ANNOUNCEMENTS

- CDR Tonight: 7:30-10:30 PM ARMS 3115
- Class Shirts – We’ll do the t-shirt option
- Coming Soon:
  • Report-Writing Guidelines
8:32 – Parth S.
8:40 – Krista G.
8:46 – Michael C.
8:52 – Jose Miguel B.
- End Morning Session
10:32 – Spencer G.
10:38 – Ryan A.
10:44 – Hani K.
10:50 – Ben F.
10:56 – Jessica C.
Break
11:12 – Eric M.
11:18 – Cameron H.
11:24 – Erik S.
11:30 – Andrew E.
11:36 – Arika A.
Break
11:52 – Finu L.
11:58 – Bryan F.
12:04 – Eric F.
12:10 – Tas Powis
12:16 – Divinaa B.
12:22 – Joe A.
PARTH SHAH | APM
LAUNCH PLANNING & RISK ASSESSMENT
2/27/2014

- COMPLETE MISSION TIMELINE
- UPDATED RISK ASSESSMENT
MISSION TIMELINE

- Qualitative representation of entire
  - In conjunction with launch planning with Erik Slettehaugh

- Nominal Mission Duration:
  - Communication Satellites: 165 days
  - Initial Launch Phase: 636 days
  - Crew to Moon: 4 days
    - Same for return to Earth
  - Total Mission Time: 5972 days/16 years 4 months
    - Start 1/1/2014
### PROJECT ARTEMIS RISK ASSESSMENT

**Mission Requirements:**
- >90% colonists’ mission success
- >95% returning crew home safe

**Most data from launch history reports, NASA logs**

**Phase 8 from three main sources**
- Proper re-entry angle (0.99)
- Proper heat-shield (0.99)
- Parachute deployment (0.99)
  - No Failures in 50 years

### Events/Phases

<table>
<thead>
<tr>
<th>Events/Phases</th>
<th>Probability of Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Single Launch Capability of LV</td>
<td>~ 0.990</td>
</tr>
<tr>
<td>2. Flight from Earth to LEO</td>
<td>~ 0.999</td>
</tr>
<tr>
<td>3. LEO to Low Lunar Orbit (LLO)</td>
<td>~ 0.999</td>
</tr>
<tr>
<td>4. Landing on the Moon</td>
<td>~ 0.972</td>
</tr>
<tr>
<td>5. Living on the Moon</td>
<td>~ 0.969</td>
</tr>
<tr>
<td>6. Launch from Moon</td>
<td>~ 0.959</td>
</tr>
<tr>
<td>7. LLO to LEO</td>
<td>~ 0.999</td>
</tr>
<tr>
<td>8. Earth EDL</td>
<td>~ 0.988</td>
</tr>
</tbody>
</table>

**Overall Mission Success:**
~0.881

**Crew Mission Return**
~0.9465

### Catastrophic Events:
- Resupply Mission Failure
  \[
P(\text{fail}) = 1 - (P_1 \times P_2 \times P_3 \times P_4) = 0.027
\]
- De-pressurization scenarios (habitat, rover)
  \[
P(\text{fail}) = 0.0001 \quad [9]
\]
- Failure to lower habitat into Lunar Skylight
  \[
P(\text{fail}) = 0.001 \quad (\text{Assumption})
\]
- Lower the habitat into Shackleton crater
  \[
P(\text{fail}) = 0.001 \quad (\text{Assumption})
\]
- Medical emergencies
  \[
P(\text{fail}) = 0.001 \quad [8]
\]
Failure to Launch from the Moon

Failure to Launch from the Moon

Failure to Land on the Moon

PHASE 4

Engine Failure

Landing Leg, Deploy Failure

Egress Failure

PHASE 6

Engine Failure

Pressurization Failure for Crew Moon Lander

Lander Systems Failure

Failure to properly maintain propellant

Failure to ignite at Launch

Control Systems Failure

Structural Damage to Lander

$$P(A \text{ or } B) = P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

Parth Shah | APM
KRISTA GARRETT | MISSION DESIGN

CREW TRANSPORT VEHICLE

2/27/2014

- DESIGN CHANGES FOR CREW VEHICLES
- CTV SIZING AND LAUNCH REQUIREMENTS
- PROPULSION SYSTEMS FOR CREW VEHICLES
DESIGN CHANGES FOR CREW VEHICLES

