M.A.S.H.E.R.

Mars Advanced Safe Haven Equipped Rover

Andrew Purpura
Eric Gooden
Joey Friedman
Blake Tromanhauser
Shannon Flanagan
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Project Requirements

• Assume a Martian Ground Base/Fuel Depot already exists
• Terrain
  – Max Slope Ascend/Descend: ± 25°
  – Clearance: 35 cm
  – Obstacle Step: 30 cm
• Safe Haven
  – Support life until rover reaches base
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- **Power/Mobility**
  - Maximum Range: 120 km
  - Nominal Speed: 10 km/hr
  - Maximum Speed: 16 km/hr
  - Enough power for onboard systems
  - Must be able to tow vehicle of equal mass up 25° slope

- **Navigation**
  - Over-the-horizon
  - No external references
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Martian Weather

- Composition of Atmosphere
- 95.3% carbon dioxide
  - Remainder nitrogen, argon, oxygen (.13%)…
- Average Pressure 6 millibars (Earth=1013 millibars)
- Diameter 6779 km (approx. half the diameter of Earth)
- Average Surface Temperature = 218 K (-55°C) with MIN = 140 K (-133°C) and MAX = 300 K (27°C)
- Dust Storms range from a few kilometers in size to global.
- Usually last a few days
Material Selection
Rover’s Structural Design
Suspension

Joseph Friedman
Material Selection

- Titanium Alloy Ti-6Al-4V:
  - Used for:
    - Main rollbar/frame
    - Stairs
    - Suspension
    - Safe-haven assembly
  - Beneficial Properties:
    - Withstand large temperature gradients
    - Low coefficient of thermal expansion ($8.6 \times 10^{-6}$ $\mu$m/m$K$)
    - 3 times strength/weight ratio of Al
    - Will resist damaging effects of Martian environment

- Aluminum floorboard
- High-strength aluminum wire-mesh for 6 tires

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Front View of Vehicle

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Side View of Vehicle
3-D View of Vehicle
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Suspension

• Rocker-Bogie suspension
  – Developed by Jet Propulsion Laboratory mechanical Engineer Don Bickler in 1989
  – No axles or springs; instead it has 6 wheels attached to platform
  – Rockers and bogies attach wheels to platform and to each other

• Adapts to rough terrain

• Even normal force on all 6 tires

• Climbs obstacles 2X wheel diameter

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Rocker Bogie in action

Performing a Turn (33 sec)  Climbing over a rock (44 sec)


http://mars.sgi.com/rovercom/pix.html
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Safe Haven and Seats

Eric Gooden
Safe Haven Requirements

- To sustain life till the rover can return to base or other safe location
- Simple to use, don or deploy in an emergency situation
- Allow continued operation of the rover while safe haven is in use
Descends Tube

Collapsed tube is stored in the ceiling above each seat. When activated, the tube descends and locks into the floor, creating a pressurized enclosure.
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Dimensions

- Retracted height
  - 0.4 m
- Deployed height
  - 2.15 m
- Outer radius
  - 60 cm
- Inner radius
  - 52.5 cm
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Construction

• View Window
  – K-Resin from CPChem: styrene-butadiene copolymer
    • KR03 Sheet
    • KR10 Film

• Main structure
  – ILC Dover Structural Fabric with external reinforcing webbing
  – Multi-layer construction similar to the EMU Pressure Garment

• Locking Ring
  – Aluminum with rubber gasket seal
K-Resin Comparison

• KR03 Sheet
  – Rigid structure
  – No oxygen transmission
  – 90% light transmission
  – 26 MPa Tensile Strength

• KR10 Film
  – Flexible
  – Oxygen transmission of 173 cc*mm/m²*24hr
  – 94% light transmission
  – 26 MPa Tensile Strength
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Calculations

The safe haven will be pressurized with 100% oxygen at 25.51 kPa, the same as the Apollo EMU.

The average atmospheric pressure on Mars is 600 Pa.

