerance and antisymmetry.
- Active bolt hard dock chosen due to 2x mass savings over passive latches.
- Spring-loaded dust covers ensure no particles get into threads when not in base assembly.



A-A Soft Dock



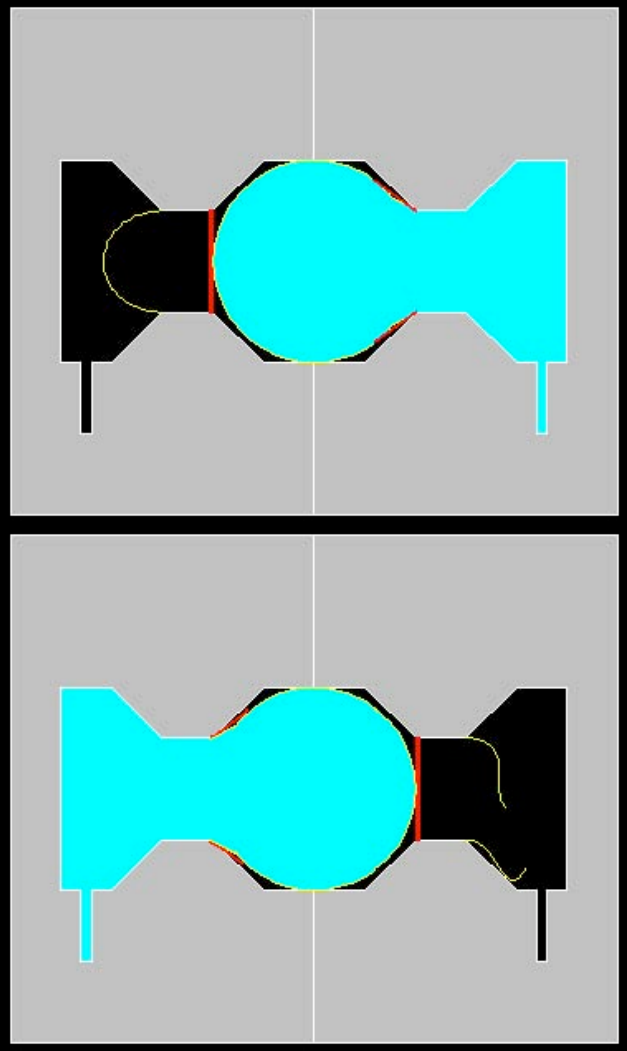


A-A Hard Dock

MORPHLAB

Pressure Seal

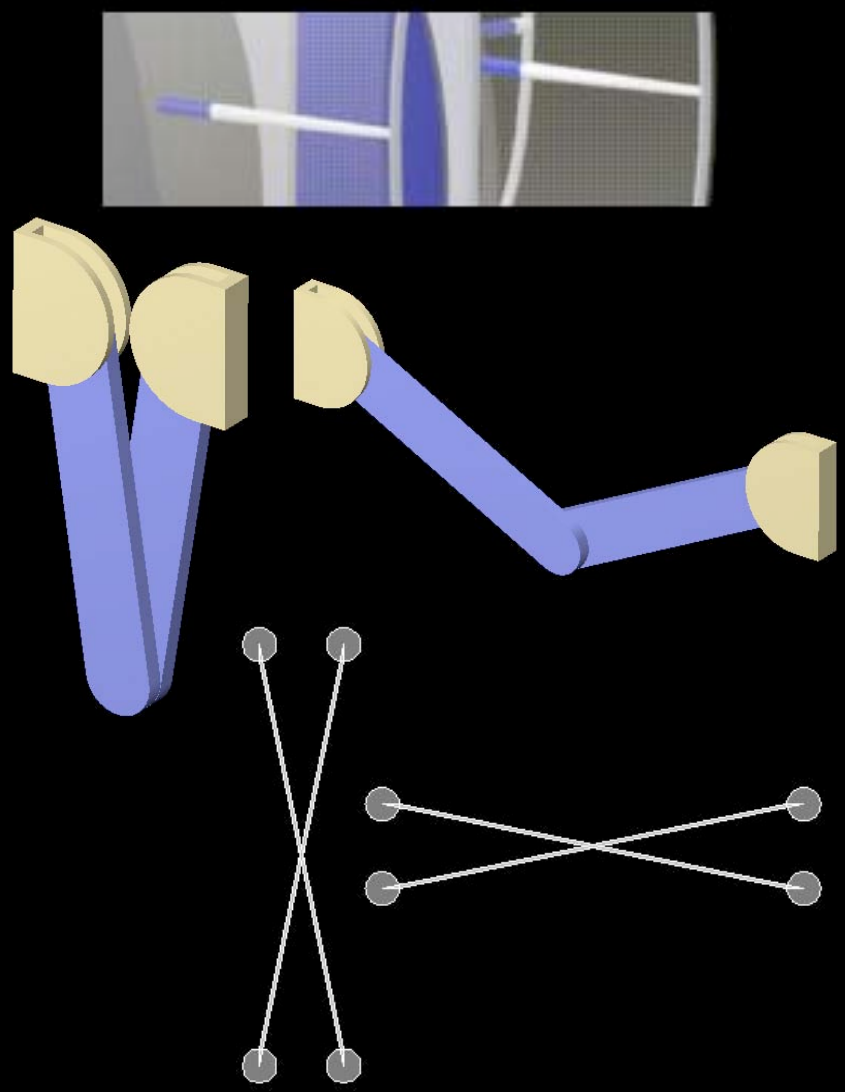
- After hard dock, PVC pressure seal bladder inflates in order to form a self-sealing pressure seal.
- In the event of a rupture in the bladder, the other pressure seal bladder can inflate to seal the leak.
- Spring-loaded dust cover prevents dust and UV radiation from degrading the PVC when not in base assembly.
- Pressurization lines carried with extension mechanism.



MORPHLAB

Extension Mechanism

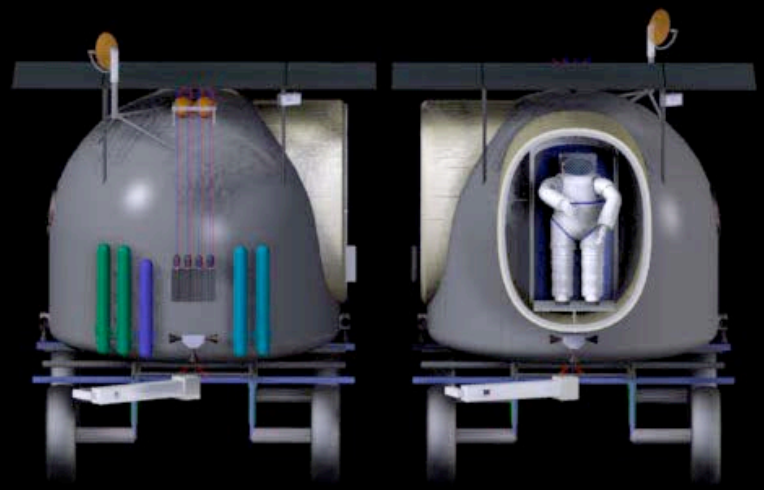
- Exact mechanism has not yet been chosen, the candidates are:
  - Telescoping tube
    - Can also be used to transfer power and water
  - Rotators and beams
    - Can be used for precision alignment of mating rings
  - Extending beams
    - Easily adapted from chassis



MORPHLAB

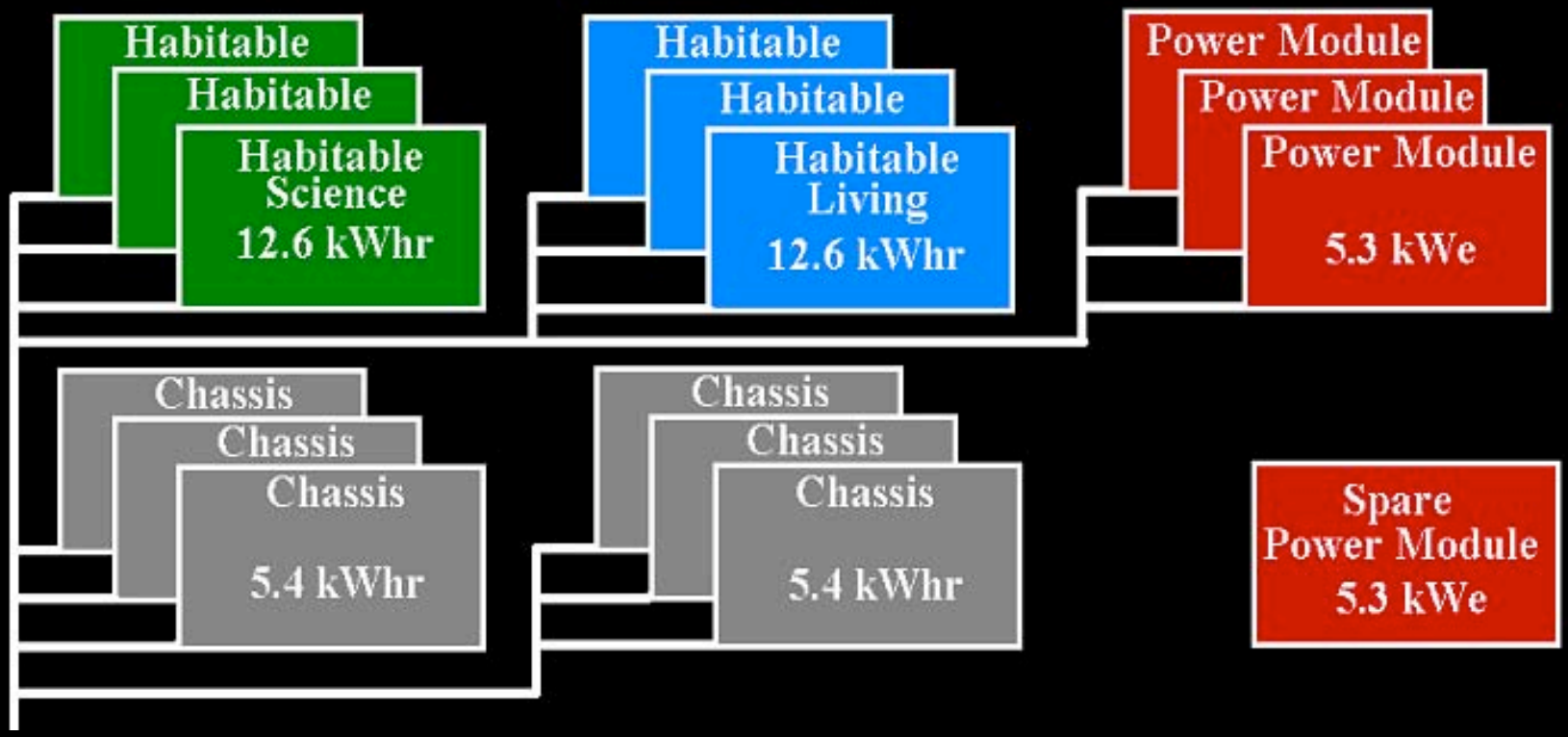
Mating Sequence

- Initial alignment with chassis wheels
- Initial tunnel extension
- Terminal alignment via sensors
- Terminal tunnel extension
- Soft dock
- Extend bolts
- Hard dock
- Pressure seal inflation
- Pressure bladder inflation
- Exterior walkway deployment
- Doors open to circulate air



MORPHLAB

Base Peak Power System



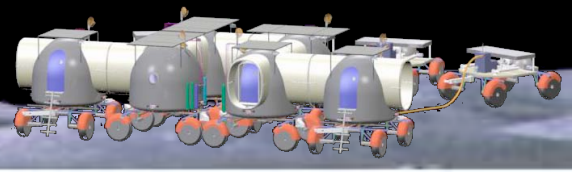
Maximum Power Output:
20.4 kWe (for 24 hours) With 3 DIPS

MORPHLAB Net Battery Totals

Mass: 870 kg

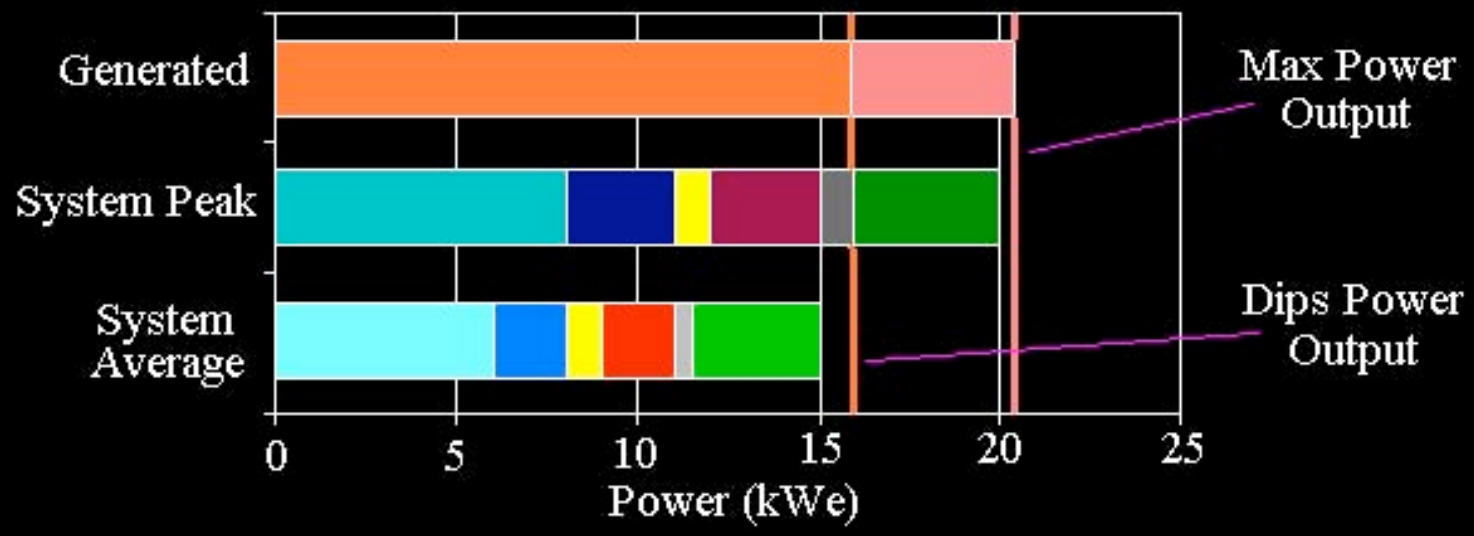
Storage Capacity: 108 kWhr

24 Hour Discharge: 4.5 kWe



MORPHLAB

Base Power Budget



Generated Power

DIPS*	15.9 kWe
Battery	4.5 kWe
Total	**20.4 kWe**

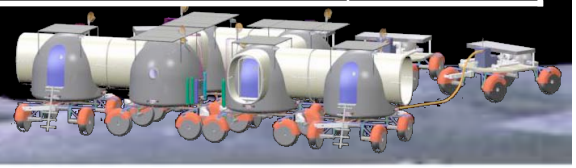
*Output of 3 Power Modules

Base System Average

Crew Systems	6 kWe
Avionics	2 kWe
House Keeping	1 kWe
Thermal Control	2 kWe
Battery Recharge	0.5 kWe
Science	3.5 kWe
Total	**15 kWe**

Base System Peak

Crew Systems	8 kWe
Avionics	3 kWe
House Keeping	1 kWe
Thermal Control	3 kWe
Battery Recharge	1 kWe
Science	4 kWe
Total	**20 kWe**



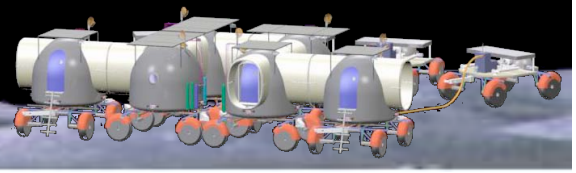
MORPHLAB

Crew Systems

Design Constraints:

- All crew interfaces shall
  - Accommodate the 95th percentile American male to the 5th percentile Japanese female (L1)
  - Adhere to NASA STD-3000 (L2)
- For optimal performance on long duration missions
  - Minimum surface area = 61 m^2
  - Min. ceiling clearance = 2.2 m
  - Min. interior volume = 135 m^3
- Nominal mission consists of
  - 4 member crew (L4)
  - Capable of daily 2 person EVAs (L5)
  - Zero pre-breathe time for EVAs (L9)
- Emergency requirements
  - 180 day subsistence food stock (L6)
  - At least 2 IVA exits from each module
  - EVA bailout options(L8)

* IVA = Inter-Vehicular Activities

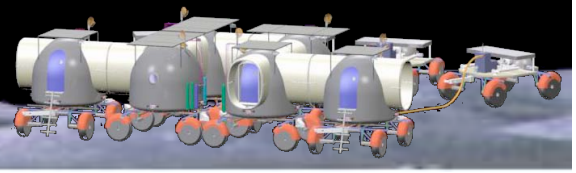


Cat McGhan &
Jessica Seidel

MORPHLAB

MORPHLAB vs. LMLSTP

- Lunar-Mars Life Support Test Project (LMLSTP)
  - NASA/ Johnson Space Center project
  - 4 crew members spending 90 days in a closed-loop life support system habitat
  - Habitable Surface Area = 58.44 m^2
  - Habitable Volume = 163.63 m^3
- Total for MORPHLAB base configuration
  - Habitable Surface Area = 75.4 m^2
  - Habitable Volume =198 m^3



MORPHLAB

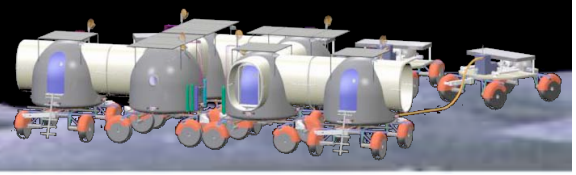
Module Subtypes

Habitable-Living:

- 2 Crew quarters
  - Sunken SPE-shielded beds
  - Sanitary systems, main level
- 1 Galley
  - Food preparation area
  - Exercise area, lounge
  - Backup quarters (I3 & I11)
- ECLSS systems
  - Vapor Phase Catalytic Ammonia Removal
  - Multi-filtration
  - Supercritical Waste Oxidation

Habitable-Science:

- 2 EVA areas
  - Main airlocks, dust removal
  - Repair area, tool storage
  - Durable experimentation area
- 1 Experiment area
  - Finer specialized equipment
  - Backup galley (I3 & I11)
- ECLSS systems
  - Water Vapor Electrolysis
  - Electrochemical Depolarized Cells
  - Sabatier
  - Trace Contaminant Control

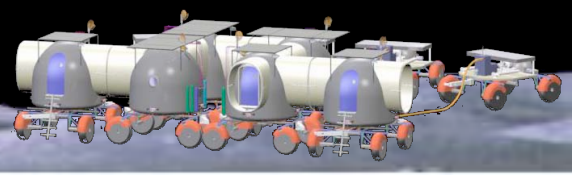


Cat McGhan &
Syed Hasan

MORPHLAB

Atmosphere Selection

- Cabin pressure set at 57.1 kPa
  - Design Considerations:
    - Pressure low enough to allow R value under 1.6 (NASA standard)
    - Pressure high enough to allow for minimum fire risk
- 40% O_2, 59% N_2, 1% CO_2
  - Calculations of partial pressures of each of the gas' minimum and maximum levels for long duration exposure were used to determine this make-up
  - Levels for hyperoxia, hypoxia, CO_2 toxicity, and fire prevention from NASA STD-3000 document



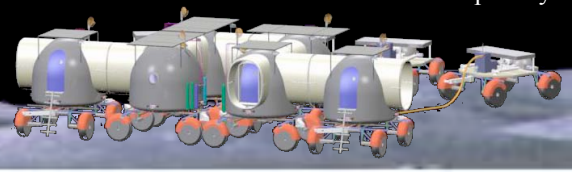
MORPHLAB

ECLSS – Overview

Oxygen Generation:	Water Vapor Electrolysis
Carbon Dioxide Removal:	Electrochemical Depolarization Concentrator
Carbon Dioxide Reduction:	Sabatier
Trace Contaminant Control:	Trace Contaminant Control System
Water Distillation:	Vapor Phase Catalytic Ammonia Removal
Water Filtration:	MultiFiltration
Solid Waste Removal:	Supercritical Water Oxidation

Subsystem	WVE	EDC	Sabatier	TCC	VAPCAR	MF	SCWO
Weight (kg)	144.00	44.40	17.90	100.00	68.00	3.90	694.00
Volume (m^3)	0.75	0.07	0.04	0.30	0.24	0.0012	2.12
Power Req. (kW)	1.60	0.15/0.11	0.05	0.15	0.10	0.0004	1.44

* All values for crew per day



MORPHLAB

ECLSS – Needs and Effluents

Needs	Supply (kg)
Oxygen	3.36
Hygiene Water	101.6
Supply Water	9.48
Solids	2.48

Effluents	Product (kg)
Carbon Dioxide	4.00
Hygiene Water	101.6
Supply Water	6.00
Solids	0.44

* All values for crew per day

Oxygen - Shortage of 0.40 kg per crew/day

Water vapor Electrolysis produces 2.96 kg per crew/day while 3.36 kg is required

Hygiene Water – no shortage.

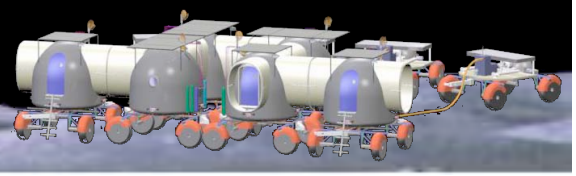
Multifiltration produces 100% water resupply up to flow of 114 kg day (> 101.6 kg)

Supply Water – Shortage of 3.48 kg per crew/day

Vapor Phase Catalytic Ammonia Removal System produces 100% water resupply up to flow of 13 kg/day (> 6 kg). 6.00 kg or supply water is recycled while 9.48 kg is required.

Solids – 2.48 kg required per day

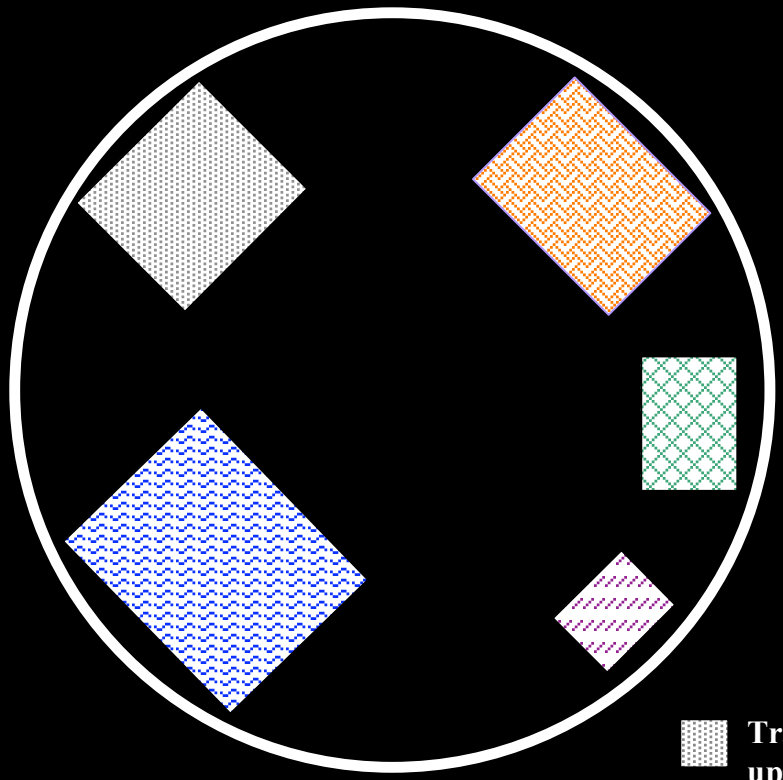
Supercritical Waste Oxidation has 0% resupply flow rate. All solids needed must be provided using food.