- **Problem:**
  - Cannot store LH$_2$ for 4 and 2/7 years

- **Design changes:**
  - Crew Lunar Lander Ascent Stage
    - MMH and N$_2$O$_4$
    - Ascent stage propellant sent on cargo vehicle
  - Staging for transporter
    - First stage: LOX/LH$_2$
    - Second stage: LOX/RP-1

- Changes propellant masses for entire CTV
Need 2 separate launches

- 1st launch:
  - Crew capsule
  - Lunar lander
  - Descent propellant
  - Transporter second stage
  - Second stage propellant

- 2nd launch:
  - Transporter first stage
  - First stage propellant

<table>
<thead>
<tr>
<th>CTV Component</th>
<th>Mass (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew capsule + crew</td>
<td>7.51</td>
</tr>
<tr>
<td>Lander + descent propellant</td>
<td>33.30</td>
</tr>
<tr>
<td>Transporter + propellant</td>
<td>105.85</td>
</tr>
<tr>
<td>CTV total</td>
<td>146.66</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CTV Launches</th>
<th>Mass (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Launch</td>
<td>50.45</td>
</tr>
<tr>
<td>Second Launch</td>
<td>96.21</td>
</tr>
</tbody>
</table>
MICHAEL CREECH | MISSION DESIGN

OPTIMAL TRAJECTORIES

2/27/2014

- L1 AND L2 OPTIMAL TRAJECTORIES
- ΔV AND TOF
TRAJECTORY TO L1

- $\Delta V = 3.22 \text{ km/s}$
- $\text{TOF} = 76.49 \text{ days}$

Michael Creech | Mission Design
**TRAJECTORY TO L2**

- $\Delta V = 3.20 \text{ km/s}$
- TOF = 90.94 days
EP CARGO VEHICLE
DATE: 27 Feb 2014

- ELECTRIC PROPULSION VEHICLE CONFIGURATION
EP SYSTEMS OVERVIEW

- **Thrusters**
  - 6 VASIMR Vx-200 [1]
  - Packed in units of 2 thrusters

- **Propellant**
  - Argon

- **Nuclear power production**
  - SAFE-400 [2]

- **Structures**
  - Carbon fiber/Aluminium

<table>
<thead>
<tr>
<th></th>
<th>MASS (Mg)</th>
<th>POWER (MWe)</th>
<th>VOLUME (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrusters</td>
<td>3.720</td>
<td>1.2 (required)</td>
<td>12</td>
</tr>
<tr>
<td>Propellant</td>
<td>26.344</td>
<td>-</td>
<td>14.136</td>
</tr>
<tr>
<td>Nuclear Power Production</td>
<td>10.297</td>
<td>1.2 (produced)</td>
<td>15.534</td>
</tr>
<tr>
<td>Structure</td>
<td>4</td>
<td>-</td>
<td>1.482</td>
</tr>
<tr>
<td>Total</td>
<td>57.669*</td>
<td>1.2</td>
<td>56.097*</td>
</tr>
</tbody>
</table>

* Accounting for a safety factor of 1.3
Diameter: 9.8m
Height: 2m
- ADDITIONAL REACTION CONTROL REQUIREMENTS FROM THRUSTER MISALIGNMENT AND CENTER OF MASS OFFSET
- CONTROL SYSTEM OVERVIEW
**ADDITIONAL DELTA-V**

\[
I = \begin{bmatrix}
3.844E6 & 0.015 & 9.895 \\
0.015 & 3.847E6 & 5.687 \\
9.895 & 5.687 & 1.305E6
\end{bmatrix} \text{ kg} \cdot \text{m}^2
\]

Courtesy of Arika Armstrong

- Center of Mass offset and Thruster Misalignment cause undesirable torques.

\[
d\frac{V_x}{dV_z} = 1.75\% \text{ for } \alpha = 1 \text{ deg} \\
d\frac{V_x}{dV_z} = 0.87\% \text{ for } \alpha = 0.5 \text{ deg} \\
d\frac{V_x}{dV_z} = 3.49\% \text{ for } \alpha = 2 \text{ deg}
\]
CONTROL SYSTEM OVERVIEW

