Project Overview

Project Design Structure

Flight Rover
Design the smallest practical pressurized rover to support Constellation sortie-class missions with independent delivery to moon

Design →
← Test Results

Rover Mock-up
Validate critical issues in habitability and crew operations by constructing a full-scale mock-up of the rover cabin and external interfaces

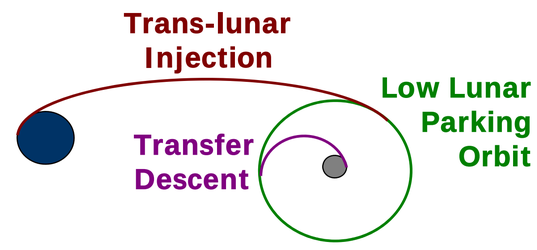
Field Rover
Start the design and development process for a fully functional Earth simulation rover for near-term lunar analogue studies

Outpost Rover
Develop a variant of the basic sortie rover to support Constellation outpost construction and operations

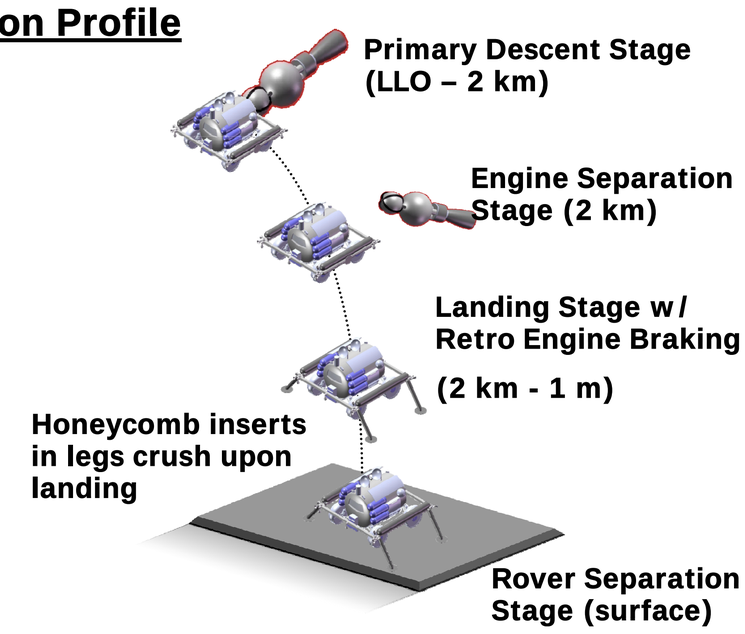
TURTLE Capabilities

- Suitports and external platform provide astronaut ingress/egress
- Range: 25 km radius around lander over two three-day sorties
- External containers for science equipment and samples
- Supplemental airlock for moving items between rover interior and exterior
- Stability margins: 37° longitudinal, 48° lateral
- 3.45 m length x 3.24 m width x 2.93 m height
- Total initial mass: 1750 kg, with all consumables but no suits or astronauts

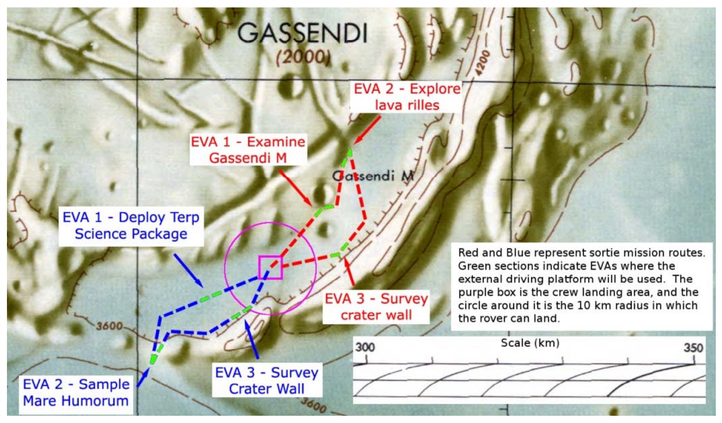
Mission Profile



Burn	Delta V
Delta-IV Heavy to TLI	
TLI to Low Lunar Parking Orbit	800 m/s
Transfer Descent	135 m/s
Retro Engine Braking	1725 m/s
Landing	80 m/s



TURTLE will autonomously rendezvous with crew who will land less than 10 km away → Two crew members will board TURTLE for a three day mission with three EVAs traveling up to 25 km from base → Upon return, two other astronauts will board TURTLE for a second three day mission



Gassendi Crater Sample Mission Profile

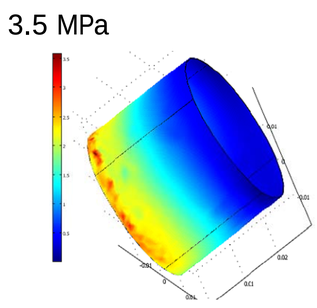
The sample mission profile shown to the left can be modified for various landing sites to fulfill TURTLE's science goals.