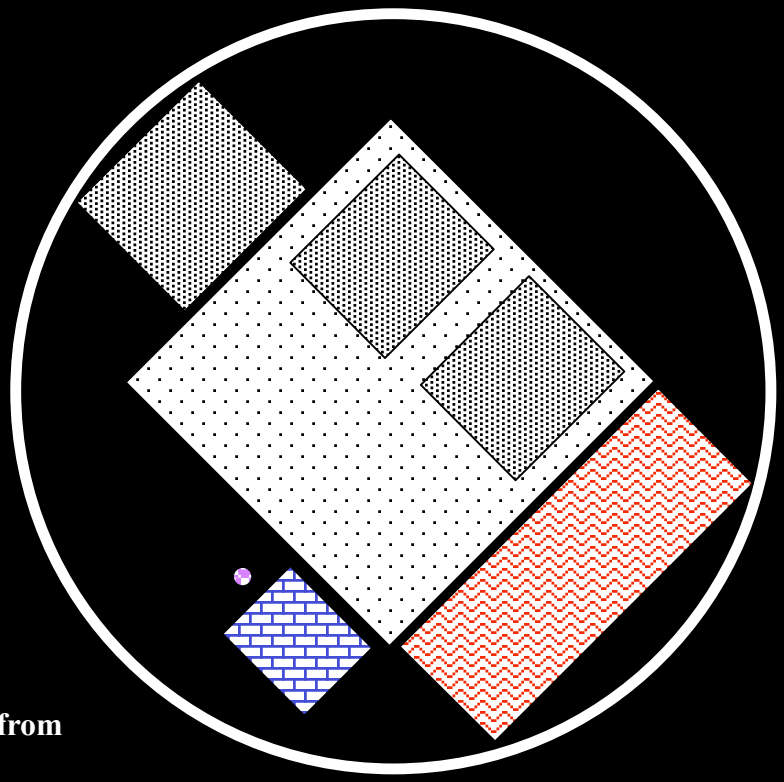
MORPHLAB

ECLSS – Interior Layouts

Habitat Module Basement – Science/EVA



Habitat Module Basement – Living/Bed



Trap door from upstairs

Water Vapor Electrolysis

Electrochemical Depolarization Concentrator

Vapor Phase Catalytic Ammonia Removal

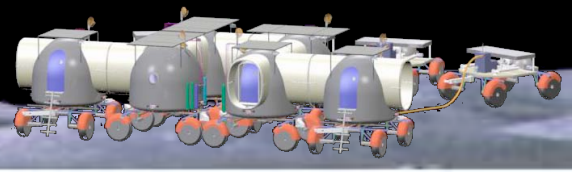
Supercritical Waste Oxidation

Sabatier

Trace Contaminant Control

Multifiltration

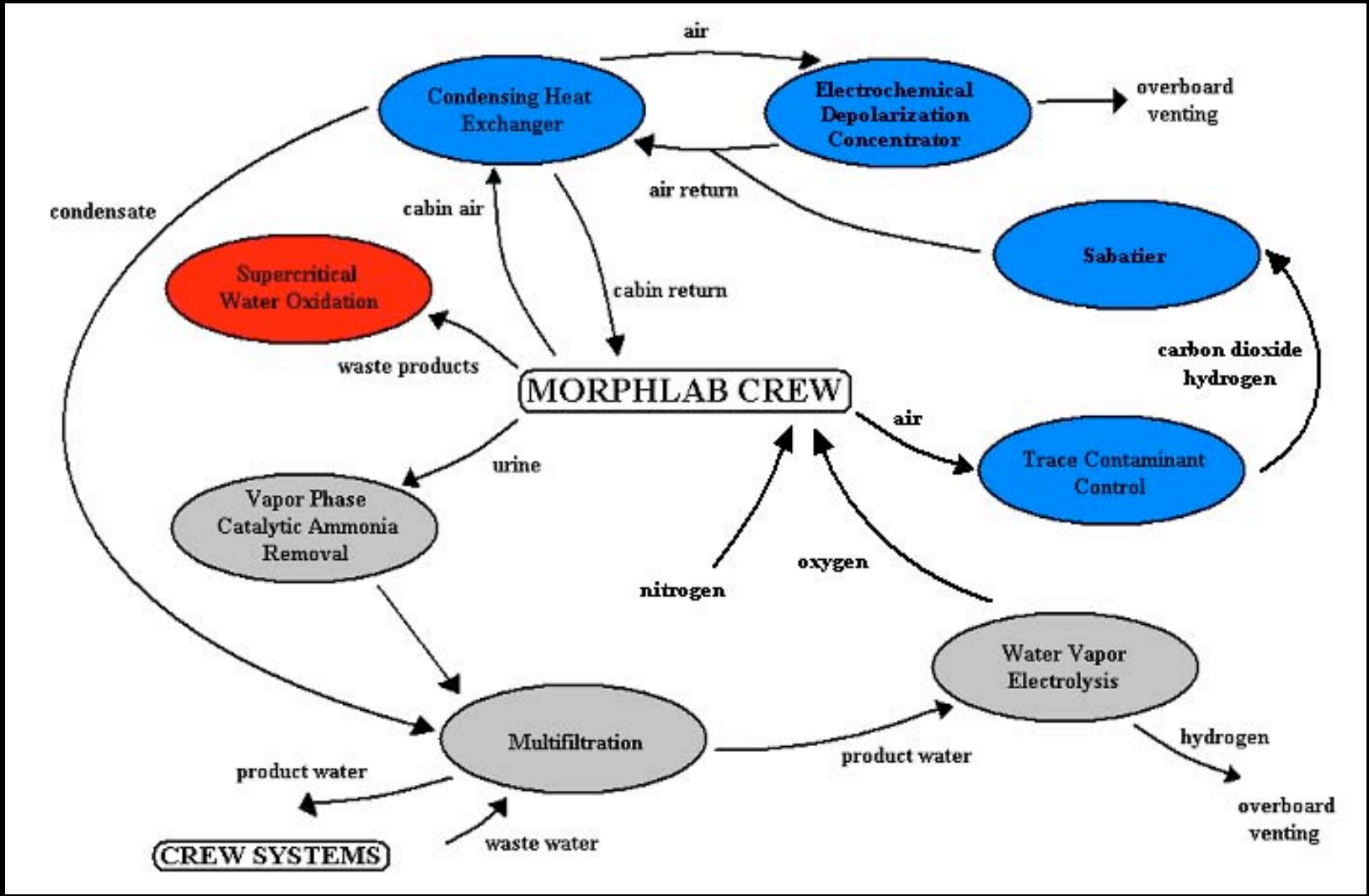
Sleeping Quarters

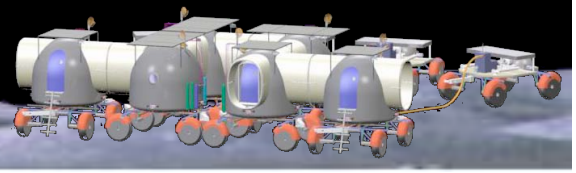


Syed Hasan

MORPHLAB

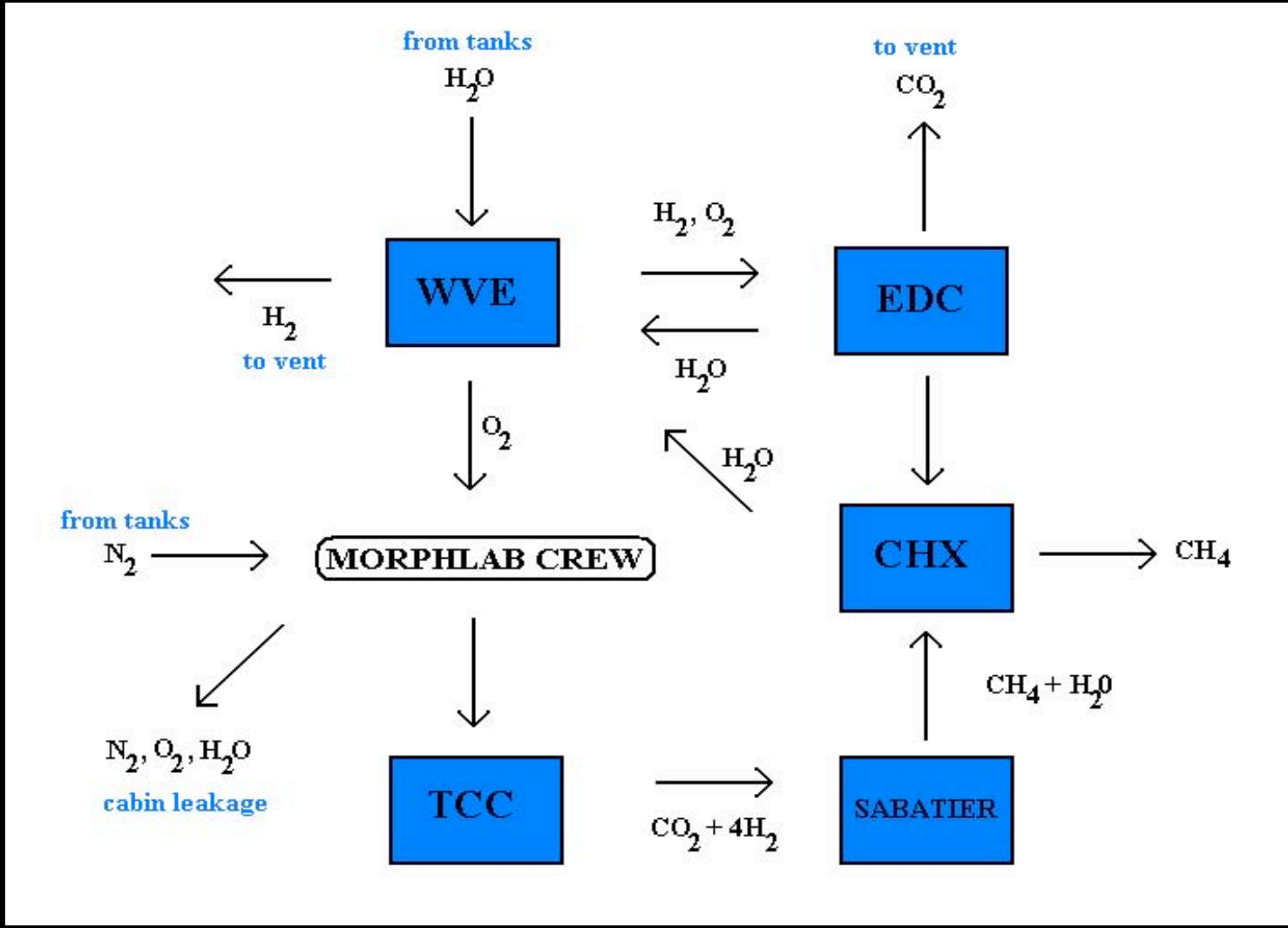
ECLSS Flow Diagram





MORPHLAB

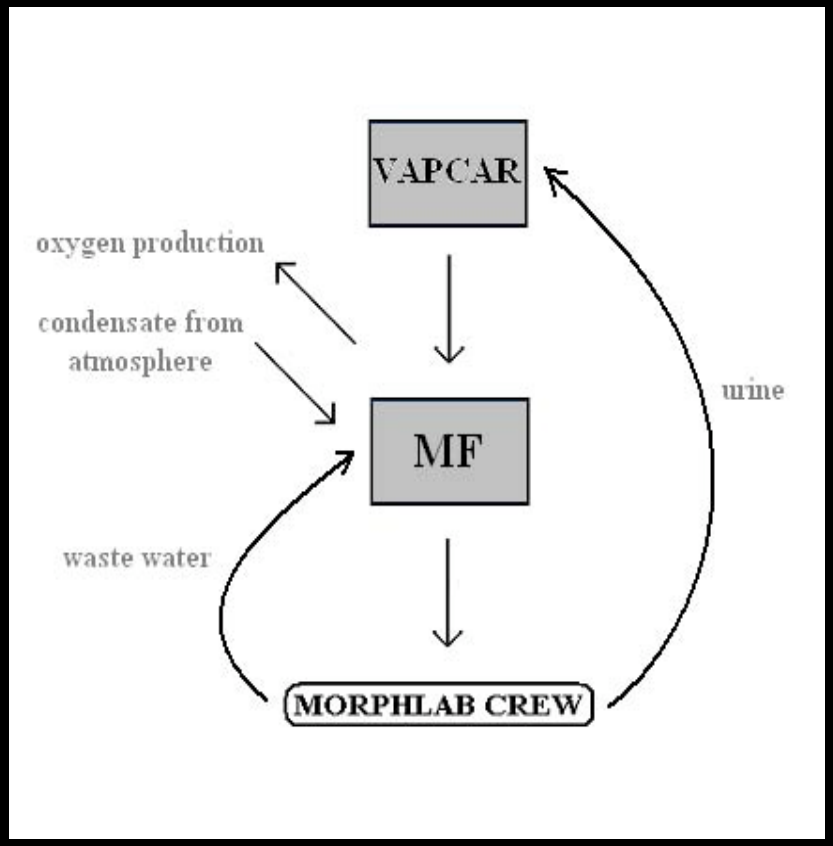
Air Flow Diagram



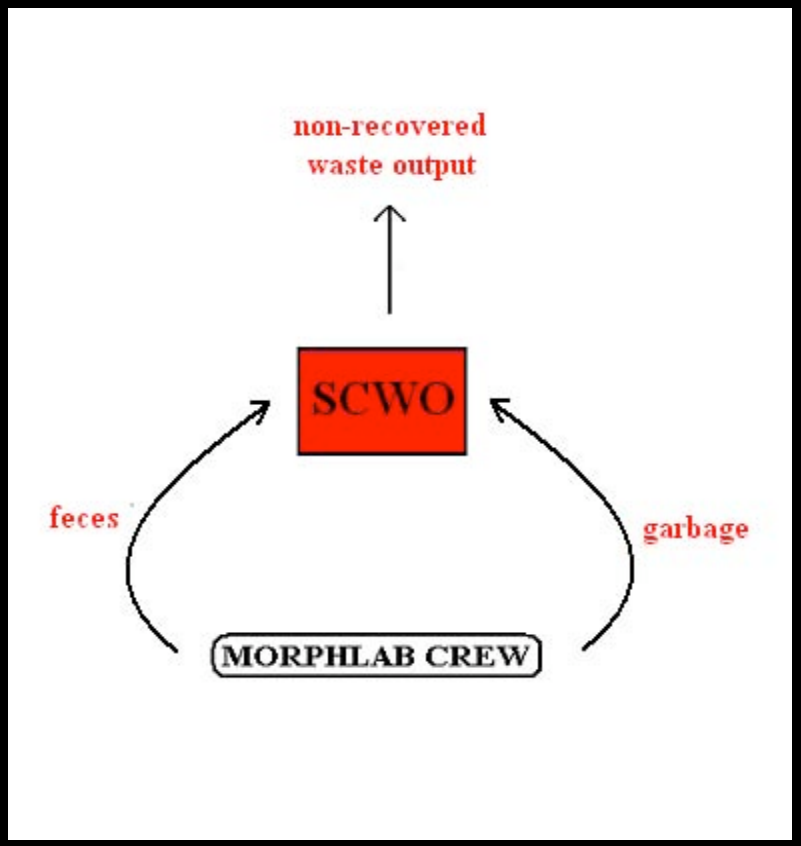
MORPHLAB

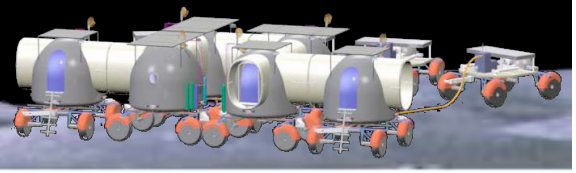
Water and Waste Flow Diagrams

WATER FLOW



WASTE FLOW





MORPHLAB

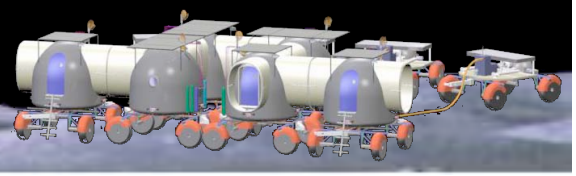
ECLSS - Summary

Subsystem	Weight (kg)
Water Vapor Electrolysis	144.0
Electrochemical Depolarization Concentrator	44.4
Sabatier	17.9
Trace Contaminant Control System	100.0
Vapor Phase Catalytic Ammonia Removal	34.0
MultiFiltration	2.0
Supercritical Water Oxidation	347.0

Module	Weight (kg)
Science/EVA	306.3
Living/Bed	383.0

Supply needed per mission (84 days)

Product	Amount (kg)
Oxygen	33.6
Hygiene Water	0.0
Supply Water	292.3
Solids	208.3

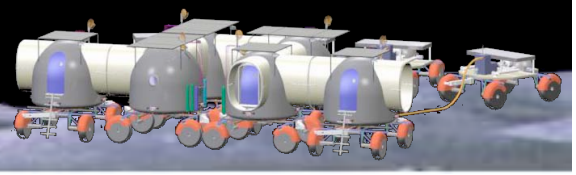


MORPHLAB

Logistics Depot

- Will be launched before every mission containing re-supply of provisions
- Exterior of habitable module, with provisions in place of interior equipment
- First depot:
  - Supplies provisions for two months
  - Contains mobile Robonauts to perform maintenance throughout program
  - Contains two lunar rovers

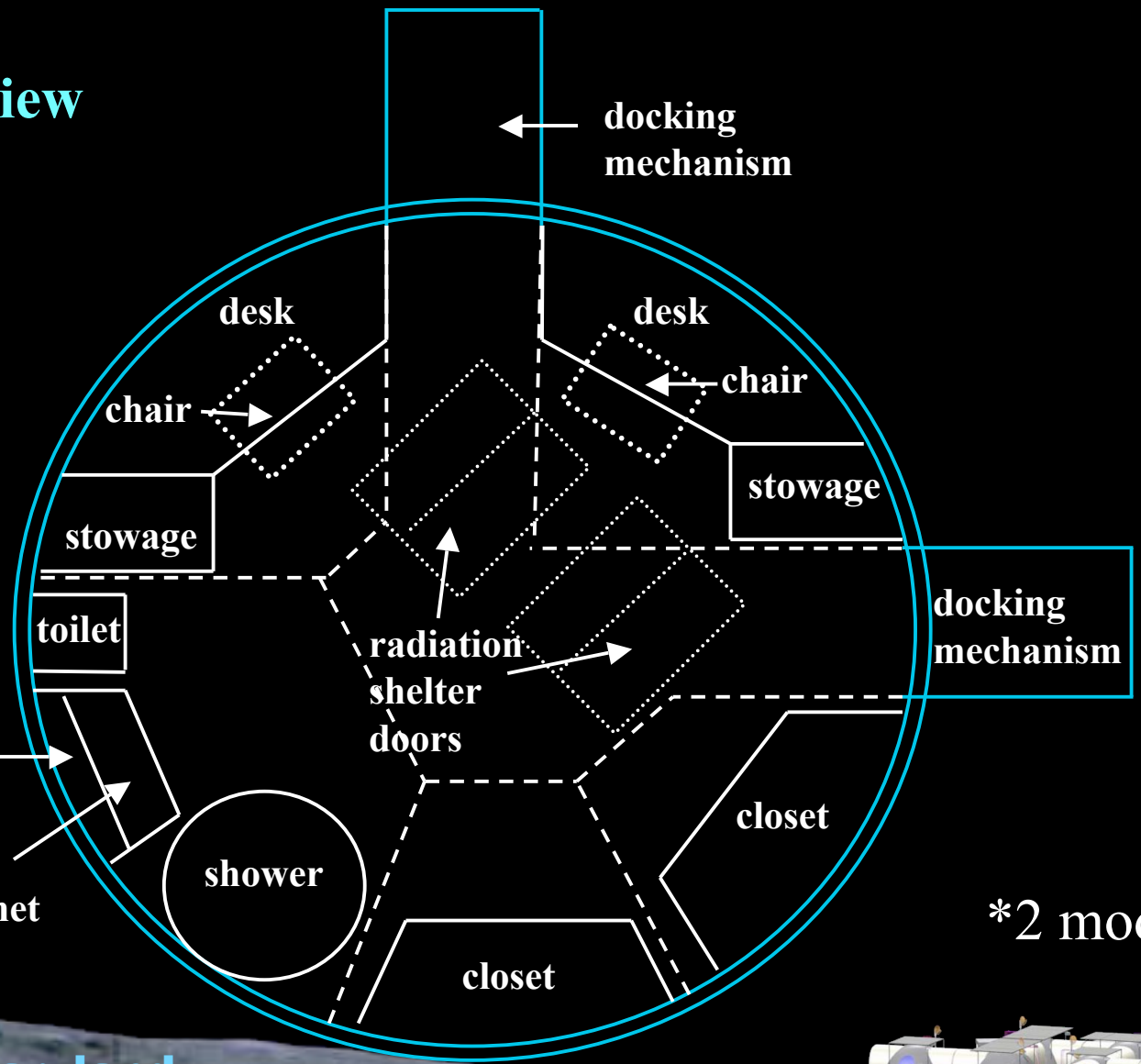
ITEM	MASS (kg) First mission – 56 days Logistics Depot 1	MASS (kg) Remaining missions - 84 days Logistics Depot 2-10
Oxygen gas	50	75
Oxygen tanks (6)	230	345
Nitrogen gas	36	53
Nitrogen tanks (6)	205	308
Water	195	292
Water tanks (6)	21	31
Food	139	208
Robonaut on wheels (2)	312	-
DC battery	44	44
Landing legs	212	212
Science instruments	563	563
Hull	410	410
Lunar Rovers (2)	416	-
TOTAL	2833	2542