- Total Power Consumption: 116 W
- Total Mass: 17 kg + 8.5 kg x 6
- Total Volume: .037 m^3
- Reaction Control Thrusters: MR-80B Throttling Rocket Engine Assembly (x6)
  - Station Keeping Delta-V – (50+20) = 70 m/s
  - Thrust Range – 31 N to 3780 N
  - Specific Impulse – 215 s
  - Propellant Mass (Hydrazine): 3.88 Mg

Courtesy of Sean Snoke
RYAN ALLEN | CONTROLS
CREW TRANSPORT VEHICLE
2/27/2014

- RADIO INTERFEROMETER ARRAY
- CTV THRUSTER SELECTION
**RADIO INTERFEROMETER ARRAY**

- 300 Stations deployed in crater
- Polyimide film rolled up for storage
- Each station stored in hexagonal case
- Interferometer Deployment Rover

![Diagram of interferometer array](image)

**Component** | **Mass [kg]** | **Volume [m^3]** | **Notes**
--- | --- | --- | ---
Polyimide film (6) | 18 | 0.018 | Assuming 20 g/cm^2 Kapton film
Station hub | 1 | 0.04 | Contains computational chips
Battery | 6 | 0.01 | Provides 3.73 W
Solar Panel | 2 | 0.005 | Charges during lunar day

| **Total System Specifications** | **8.4 Mg** | **175.5 m^3** | **1.12 kW** |
--- | --- | --- | ---
Calculations assisted by Eric Menke and Tas Powis.

---

Figure and design based on Dark Ages Lunar Interferometer, DALI (Contacted Dayton Jones, telephone, 2/24/14 5:02 pm)
CTV THRUSTER SELECTION

- 85.6 m/s delta-v required for CTV station-keeping for 4 2/7 year orbit (from Tom Rich)
- MR-106E 22N Rocket Thrusters enable CTV to rotate 180° in 1.067 minutes.
- 12 Hydrazine Monopropellant thrusters
- 7 Model OST 31/0 Hydrazine tanks

Inertia Tensor (from Scott Sylvester)

<table>
<thead>
<tr>
<th>Mass [kg]</th>
<th>Volume [m^3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propellant</td>
<td>550.611</td>
</tr>
<tr>
<td>Tanks and Rockets</td>
<td>52.42</td>
</tr>
<tr>
<td>Total</td>
<td>603.03</td>
</tr>
</tbody>
</table>

Figure generated by Spenser Guerin
LIGHT ROVER AND HABITAT ENERGY ESTIMATION
**Light Rover**

**Mission**
- Num. Crew: 2
- Duration: 10 days

**Dimension**
- Rover (total area): 6.8 m²
- Bathroom: 0.6 m²

**Item**
- Bed / chair: 2
- Table: 3
- Light: 2
- Monitor (or Oculus Rift): 2
- Storage 1 (Food & Water & Emergency medical kit): 0.50 m³
- Storage 2: 0.22 m³
- Waste Box: 0.12 m³
- lights: 20 watt

---

Fig. 1: Light rover inside, Hani Kim

Fig. 2: NASA Z-1 Spacesuit Back, Hani Kim
Based on Busyminds.ae
(http://busyminds.ae/technews/201207/17221/nasas-next-spacesuit-makes-astronauts-look-like-trash-bags-space/)
### Habitat Energy consumption

Energy provided: 88 kW

<table>
<thead>
<tr>
<th>Categories</th>
<th>kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>1.33 (3)</td>
</tr>
<tr>
<td>Water recycle</td>
<td>2.5</td>
</tr>
<tr>
<td>Game room</td>
<td>3</td>
</tr>
<tr>
<td>Computer</td>
<td>8.69</td>
</tr>
<tr>
<td>Thermo Control</td>
<td>4.2</td>
</tr>
<tr>
<td>Kitchen</td>
<td>4</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.5</td>
</tr>
<tr>
<td>Communication</td>
<td>0.15</td>
</tr>
<tr>
<td>Waste Manage system</td>
<td>5</td>
</tr>
<tr>
<td>Food Growing (Aeroponic)</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>37.368</strong></td>
</tr>
</tbody>
</table>
Ilmenite
- Mixture of iron, titanium, and oxygen