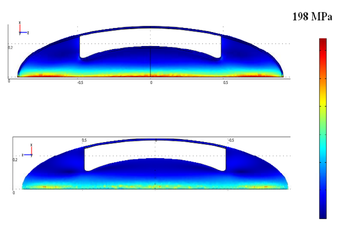
- Deploy science equipment for longterm data collection
- Collect data to help advance the lunar base design
- Obtain samples for study on Earth
- Perform basic analysis of samples on the moon
- Increase understanding of lunar habitability

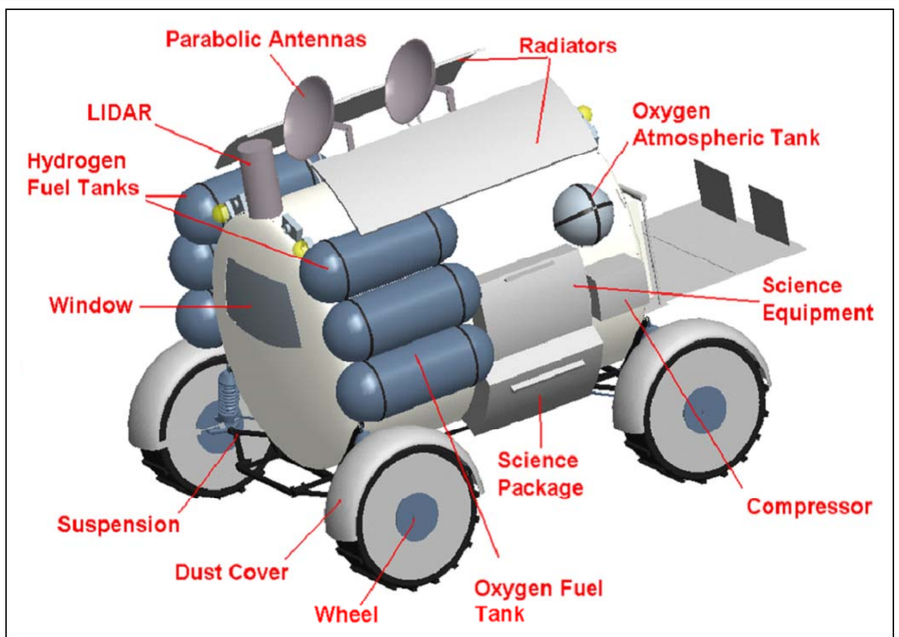
TURTLE Design

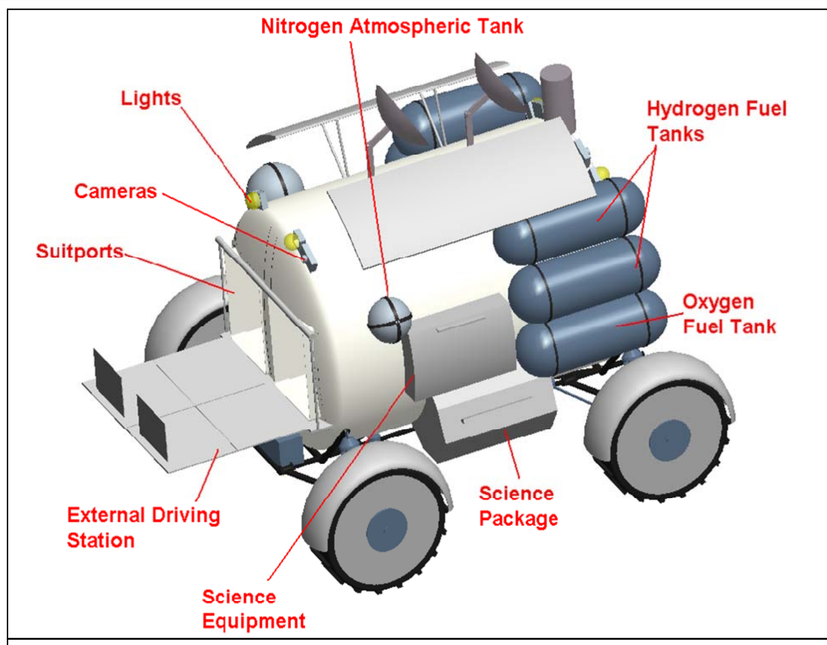
Pressure Shell

- Graphite Epoxy T300/934
- Safety Factor = 3
- Geometry
  - Cylinder 2.43 m long, 1.83 m diameter
  - Semi-elliptical endcaps extend 0.325 m
- Double-layered shell built around chassis
- 8.4 mm inner layer in cylinder, rising to 10 mm on endcaps
- 2 mm outer layer for micrometeoroid protection
- Max stress: 198 MPa
- Mass 240 kg