Habitable-Living: Crew Quarters

MORPHLAB

Top View

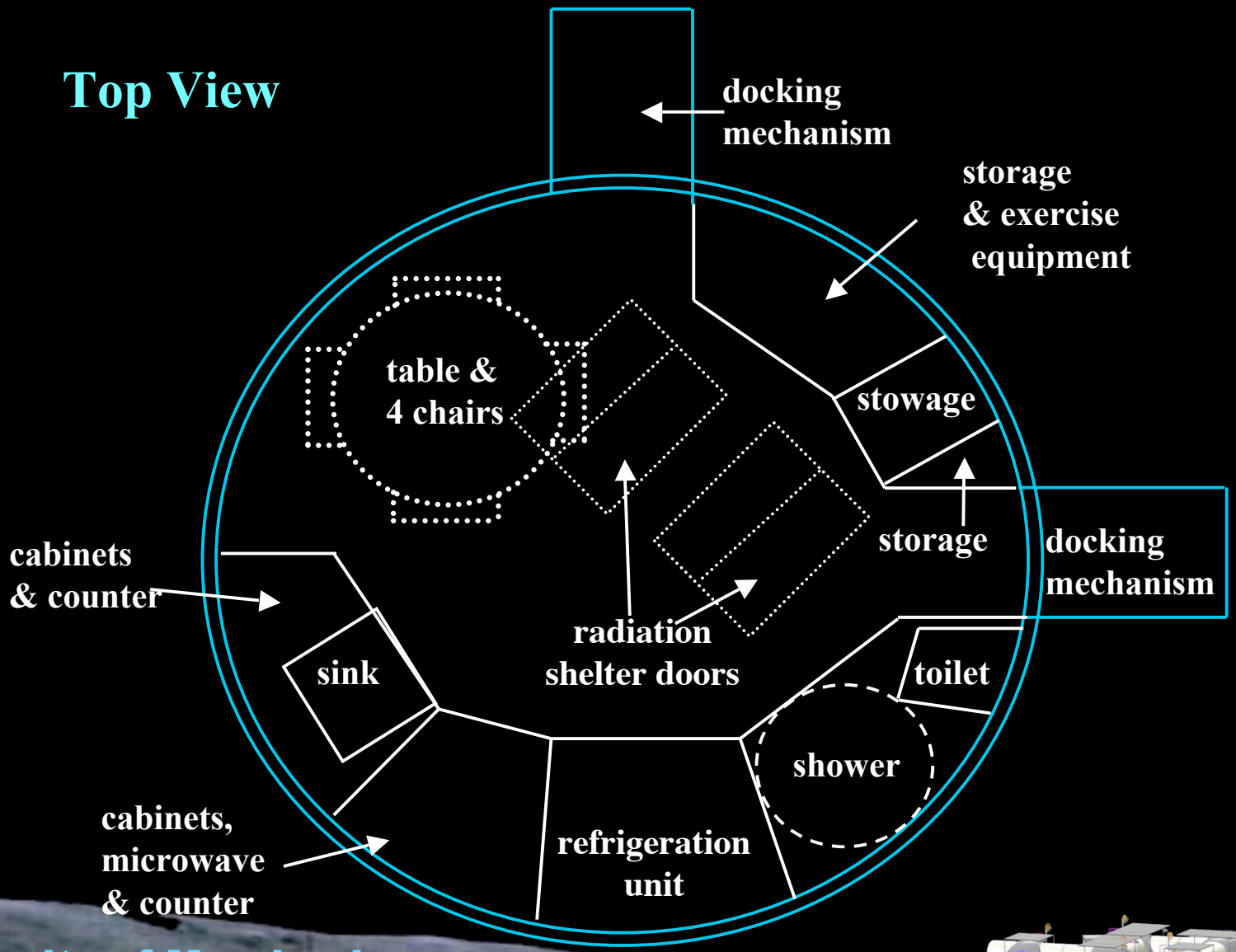


*2 modules

Habitable-Living: Galley

MORPHLAB

Top View

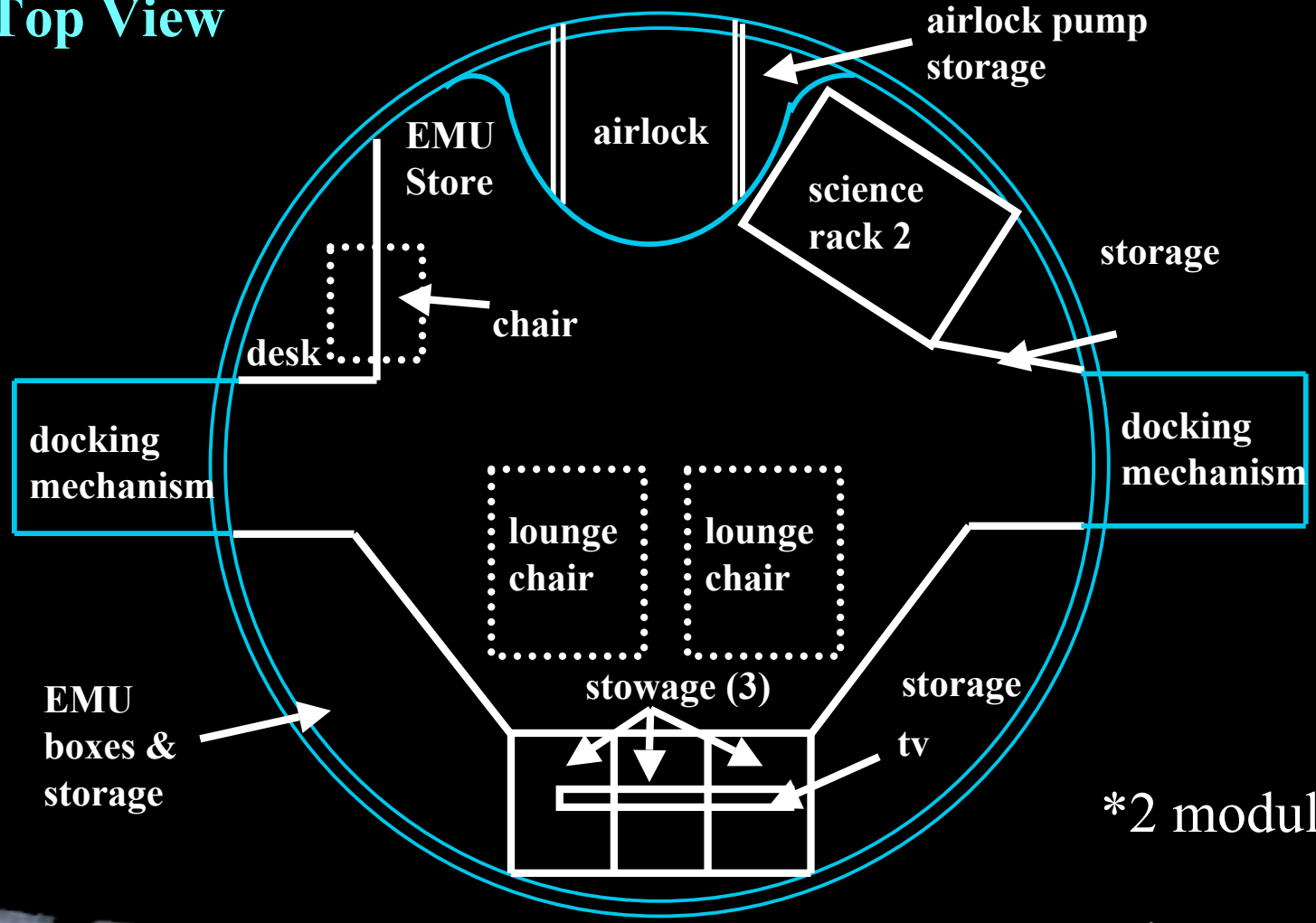


Jessica Seidel

Habitable-Science: EVA

MORPHLAB

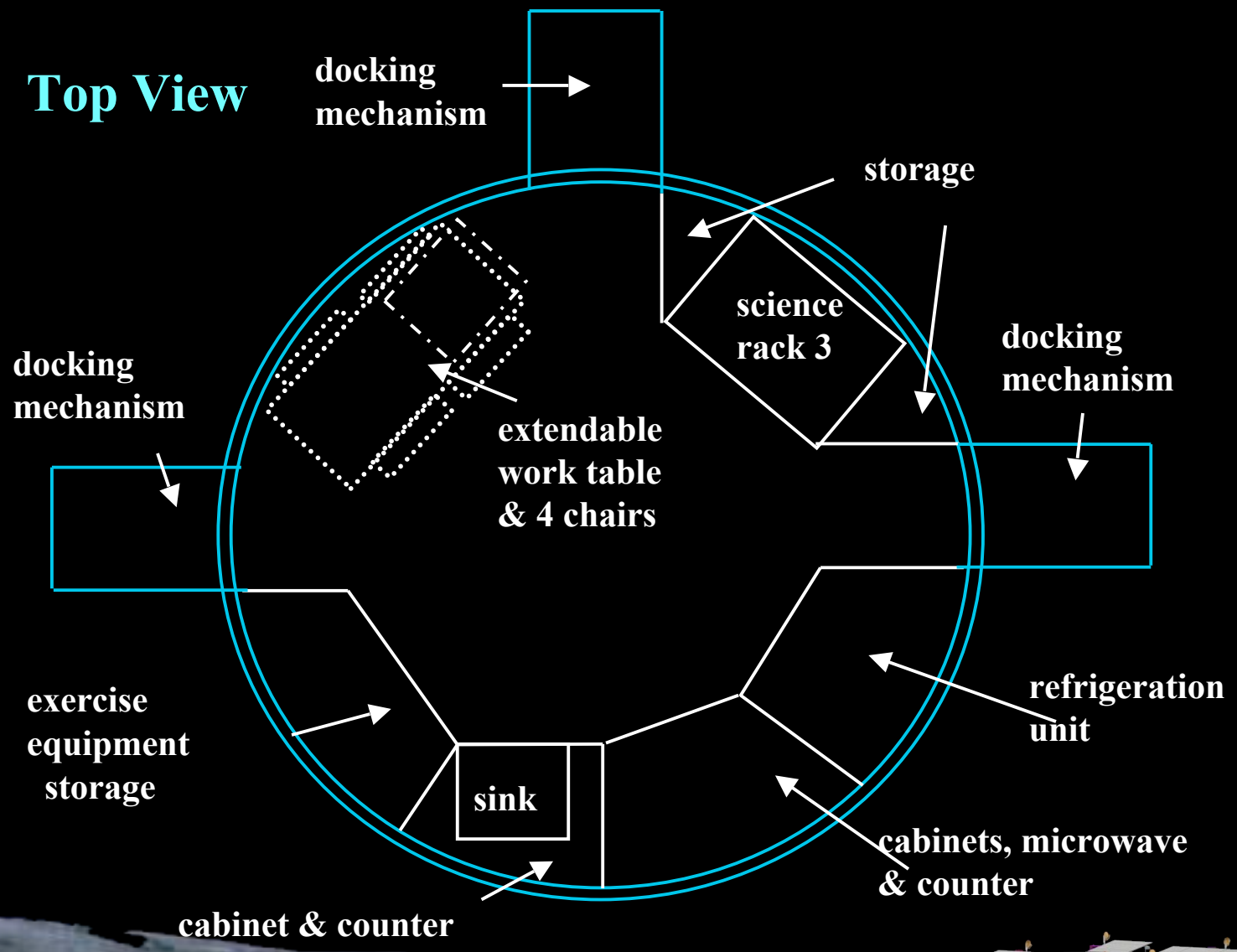
Top View



*2 modules

Habitable-Science

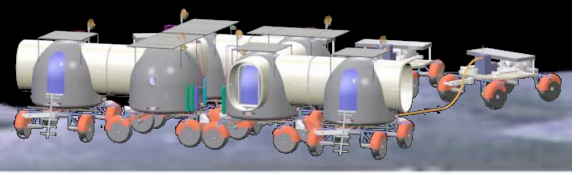
MORPHLAB



MORPHLAB

Interior Acoustics

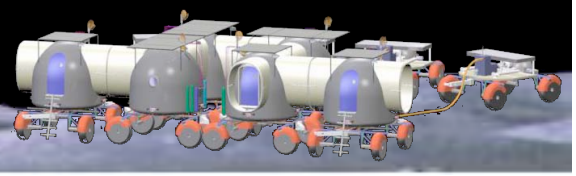
Sound Pressure Level in dB	Duration	Performance Effects
30-40	Continuous	No conversation interference
60-70	Continuous	Voices must be raised significantly; telephone use difficult
85	Long	Protective earwear must be worn
100	Sudden onset	Reflex response of tensing, grimacing, covering the ears, and urge to avoid or escape
114	Sudden onset	Pain in the ears
120	Continuous	Hearing loss occurs
150	2 minutes	Reduced visual acuity; chest wall vibrations; gag sensations; respiratory rhythm changes
167	Sudden onset	Human lethality



MORPHLAB

Computer User Interface

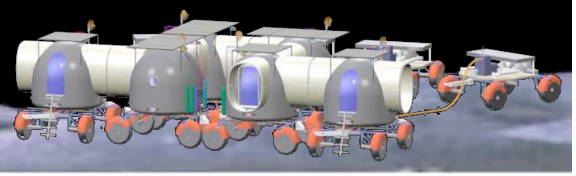
- Will be LCD flat panel, touch screen mounted on the walls in the habitable modules
  - Currently have 18” LCD touch screen panels that weigh less than 2kg
  - No external input devices reduces clutter inside module
- System of menus to browse different command options
  - Sensor monitoring
    - ECLSS
    - Power grid
    - Computer status
    - Communication status
  - Communications with Earth
  - Communications with other modules
  - EVA support
    - Communications with Astronauts
    - Tele-operation of rovers
  - Entertainment



MORPHLAB

Alerts for Sensor System

- Integrated sensors for
  - air and water composition
  - pressure levels
  - system integrity
- Monitoring Computer System (MCS)
  - sensors are all tied into it; tracks changes in the levels
  - issues commands to the appropriate system to make adjustments if optimal levels are not met
  - communicates problems to the crew via yellow and red alert alarms when problems occur



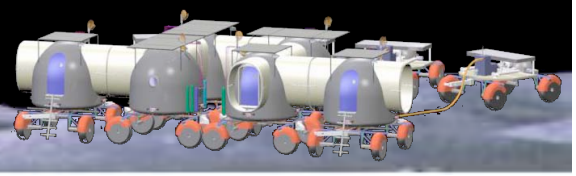
MORPHLAB

System Levels – ECLSS

System	Red, low	Nominal	Red, high
Electrochemical Depolarized Concentrator	291K	--	297K
Sabatier	366.5K	700K	811K
Trace Contaminant Control	-- --	723K, 100kPa	-- --
Vapor Phase Catalytic Ammonia Removal	-- 50kPa	350K, 80kPa	723K, 200kPa
Multifiltration	289K, 70kPa	-- --	328K, 210kPa
Supercritical Water Oxidation	647K, 22.1MPa	923K, 25.3MPa	1023K, --

- Note: Yellow levels are 10% in from Red levels

Cat McGhan, Syed Hasan



System Levels – Atmosphere

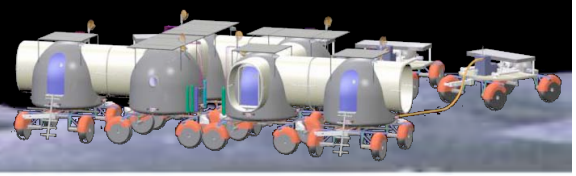
- For internal working considerations only:

Gas	Red, low	Yellow, low	Nominal	Yellow, high	Red, high
O_2	18.62kPa, 32.5%	21.38kPa, 37.3%	22.89kPa, 40%	34.48kPa, 60.2%	41.38kPa, 72.28%
CO_2	-- --	-- --	0.4kPa, 0.69%	1.01kPa, 1.7%	3.54kPa, 3.5%

- For EVA considerations only:

R-factor	Red, low P_{module}, high N_2%	Yellow, low P_{module}, high N_2%
1.3	52.41kPa, 63.5%	55.17kPa, 60.5%
1.4	55.17kPa, 65%	57.93kPa, 62%
1.6	60.69kPa, 68%	62.76kPa, 65%

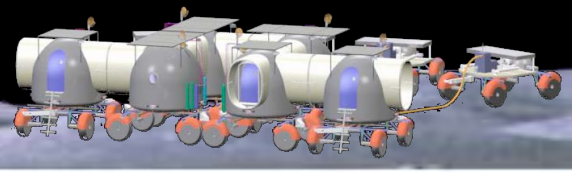
- P_{suit} = 25.7kPa, P_{module} = 57.2kPa nominal
- O_2% = 100% - N_2% - 1% CO_2



MORPHLAB

Other Monitoring

- Fire protection
  - minimal because of the atmospheric composition
  - fire extinguishers are present to put out small fires
- Health monitoring
  - occurs on a daily basis
  - is part of the exercise routine for data collection on the effects of a low-gravity environment on the human physiology



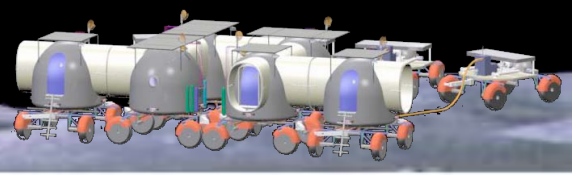
MORPHLAB

Crew Activity

- Crew Schedule Guidelines:
  - The crew may adjust the schedule to that day's science
  - The following guidelines should be followed when adjusting daily schedule (L2)
    - Crew members must eat at least once every 7 hours
    - 2 hours delegated for exercise and recreation each day
    - 8 hours of sleep a day
- EVA rotation:
  - Two, two person teams will alternate daily EVAs
  - Teams will alternate crew members every week

Sample Crew Schedule:

Daily schedule	Crewmember Task
0000 - 0600	Sleep
0600 - 0700	Hygiene/Breakfast
0700 - 0800	Daily Coordination
0800 - 1300	EVA/Tasks
1300 - 1400	Lunch
1400 - 1700	EVA/Tasks
1700 - 1900	Exercise & Recreation
1900 - 2000	Dinner
2000 - 2100	Hygiene
2100 - 2200	Downtime
2200 - 2400	Sleep



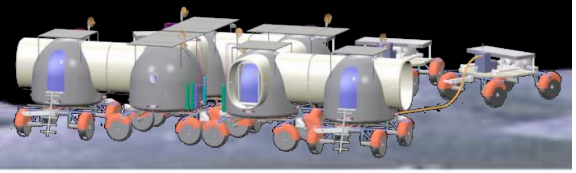
MORPHLAB

Food & Water

- Level 1 requirements state that MORPHLAB must hold 180 days of food at a subsistence level in addition to the 90 days nominal mission supply (L1)

Data based off ISS daily consumables	kg/person-day	Single manned mission requirement (kg)
Drinking water	1.6	576
In food water	1.15	414
Food preparation water	0.75	270
Food	0.62	223

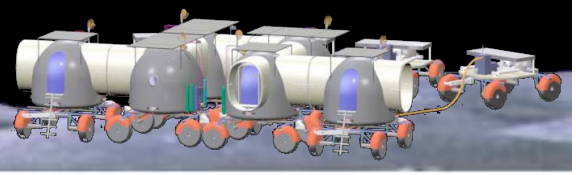
- Subsistence level will contain mostly EVA food bars & nutritional supplements, estimated weight=100kg



MORPHLAB

Nutrition

- NASA STD-3000 states crew member diet must meet FDA nutritional requirement standards (L2)
- Daily caloric intake based on weight in kg
  - Men
    - 18-30 years: kcal/day = 1.7 (15.3*Weight + 679)
    - 30+ years: kcal/day = 1.7 (11.6*Weight + 879)
    - Range: 2791.9 - 3716.3 kcal/day
  - Women
    - 18-30 years: kcal/day = 1.6 (14.7*Weight + 496)
    - 30+ years: kcal/day = 1.6 (8.7*Weight + 829)
    - Range: 1897.12 – 2244.8 kcal/day
- An additional 500 kcal/day should be added when an EVA occurs

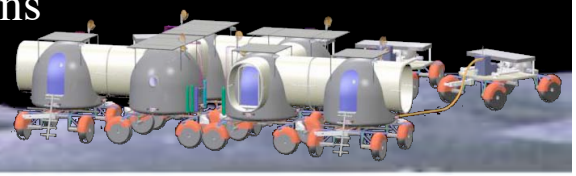


MORPHLAB

Nutrition

Nutrient	Requirement	Nutrient	Requirement
Protein	12-15% total energy consumed	Biotin	100 µg
Carbohydrate	50-55% total energy consumed	Pantothenic Acid	5 mg
Fat	30-35% total energy consumed	Calcium	1000-1200 mg
Fluid	238-357 ml per MJ consumed	Phosphorus	1000-1200 mg
Vitamin A	1000 µg	Magnesium	350 mg
Vitamin D	10 µg	Sodium	1500-3500 mg
Vitamin E	20 mg	Potassium	3500 mg
Vitamin K	80 µg	Iron	10 mg
Vitamin C	100 mg	Copper	1.5-3.0 mg
Vitamin B_{12}	2 µg	Manganese	2.0-5.0 mg
Vitamin B_6	2 µg	Fluoride	4 mg
Thiamin	1.5 mg	Zinc	15 mg
Riboflavin	2 mg	Selenium	70 µg
Folate	400 µg	Iodine	150 µg
Niacin	20 mg	Chromium	100-200 µg

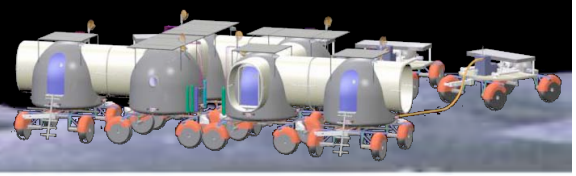
ISS Daily Nutritional Recommendations



MORPHLAB

Food Storage

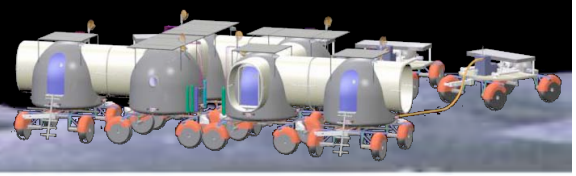
- Three levels of storage
  - Frozen: includes most entrees, vegetables, baked foods, grains, and desserts
  - Refrigerated: fresh-treated fruits and vegetables, extended-shelf-life refrigerated foods, dairy products
  - Ambient: thermostabalized, irradiated, aseptic-fill, shelf-stable natural-form foods, and rehydratable beverages
- 180 subsistence level kept on board at all times, split up evenly between modules
  - Diet will consists of EVA food bars and nutritional supplements
- Nominal manned mission food supply will be sent up via Logistics Depot before each manned mission
  - Food will be stored in 2 week supply containers
  - Containers will have straps so it can be carried onboard during the first EVA



MORPHLAB

EMU Selection

	I-Suit	MK III	AX5	A7LB	Shuttle EMU
Weight- Suit	63.9 kg	67.5 kg	83.25 kg	22 kg	50 kg
Weight- PLSS	15 kg	15 kg	never fitted	26 kg	15 kg
Total Weight	78.9 kg	82.5 kg	83.25 kg	48 kg	65 kg
Operating Pressure	3.75 psi	8.3 psi, tested at 4.3 psi	8.3 psi	3.7 psi	4.3 psi
R value	1.3	1.14 (at 4.3 psi)	0.59	1.3	1.14
Suit type	Soft	Hybrid	Hard	Soft	Soft w. hard upper torso
Manufacturer	ILC Dover	ILC Dover	NASA Ames	ILC Dover	ILC Dover
Entry	Waist	Back	Back	Waist	Waist
Storing	Bags	Hung	Hung	Bags	Bags & Hung
Year developed	1998	1988	1980s	1970s	Late 1970s/ early 80s