Lunar Oxygen Extraction Process
- Vacuum pyrolysis

Steps to obtaining pure $O_2$ \[1\]
1. Construction robots bring regolith to the pilot plant
2. A hopper in the system filters the dust into the first reaction chamber
3. Using solar reflectors, the vessel is heated to $\sim 600$ C
4. Hydrogen is introduced and the mixture is fed into the main reaction chamber
5. Solar heating is used, again, to raise temperature to above 900 C
6. Water is extracted from this reaction and is sent through electrolysis where hydrogen and oxygen are separated
- The hydrogen can then be used to react with the new regolith

$$FeTiO_3 + H_2 \rightarrow Fe + TiO_2 + H_2O \rightarrow H_2 + \frac{1}{2} O_2$$
## HF: HABITAT OXYGEN

<table>
<thead>
<tr>
<th>Element</th>
<th>Mass [kg]/yr</th>
<th>Power [kW]/yr</th>
<th>Volume [m³]/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen (O2)</td>
<td>298.23</td>
<td>~ 4.5</td>
<td>0.739</td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>782.86</td>
<td>~ 4.5</td>
<td>2.22</td>
</tr>
</tbody>
</table>

- Research shows that the efficiency is ~ 11% in retaining oxygen from regolith. [1]
- In order to maintain standard conditions in Habitat, must mine ~ 2711 kg of regolith for processing as well as resupplying Habitat with 782.86 kg of nitrogen every year.
- Can power the extractor via solar panels or reactors. (electrolysis)
- System occupies 0.13 m^3 of space.
RESUPPLY UPDATE

KITCHEN AND LAB APPLIANCES

Z-1 SPACESUIT SPECIFICATIONS
### Resupply

- **67 week initial supply**
  - 5 week full freeze dried supply\(^1\)\(^3\)
  - 62 weeks of 43% of required food freeze dried supply
  - Includes entire Water Recovery System (WRS) and initial water for WRS and food growth use

- **12 month resupply**

<table>
<thead>
<tr>
<th></th>
<th>Initial Mass (Mg)</th>
<th>Initial Volume (m(^3))</th>
<th>Resupply Mass (Mg)</th>
<th>Resupply Volume (m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>3.560</td>
<td>14.83</td>
<td>2.511</td>
<td>10.46</td>
</tr>
<tr>
<td>Water*(^3)</td>
<td>8.630</td>
<td>10.965</td>
<td>2.480</td>
<td>2.480</td>
</tr>
<tr>
<td>Total</td>
<td>13.255</td>
<td>29.28</td>
<td>4.535</td>
<td>13.785</td>
</tr>
</tbody>
</table>

*Water values from Taylor Schultz*
No need for a refrigerator, food will stay for two weeks\[^4\]

<table>
<thead>
<tr>
<th>Appliance [^2]</th>
<th>Quantity</th>
<th>Mass (kg)</th>
<th>Volume (m(^3))</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection Oven</td>
<td>2</td>
<td>33</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td>Sink</td>
<td>5</td>
<td>5</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>91</td>
<td>2.60</td>
<td>7</td>
</tr>
</tbody>
</table>

Z-1 spacesuit\[^6\][\(^7\)]
- Mass\[^5\]: ~70 kg
- Volume\[^5\] (folded in a box): ~0.3 m\(^3\)
- Length\[^5\] (fully extended): ~2.0 m
- Portable life support system (PLSS)

Z-1 spacesuit attachment to a vehicle, based on NASA diagram \[^7\]
FAR-SIDE DISH SIZING

HEAVY AND LIGHT ROVER EMERGENCY EVACUATION PROCEDURES
### Far-side Base Parabolic Dish Specs.

<table>
<thead>
<tr>
<th></th>
<th>CTV</th>
<th>Lander, Rovers, Con. ‘Bots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>20 kg</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>61 W</td>
<td>131 W</td>
</tr>
<tr>
<td>“Box” Volume</td>
<td>1.094 m³ – 1.318 m³</td>
<td></td>
</tr>
<tr>
<td>Outbound Data</td>
<td>4 Mbps</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>1.15 m</td>
<td></td>
</tr>
</tbody>
</table>
SAMPLE CARRIER RE-ENTRY
2/27/2014

- SCIENCE SAMPLE CARRIER LANDING LOCATION
- PARACHUTE SIZING
SAMPLE CARRIER LANDING LOCATION

Trajectory

Max G's
Max Heat Flux

Altitude (km)

Downrange (km)