---

<table>
<thead>
<tr>
<th>Dimensions of the safe haven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius (m)</td>
</tr>
<tr>
<td>0.5625</td>
</tr>
<tr>
<td>Height (m)</td>
</tr>
<tr>
<td>1.4</td>
</tr>
<tr>
<td>Volume (m³)</td>
</tr>
<tr>
<td>1.39</td>
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</table>

<table>
<thead>
<tr>
<th>Conditions Inside the Safe Haven</th>
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<tbody>
<tr>
<td>Air Pressure (Pa)</td>
</tr>
<tr>
<td>25,510.60</td>
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</table>

<table>
<thead>
<tr>
<th>Conditions Outside the Safe Haven</th>
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</thead>
<tbody>
<tr>
<td>Avg. Atmospheric Pressure (Pa)</td>
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<tr>
<td>600</td>
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</table>

<table>
<thead>
<tr>
<th>Net Force (kN)</th>
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</thead>
<tbody>
<tr>
<td>123.26</td>
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</table>
Life Support Systems

• The safe haven will provide a 100% $O_2$ atmosphere at 25.51 kPa for up to 12 hours.
• Will have an integrated air purification system to supplement the EMU.
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Seats and Control Interface

• Each seat contains all the necessary controls to operate the rover, even while the Safe Haven is deployed.
• Movement controlled by a single control stick, all other functions accessed through a large touch sensitive LCD Screen.
• LCD Screen retracts to below an armrest to allow simple entry and exit from the rover.
• Astronauts secured by a mechanism which locks into the back of their EMU.
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Power System

Blake Tromanhauser
Power System

• How a Fuel Cell works
• Power Needs
• Real system Comparison
• Blake 120
• Masher 15
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Power System - How a Fuel Cell works

http://www.ballard.com/popup_howtech.htm
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Power System – power needs

\[ P_{\text{eff}} = FV \]

\[ F = (F_r + mg \sin \theta + ma) \]

\[ F_r = mCr g \cos \theta \]

\[ P_{\text{eff}} = 102187W \]
Power System – Real System Comparison

- Rated net Power: 85 kW continuous
- Current: 300 Amps
- DC Voltage: 284 Volts
- Weight: 96 kg
- Volume: .075 m$^3$

Mark 902
http://www.ballard.com/tD.asp?pgid=47&dbid=0
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Power System – Real System Comparison

Rated net Power: 1200 W continuous
Current: 46 Amps
DC Voltage: 22 - 40 Volts
Weight: 13 kg
Volume: .046 m³

Nexa™
http://www.ballard.com/tD.asp?pgid=750&dbid=0
Power System – Real System Comparison

\[
\frac{P_{\text{Blake120}}}{P_{\text{Mark902}}} = \frac{120000W}{85000W} = 1.412
\]

\[
I_{\text{Blake120}} = 1.412I_{\text{Mark902}} = 423.6\text{Amps}
\]

\[
V_{\text{Blake120}} = 1.412V_{\text{Mark902}} = 401\text{volts}
\]

\[
W_{\text{Blake120}} = 1.412W_{\text{Mark902}} = 136\text{kg}
\]
# Fuel Cell Specifications

<table>
<thead>
<tr>
<th></th>
<th>Nexa™</th>
<th>Mark 902</th>
<th>Blake 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output (kW)</td>
<td>1.2</td>
<td>85</td>
<td>120</td>
</tr>
<tr>
<td>Current (A)</td>
<td>46</td>
<td>300</td>
<td>423.6</td>
</tr>
<tr>
<td>DC Voltage (volts)</td>
<td>22-50</td>
<td>284</td>
<td>401</td>
</tr>
<tr>
<td>Volume ($m^3$)</td>
<td>4.62x10^{-2}</td>
<td>7.54x10^{-2}</td>
<td>1.12x10^{-1}</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>13</td>
<td>96</td>
<td>136</td>
</tr>
<tr>
<td>Consumption Rate ($\frac{kg}{hr}$)</td>
<td>1.48</td>
<td>Classified</td>
<td>148</td>
</tr>
</tbody>
</table>
# Motor Specifications

<table>
<thead>
<tr>
<th></th>
<th>RE 75</th>
<th>MASHER 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Input ($P_{in}$)</td>
<td>291W</td>
<td>120kW</td>
</tr>
<tr>
<td>Power Output ($P_{out}$)</td>
<td>250W</td>
<td>103kW</td>
</tr>
<tr>
<td>Efficiency (E)</td>
<td>86%</td>
<td>86%</td>
</tr>
</tbody>
</table>
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Navigation System