MORPHLAB

EVA Support

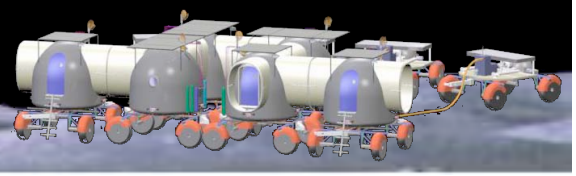
- I- Suit
  - Manufactured by ILC- Dover
  - Soft bodies suit increases mobility and decreases weight
  - Waist entry
  - 8 suits for redundancy (I4)
    - 4 come up with crew, fitted specifically for them
    - 4 kept on board, general sizes with interchangeable section
  - 80 kg weight with Portable Life Support System (PLSS)
  - 8 hours of nominal breathing, 45 minutes of emergency life support
  - 25.7 kPa, 100% O_2 atmosphere
  - Zero pre-breathe (L9)
    - R value of 1.3

http://strangeblue.iwarp.com spacesuits/ILC.html

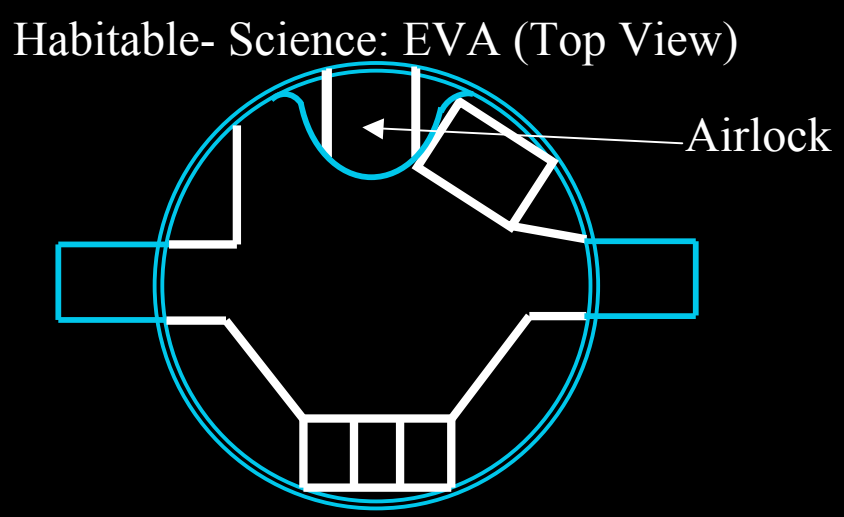
MORPHLAB

Emergency EVA Access

- Level 1, L8: System shall provide emergency access and EVA bailout alternatives
- Airlock connections between modules will serve as pressure doors in case of decompression and also as emergency bailout hatches
- Procedure for emergency egress:
  - Put on EVA suit
  - Make sure all doors are closed and sealed
  - Disengage umbilical walkway
  - Open hatch door to outside
  - Deploy flexible ‘rope’ ladder from floor and egress



Airlock

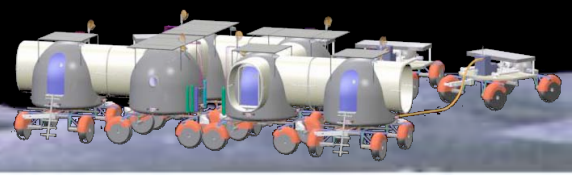


- 101 kg total mass
  - 50 kg structure
  - 22 kg inner door (pressure hatch)
  - 10 kg ladder
  - 14 kg pump
  - 5 kg tubing
- Accommodates one person in I-suit
  - 0.8 m x 0.8 m x 2.0 m high
- Depressurized and Re-pressurized
  - Most of airlock air pumped back into module before outer door is opened
  - Air shower from above when air returns to airlock

MORPHLAB

Airlock

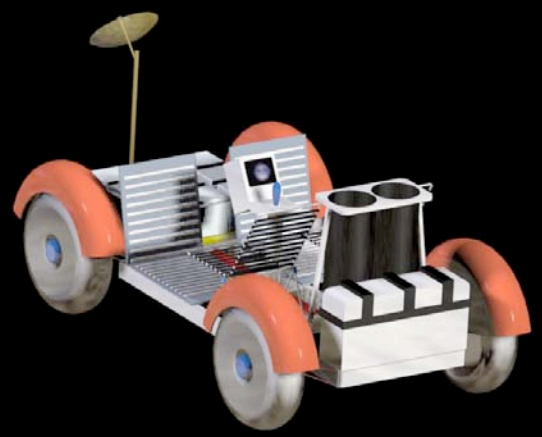
- Pump similar to Dekker Vacuum Technologies DuraVane RVD007L
  - Chosen based on: mass, ultimate vacuum, speed to depressurize
  - 14 kg mass
  - 12 kPa ultimate vacuum
  - 0.2 m^3/min pumping speed, depressurizes airlock in 7 minutes

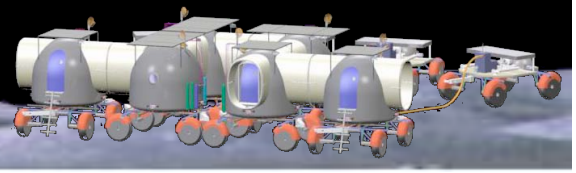


MORPHLAB

Lunar Roving Vehicle

- Level 1 requirements lead us to selection of a rover
  - MORPHLAB shall have daily EVAs by two astronauts (L5), and that they must be able to travel within a radius of 10 km from the base (M4)
    - A 10 km-radius circle is too much area for astronauts to explore on foot, so they need a rover
  - A rover will allow them to bring back soil and rock samples, as in the Level 1 requirements (M3)
  - The rover can be used to transport the astronauts from the landing vehicle to MORPHLAB (M5)

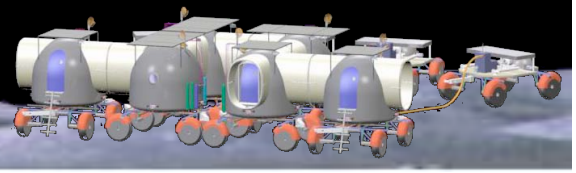




MORPHLAB

Lunar Roving Vehicle

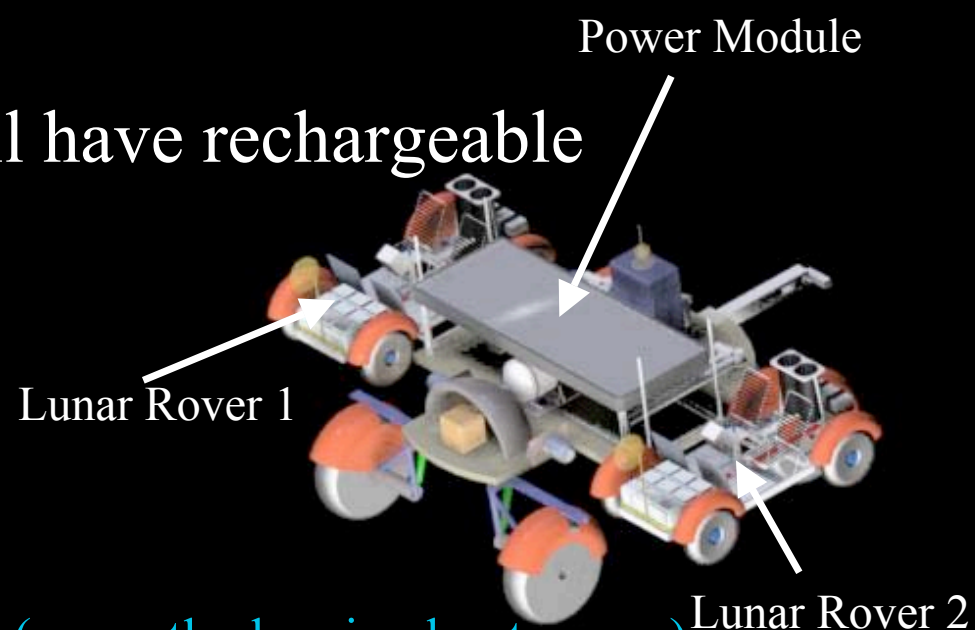
- Based on Apollo Lunar Roving Vehicle
  - 208 kg mass
  - 3.1 m long, 1.8 m wide, 1.2 m high
  - Carries up to 490 kg payload including astronauts, samples, and equipment
  - Folds up to 0.85 m^3 for storage
  - Top speed 14 km/h
  - Can go over obstacles 30.5 cm high, crevasses 70 cm wide
  - Travels on 25° slopes, parks on 35º slopes
  - Pitch and roll stability of ±45º
- Will have two modules to meet redundancy requirement (I3 & I11)



MORPHLAB

Lunar Roving Vehicle

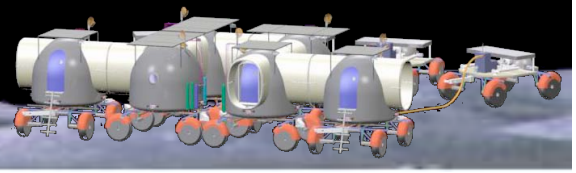
- Original Apollo LRV batteries not acceptable
  - Two 36 V silver-zinc batteries
  - 78 hour lifetime
- MORPHLAB LRV will have rechargeable batteries
  - Two 36 V lithium ion
  - 112 W constant power
  - 11 kg mass
  - Rechargeable
    - Plug into habitat module (currently drawing least power)
    - Budgeted 200 Watts per hour to recharge in 8 hours
- Batteries aren't sufficient for 3 month traverse, so the rovers are transported on the power modules



MORPHLAB

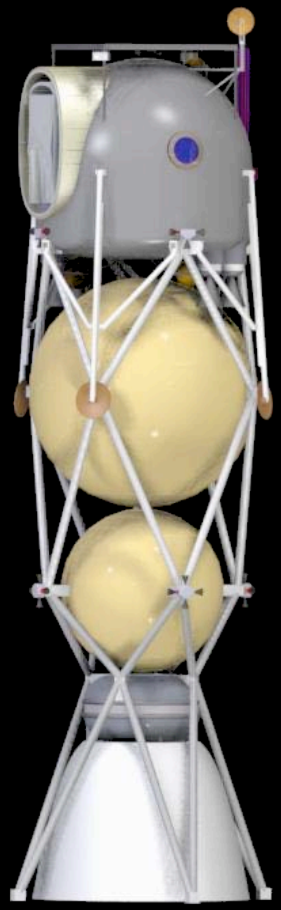
Lunar Roving Vehicle

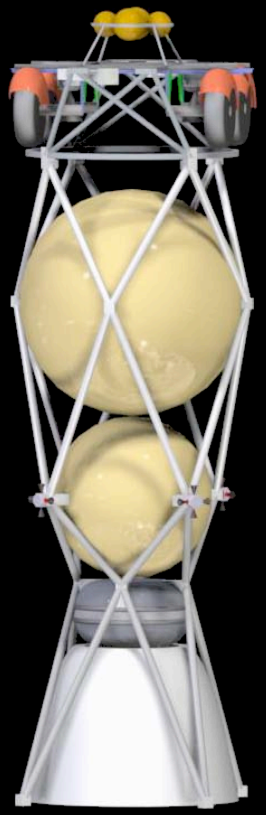
- Payload Breakdown
  - 2 astronauts, 95 percentile American males: 197 kg
  - 2 Mark III Suits & PLSS: 148 kg
  - Lunar samples and soil instruments: 95 kg
  - Communication/control/camera equipment: 10 kg Total: 450 kg
- Speed is useful
  - 14 km/h for an 8-hour EVA gives 112 km of travel total
  - Can return from 10 km in 43 minutes if needed

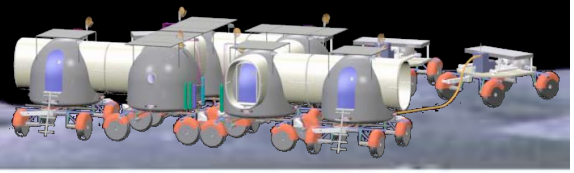


MORPHLAB

Getting to the Moon



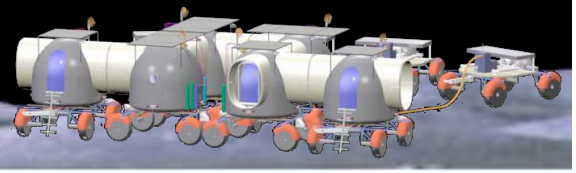




MORPHLAB

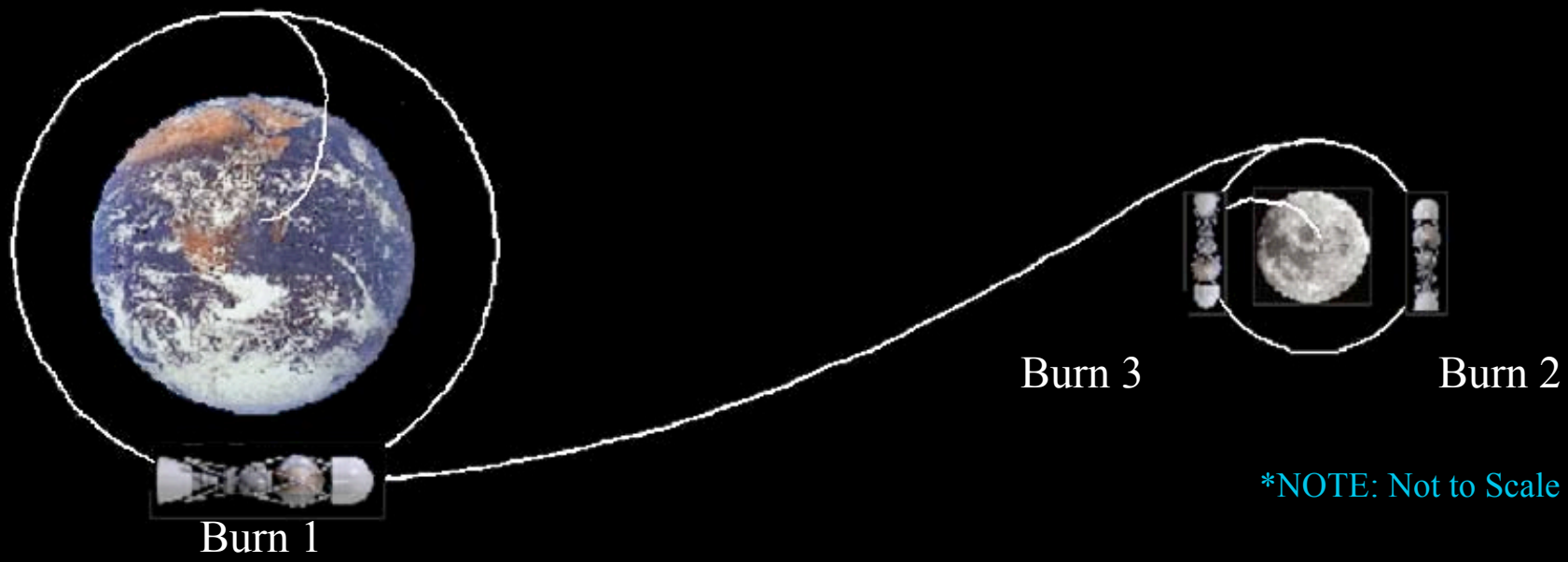
Getting to the Moon Topics

- ΔV Calculations
- Launch Options
- Multi-Stage System
- RCS
- Landing Autonomy
- Landing Zone
- Landing Legs
- Chassis Transit



MORPHLAB

ΔV Requirements



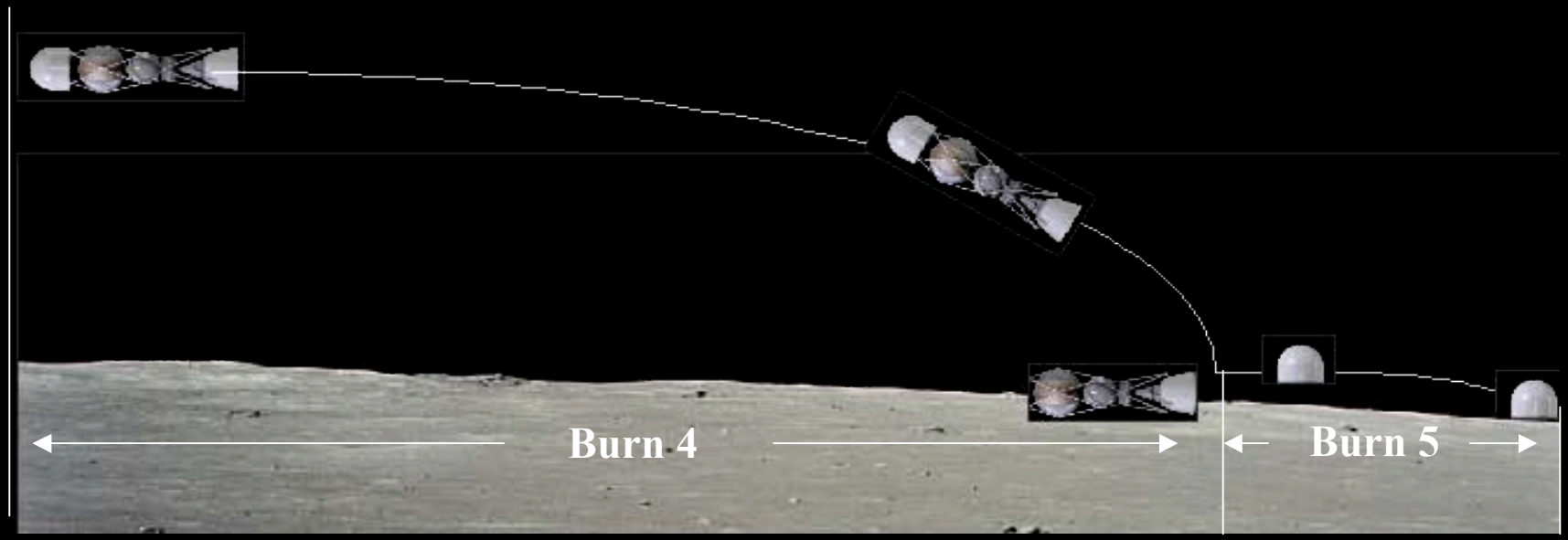
*NOTE: Not to Scale

Burn #	Burn Description	ΔV
1	LEO to LTO	3.14 km/s
2	LTO to LLO	.84 km/s
3	LLO to LD	.01 km/s

LEO = Low Earth Orbit
(alt =185km, 28.5º)
LTO = Lunar Transfer Orbit
(6560km X 386200km)
LLO = Low Lunar Orbit
(alt = 50km)
LD = Lunar Descent
(50km x 10km)

MORPHLAB

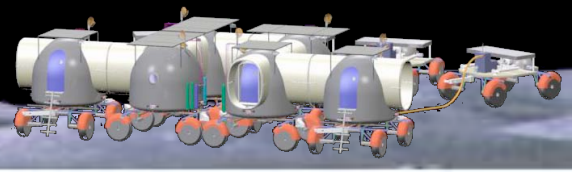
ΔV Requirements



Burn #	Burn Description	ΔV
4	Braking and Approach	1.88km/s
5	Landing	.26 km/s

Total ΔV = 6.13 km/s

*NOTE: Not to Scale



Russell Parker

MORPHLAB

Launch Vehicle Options

- Level 1 Requirement:

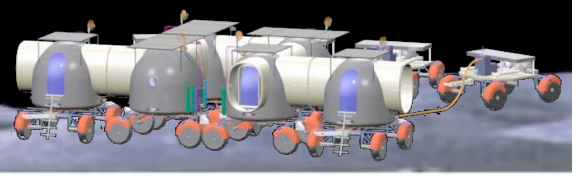
  All components for MORPHLAB system installation and operation shall be designed for launch on the Atlas V, Delta IV Heavy

- LEO Mass: Delta IV vs. Atlas V
  - Delta IV-H ~ 25,800 kg
  - Atlas V-551 ~ 20,000 kg
- Delta IV-H 2nd Stage to LEO vs. LTO.
  - Mass after LTO insertion burn:
    - Delta IV to LEO 8350kg
    - Delta IV to LTO 12980kg

- One Stage vs. Two Stages
  - Assuming:

Stage	Isp	Inert Mass Fraction	ΔV
1st	465	.01	5.87
2nd	350	.07	.26

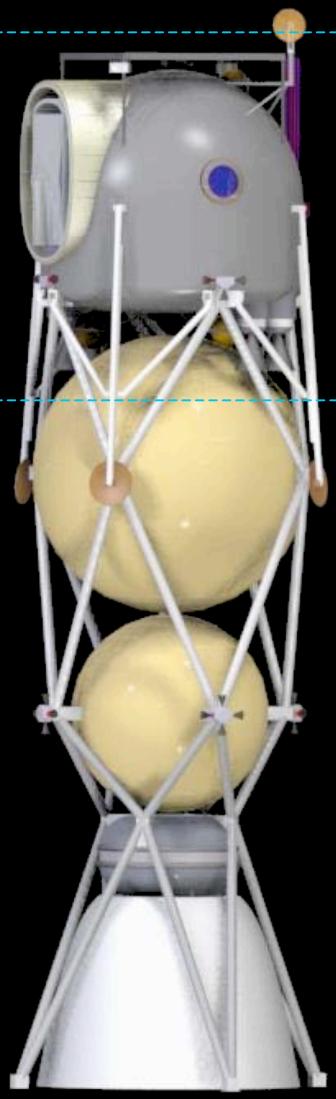
  - Payload (Landed Usable Mass)
    - One Stage 4200 kg
    - Two Stage 3800 kg



MORPHLAB

Two Stage System

- Despite lower mass still going with a two stage system.
- Benefits:
  - Allows us to take advantage of a high Isp engine for majority of burns
  - Easily dispose of large propellant tanks and main engine
  - Decrease ground clearance (smaller landing legs)
  - Landing stage can be moved out of the way by Power Module dexterous arm. (largest mass = 45kg)



Lunar Landing Stage

(Second Stage)

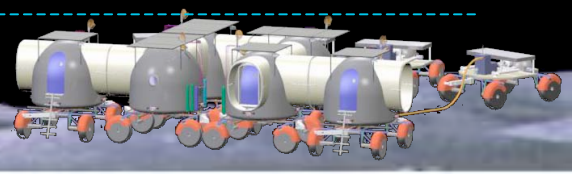
with Habitable module

$\Delta V = .26$ km/s

Lunar Transfer and Approach Stage

(First Stage)

$\Delta V = 5.87$ km/s



MORPHLAB

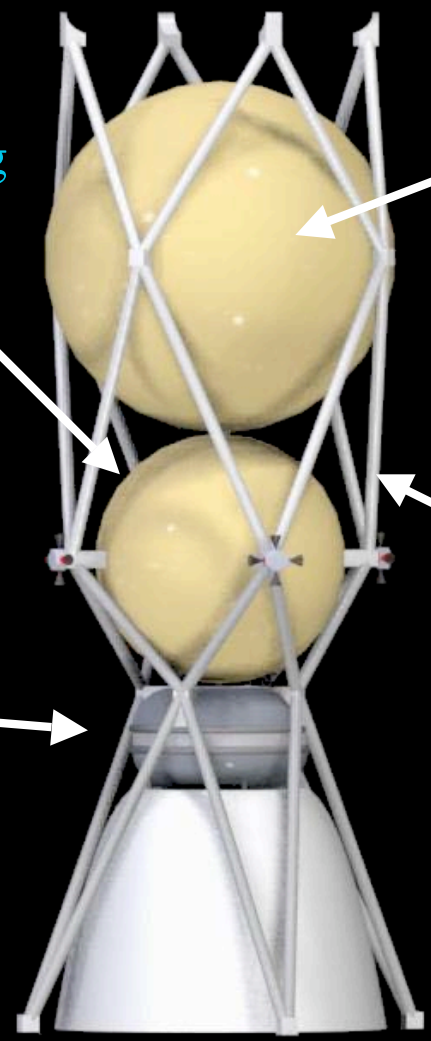
Lunar Transfer and Approach Stage

LOX Tank

- Propellant Mass: 15960 kg
- Tank Mass: 560 kg
- Insulation Mass: 50 kg
- Variable Density Multi-Layer Insulation to reduce boil off from radiation