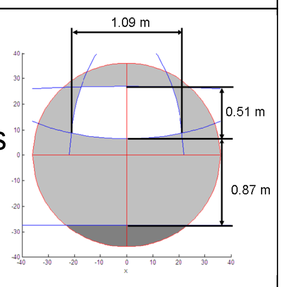






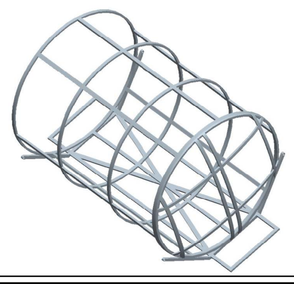
Driving Window

- Double-paned
  - Inner: 20 mm fused silica glass
  - Outer: 13 mm aluminosilicate glass
- FOV: 45° L/R, 20° down, 5° up



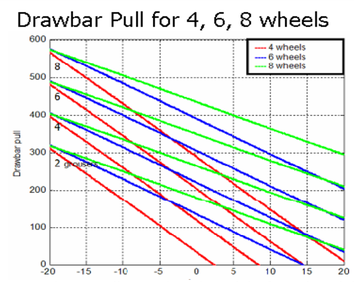
Chassis

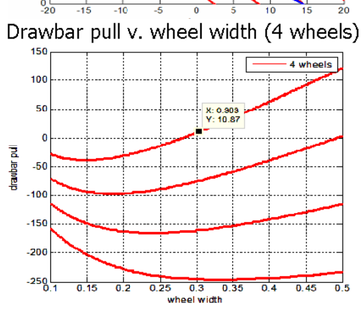
- Aluminum Alloy 6061-T6
- Safety Factor = 1.4
- Minimum 15% margin of safety for each piece
- Mass 163 kg



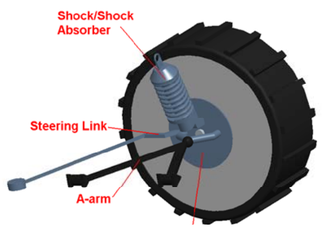
Terramechanics

- Non-pneumatic Al Alloy 2024
- 1 m wheel diameter for 0.5 m ground clearance
- 8 grousers
- 0.3 m wheel-width
- Top speed 15 km/hr on level ground
- Stopping distance: 4.34 m over 2.1 s
- 9.2 m turning radius at top speed, on level ground
- TURTLE accommodates 20° slope with positive drawbar pull

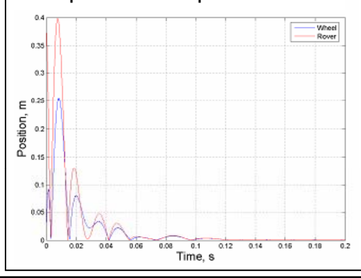




Mobility System



Suspension Displacement

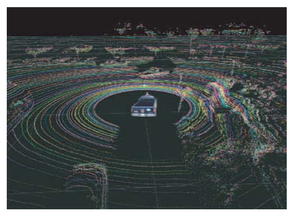


- 4 wheels, independently steered and powered
- Suspension system: MacPherson struts
  - Spring const. 35 kN/m
  - Damp const. 1 kN·s/m
- DC brushless wheel hub motors with 5:1 gear train
- Steering control: linear actuators; 18° steering angle
- Magnetic braking from motors and Ti-Carbide discs

Avionics

Navigation & Autonomy

- Autonomously rendezvous with crew or outpost
- Determines rover's lunar position
- Maps and navigates around obstacles with LIDAR (TRL 4)



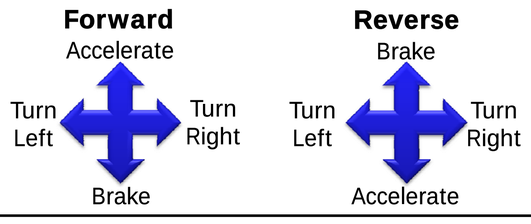
LIDAR Point Cloud
Image: Velodyne Acoustics, Inc.