Andrew Purpura
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Navigation

• Manned
  – Path Tracking by Inertial Measurement Unit (IMU)
  – CPU Interface
  – Operating Conditions
  – Power Requirements
  – Operating Range
  – Maps

• Unmanned
  – Provided for future upgrades

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Inertial Measurement Unit (IMU)

- Northrop Grumman Navigation Systems Division
- LN-200s
- Fiber optic accelerometers and gyro
- Measures change in velocity in X, Y, and Z directions
- Measures change in orientation of X, Y, and Z axes
CPU Interface

- Digital data bus from IMU to CPU
- Data is collected for use in tracking motion of vehicle
- Collects data and computes speed, heading, altitude, fuel consumption, data on operating conditions/failures
- Data displayed via monitor onboard vehicle
- All data sent to base with communications info.
Operating Conditions

- Factors
  - Temperature (Mars min. -133°C, max. 27°C)
  - Pressure
  - Magnetic Field
  - Sand and Dust
- Only heating are needed (supplied by fuel cell)

<table>
<thead>
<tr>
<th>Continuous Operation Temperature</th>
<th>-54°C to +71°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Operating/Storage Temperature</td>
<td>-62°C to +85°C</td>
</tr>
<tr>
<td>Temperature Shock Rate</td>
<td>-54°C to +85°C at 20°C/min</td>
</tr>
<tr>
<td>Sand/Dust</td>
<td>Air tight protection</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
Power Requirements

- Once minimum input current is reached IMU will turn on
- Average power does not exceed 16 Watts

<table>
<thead>
<tr>
<th>Input Voltage [V DC]</th>
<th>Tolerance [%]</th>
<th>Ripple [mV] peak-peak</th>
<th>Load Current [mA]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Start up</td>
</tr>
<tr>
<td>+5</td>
<td>±5</td>
<td>150</td>
<td>2400</td>
</tr>
<tr>
<td>-5</td>
<td>±5</td>
<td>150</td>
<td>700</td>
</tr>
<tr>
<td>+15</td>
<td>±5</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>-15</td>
<td>±5</td>
<td>300</td>
<td>40</td>
</tr>
</tbody>
</table>
Operating Range

- **Gyro**
  - Range of 1432 deg/sec
  - Capable of measuring rates of up to 1000 deg/sec and accelerations of up to 100,000 deg/sec²

- **Accelerometer**
  - Range of 40.8 g
  - 100 μg sensitivity
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Measurement Error

- Measurement recorded is a function depending on:
  - Real measurement
  - Gain
  - Offset
  - Random errors
  - Nonlinear errors
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Maps

- Satellite images
- Landmark Labeled
  - Large rock formations
  - River beds
  - Mountains/craters
Unmanned Vehicles

- M.A.S.H.E.R.’s limited range can be expanded by unmanned vehicles
- Data collected by rover and sent to earth via M.A.S.H.E.R.
- M.A.S.H.E.R. is designed to be ready for such an upgrade
Communications System

Shannon Flanagan
Communications

3 Components

• Rover to Mars Ground Base
• Mars Ground Base to MARSNet
• MARSNet to Deep Space Network
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Critical Frequency and Inclination

\[
f_{crit} = \frac{(9 \times 10^3) \sqrt{N_e}}{\cos \phi} = \frac{(9 \times 10^3) \sqrt{8.1 \times 10^4 (cm^3)}}{\cos(262)} = 2.65 MHz
\]
Combination Monopole/Quadrifilar Helix Antenna

- Quadrifilar Helix receives signal directly
- Monopole utilized in situations of inadequate signal strength, such as might occur in a canyon