Modified Pratt and Whitney RL-10B-2

- Isp: 465s
- Mass : 280 kg
- *Thrust can be throttled*

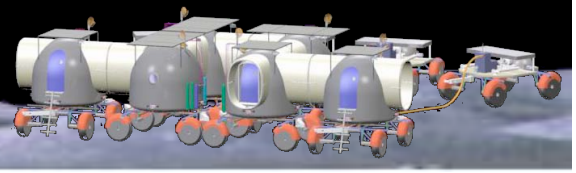


LH2 Tank

- Propellant Mass: 2720 kg
- Tank Mass: 550 kg
- Insulation Mass: 200 kg
- VD-MLI to reduce boil off from radiation

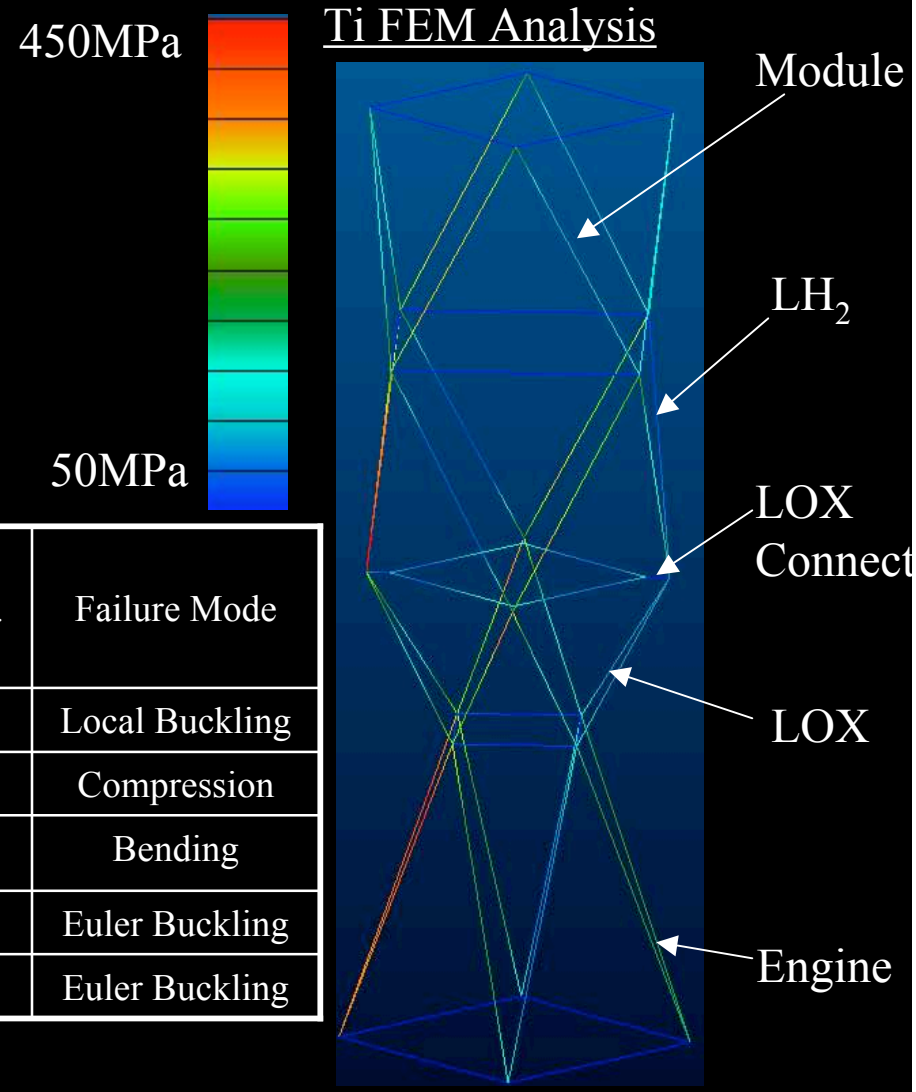
Titanium Thrust Structure

- Support loads of:
  - 6g's vertical
  - 2.5g's lateral
- Low Thermal Conductivity to decrease boil off
- Mass = 920kg



Structural Analysis

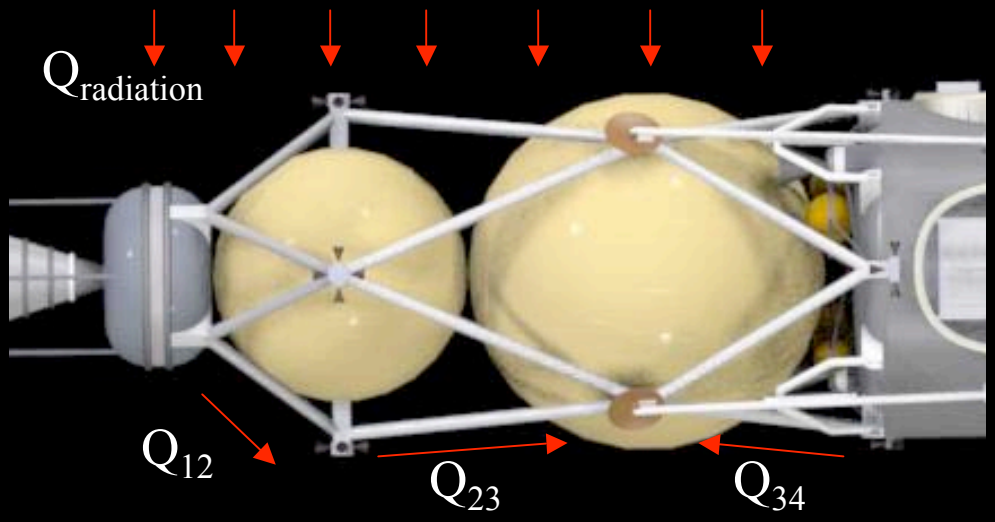
- Launch loads:
  - 6 g's vertical
  - 2.5 g's lateral
- Material comparison
  - Al ~ 1340kg
  - Titanium ~ 920 kg



Truss Member	Dimension (m)			M.S.	Failure Mode
	O.D.	I.D.	Length		
Engine	.350	.346	4.31	.013	Local Buckling
LOX	.105	.100	2.42	.10	Compression
LOX Connect	.300	.250	.30	2.7	Bending
LH_2	.200	.198	3.38	.009	Euler Buckling
Module	.200	.198	3.40	.25	Euler Buckling

MORPHLAB

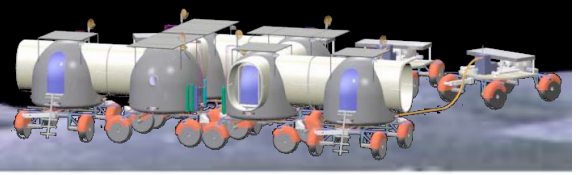
Thermal Analysis



Component	Assumed Temperature
Engine	270 K
LOX Tank	80 K
LH_2 Tank	4 K
Module	270 K

Flow	Source	Sink	Area	Q
Q_{12}	Engine	LOX	.031 m^2	16.2 W
Q_{23}	LOX	LH_2	.007 m^2	.13 W
Q_{34}	Module	LH_2	.007 m^2	3.24W
$Q_{radiation}$	Sun	LH_2	27.5 m^2	2.10W
$Q_{radiation}$	Sun	LOX	14.0 m^2	4.12W

- Given:
  - K_{Ti} = 6.7 W/m-K
  - L_{O2} = 213 kJ/kg
  - L_{H2} = 446 kJ/kg
- Boil Off
  - LOX = 29.7kg (.19%)
  - LH2 = 5.7kg (.21%)

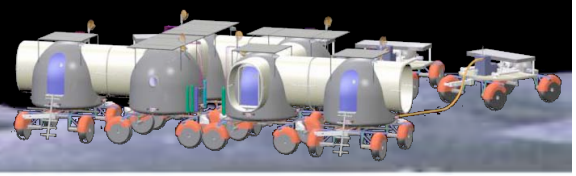


MORPHLAB

Descent Engine

- Descent Engine's Responsibility
  - Hovering
    - Modules hovers for 60 seconds
    - During hovering the lunar surface will be surveyed
  - Landing
    - The engine used to carry the module within the designated landing zone
    - The engines are throttled to low thrust for soft landing on landing legs onto the lunar surface
  - Descent Engines Considered

	Thrust(N)	Isp(sec)	length(m)	diameter(m)	gimbaled(deg)	mass(kg)
S3K (DASA/EADS)	3500	352	1.03	0.53	no	14.5
OMV Variable Thrust Engine (TRW)	578	308	0.7005	0.2713	10-100	6.8
RS-28 (Rocketdyne)	2670	220	?	?	no	12.7
RS-21 (Rocketdyne)	1330	294	?	?	no	8.4



MORPHLAB

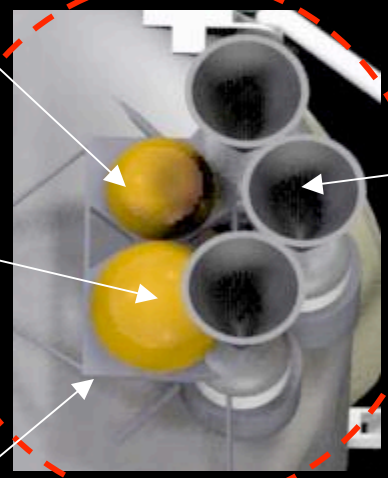
Landing Stage

MON3 Tank(2)

- Propellant Mass : 72 kg/tank
- Tank Mass : 22.5 kg/tank

MMH Tank(2)

- Propellant Mass : 95 kg/tank
- Tank Mass : 45 kg/tank



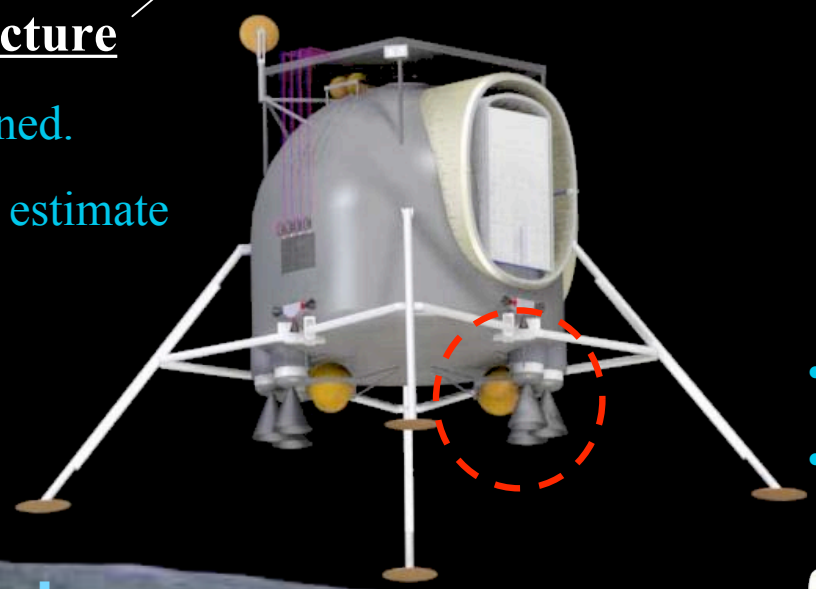
Modified

EADS S3K (6)

- Isp: 350s
- Mass : 14.5 kg
- Full Throttle : 3500 N
- *Thrust can be throttled*

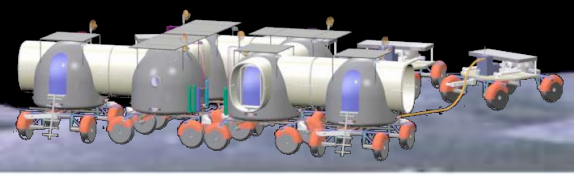
Support Structure

- Still being determined.
- Conservative mass estimate of 150 kg.



He Pressure Tank

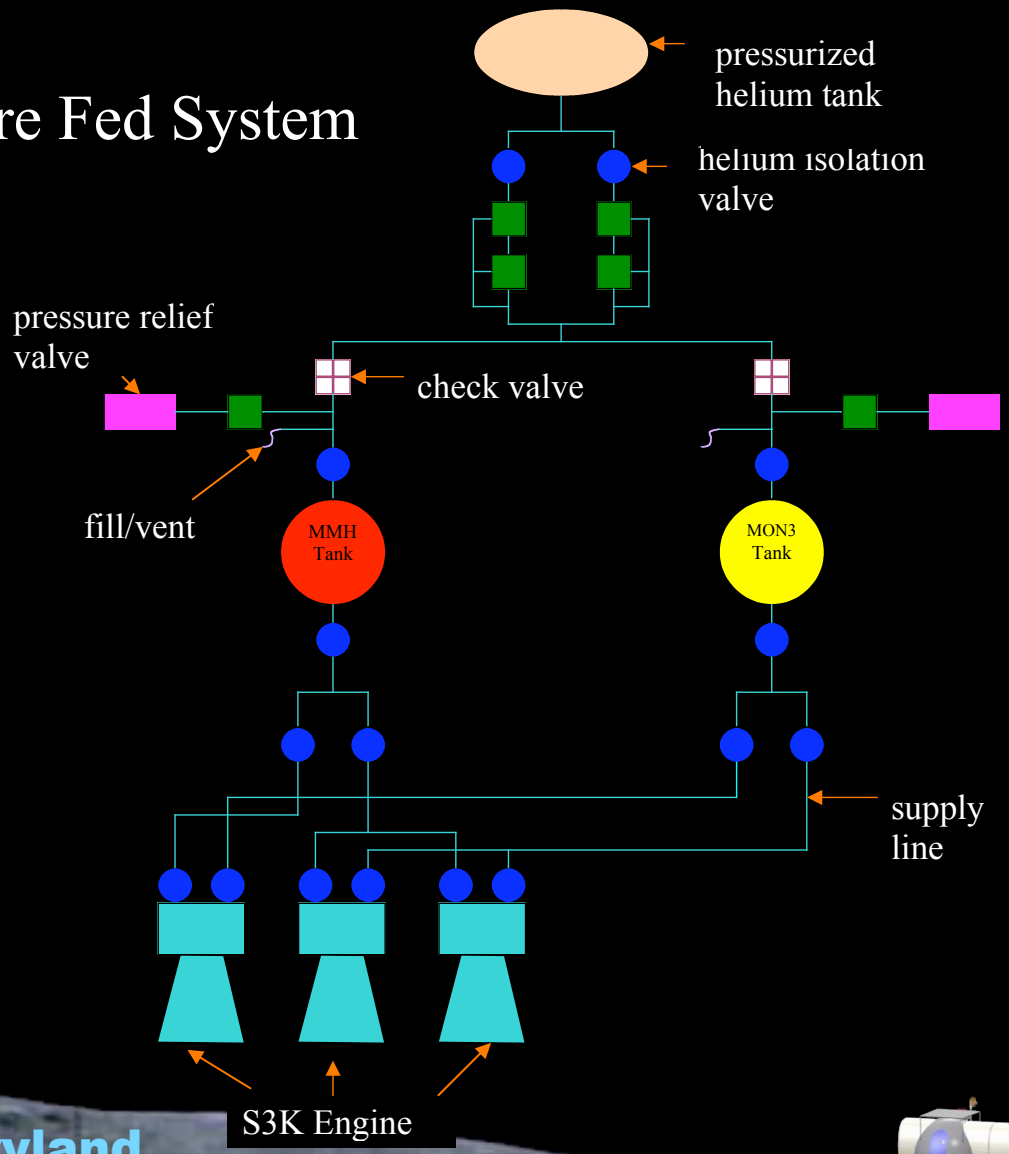
- Not shown on model.
- He and Tank Mass < 5 kg



Tia Burley & Russell Parker

Landing Engine Schematic

Pressure Fed System



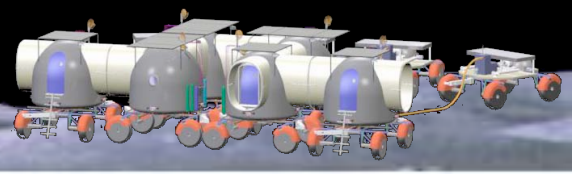
University of Maryland
CDR 04/19/04
Tia Burley

MORPHLAB

Reaction Control

- Reaction Control System's (RCS) Responsibility
  - Attitude control during orbital maneuvering
  - Small translation maneuvers
  - Assist descent engine with landing maneuvers
- Reaction Control Thrusters Considered

Rocket Thrusters	Thrust(N)	Isp(sec)	length(m)	diameter(m)	throttled %	mass(kg)
CHT 20 (EADS)	20	230	0.195	0.033	40-100	0.395
S22 (EADS)	22	290	0.212	0.055	?	0.65
R-1E (Marquardt)	110	280	0.279	0.15	60-140	3.7
MR-107 (Rocket Research)	178	236	0.218	0.066	28-140	0.885



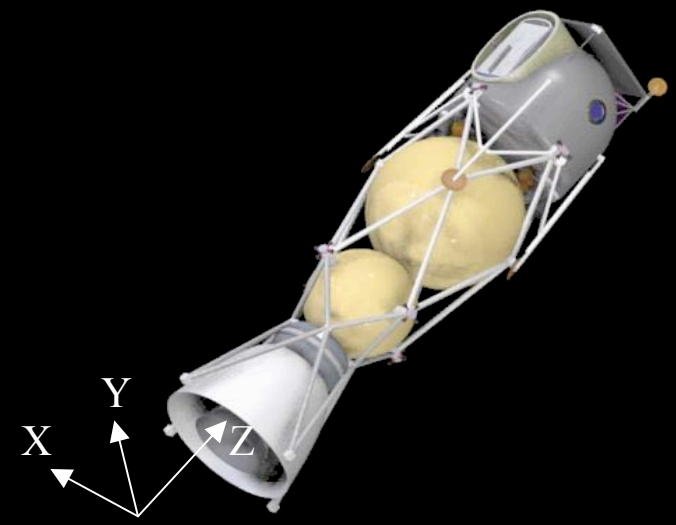
MORPHLAB

Reaction Control System

- Assume RCS only necessary to prevent rotational drift during transit.
- RCS uses Kaiser Marquardt R-1E (68N) located on thrust structure at LOX connection and on Module

Axis	Max T	Rotational Velocity	Allowable Drift	Duty Cycle
X	532 N-m	.01 °/s	+/- 5°	33s
Y	532N-m	.01 °/s	+/- 5°	33s
Z	268N-m	.01 °/s	+/- 5°	63s

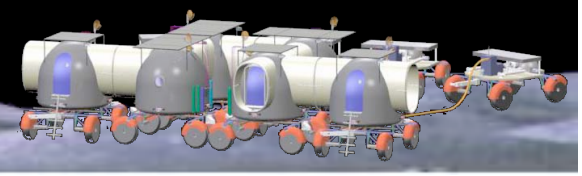
- Total burn time + 50% Margin = 192s



After 1st Burn, approximate values

- $I_{xx} = 1.62 \times 10^5$ kgm^2
- $I_{yy} = 1.62 \times 10^5$ kgm^2
- $I_{zz} = 4.2 \times 10^4$ kgm^2
- c.g. = 8.3 m (z-direction)

Tia Burley & Russell Parker



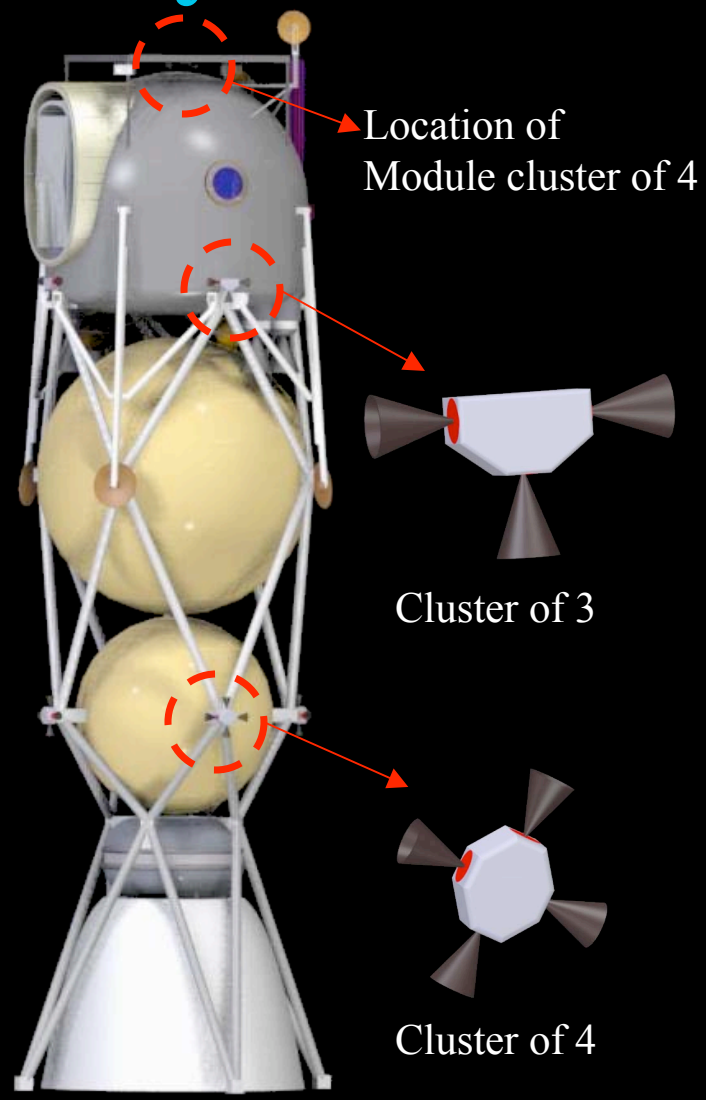
MORPHLAB

Reaction Control System

- Kaiser Marquardt R-1E
  - Variable Thrust (68N – 158N)
  - MMH/N_2O_4
  - Isp = 280s
  - Mass Flow Rate
    - MMH = .0354 kg/s
    - N_2O_4 = .0256 kg/s
  - Mass = 3.7 kg
- Mass Breakdown

Component	Mass
Propellant	11 kg
Engines	118 kg
Tanks	2 kg
Structures	20 kg*
TOTAL	151 kg

*Structural Mass still being determined. 20kg is an approximation



Tia Burley & Russell Parker

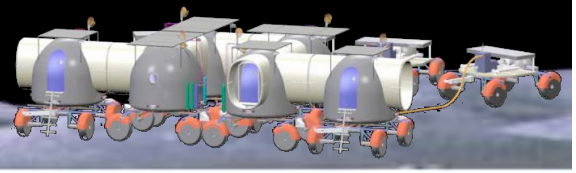
MORPHLAB

Launch System Mass Summary

	Launch Transfer and Approach Stage	Landing Stage	Reaction Control System
Engine	RL-10B-2 280 kg	S3K (6) 14.5 kg each	R-1E (32) 3.7 kg each
Propellant	LOX/LH2 18675 kg	MON3/MMH 330 kg	N_2O_4/MMH 11 kg
Tanks and Insulation	1350 kg	130 kg	2 kg
Structure	920 kg	150 kg	20 kg