40.492 N
121.107 W

Utah Test and Training Range

40.492 N
113.6367 W

h = 125 km
r = 6371 km

Cameron Horton | Aerodynamics
Drag Equation

**Parachute Sizing**

\[ A_p = \frac{2gm}{\rho C_d V^2} \]

- \( g = 9.81 \text{ m/s}^2 \)
- \( m = \text{mass of capsule} = 632.01 \text{ kg} \)
- \( \rho = 1.225 \text{ kg/m}^3 \)
- \( C_d = \text{Coeff. of Drag of parachute} = 0.75 \)
- \( V = \text{descent velocity} = 88 \text{ m/s} \)  

\[ A_p = 1.96 \text{ m}^2 \]

\[ A_T = \frac{b \cdot h}{2} \]

\[ \frac{A_p}{16} = \frac{r^2 \cos\left(\frac{360^\circ}{2n}\right) \sin\left(\frac{360^\circ}{2n}\right)}{2} \]

\[ r = \sqrt{\frac{A_p}{8 \cos\left(\frac{360^\circ}{2n}\right) \sin\left(\frac{360^\circ}{2n}\right)}} \]

\[ r = 0.872 \text{ m} \]

\[ d = 1.665 \text{ m} \]
PAYLOAD CONFIGURATION

- LAUNCH PHASES & COM SAT LV
- COST FOR LAUNCHES

2/27/2014
**Assume:** Payload to Lunar Surface w/ SLS, Mass: 24Mg; Volume: 460m^3

<table>
<thead>
<tr>
<th>Launch #</th>
<th>Launch Phase</th>
<th># of Launches</th>
<th>Total Mass (Mg)</th>
<th>Total Volume (m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>COM Sats</td>
<td>4</td>
<td>1.58</td>
<td>2.7</td>
</tr>
<tr>
<td>5-6</td>
<td>Construction Vehicles &amp; Hab Equipment</td>
<td>2</td>
<td>43.817</td>
<td>152.34</td>
</tr>
<tr>
<td>7-8</td>
<td>Heavy Rovers</td>
<td>2</td>
<td>39.88</td>
<td>106.54</td>
</tr>
<tr>
<td>9-12</td>
<td>Light Rovers &amp; Waypoint Equipment</td>
<td>4</td>
<td>88.353</td>
<td>189.73</td>
</tr>
<tr>
<td>13-14</td>
<td>Habitat Pods &amp; Consumables</td>
<td>2</td>
<td>47.821</td>
<td>771.08</td>
</tr>
<tr>
<td>15-16</td>
<td>Crew Transport Vehicle</td>
<td>2</td>
<td>162.46</td>
<td>92.87</td>
</tr>
<tr>
<td>17-19</td>
<td>Resupply</td>
<td>3</td>
<td>31.24</td>
<td>91.37</td>
</tr>
<tr>
<td>20</td>
<td>Skylight Repel System</td>
<td>1</td>
<td>10.56</td>
<td>184.24</td>
</tr>
<tr>
<td></td>
<td>Total for All Colonies</td>
<td>50</td>
<td>425.711</td>
<td>1590.87</td>
</tr>
</tbody>
</table>

*Split launch: 7, 8, & 10: Shackleton Base: 300 Interferometer Cubes & Bot

26/26 Successful Launches

<table>
<thead>
<tr>
<th>Minotaur VI+ 92&quot; (Lunar Orbit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Launch Mass:</td>
</tr>
<tr>
<td>Max Launch Volume:</td>
</tr>
<tr>
<td>Cost per Launch:</td>
</tr>
</tbody>
</table>

Credit: John Steinmeyer, Orbital Sciences Corp. Provided Minotaur LV details & cost estimations

Credit for CAD: Nick LaPiana
## Launch Cost Breakdown per Colony

<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>Cost / Launch ($1M)</th>
<th># of Launches</th>
<th>Cost ($1M)</th>
<th># of Launches</th>
<th>Cost ($1M)</th>
<th># of Launches</th>
<th>Cost ($1M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS 10m</td>
<td>$500.00</td>
<td>15</td>
<td>$7,500.00</td>
<td>15</td>
<td>$7,500.00</td>
<td>16</td>
<td>$8,000.00</td>
</tr>
<tr>
<td>Minotaur VI+ 92”</td>
<td>$60.00</td>
<td>1</td>
<td>$60.00</td>
<td>2</td>
<td>$120.00</td>
<td>1</td>
<td>$60.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$7,560.00</strong></td>
<td><strong>16</strong></td>
<td><strong>$7,500.00</strong></td>
<td><strong>17</strong></td>
<td><strong>$7,620.00</strong></td>
<td><strong>17</strong></td>
<td><strong>$8,060.00</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Launch</th>
<th># of Launches</th>
<th>Cost ($1M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>$23,240.00</td>
</tr>
</tbody>
</table>