Command & Data Handling

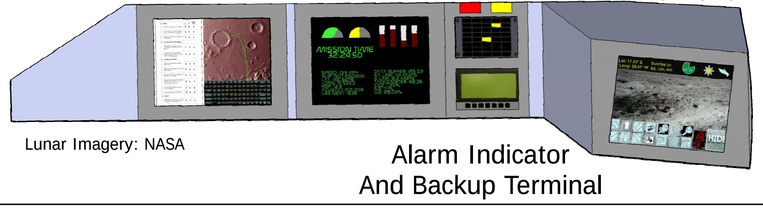
- Components connected by an Avionics Full Duplex Ethernet (AFDX) network (TRL 4)
- Three next generation RAD 750 computers (TRL 7)
- Distributed Computing Units (DCU) powered by Field Programmable Gate Arrays (FPGA)
- DCUs run control loops for life critical systems

Console & Control Layout

Controls:



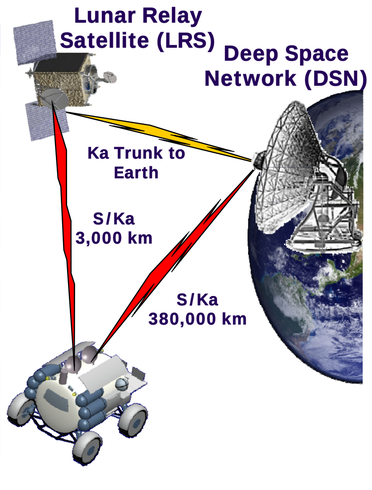
Console:



Lunar Imagery: NASA

Communications

	Ka-Band	S-Band
Max Data Rate	120 Mbps	20 Mbps
Direction	Transmit	Two-Way
Antennas	53 cm Parabolic HGA	Omni/Parabolic HGA
Gain	40 dBi	0 dBi/20 dBi
System Power	50	250
RF Power	2	100
Optimal Receiver	LRS	LRS
Optimal Link Margin	9.4	3.0
Use While Moving	No	Yes
Usable Antennas	2	5
Transceivers	2	3



Project TURTLE:
Terrapin Undergraduate Rover for Terrestrial Lunar Exploration

University of Maryland

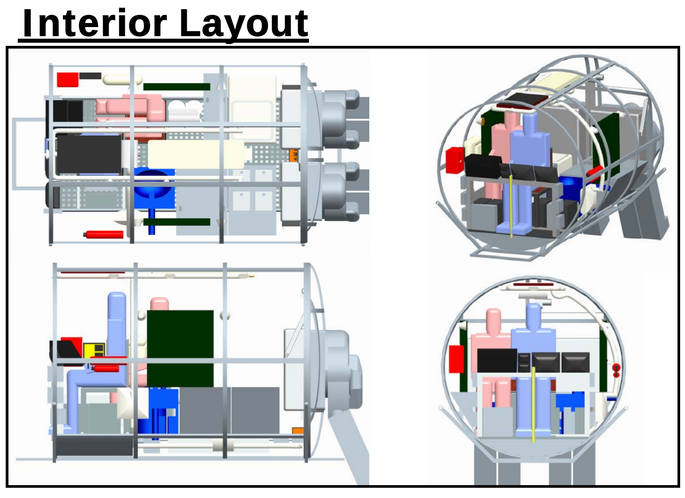
David Berg, James Briscoe, Kanwarpal Chandhok, Joshua Colver, Enrique Coello, Aaron Cox, Stuart Douglas, Andrew Ellsberry, Sara Fields, David Gers, Zohaib Hasnain, Ali Husain, Madeline Kirk, Jason Laing, May Lam, Jason Leggett, Michael Levashov, Ryan Levin, Joseph Lisee, Omar Manning, Thomas Mariano, Jessica Mayerovitch, Brian McCall, David McLaren, Adam Mirvis, Ryan Murphy, Aleksandar Nacev, Hasan Oberoi, Ugonma Onukwubiri, Stephanie Petillo, Tiffany Russell, Matt Schaffer, Ali-Reza Shishineh, Jacob Zwillinger