Resultant available landed mass: 3700 kg

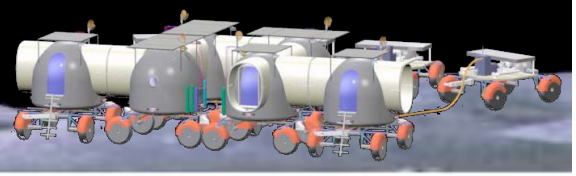
Tia Burley & Russell Parker



MORPHLAB

Landing Requirements

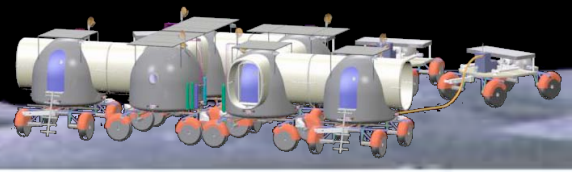
- Level 1 Requirements:
  - Each MORPHLAB module shall be capable of successful landing and operations with any or all of the following conditions occurring simultaneously:
    - 10° slope, any direction
    - 0.5 m diameter boulder anywhere in landing footprint
    - residual vertical velocity 1 m/sec
    - residual horizontal velocity 0.5 m/sec
  - Landing systems onboard MORPHLAB modules shall be capable of operating in on-board autonomous control
- Derived Requirements:
  - Upon landing chassis, habitable module must connect to power module within 24 hours



MORPHLAB

Landing Determination

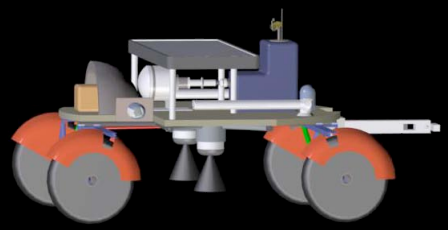
- Prior to descent
  - Mapping satellite will provide preliminary terrain analysis of 1.4m resolution to determine ideal landing zone of .10km
  - Ideal landing zone will be relatively flat, and have few terrestrial hazards, cliffs or craters which can disturb communications
  - Trajectory corrections will keep us in the target footprint of 100m with terrestrial hazards greater than 1.4m known
- Autonomous Descent
  - Power Modules:
    - LIDAR will distinguish objects down to .5m , determine slopes of >10 deg, determine any zone considered unsafe
  - Habitable and chassis modules:
    - Power modules guide to safe landing



MORPHLAB

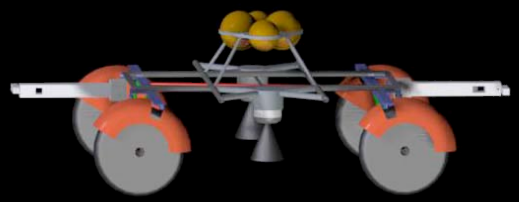
Landing Order and Sensors

Power Module



1,2,3,4

Chassis Modules



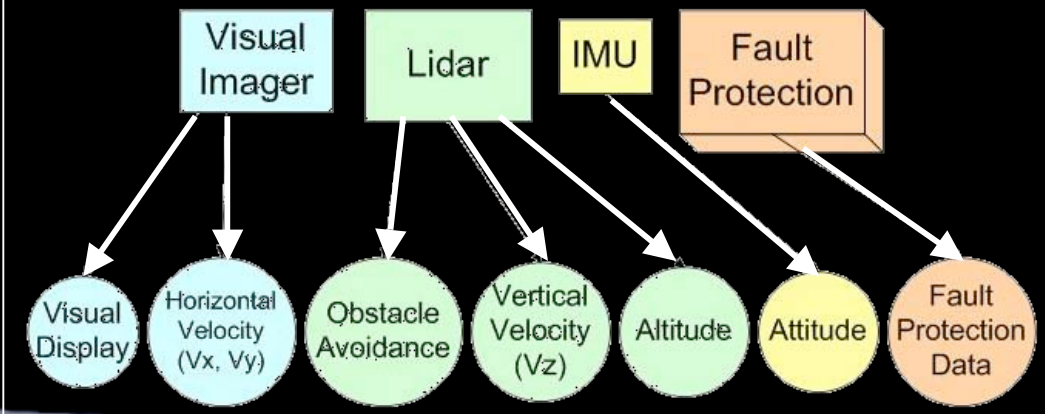
5,6,7,8,9,10

Habitable Module

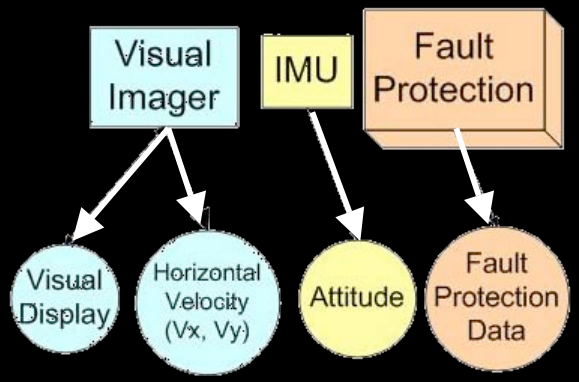
11, 12,13,14,15,16

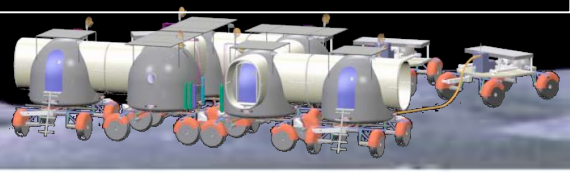
Landing Order

Power Module Landing Sensors



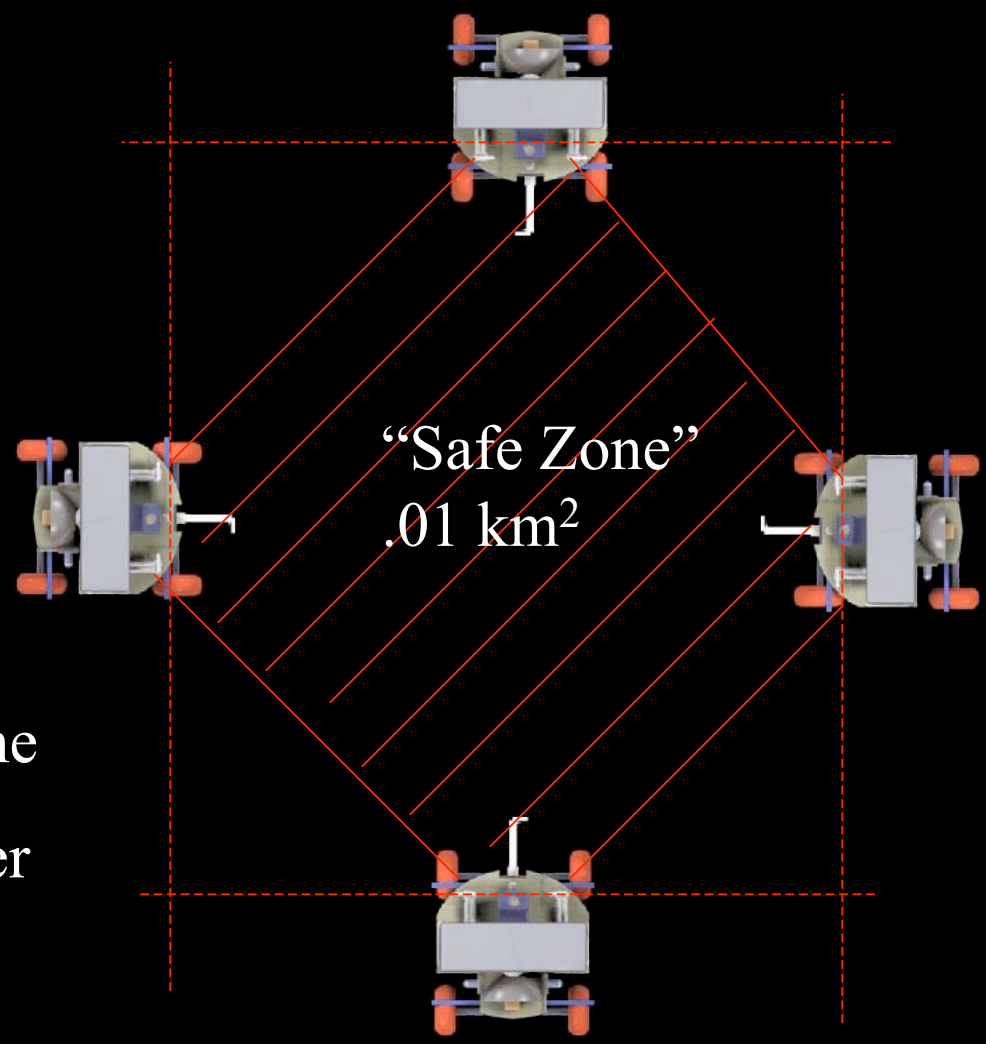
Chassis & Habitable Sensors





Landing Footprint

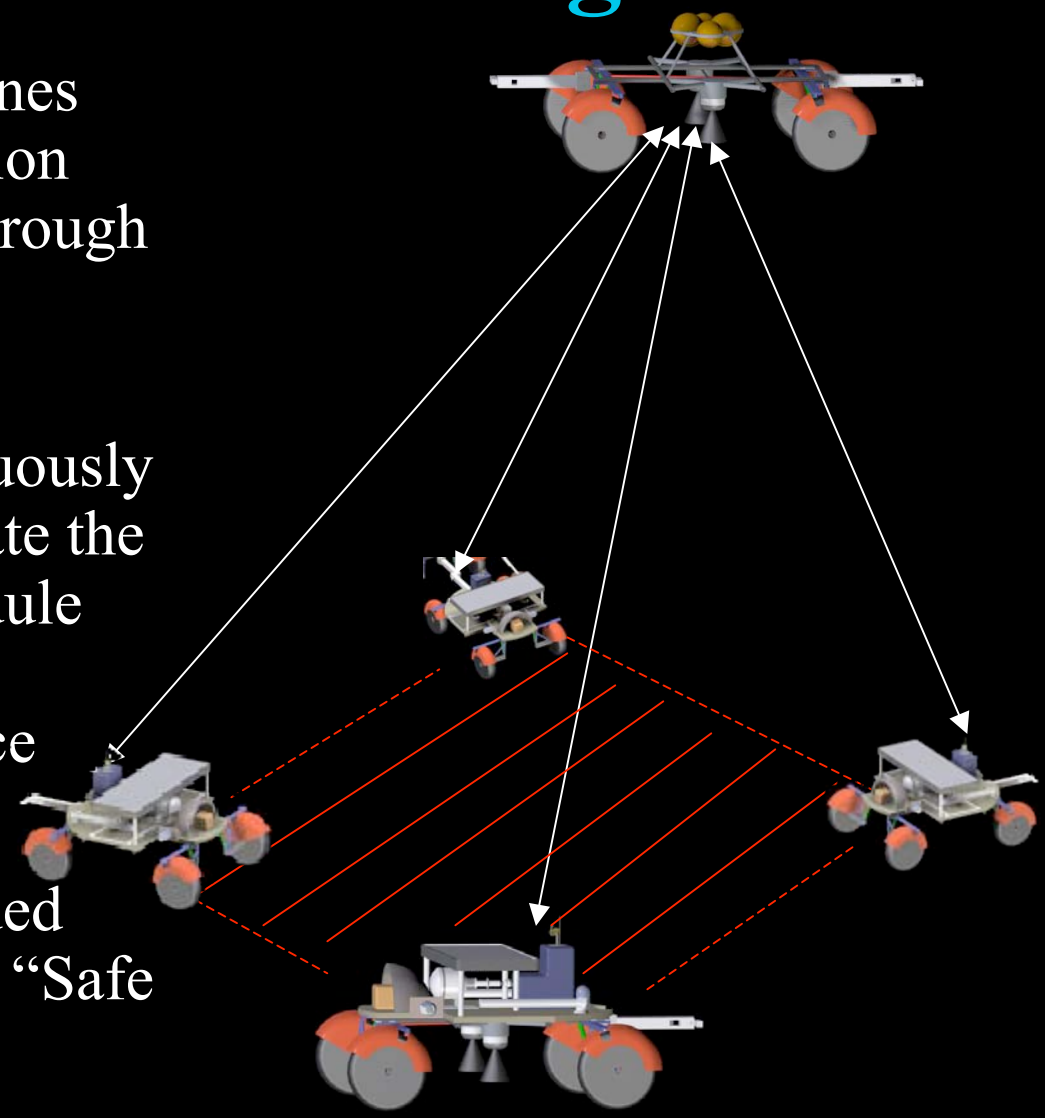
- Upon touchdown, LIDAR rotates forward to be used as obstacle avoidance
- Power modules reposition 100m apart in a diamond formation
- The diamond area, .01km^2, will be scanned using LIDAR to construct a safe landing zone
- If unsafe landing zone, power modules will reposition until safe area found



MORPHLAB

Chassis Landing

- Power module determines chassis's relative position and descent velocity through triangulation
- Power modules continuously update and communicate the data to the chassis module providing real time navigation and guidance
- Chassis module is guided and landed within the "Safe Zone"

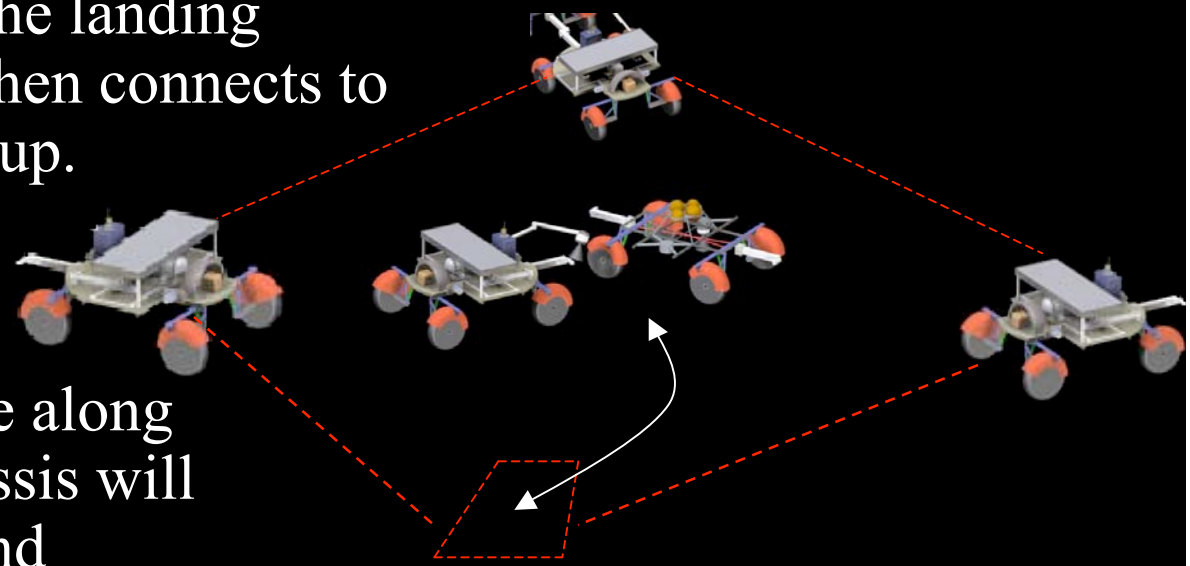


MORPHLAB

Chassis Recovery

- After successful landing of chassis, power module retrieves the chassis
- In the retrieval process the power module removes the landing engines first and then connects to chassis for power up.

- Chassis and power connection must occur within 24 hours



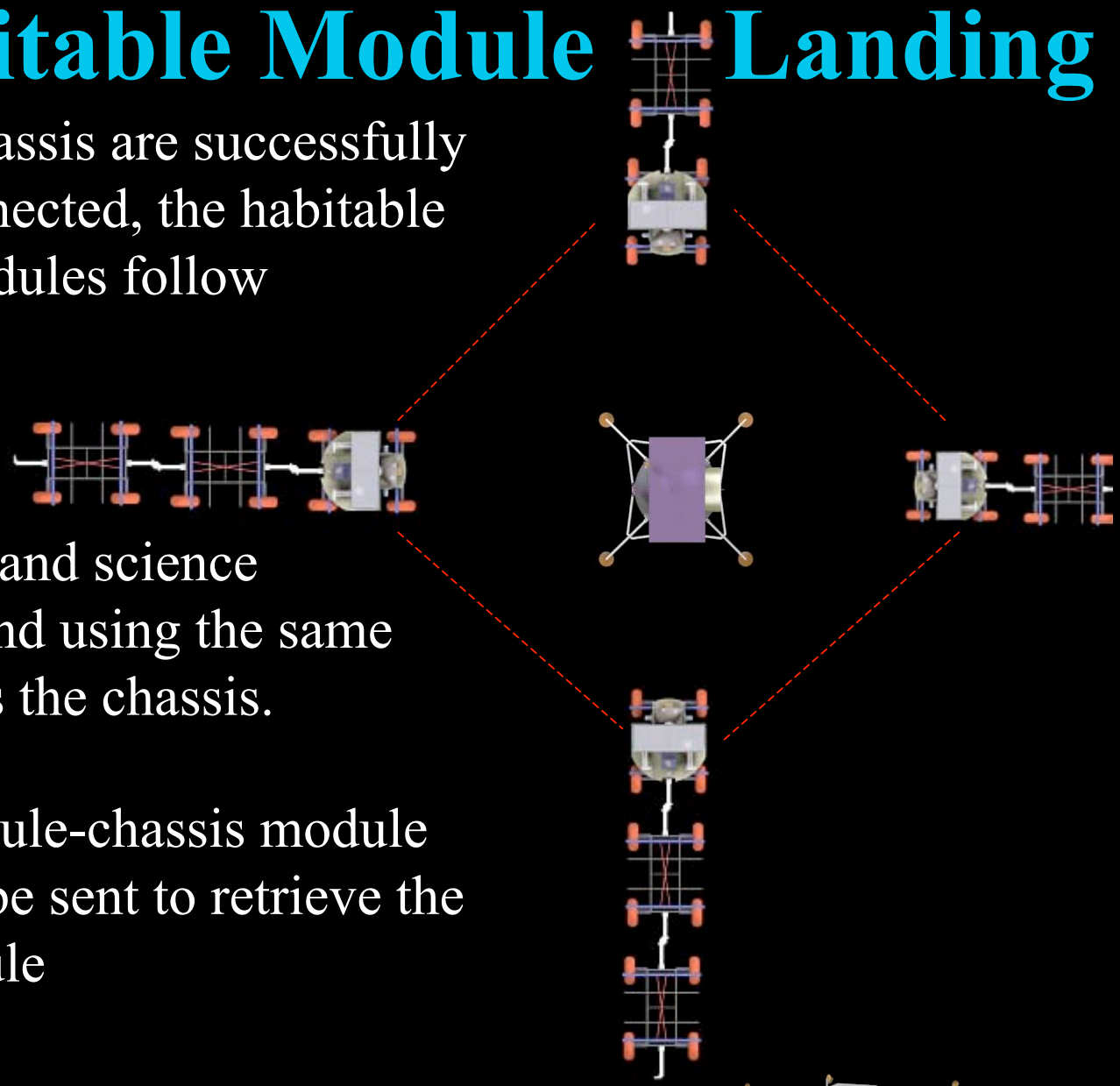
- The power module along with connected chassis will return to the diamond formation waiting for next chassis's descent

- This retrieval process will occur for all 6 chassis

MORPHLAB

Habitable Module Landing

- After All 6 chassis are successfully landed and connected, the habitable and science modules follow

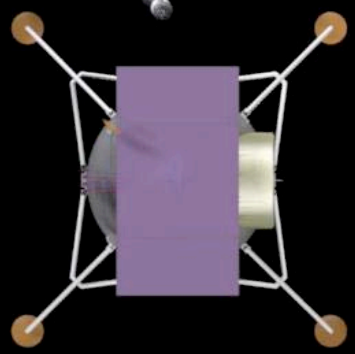


- The habitable and science modules will land using the same exact process as the chassis.