*Pricing may decrease for multiple orders*
ANDREW EMANS | STRUCTURES
HABITAT STRUCTURES
02/27/2014

- CHECKPOINT DESIGN
- HABITAT ACCESS
- FINAL DESIGN OF HABITAT SHIELDING
CHECKPOINTS AND HAB ACCESS

- Checkpoints will be fabricated from empty cargo pods mostly covered in regolith with the exception of an exposed entrance.
- Main service hatch is on the side of the rec module which can be accessed by driving down the regolith ramp into the ‘garage’.
- Two pressurized tunnels, one connected to each module, that come out of the ground vertically to dock with rovers.
  - Mass: 0.156 Mg
  - Volume: 50 m$^3$
  - Total Mass per Hab: 0.312 Mg
  - Total Volume: 100 m$^3$
FINAL DESIGN OF HABITAT SHIELDING

- Made out of carbon fiber panels
- Factor of safety of 2
- Mass: 11.3 Mg
- Volume: 7.07 m$^3$
CARGO STRUCTURE

2/27/2014

- CARGO CONTAINER/LANDER UPDATES
- SCISSOR LIFT
# Detailed Cargo/Lander Design

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass [Mg]</th>
<th>Volume [m^3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Cargo</td>
<td>23</td>
<td>456</td>
</tr>
<tr>
<td>Cargo Pod Structure</td>
<td>4.894</td>
<td>470.6</td>
</tr>
<tr>
<td>Cargo Rails</td>
<td>0.292</td>
<td>0.066</td>
</tr>
<tr>
<td>Lander Rails</td>
<td>0.274</td>
<td>0.062</td>
</tr>
<tr>
<td>Cargo/Lander Clamp</td>
<td>0.376</td>
<td>0.084</td>
</tr>
<tr>
<td>Propellant Tanks</td>
<td>0.728</td>
<td>43.7</td>
</tr>
<tr>
<td>Propellant</td>
<td>38.79</td>
<td>43.46</td>
</tr>
<tr>
<td>Lander Structure</td>
<td>0.677</td>
<td>217.1</td>
</tr>
<tr>
<td>Engine</td>
<td>0.5</td>
<td>8</td>
</tr>
<tr>
<td>Landing Gear</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>Total Lander/Cargo</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Rails: total of 0.566 Mg

Clamps: 0.33 Mg (Cargo/Electric)
0.38 Mg (Cargo/Lander)

Contributions from Sean Snoke & Jose Miguel Blanco
10 kW Power
8x4x0.5 m
2 Mg
COMMUNICATION SATELLITE, CREW TRANSFER VEHICLE

2/27/2014

- COMMUNICATION SATELLITE PROPULSION SELECTION
- PROPULSION SPECS
- CREW TRANSFER VEHICLE CRYOGEN STORAGE PROBLEM
- SOLUTION
Tom Rich (Mission Design) – frozen Molniya orbits reduce station keeping cost ~116.71 m/s

Resulted in much smaller propellant mass and smaller thrusters

<table>
<thead>
<tr>
<th>MR-103M 1N Rocket Engine Assembly</th>
<th>Propellant: Hydrazine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>67.4</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>0.4</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>0.3</td>
</tr>
</tbody>
</table>
CREW TRANSPORT VEHICLE ASCENT TANK SIZING

- Issue called for separate tanks of storable fuel brought by cargo vehicle
- Reduced overall mass of vehicle, cost of additional launches (+1 per colony)
  - Special thanks to Krista Garrett (Mission Design) and Eric Flores (Propulsion)
- Total Propellant Tank Mass: 1.37 Mg
- NTO mass: 11.433 Mg
- MMH mass: 4.38 Mg
- Total Prop/Tank Mass: 17.2 Mg
- Use Cargo Transport Vehicle
- Using combo of MLI and active thermal protection
BRYAN FOSTER | PROPULSION