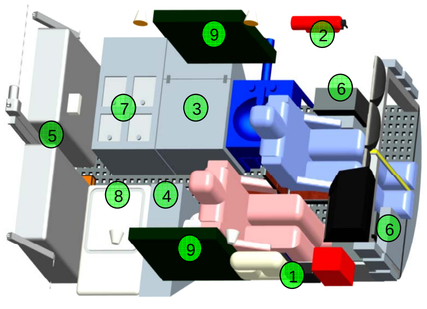
Advisors: Dr. Dave Akin and Dr. Mary Bowden

TURTLE Design

Crew Systems

Interior Layout



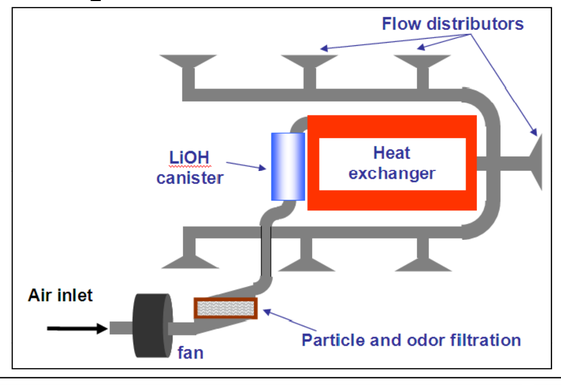


1. First aid kit, AED, supplemental oxygen
2. Fire extinguishers
3. Food / food waste storage
4. Clothing storage
5. Suitports
6. Computers
7. Storage locker
8. Supplemental Airlock
9. Beds (stowed)

Life Support Systems

Atmosphere

- Cabin pressure: 55.2 kPa / 8 psi (Identical to LSAM)
- Atmospheric composition: 39% O_2, 61% N_2, R-Factor = 1.4, for zero-prebreathe EVAs (based on EMU parameters)
- Distributors circulating at 2.03 m^3/min
- LiOH, particulate filters and activated charcoal to maintain cabin atmosphere
- O_2 and pressure sensors allow computer control of regulators on O_2 and N_2 tanks

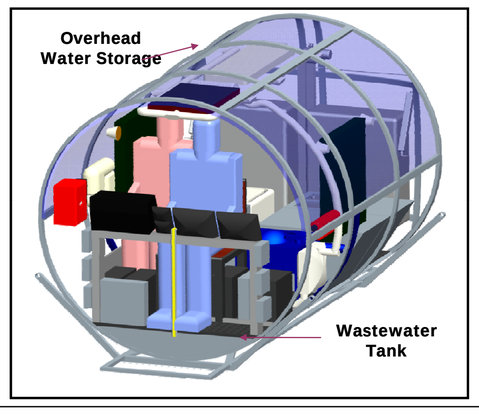


Nutrition

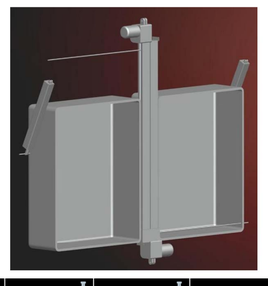
- Water management: Continuous re-supply from fuel cells, with microbial filter and 0.5 ppm iodine
- Diet corresponds to World Health Organization for 95th percentile male with high physical activity level, representative of Skylab astronaut diet

Radiation

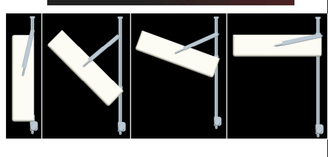
- Potable water tank overhead for GCR shielding
- SPEs treated as contingency scenarios: seek shelter beneath rover or employ natural landforms



Suitport

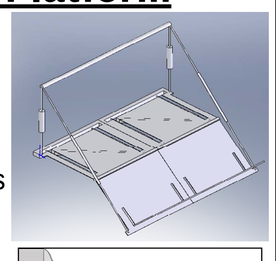


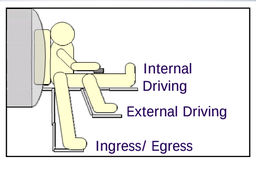
- Decreased mass and volume for EVAs: 145 kg, 0.25 m^3
- "Garage door" movement sweeps less than 0.5 m^3
- Passive mechanisms preferred for connections
- Seals: inflatable isomeric materials, standard o-rings, dust mitigation



External Driving Platform

- Ingress/egress, plus three powered configurations: launch, internal driving, external driving
- Adjustable components to accommodate all required astronaut geometries
- Mass is approximately 30 kg including actuators