- A power module-chassis module assembly will be sent to retrieve the habitable module

MORPHLAB

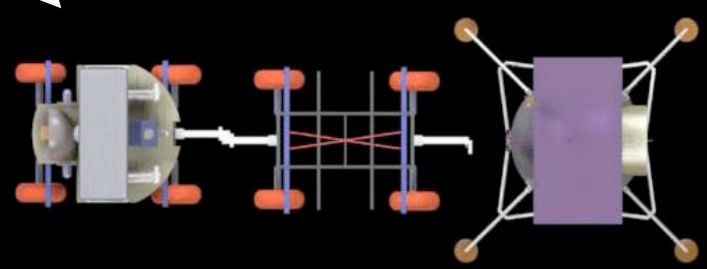
Chassis Recovery

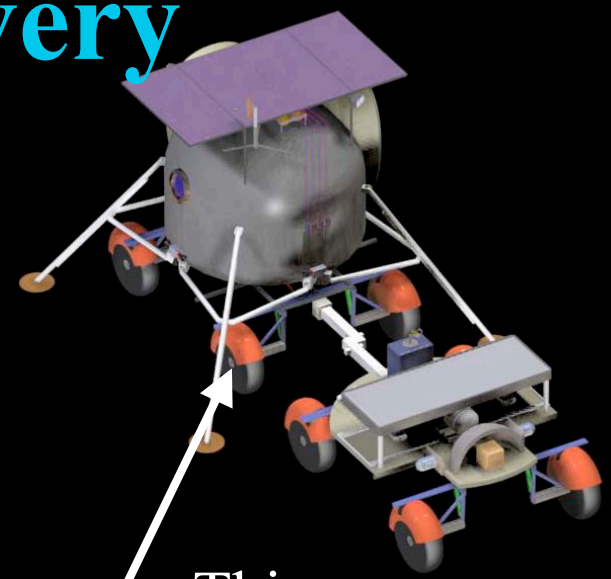


- The power module will first remove the descent engines

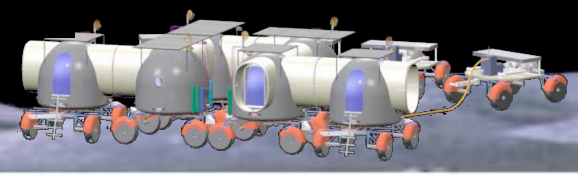
- The chassis will then be commanded to drive under the habitable module and establish a permanent connection

- This connection also is required to take place within 24 hours





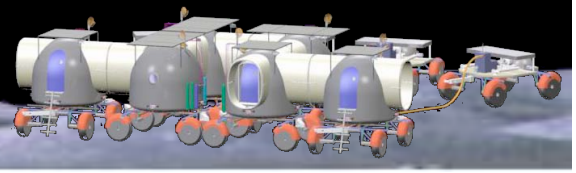
- This process will repeat until all habitable modules have establish permanent connections with the 6 chassis



MORPHLAB

Landing Summary

- Power modules land using full sensor suite
- Chassis and habitable modules landing without LIDAR utilize navigation and guidance provided by the power modules
- Chassis and habitable modules must connect with power modules within 24 hours
- All retrieval processes are guided and commanded by the power modules



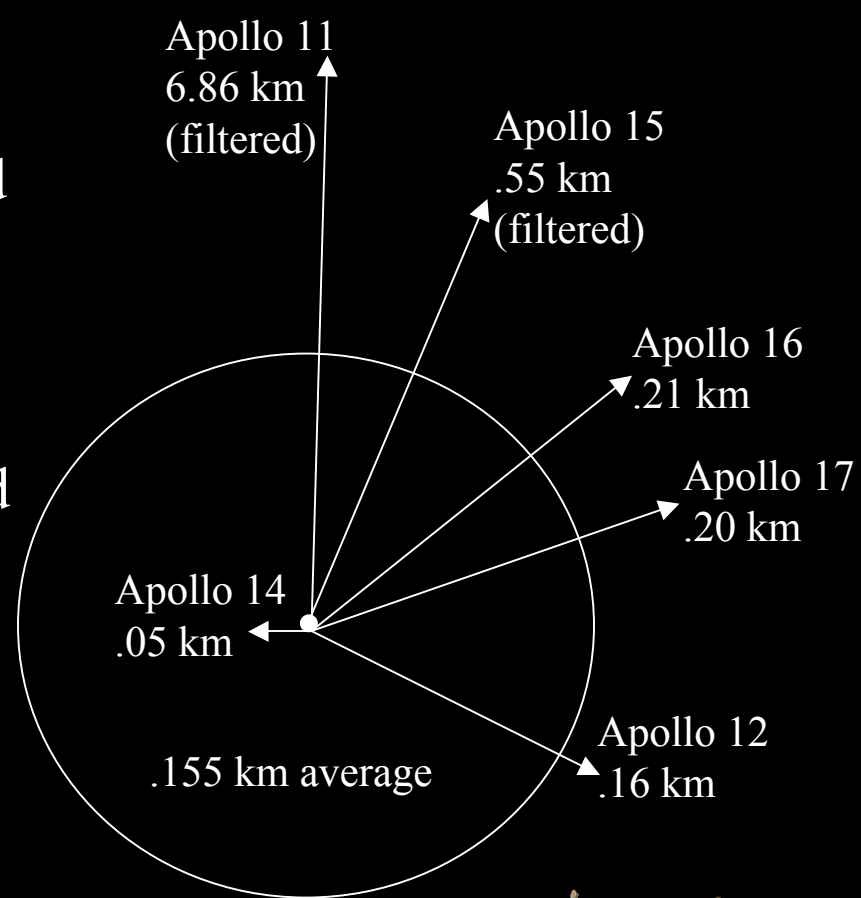
MORPHLAB

Landing Zone

- Landing zone is based upon Apollo actual off target data
- The data was then filtered
- A standard deviation and average value was then found
- Then a technology advancement reduction taken (30% off Apollo numbers)
- A new standard deviation and average were then calculated

Standard deviation	New Standard deviation
.155 km	.0406 km
Average	New Average
.068 km	.0204 km

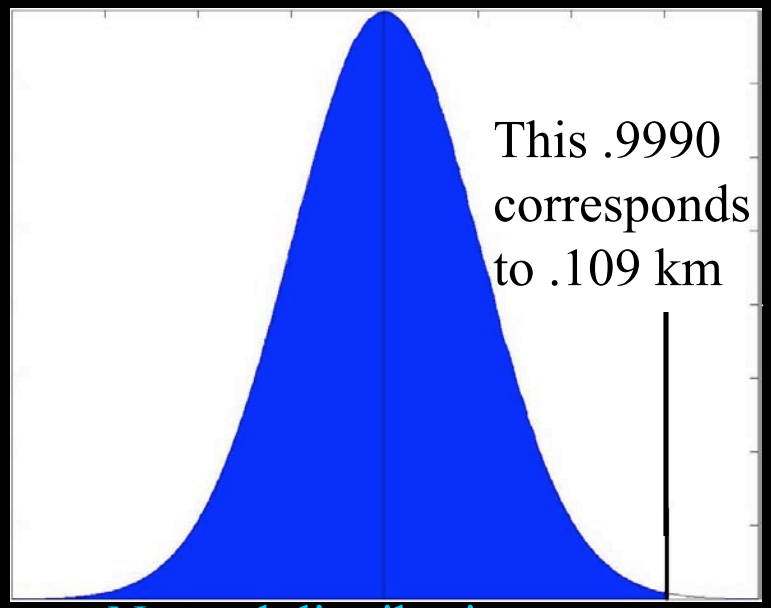
Apollo Distances from Target Landing Site



MORPHLAB

Landing Zone

- The new Standard deviation and average were normalized and then applied to a normal distribution curve to find a .9990 probability of success
- This value then applied to the average gives us the probability of .9990 of being within a circle of that radius of the target site
- So, this leaves us with a landing zone with a circular radius of .109 km for the first module (power) to land in



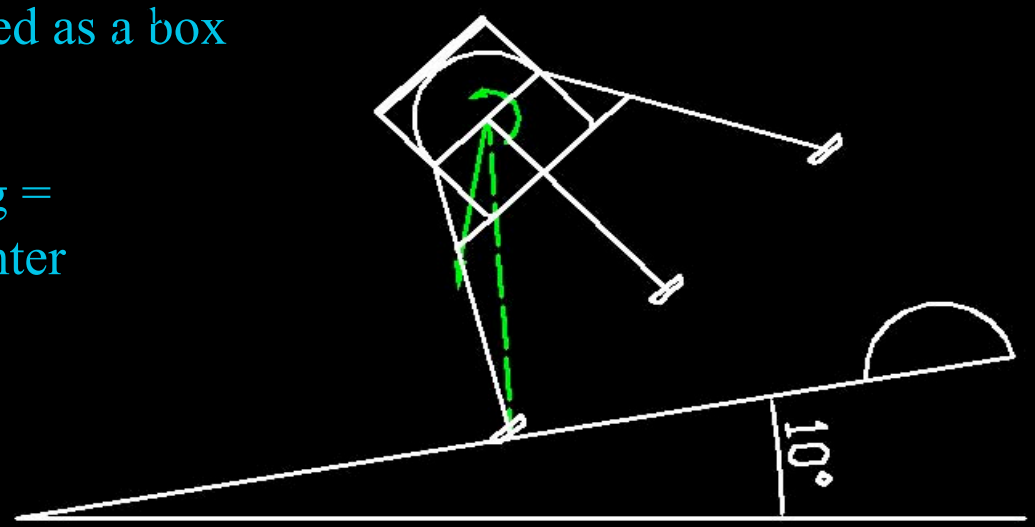
Normal distribution curve

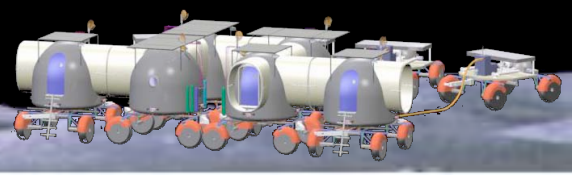
- Other modules will land close to the first one, due to landing beacons being placed after power module landing, allowing them to land within meters of the power module

MORPHLAB

Landing Stability Analysis

- Level 1 Requirement
  - MORPHLAB modules must be able to land on a 10° slope with residual 1.0 m/s vertical and 0.5 m/s lateral velocities
- Assumptions
  - 2-D motion & rigid body dynamics
  - Collisions are perfectly inelastic
  - Habitable module modeled as a cylinder and power module modeled as a box
- Analysis
  - Energy req. for tipping = potential energy of center of gravity – kinetic energy of vehicle

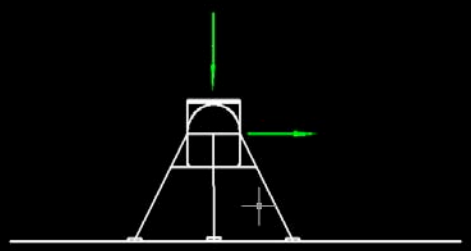




Landing Stability Analysis

MORPHLAB

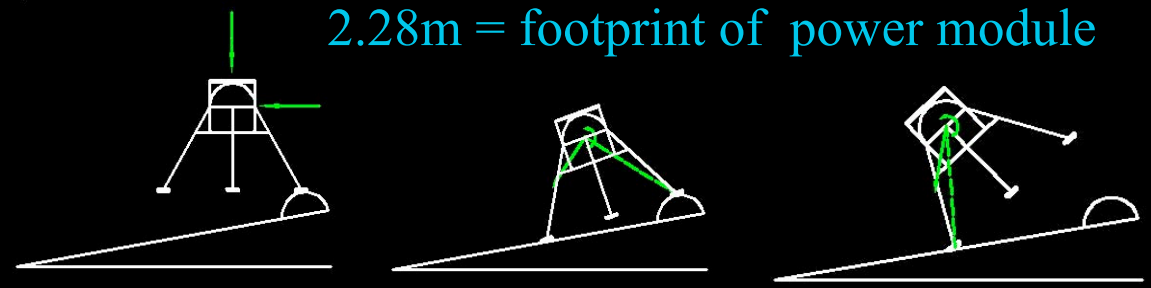
Case A



Case B

7.30m = footprint of habitable module

2.28m = footprint of power module



No-failure of power or habitable module

Case C

7.10 = footprint of habitable module

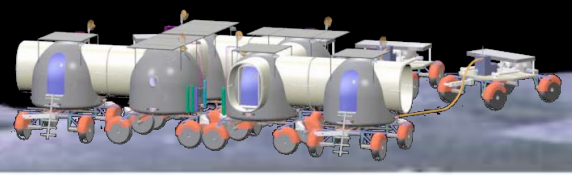
2.22 = footprint of power module

No-failure

Habitable module footprint = 7.60m → stable

Power module wheel base = 3.3m wide 4.2m long → stable

Abraham Daiub

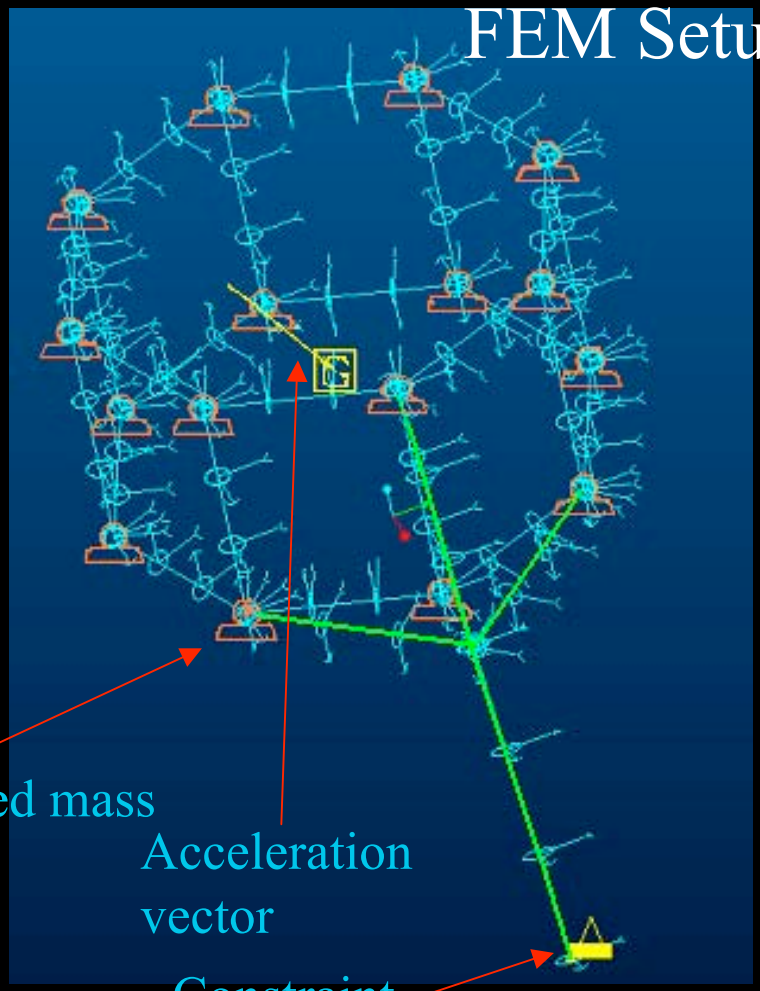


Design of Landing Legs for Habitable Module

MORPHLAB

- Level 1 Requirement
  - MORPHLAB modules must be able to land on 10° slope with residual 1.0 m/s vertical and 0.5 m/s lateral velocities
- Assumptions
  - 63 m/s^2 axial , 1.63m/s^2 lateral
  - Loads through of CG carried by stringers
  - Footpad constrained 1.

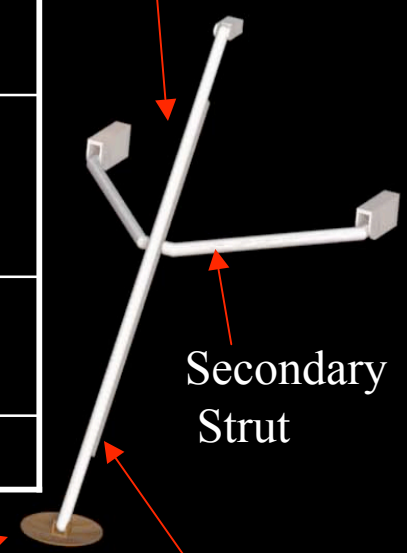
FEM Setup



MORPHLAB

Design of Landing Legs for Habitable Module

Member	ID (m)	OD (m)	Length (m)	S.M.	Max. Stress (MPa)	Failure Mode
Primary Upper Strut	.128	.130	1.45	0.379	388	Euler Buckling
Primary Lower Strut	.118	.120	2.67	0.052	526	Local Buckling
Secondary Strut	.099	.100	0.722	0.196	290	Local Buckling
Foot-pad	0	.5	0.30	.25	874.2	Bending



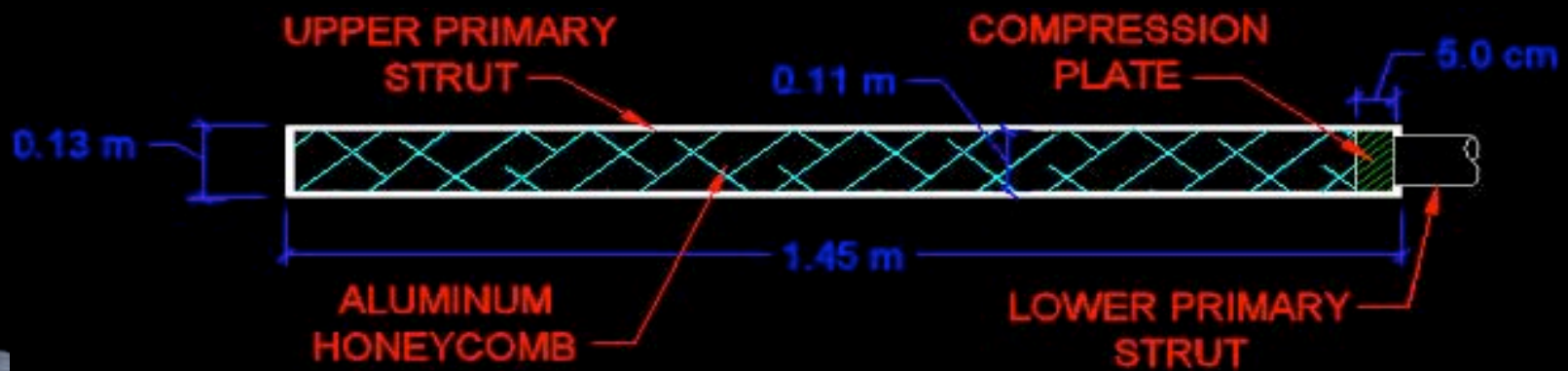
Design of Landing Legs for Habitable Module

- Requirement
  - Absorb all kinetic energy with one load limiter
  - Residual velocity 1.0 m/s axial and 0.5 m/s lateral

http://www.mcgillcorp.com/alcore/datasheets/spiral-0600.pdf

Parameters

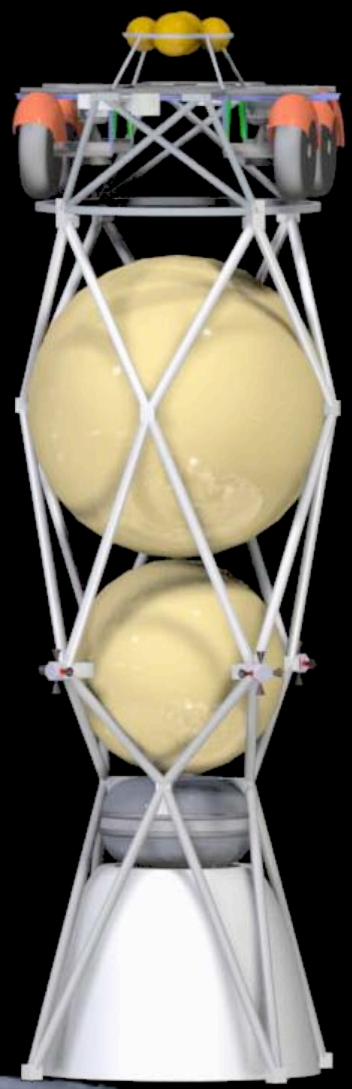
Length (m)	1.40
Cross section (m^2)	0.0129
Mass (kg)	0.342



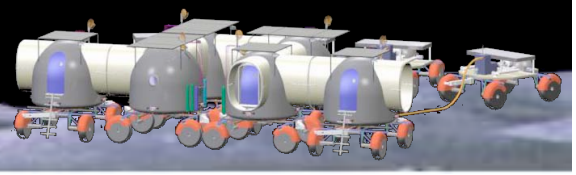
Abraham Daiub

MORPHLAB

Chassis During Transit to Moon



- Wheels retracted inward toward center of thrust structure to allow chassis to fit within dynamic envelop of Delta IV-H 5m payload fairing.
- Launch loads transferred two four points at ends of 2 chassis 'launch beams.'
- Maximum load acted on chassis during transit and launch occur during Delta IV – H main engine cutoff. Axial acc. = 6g's, later acc = 2.5g's. Chassis capable of supporting 3500 kg (including itself) during transit and launch.



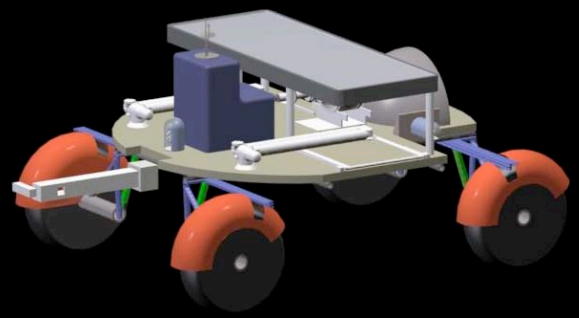
MORPHLAB

Chassis Landing

Maximum landed mass = 3500kg

Maximum impact deceleration designed for = 6 lunar g's

Max deceleration is a very conservative estimate derived from our requirement that the maximum residual velocity during landing cannot exceed 1m/s and assuming that the deceleration during impact will not occur in less that 1/10th of a second.

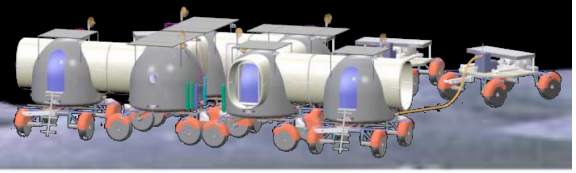


Worst cases for struts and axles correspond to a power module initially touching down with only one wheel.

Landing loads can act in all three directions and create greater stresses in each member for different loading directions.

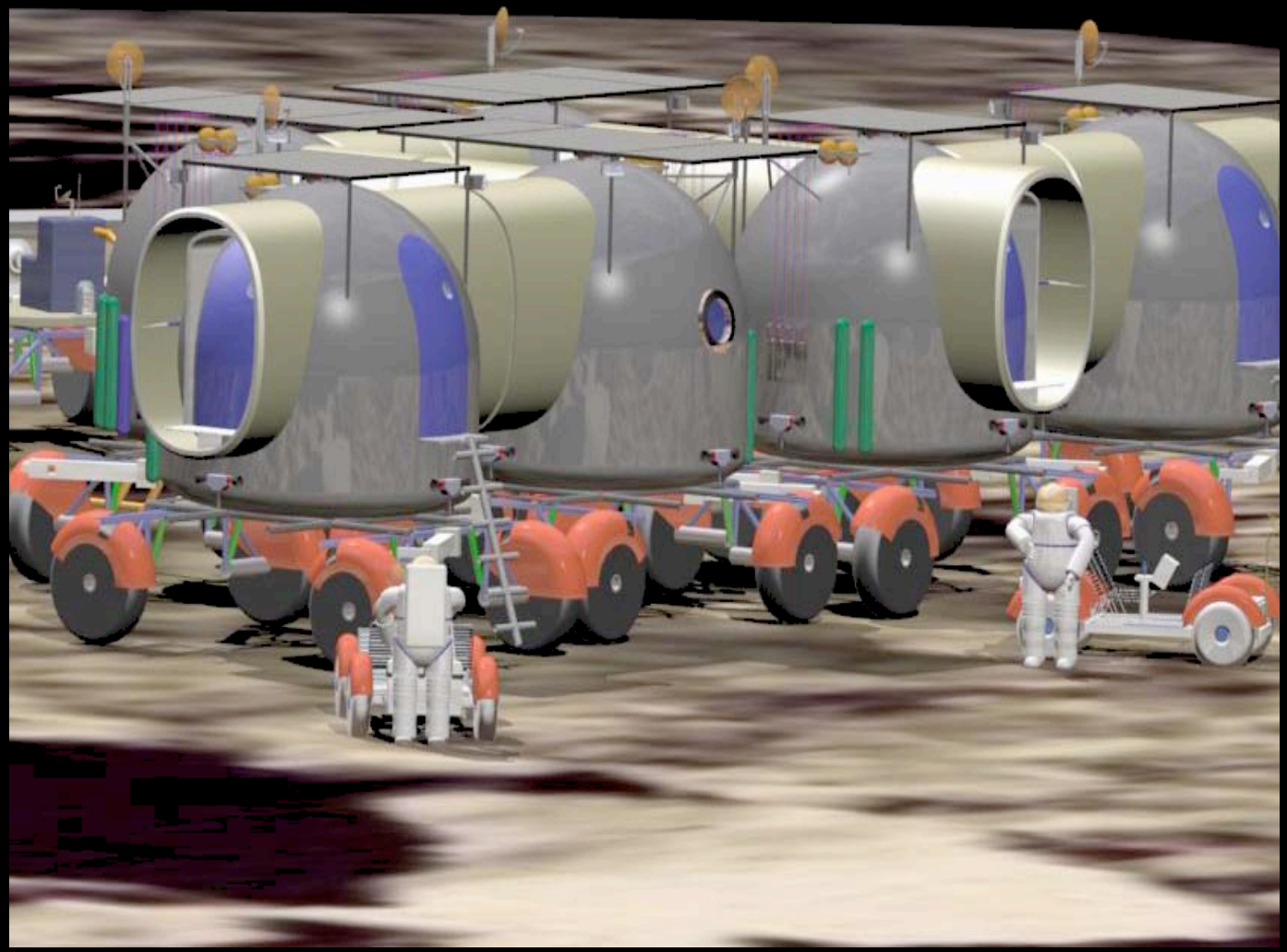
All cases closely examined and modeled using ProEngineer.