SCIENCE SAMPLE RETURN

2/26/2014

- UPDATED ROCKET DATA
- LAUNCH SUPPORT SYSTEM
# Updated Rocket Data

<table>
<thead>
<tr>
<th>Structure Mass (Mg)</th>
<th>Propellant Mass (Mg)</th>
<th>Insulation Mass (Mg)</th>
<th>Navigation Systems Mass (Mg)</th>
<th>Battery Mass (Mg)</th>
<th>Total Launch Mass (Mg)</th>
<th>Total Launch Volume (m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.68</td>
<td>4.47</td>
<td>0.0093</td>
<td>0.0115</td>
<td>0.0800</td>
<td>5.16</td>
<td>16.55</td>
</tr>
</tbody>
</table>

- Designed for multiple sample types (200 kg Rock, 50 kg Regolith)
- Uses the cargo vehicle navigation system

Model Design by Cameron Horton
**Launch Support System**

- Contain and store rockets
- Allows easy access to rockets
- Rocket mass replaced with regolith after launch
- Flame trench under pod deflects exhaust

<table>
<thead>
<tr>
<th>Rocket Mass (Mg)</th>
<th>Launch Tube Mass (Mg)</th>
<th>Launch tube width (m)</th>
<th>Hold Down Posts Mass (Mg)</th>
<th>Hold Down Post Volume (m^3)</th>
<th>Total Vehicle Mass (Rockets + Modifications) (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.64</td>
<td>1.71</td>
<td>1.44</td>
<td>0.0353</td>
<td>0.004</td>
<td>22.915</td>
</tr>
</tbody>
</table>

![Diagram of Launch Support System](Image)
NEW PROPULSION CONFIGURATION

CTV PROPULSION SYSTEM BREAKDOWN
## NEW PROPULSION SYSTEM CONFIGURATION

<table>
<thead>
<tr>
<th>Stage</th>
<th>Final Engine</th>
<th>Isp [Sec]</th>
<th>Propellant</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM Ascent Stage</td>
<td>RD-0242M1</td>
<td>343</td>
<td>MMH/N2O4</td>
</tr>
<tr>
<td>LM Descent Stage</td>
<td>RL10-B2</td>
<td>462</td>
<td>LH2/LOX</td>
</tr>
<tr>
<td>CTV 1&lt;sup&gt;st&lt;/sup&gt; Stage</td>
<td>J-2X</td>
<td>448</td>
<td>LH2-LOX</td>
</tr>
<tr>
<td>CTV 2&lt;sup&gt;nd&lt;/sup&gt; Stage</td>
<td>RD-120</td>
<td>350</td>
<td>RP-1/LOX</td>
</tr>
</tbody>
</table>

2 Stage Configuration

Credit to: Krista Garret
## CTV Prop System Breakdown

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lunar Lander</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ascent Stage</td>
<td>15.82</td>
<td>12.86</td>
<td>4.38</td>
<td>4.98</td>
<td>0.46</td>
<td>11.43</td>
<td>7.89</td>
<td>0.91</td>
</tr>
<tr>
<td>Descent Stage</td>
<td>35.19</td>
<td>98.43</td>
<td>5.12</td>
<td>72.05</td>
<td>0.66</td>
<td>30.08</td>
<td>26.38</td>
<td>0.32</td>
</tr>
<tr>
<td><strong>Crew Transport Vehicle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTV First Stage</td>
<td>86.86</td>
<td>252.69</td>
<td>13.36</td>
<td>188.22</td>
<td>1.71</td>
<td>70.53</td>
<td>64.47</td>
<td>0.79</td>
</tr>
<tr>
<td>CTV Second Stage</td>
<td>4.39</td>
<td>4.29</td>
<td>1.22</td>
<td>1.51</td>
<td>0.018</td>
<td>3.17</td>
<td><strong>2.78</strong></td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>139.29</strong></td>
<td><strong>368.27</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Includes 60 Sec. Hovering Capability: **0.32 Mg**
ANDREW POWIS | POWER/ THERMAL

ROVER POWER SYSTEMS

2/27/2014

- LUNAR RADIATION ENVIRONMENT
- BATTERY SYSTEM UPDATE
- ROVER SPECIFICATIONS
LUNAR RADIATION ENVIRONMENT

Incident Solar Radiation

Solar Insulation

Thermal Insulation + Black Paint

Reflected Solar Radiation & Emitted Infra-Red

Cabin Temperature (K)

Radiation Distribution

Andrew Powis | Power/Thermal
Conservative projections give 5% improvement in Lithium-Ion battery performance per annum. Over an 8 year development time this corresponds to a 51% performance gain.