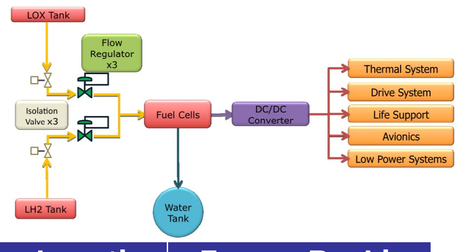




TURTLE Power

Three Proton Exchange Membrane fuel cells

- Three-fold redundancy: One fuel cell is able to power all rover systems
- Power requirements broken into five stages as shown below



	Avg. Power Req'd. (W)	Stage Length (hrs)	Energy Req'd. (kWhr)
Transfer Stage	290	167	48
Descent & Landing Stage #1	1330	0.92	1.2
Descent & Landing Stage #2	1070	0.08	0.1
Standby Stage	430	220	92
Sortie Mission Stage	3240	190	622
Total	**—**	**578**	**764**

Fuel cells supplied with cryogenic liquid oxygen and liquid hydrogen. After reaction, potable water is stored for use by astronauts during the mission. (TRL 3)

Fuel Tank Boil-off:

- Boil-off effects from solar heating converts the liquid propellants into unusable gases
- Excess fuel, tank size, and perforated MLI insulation layer (TRL 7) requirements were determined for a desired usable fuel mass
- Redundancy, mass, and space restrictions were considered when choosing number and size of tanks

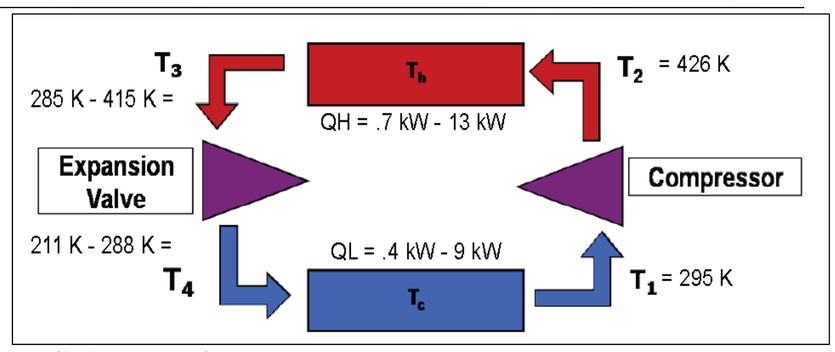
	Number of Tanks	Mass of Fuel	Diameter	Length	Layers of MLI	Percent Extra Fuel
LOX	2	243 kg	46.4 cm	82 cm	1	2.9%
LH_2	4	32.9 kg	50 cm	82 cm	2	10.8%

TURTLE Thermal Control

Without active control, solar heating and internal component heat (813 W) raise thermal equilibrium temperature to 330 K (beyond habitable limits)

- Passive Control: Aeroglaze A276 white paint (TRL 9)
- Active Control: Helium gas heat exchanger (TRL 4)

- Single phase helium gas exchange system: chosen for simplicity and robustness
- Heat removed by an internal heat exchanger, then expelled through external radiator
- The gas is compressed so that the efficiency is maximized without reaching unrealistic mass flow rates
- The coefficient of performance for this system is 2.2



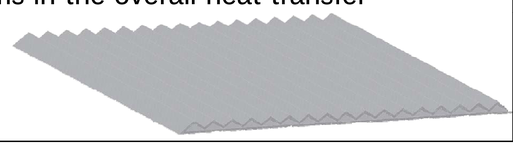
Heat Exchangers

Internal

- Piping containing cold gas absorbs energy from the cabin air passed over it
- Film heat transfer coefficients of the moving gas were used to determine the necessary diameter (1 cm) and length (21 m) of the pipes

External

- Corrugated radiator design with a planar area of 8 m² maximizes radiation area
- Radiator cross section composed of equilateral right triangles with thickness 2 mm and height 3.7 cm (chosen using the heat flux terms in the overall heat transfer system)



