**Mission Profile**

<table>
<thead>
<tr>
<th>Burn</th>
<th>Delta V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta-IV Heavy to TLI</td>
<td>Delta V</td>
</tr>
<tr>
<td>TLI to Low Lunar Parking Orbit</td>
<td>800 m/s</td>
</tr>
<tr>
<td>Transfer Descent</td>
<td>135 m/s</td>
</tr>
<tr>
<td>Retro Engine Braking</td>
<td>1725 m/s</td>
</tr>
<tr>
<td>Landing</td>
<td>80 m/s</td>
</tr>
</tbody>
</table>

Honeycomb inserts in legs crush upon landing. 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.

**TURTLE Capabilities**

- Suitsports 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

**Pressure Shell**

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

**Driving Window**

- Double paneled
- 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 2.5
- 9.2 m turning radius at top speed, on level ground
- TURTLE accommodates 20° slope with positive drawbar pull

**Mobility System**

- 4 wheels, independently steered and powered
- Suspension system: MacPherson struts
- Spring const. 35 kN/m
- Damp const. 1.8 kN m/s
- 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

**Navigation & Autonomy**

- Autonomous rendezvous with crew who will land less than 10 km away
- Determines rover’s lunar position
- Maps and navigates around obstacles with LIDAR (TRL 4)

**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**

- Driver’s Interface 2x DU-1310
- Navigator’s Interface DU-1310
- Lunar Integrity, MSA
- Alarm Indicator
- And Backup Terminal

**Avionics**

- Video: Velodyne Acoustics, Inc.

**Communications**

- Deep Space Network (DSN)
- Lunar Relay Satellite (LRS)

**TURTLE Design**

- Project Overview
- Rover Separation Stage (surface)
- Transfer Descent
  - Low Lunar Parking Orbit
- Engine Separation Stage (2 km)
- Landing Stage w/ Retro Engine Braking
  - (2 km - 1 m)

**Flight Rover**

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

**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

**Outpost Rover**

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

**Mission Overview**

- Primary Descent Stage (LLO - 2 km)
- 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.

**Safety Factor**

- Determines rover’s lunar position
- Maps and navigates around obstacles with LIDAR (TRL 4)

- Components connected by an Avionics Full Duplex Ethernet (AFDX) network (TRL 4)
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**Project TURTLE:**
Terrapin Undergraduate Rover for Terrestrial Lunar Exploration

University of Maryland


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. Suitsports
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% O₂, 61% N₂, R-Factor = 1.4, for zero-prebreath EVAs (based on EMU parameters)
- Distributors circulating at 2.03 m³/min
- LIOH, particulate filters and activated charcoal to maintain cabin atmosphere
- O₂ and pressure sensors allow computer control of regulators on O₂ and N₂ 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 m³
- "Garage door" movement sweeps less than 0.5 m³
- 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

<table>
<thead>
<tr>
<th>Stage</th>
<th>Avg. Power Req'd (kW)</th>
<th>Stage Length (hrs)</th>
<th>Energy Req'd. (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Stage</td>
<td>290</td>
<td>167</td>
<td>48</td>
</tr>
<tr>
<td>Descent &amp; Landing #1</td>
<td>1330</td>
<td>0.92</td>
<td>1.2</td>
</tr>
<tr>
<td>Descent &amp; Landing #2</td>
<td>1070</td>
<td>0.08</td>
<td>0.1</td>
</tr>
<tr>
<td>Standby Stage</td>
<td>430</td>
<td>220</td>
<td>92</td>
</tr>
<tr>
<td>Sortie Mission Stage</td>
<td>3240</td>
<td>190</td>
<td>622</td>
</tr>
<tr>
<td>Total</td>
<td>~578</td>
<td>764</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Number of Tanks</th>
<th>Mass of Fuel</th>
<th>Diameter</th>
<th>Length</th>
<th>Layers of MLI</th>
<th>Percent Extra Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOX</td>
<td>2</td>
<td>243 kg</td>
<td>46.4 cm</td>
<td>82 cm</td>
<td>1</td>
</tr>
<tr>
<td>LH₂</td>
<td>4</td>
<td>32.9 kg</td>
<td>50 cm</td>
<td>82 cm</td>
<td>2</td>
</tr>
</tbody>
</table>

**TURTLE Thermal Control**

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

**Internal**

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

**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**

<table>
<thead>
<tr>
<th>Components</th>
<th>Rel LOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suptport Systems</td>
<td>.998</td>
</tr>
<tr>
<td>Wheels</td>
<td>.999</td>
</tr>
<tr>
<td>Motors</td>
<td>.999</td>
</tr>
<tr>
<td>Suspension</td>
<td>.990</td>
</tr>
<tr>
<td>Avionics Hardware</td>
<td>.983</td>
</tr>
<tr>
<td>Software</td>
<td>.999</td>
</tr>
<tr>
<td>Fuel Tanks</td>
<td>.999</td>
</tr>
<tr>
<td>Thermal/Radiation</td>
<td>.980</td>
</tr>
<tr>
<td>Final</td>
<td>.973</td>
</tr>
</tbody>
</table>

**Critical TRLs**

**TRL 1-3**
- Suptport connections
- Suptport 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
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 LH₂
  - 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

Final Product

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

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.

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

Acknowledgements
The TURTLE Team would like to thank Maryland Space Grant
Consortium for generously funding our rover mock-up,
NASA/USRA for RASC-AL travel funds, and the Space Systems
Laboratory for mockup fabrication and testing support.