Proposal: Unmanned Ground Vehicle
Alternative Energy and Sensors Research

“Under this research program, the recipient will design, build, and test the performance of a MULE and another smaller UGV that employs alternative forms of energy…”
**MULE Variants Defined by Future Combat Systems and Requirements**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Vehicle Weight (GVW)</td>
<td>5000 lb</td>
</tr>
<tr>
<td>Payload</td>
<td>1926 lb (2400lb goal)</td>
</tr>
<tr>
<td>Transportability (3 units minimum)</td>
<td>USAF C-130 Roll-on/Roll-off Transportable</td>
</tr>
<tr>
<td>Range</td>
<td>62 miles on-road, 31 miles cross-country</td>
</tr>
<tr>
<td>Fuel Sustainment</td>
<td>3 days of high-intensity operation without refueling</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-60 to 140 degrees F</td>
</tr>
<tr>
<td>Power Generation</td>
<td>Must generate exportable power, capable of interfacing with the Land Warrior Battery System</td>
</tr>
<tr>
<td>Wearout</td>
<td>No assemblies/components requiring replacement in less than 9300 miles or 2 years of operation</td>
</tr>
</tbody>
</table>

Proposal:
“The MULE is a ground vehicle weighing up to 1 ton that performs military transportation missions…”

Photo: Lockheed Martin
MULE Variants Defined by Future Combat Systems and Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Surface Speed</td>
<td>32 mph</td>
<td>56 mph</td>
</tr>
<tr>
<td>Complex Terrain Speed</td>
<td>5 mph</td>
<td>13 mph</td>
</tr>
<tr>
<td>Dash Speed</td>
<td>0 to 30mph in less than 12 seconds</td>
<td>--</td>
</tr>
<tr>
<td>Towing Speed</td>
<td>28 mph</td>
<td>--</td>
</tr>
<tr>
<td>Approach/Departure Angle</td>
<td>15 degrees</td>
<td>--</td>
</tr>
<tr>
<td>Grade Climbing</td>
<td>60%</td>
<td>--</td>
</tr>
<tr>
<td>Side Slope Traverse</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Vertical Obstacle (Step Climbing)</td>
<td>20 inches</td>
<td>28 inches</td>
</tr>
<tr>
<td>Gap Crossing</td>
<td>28 inches</td>
<td>40 inches</td>
</tr>
<tr>
<td>Water Fording Depth</td>
<td>30 inches</td>
<td>50 inches</td>
</tr>
<tr>
<td>Turning Radius</td>
<td>16.5 feet (curb-to-curb)</td>
<td>--</td>
</tr>
</tbody>
</table>

Proposal:
“Design a MULE transport that can travel at speeds of approximately 30 to 40 miles per hour on improved roads using a diesel hybrid electric power train and travel at walking speeds of 4 miles per hour for at least twenty minutes with silent propulsion.”

Photo: Lockheed Martin
AFG Assignments: Early Fall 2005

• Begin to think about how constraining requirements affect vehicle design
• Begin to think about how a vehicle is designed
AFG Assignment #1

Use the performance specifications to *bracket* certain vehicle requirements:
Vehicle Weight/Payload Weight; CG Location; Vehicle HP; Drive Mechanism; Ground Clearance; Tractive Coefficient; Vehicle Mass Density; Payload Mass Density

Example: X, Y, Z are driven by gap crossing, payload capacity, stability, visibility, transportability, and existing vehicles
MULE Core Areas: AFG Sub-Teams?

- Chassis and Suspension
- Mission Equipment Package
- Powertrain
- Controls and Communication
- Sensor Suite
AFG Assignment #2

• Categorize pieces of the vehicle into group and subsystem responsibility
• Parallel assignment
  – Investigate advantages & disadvantages of a complete vehicle design vs. purchase and modify existing vehicle
  – Investigate alternative fuel sources to power vehicle
MTU/ARL Kickoff Meeting

MULE Discussions

• ARL would like to keep the primary focus of the MULE program within the Directed Energy Activities (i.e. Alternative Fuels)

• #1 Primary Objective is to build a vehicle that has a dual-mode operation (normal and stealth) and dual power.