Conclusions

Reliability

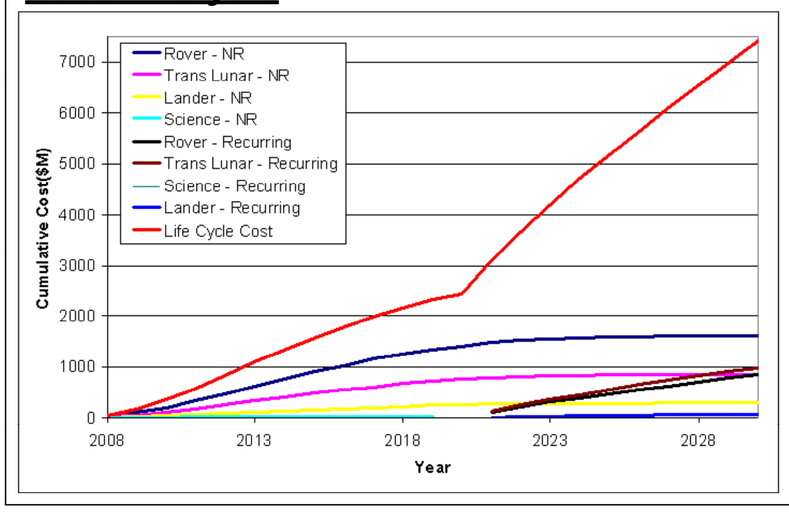
Components	Rel LOM
Suitport Systems	.9998
Wheels	.9900
Motors	.9990
Suspension	.9900
Avionics Hardware	.9983
Software	.9990
Fuel Tanks	.9990
Thermal/Radiation	.9980
Batteries	.9990
Final	**.9723**

Critical TRLs

TRL 1-3

- Suitport connections
- Suitport mechanisms
- Suit with detachable PLSS
- Lander leg honeycomb inserts
- Lander detachment mechanisms
- Cryogenic PEM fuel cells

Cost Analysis



Assumptions:

1) Use existing launch vehicle (no DDT&E)
2) Initial flight in 2020
3) 85% construction learning curve
4) Ten missions total

Total Cost: $7.4 billion

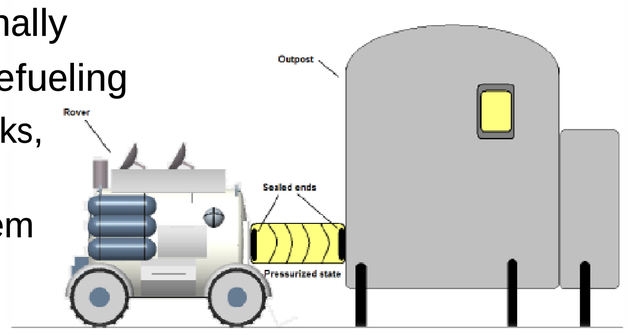
Rated at a CRL of 4 based on preliminary design readiness

System	Non-Recur.	Recur.	Tot. ($M)
Rover	1600	850	2450
Transit	850	990	1840
Lander	280	250	530
Science Package	25	78	103
Delta-IV	-	2500	2500
Total	**2800**	**4700**	**7400**

Outpost Rover

Outpost CONOPS - Logistics

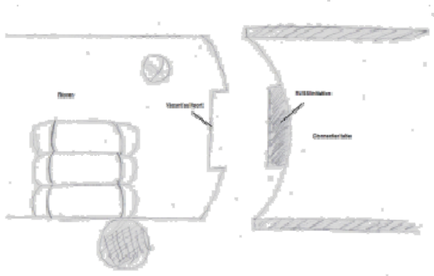
- There will be two supplies of fuel, one on the rover and one at the outpost for refueling
  - Gray waste water stored throughout a mission and then transferred to the outpost to regenerate LOX and LH_2
  - Water from solid waste possibly used to regenerate fuel
- Food, clothing and LiOH canisters resupplied by shirt-sleeve transfer
- Atmospheric gases resupplied externally
- Two possible methods for external refueling
  - Replace tanks: easy with light tanks, but requires extra tanks
  - Umbilical: more complicated system to develop, but easier to use



Docking Options

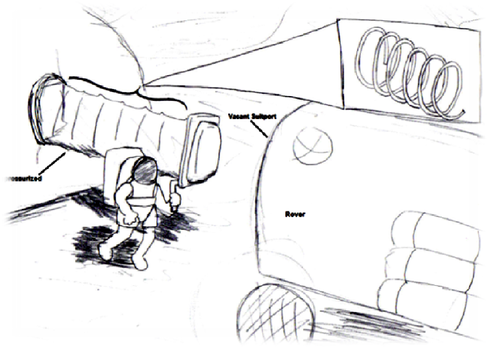
Outpost to Rover docking

- Docking using the suitport hatch as connection to a rigid docking structure at the outpost
- One astronaut would exit through the connecting suitport, aid in docking the rover, and then enter the outpost through an airlock or suitport



Retractable docking

- Retractable docking structure is depressurized and collapsed when not in use
- Extended and pressurized when docked to TURTLE's suitport



Rover Mock-up

The rover mock-up was constructed as a design tool to determine most effective and efficient interior layout and to test the feasibility of a suitport for ingress and egress.