http://www.seaveyantenna.com/pdf/about/dipole.pdf
### Rover-Mars Ground Base

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abbreviations</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>f</td>
<td>2.5</td>
<td>MHz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>( \lambda )</td>
<td>120</td>
<td>m</td>
</tr>
<tr>
<td>Inclination</td>
<td>( \varphi )</td>
<td>15.3</td>
<td>Deg</td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>( P_t )</td>
<td>40</td>
<td>W</td>
</tr>
<tr>
<td>Transmitter Gain</td>
<td>( G_t )</td>
<td>5.3</td>
<td>dB</td>
</tr>
<tr>
<td>Receiver Gain</td>
<td>( G_r )</td>
<td>2.15</td>
<td>dB</td>
</tr>
<tr>
<td>Wave Travel Distance</td>
<td>R</td>
<td>2.27x10^5</td>
<td>m</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>B</td>
<td>10000</td>
<td>Hz</td>
</tr>
<tr>
<td>System Noise Temperature</td>
<td>T</td>
<td>250</td>
<td>K</td>
</tr>
<tr>
<td>Incidental Line Loss</td>
<td>( L_i )</td>
<td>0</td>
<td>dB</td>
</tr>
<tr>
<td>Free Space Loss</td>
<td>( L_s )</td>
<td>87</td>
<td>dB</td>
</tr>
<tr>
<td>Signal to Noise Ratio</td>
<td>S/N</td>
<td>91.44</td>
<td>dB</td>
</tr>
</tbody>
</table>
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Mars Network (MarsNet)

• Constellation of microsatellites (Microsat) and Areo-stationary relay satellites (MARSat)
• Similar to high-bandwidth geostationary communications satellites
• M.A.S.H.E.R. will utilize a MARSat
• High-power, high-frequency X-band transceiver and pointable, high-gain, 1.3-m dish antenna
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### Mars Ground Base-Mars Network

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abbreviation</th>
<th>Value</th>
<th>Units</th>
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<tbody>
<tr>
<td>Frequency</td>
<td>f</td>
<td>8400</td>
<td>MHz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>$\lambda$</td>
<td>0.0356</td>
<td>m</td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>$P_t$</td>
<td>100</td>
<td>W</td>
</tr>
<tr>
<td>Transmitter Gain</td>
<td>$G_t$</td>
<td>2.15</td>
<td>dB</td>
</tr>
<tr>
<td>Receiver Gain</td>
<td>$G_r$</td>
<td>35.99</td>
<td>dB</td>
</tr>
<tr>
<td>Distance Between Base and MARSat</td>
<td>R</td>
<td>4x10^7</td>
<td>m</td>
</tr>
<tr>
<td>System Noise Temperature</td>
<td>T</td>
<td>750</td>
<td>K</td>
</tr>
<tr>
<td>Incidental Line Loss</td>
<td>$L_i$</td>
<td>0</td>
<td>dB</td>
</tr>
<tr>
<td>Free Space Loss</td>
<td>$L_s$</td>
<td>202.9</td>
<td>dB</td>
</tr>
<tr>
<td>Signal to Noise Ratio</td>
<td>S/N</td>
<td>25.5</td>
<td>dB</td>
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</tbody>
</table>
Deep Space Network

- Network of antennas that supports interplanetary spacecraft missions
- 3 locations, 120° apart around the world
- Antenna sizes at each location: 34-m HEF, 34-m BWG, 26-m, 70-m
- 34-m HEF antenna chosen for cost and availability

Courtesy of DSN website
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**MarsNet-DSN**

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Value</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>Frequency</td>
<td>f</td>
<td>8400</td>
<td>MHz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>λ</td>
<td>0.0356</td>
<td>M</td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>P_t</td>
<td>40</td>
<td>W</td>
</tr>
<tr>
<td>Transmitter Gain</td>
<td>G_t</td>
<td>35.99</td>
<td>dB</td>
</tr>
<tr>
<td>Receiver Gain</td>
<td>G_r</td>
<td>66.9</td>
<td>dB</td>
</tr>
<tr>
<td>Distance Between MARSat and DSN</td>
<td>R</td>
<td>2.92x10^8</td>
<td>m</td>
</tr>
<tr>
<td>System Noise Temperature</td>
<td>T</td>
<td>250</td>
<td>K</td>
</tr>
<tr>
<td>Incidental Line Loss</td>
<td>L_i</td>
<td>0</td>
<td>dB</td>
</tr>
<tr>
<td>Free Space Loss</td>
<td>L_s</td>
<td>220.3</td>
<td>dB</td>
</tr>
<tr>
<td>Signal to Noise Ratio</td>
<td>S/N</td>
<td>68.7</td>
<td>dB</td>
</tr>
</tbody>
</table>
Public Outreach

• RDR, CDR, FDR presented at Embry Riddle Aeronautical University
• Project was presented at Massachusetts Institute of Technology During Marsweek 2004
• Project will be presented at the 2004 RASC-AL competition
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Questions?