Problem Statement

• Design a System That Can Successfully Excavate Martian Regolith
  – Self-Healing
  – Efficient
  – Low-Cost
Background

• Regolith: Unconsolidated Layers of Soils, Sediments, and Rock Fragments That Overlie Bedrock

• Bulk Excavation Required for In-Situ Resource Utilization (ISRU) Unit Processing
  – Required for Extended Missions
  – Required for Manned Missions
Background (cont.)

- Martian Soil
  - Uncleared, Some Obstacles
  - Hard Crust, Moderate Soil
    - Decreasing Porosity at Increased Depths
  - Dry
  - Slopes < 10 deg
  - Average Density = 1500 g/m$^3$
    - Dry Sand (Earth) = $1.45 \times 10^6$ g/m$^3$
Background (cont.)

- Water
  - Estimated Content at Equator
    Approx. 1%
  - Stable Crust Level
    Concentrations Increase With Latitude

- Rover
  - Technical Requirements
    - Mass/Volume Efficiency
    - Travel Capability
    - All-Season Survival
    - Self-Healing
    - Planetary Protection

- Design Parameters
  - Mobility
  - Navigation and Control
  - Autonomy
  - Environmental Stress
    Resistance/Robustness
Basic Assumptions

• Planetary Protection Requirements Fulfilled With Thermal Vacuum Cycling
  – No Return Mission
  – No Life Support on-Board

• Flight Vehicle Requirements
  – Operational Life of 16 Months
  – Maintain Water Supply Cache of 10 Tons (1016 kg)
Block Diagrams

• Outpost Based Operations
Block Diagrams (cont.)
• Remote Operations - Excavator
Block Diagrams (cont.)

- Remote Operations - Transporter
Vehicle Capability

Agents act autonomously to accomplish objectives.
- Goal-Directed
- Knowledgeable
- Persistent
- Proactive & Reactive

Agents adapt to their environment.
- Dynamic Interaction
- Alternate Methods
- Machine Learning

Note: Agents can be either static or mobile, depending on bandwidth requirements, data vs. program size, communication latency, and network stability.

Agents cooperate to achieve common goals.
- Communication Protocols
- Knowledge-Sharing
- Coordination Strategies
- Negotiation Protocols
Design Descriptions
Outpost Operations

• Arm Method
  – Arm Divided Into Various Segments, Used to Section Land for Excavation

• Bucket and Reel Method
  – Arm With a Winch System and Attached Bucket

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Design Descriptions
Remote Operations

– Once at the Desired Site, the Excavator Breaks Into Two Parts: Excavator and Transporter.

• Remote Excavator - Scraper

• Remote Excavator - Rototiller
## Trade Studies, Evaluations

<table>
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<th>hard ground crossing</th>
<th>obstacles</th>
<th>steering</th>
<th>agility</th>
<th>stability</th>
<th>power</th>
<th>productivity</th>
<th>versatility</th>
<th>complexity</th>
<th>weight/cost</th>
<th>travel speed</th>
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| O comparable | + advantageous | - wheels vs tracks dependent |

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Conclusion

• **Best Solution: Remote Excavator - Rototiller**
  – Maneuverability
    • Obstacle Avoidance
    • Differing Locals
  – Adaptability
    • Self-Healing
    • Environment
  – Productivity
    • Higher Productivity With Fewer Repetitions

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References

- Website:  http://humbabe.arc.nasa.gov/mgcm/faw/liguid.html : Mars climate
- Website:  http://www.marsnews.com : planetology

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