Construction

Rover construction began in late February and lasted until late April for the final product

Final Product

Interior Testing

- Left vs. center driving position
- Bed vs. hammock,
- Effectively place storage containers, computers, and small support items in the cabin

Suitport Testing

Suitport testing provided a way to determine if suitports are feasible for ingress/ egress for TURTLE and to test the "garage door" method of removing the PLSS

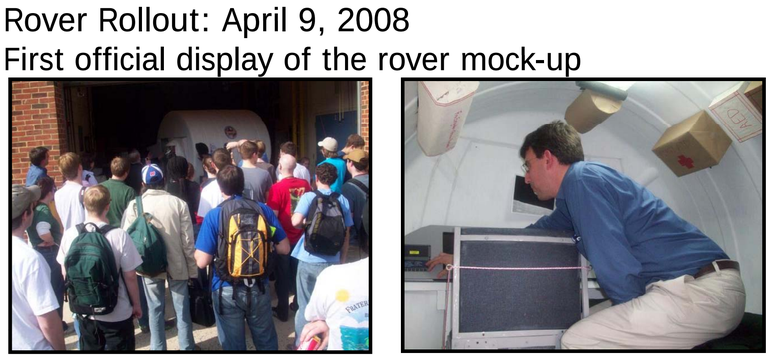
Outreach

Overview

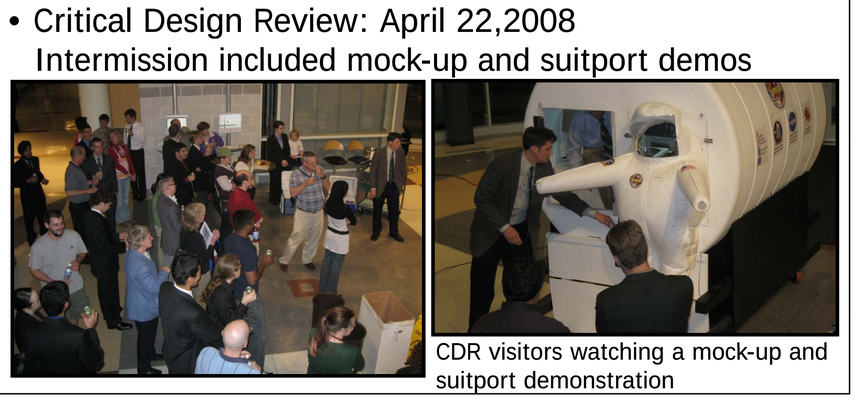
- 100% Team Participation
- 18 Events from February to May 2008
- 143 Contact Hours

Technical Community

- Preliminary Design Review: December 2007
- Baseline Design Review: March 6, 2008
- Rover Rollout: April 9, 2008
  First official display of the rover mock-up



- Critical Design Review: April 22,2008
  Intermission included mock-up and suitport demos



CDR visitors watching a mock-up and suitport demonstration

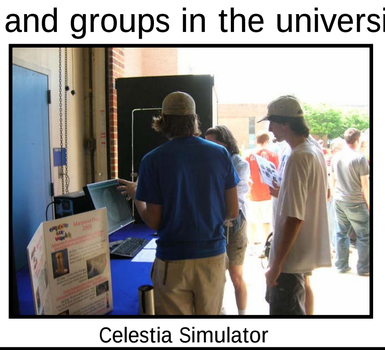
General Public

- UMD Open Houses

  Four presentations to prospective students and parents with at least three team members at each open house. The presentation covered general information about the design class and the TURTLE design.

- Maryland Day: April 26, 2008

  Maryland Day is a university-wide day of activities for the local community to view the labs, departments, and groups in the university.



Celestia Simulator

AIAA/SGT Smoke Visualization Demo

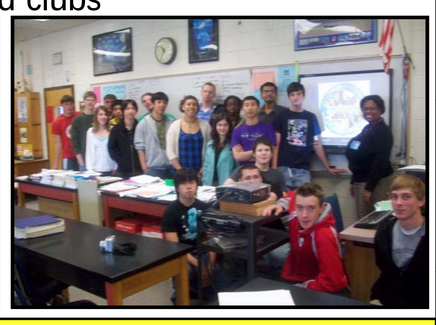
Climbing into the Mock-up

Candy Rover Construction

K-12th Grade

- Elementary School and Middle School
  Drew Elementary School toured the Space Systems Lab with 50 students and teachers on March 7th. Team members visited two area middle schools.

- High School
  Presentations at four local high schools for science and engineering class and clubs



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