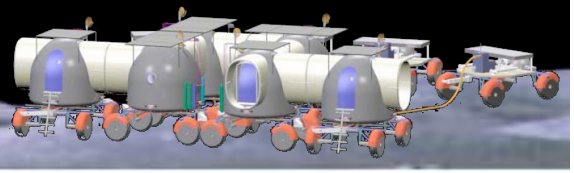
All structural member pass all worst case landing load conditions with positive margins of safety.



MORPHLAB

Mission Planning





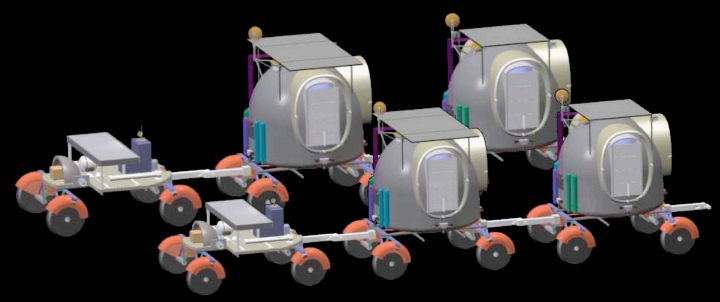
MORPHLAB

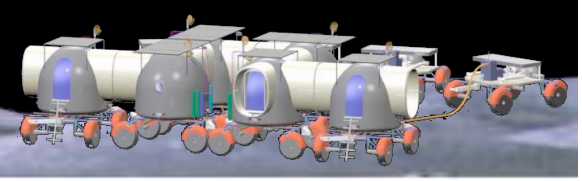
Fault Tolerance

- Level 1 Requirements:
  - *Loss of 1 module should not end mission*
  - *Loss of 2 modules should support crew until launch window occurs*

- Fail Safe Mode losses:
  - 1 Habitable-Science module
  - 1 Habitable-Living module
  - 2 Power modules

- Survival Mode losses:
  - 2 Habitable-Living modules
  - 2 Habitable-Science modules
  - 3 Power modules

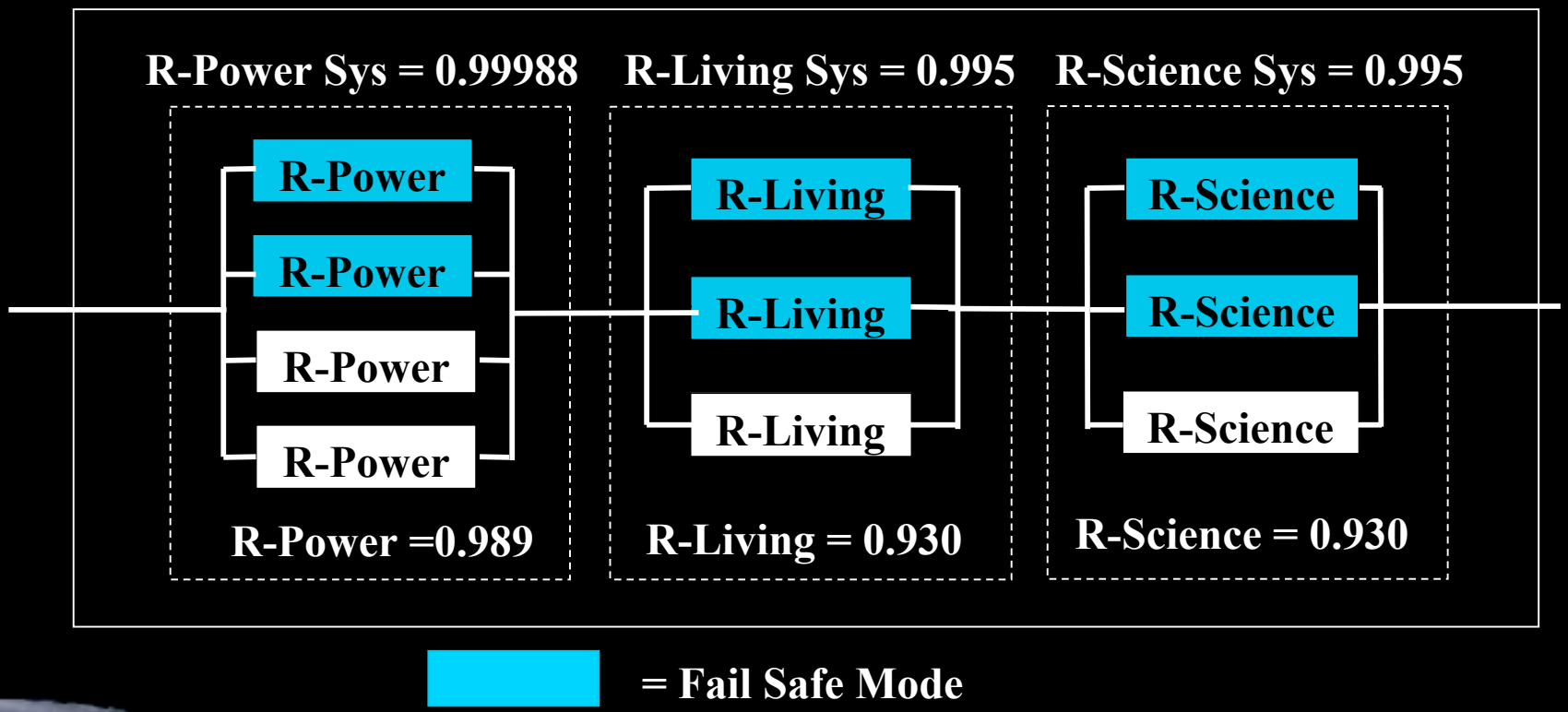




MORPHLAB

Fault Tolerance/Reliability

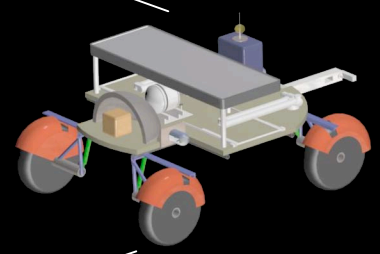
- NASA JSC - 28354 requires reliability of 0.99 for crew return
- All sub-systems will have to meet these reliability requirements by Jan. 1st 2010 with a NASA technology readiness level (TRL) of 6



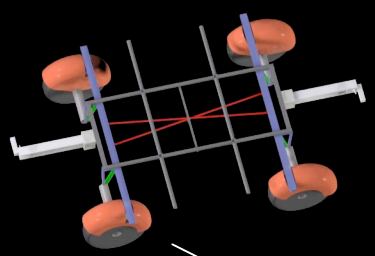
MORPHLAB

Required Sub-System Reliabilities

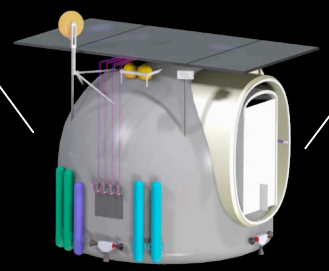
Power Module = 0.989	
Chassis Module	0.9978
DIPS	0.9955
Avionics	0.9978
Thermal	0.9978

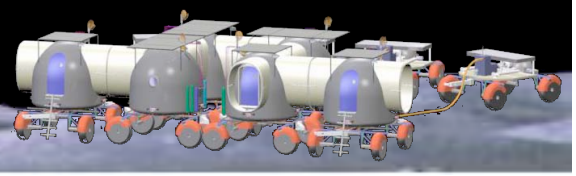


Habitable-Living and Habitat-Science Modules = 0.930	
Power Sub-systems	0.9819
Avionics	0.9819
Thermal	0.9819
ECLSS	0.9819
Docking Mechanism	0.9819



Chassis Module = 0.9978	
Brake System	0.9966
Suspension System	0.9966
Steering System	0.9966
Drive System	0.9966
Power Sub-systems	0.9966
Avionics	0.9966

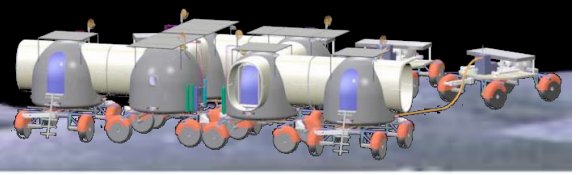




MORPHLAB

Timeline

- Historical Precedent:
  - Apollo:
    - 5 years from program start to first test
    - 2 years from testing to first human launch
    - 7 years total time from program start to human launch
  - Shuttle:
    - 5 years from program start to first test
    - 4 years from testing to first human launch
    - 9 years total time from program start to human launch

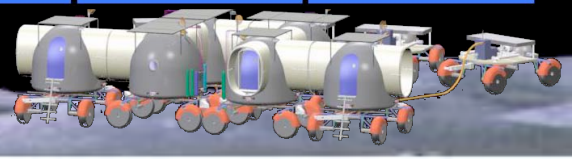


MORPHLAB

Timeline

- **Launching Phase (2013 – 2014):**
  - All landings are scheduled for local lunar dawn + 3 days
  - Launch #18 - #24 are launch windows built into the timeline in case a launch must be delayed and so that the manned missions will begin on schedule
  - LVs can be ready in 22 days, each launch is scheduled 28-30 days apart
  - Mapping satellites to be launched January 2011 to get 24 months of data and analysis about the lunar terrain
  - Communications satellites will be launched February 2017

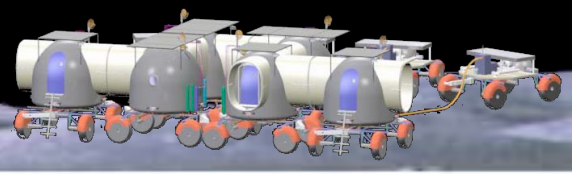
Launch #	Full Moon	Land Date	Launch Date
1	1/27/2013	1/24/2013	1/20/2013
2	2/25/2013	2/22/2013	2/18/2013
3	3/27/2013	3/24/2013	3/20/2013
4	4/25/2013	4/22/2013	4/18/2013
5	5/25/2013	5/22/2013	5/18/2013
6	6/23/2013	6/20/2013	6/16/2013
7	7/22/2013	7/19/2013	7/15/2013
8	8/21/2013	8/18/2013	8/14/2013
9	9/19/2013	9/16/2013	9/12/2013
10	10/18/2013	10/15/2013	10/11/2013
11	11/17/2013	11/14/2013	11/10/2013
12	12/17/2013	12/14/2013	12/10/2013
13	1/16/2014	1/13/2014	1/9/2014
14	2/14/2014	2/11/2014	2/7/2014
15	3/16/2014	3/13/2014	3/9/2014
16	4/15/2014	4/12/2014	4/8/2014
17	5/14/2014	5/11/2014	5/7/2014
18	6/13/2014	6/10/2014	6/6/2014
19	7/12/2014	7/9/2014	7/5/2014
20	8/10/2014	8/7/2014	8/3/2014
21	9/9/2014	9/6/2014	9/2/2014
22	10/8/2014	10/5/2014	10/1/2014
23	11/7/2014	11/4/2014	10/31/2014
24	12/6/2014	12/3/2014	11/29/2014



MORPHLAB

Timeline

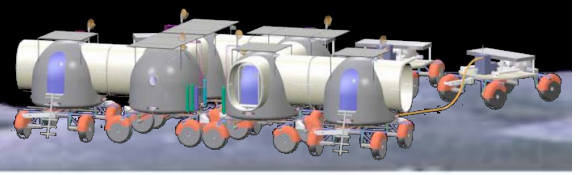
- 17 required launches before first human mission
  - Launches #1 - #4 will be the power modules
  - Launches #5 - #10 will be the chassis modules
  - Launches #11 - #16 will be the habitable modules
  - Launch #17 will be the first logistics depot
    - Each logistics depot will be launched one month before the next human arrival



MORPHLAB

Timeline

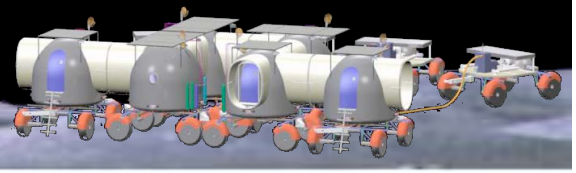
- Mission Phase (2015 – 2019+):
  - Each human mission will be 6 months apart starting June 5, 2015
    - Launch will be June 1, 2015
    - Level 1 Requirement: I10
      - System shall provide autonomous checkout and unambiguous evidence of functionality prior to committing the next human
    - The first 3 month mission will be unmanned for the first month and land the first crew at local dawn on the second
      - The human mission will be 2 months in order to stay on schedule
  - Approximately 14 days will be lost of program time when the missions change over to far side



MORPHLAB

Timeline

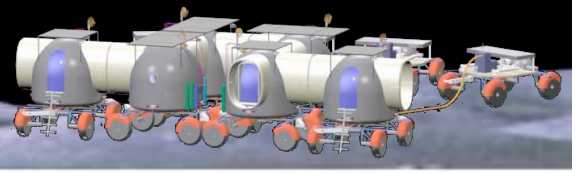
Site #	Land Day before Full Moon ***	Full Moon	Land Day	Launch Day
1	3	2-Jun-15	5-Jun-15	1-Jun-15
2	4	27-Oct-15	31-Oct-15	27-Oct-15
3	4	22-Apr-16	26-Apr-16	22-Apr-16
4	6	16-Oct-16	22-Oct-16	18-Oct-16
5	6	11-Apr-17	17-Apr-17	13-Apr-17
6	13	5-Oct-17	18-Oct-17	14-Oct-17
Far Side	Land Day after Full Moon ***			
7	14	31-Mar-18	14-Apr-18	10-Apr-18
8	8	25-Sep-18	3-Oct-18	29-Sep-18
9	9	21-Mar-19	30-Mar-19	26-Mar-19
10	10	14-Sep-19	24-Sep-19	20-Sep-19



MORPHLAB

Timeline

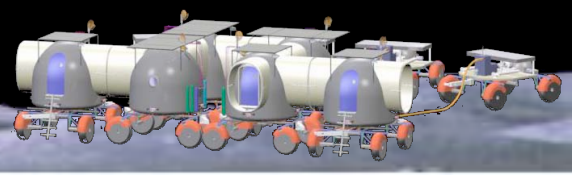
- In the event that a mission must be delayed the column labeled "Land Day before/after Full Moon" will be used to get the new landing date
- This factor will land humans at local lunar dawn + 2 days
- All full moons from 2015 – 2020 are listed in the detailed timeline document



MORPHLAB

Cost Analysis

- Level I Requirements: $51.5 Billion budget
  - Spread over 15 years
  - Derived from projected NASA spending on a lunar exploration program
- Mass-based, vehicle-level cost estimating relationship
  - Non-recurring costs
  - Production costs with 80% learning curve
  - Constants differ for launch vehicle stage, liquid rocket engine, scientific instrument, unmanned planetary, manned spacecraft



MORPHLAB

Production Costs

Vehicle Assembly

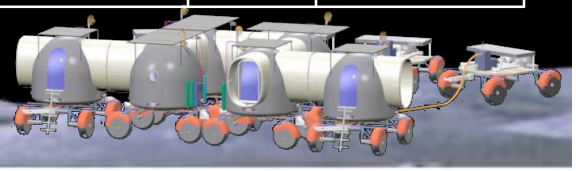
Component	Qty	Cost ($B04)
Power Module	4	1.33
Habitable-Living	3	1.99
Habitable-Science	3	1.91
Chassis Module	6	1.26
Logistics Module 1	1	1.19
Logistics Modules (2-10)	9	1.99
Total		**9.67**

Launch Structure

Component	Qty	Cost ($B04)
Thrust Structure	26	0.973
Engine	26	0.780
Small Engine	52	0.159
Total		**1.91**

Satellites

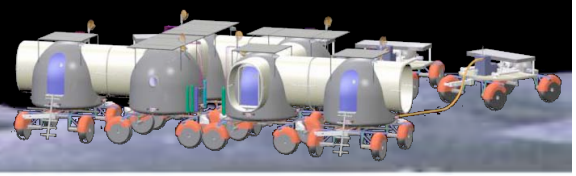
Component	Qty	Cost ($M04)
Mapping	1	67
Communications	4	115
Total		**182**



MORPHLAB

Launch Costs

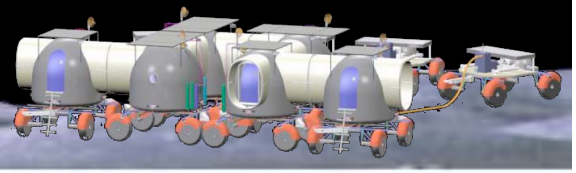
Component	Number Launches	LV	Cost ($B04)
Power Module	4	Delta IV-Heavy	0.660
Habitable-Living Module	3	Delta IV-Heavy	0.495
Habitable-Science Module	3	Delta IV-Heavy	0.495
Chassis Module	6	Delta IV-Heavy	0.990
Logistics Module 1	1	Delta IV-Heavy	0.165
Logistics Modules 2-10	9	Delta IV-Heavy	1.49
Communication Satellites	1	Atlas V	0.122
Mapping Satellite	1	Atlas V	0.122
Total			**4.54**



MORPHLAB

Wrap Factors

Factor	Percentage	Cost ($B04)
Advanced Development	0.035	0.412
Phase A Conceptual Studies	0.003	0.0353
Phase B Definition Studies	0.035	0.412
Program Support	0.15	1.77
Operations Capability Development	0.15	1.77
Launch and Landing	0.066	0.777
Program Management and Integration	0.10	1.18
Fees	0.10	1.18
Total		**7.54**



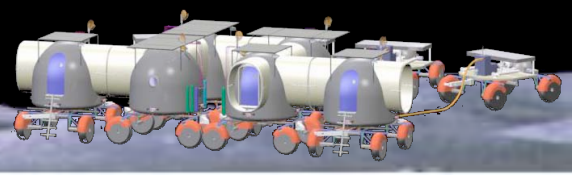
MORPHLAB

Cost Summary

	Cost ($B04)
Vehicle production	9.67
Launch structure production	1.91
Satellite production	0.182
Launches	4.53
Wrap factors	7.52
Total System Cost	**23.8**

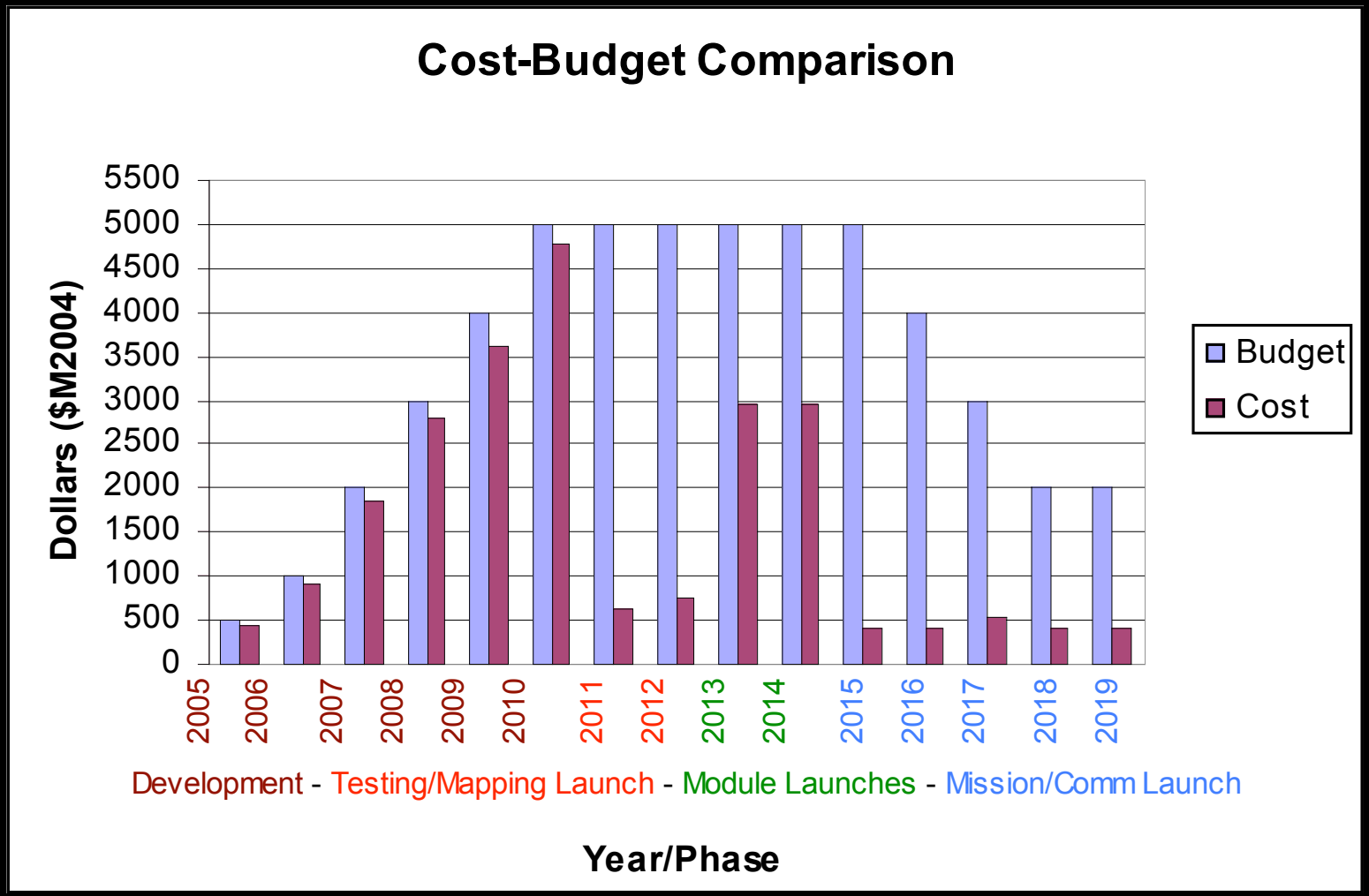
Allowable reserve factor: 0.537

Total budget with 0.4 reserve factor: $39.7 Billion



MORPHLAB

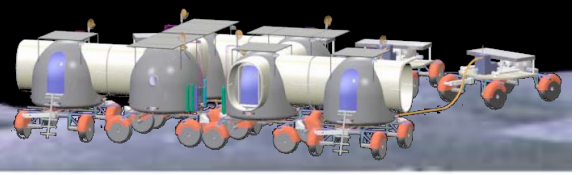
Cost Summary



MORPHLAB

Summary

- Designed to fulfill the goals of the President's new space initiative
- Stepping stone for an Earth to Mars mission
- Design utilizes existing launch vehicle technologies
- Design has great advantages over a large-scale stationary lunar base
- Inexpensive program

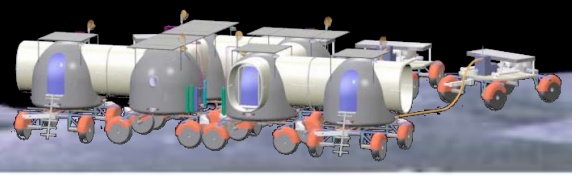


MORPHLAB

Open Items

There are a few subsystems that either have yet to be determined or need the completion of detailed analysis, these systems are:

- Radiator for the power module
- Extension for docking mechanism
- Specific computing requirements
- Interior lighting layout
- Steering and suspension mechanism
- Lunar rover storage



MORPHLAB

Acknowledgments

- Our advisors, Dr. Dave Akin and Dr. Mary Bowden, for their help and support
- All of the people who helped by giving us feedback at our Trade Study, and Preliminary Design Reviews
- Dr. Fourney and the University of Maryland's Aerospace Engineering Department