- Battery pack will be arranged with 40 packs of 90 cells in parallel.
- Output voltage of 312 Volts DC.
- Maximum current of 730 Amps. For level driving ~ 200 Amps.

<table>
<thead>
<tr>
<th>Rover</th>
<th>Heavy (kW)</th>
<th>Light (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power</td>
<td>228.5</td>
<td>151.9</td>
</tr>
<tr>
<td>Total Energy (kWh)</td>
<td>1608</td>
<td>554.9</td>
</tr>
<tr>
<td>Battery Mass (Mg)</td>
<td>7.60</td>
<td>3.23</td>
</tr>
<tr>
<td>Battery Volume (m³)</td>
<td>3.30</td>
<td>1.40</td>
</tr>
<tr>
<td>Number of Battery Cells</td>
<td>4177</td>
<td>1777</td>
</tr>
<tr>
<td>Rover Launch Mass (Mg)</td>
<td>20.85</td>
<td>10.16</td>
</tr>
<tr>
<td>Rover Launch Volume (m³)</td>
<td>32.0</td>
<td>27.0</td>
</tr>
<tr>
<td>Rover Final Mass (Mg)</td>
<td>48.85</td>
<td>10.16</td>
</tr>
<tr>
<td>Rover Final Volume (m³)</td>
<td>32.0</td>
<td>27.0</td>
</tr>
</tbody>
</table>
DIVINAA BURDER | POWER & THERMAL
CTV THERMAL SYSTEMS
2/27/2014

- THERMAL SYSTEM COMPONENTS
Thermal System

Consists of:

- Radiators
- Piping
- Heat Sinks
- Heaters
- Pumps
- Multilayer Insulation (MLI)

Radiators:

- Carbon composite
  - Light, strong, high thermal conductivity
- Panels ~ 0.004 m thick
- Mass: 300 kg
- Vol: 31 m$^3$
- Heat Dissipation: 6.3 kW
- Uses Ethylene Glycol mixture for working fluid

Side view

Top view
COMPONENTS

MLI (Multilayer Insulation)
- Wraps entire crew capsule and transporter
- Maintains heat inside
- Protects from excessive solar heating
- Mass: 285 kg

Pumps (x2)
- Moves radiator fluid
- Power: 18 W
- Vol: 0.3 m$^3$
- Mass: 79 kg
- Second pump is for back-up

Heaters
- Radioisotope heater units (RHU)
- Provides heat to the crew capsule
- Mass: 8 kg
- Vol: 0.4 m$^3$

Flash Evaporators
- Protects sides of capsule (Heat shield protects base)
- Pockets of water heated, expelled as steam from holes at top of capsule
- Mass: 50 kg of water

Heat Sinks
- Dissipates heat generated from avionics equipment
- Mass: 15 kg
- Vol: 0.03 m$^3$
JOSEPH AVELLANO | PT/CARGO
CARGO VEHICLE DESIGN
2/27/2014

- CARGO VEHICLE SYSTEM CONFIGURATION
- THERMAL PROTECTION OF PROPELLANT TANKS
- THERMAL PROTECTION FROM REACTORS
CARGO VEHICLE CONFIGURATION

- 6 RCS Thrusters (Blue)
- 2 Star Trackers (Orange)
- 4 Stilts
- Blast Door
- Ramp
- Solar Panels
- Communication Dish (White)
- Thermal Container (Gold)
THERMAL PROTECTION

• Thermal Insulation
  – Cryogenic Tanks (Argon + LOX)
  – Other Propellant Tanks (RP-1 + MMH)
  – Cargo Vehicle from Reactors
• MLI Required (Surface Area)
  – Cryogenic (30 layers)
    • 79.57 square meters
  – Other systems (15 layers)
    • 158.482 square meters

<table>
<thead>
<tr>
<th>Layers</th>
<th>Mass (kg)</th>
<th>Volume (m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>20.065</td>
<td>.4595</td>
</tr>
<tr>
<td>15</td>
<td>24.132</td>
<td>.47544</td>
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