• The vehicle platform is of secondary concern to ARL. It must be unmanned, but autonomous navigation is not a priority. They do not have MULE specifications, and are not terribly concerned with vehicle mobility.

• MTU will prepare a short proposal or presentation to give to ARL within one month that defines more specific objectives, budgets, and timelines for this project.

• Thus, MTU still has a blank sheet of paper for this project. AFG will work with KRC to “nail down” the project definition.
We initially considered a divide and conquer approach... but then realized there are too many unanswered questions. This was especially the case after the kickoff meeting at ARL on 09/08/05. Thus, we shifted the focus onto “project definition”
Proposal: Unmanned Ground Vehicle  
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“The recipient will investigate the use of alternative energy systems for meeting the design requirements of these vehicles…”
AFG Assignment #3

• Obtain vehicle parameters for Toyota Prius
• Alternative Energy Study
  – Diesel engine
  – Gasoline engine
  – Stirling engine
  – Zebra battery
  – Ultracapacitor
  – Hydrogen PEM fuel cell
  – Solid Oxide Fuel Cell
  -Nickel Metal Hydride battery
  - Lead acid battery
  - Lithium ion battery
  - Two cycle motor
**PATH FORWARD: MULE**

- Diesel / electric hybrid vehicle
- Off-road mobility and payload capacity for military applications
- Silent Propulsion capabilities with alternative energy sources (Year 2)
- Utilize Control Hardware from UGV

### SOME ALTERNATIVE FUEL OPTIONS

<table>
<thead>
<tr>
<th>Fuel Option</th>
<th>Power Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol Fuel Cell</td>
<td>6.2 w/kg</td>
</tr>
<tr>
<td>SOFC</td>
<td>14.4 w/kg</td>
</tr>
<tr>
<td>Sunpower Sterling Engine</td>
<td>27.2 w/kg</td>
</tr>
<tr>
<td>Ballard Hydrogen Fuel Cell</td>
<td>52.7 w/kg</td>
</tr>
<tr>
<td>Zebra Batteries</td>
<td>150 w/kg</td>
</tr>
</tbody>
</table>

Vehicle Power Density = \(\frac{(\mu + \sin \alpha)}{\text{\% Power Transmission Efficiency}} \times \text{Velocity}\)

@ 4mph, \(\mu + \sin \alpha = 0.3\) the Minimum Power Density = 40 W/kg
AFG Assignment #4

• Scalability study of PEM fuel cell
  – 10 W (mobile phone)
  – 1 kW (backup power)
  – 100 kW (stationary primary power, vehicle?)

• Identification of fuel cell companies
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AFG Assignment #5

- Develop UGV database
  - Pertinent to MULE and UGV projects
  - 120 pg pdf file
  - Currently maintained by Chris Green
Alternative Energy Targets

• Plug and Play
  – Commercially available (or soon to be)
  – Growth path to more power
  – Balance of plant included in package

• Fuel
  – JP-8 preferred
  – Hydrogen is acceptable (assumes JP-8 reformer technology will improve)
Fuel Cell Companies

- United Technologies
- Nuvera
- Anuvu
- Ballard
- Cellex
- Hydrogenics
- Lynntech
- Asia Pacific Fuel Cell Technologies
- Apollo Energy Systems
- Plug Power
- Palcan Fuel Cells
- General Hydrogen
End of Fall 2005

Vehicle Options

• Modify existing hybrid car
• Modify existing tracked vehicle
• Design & build new vehicle
• Modify XRV
• Half Scale RST-V
Fall 2005 / Spring 2006 Transition

• Look at additional concepts
• Down-select criteria
• Preliminary designs
• Decision point?
Spring 2006 AFG Assignments #1-3

- Vehicle requirements
  - Military preparedness criteria
  - Applicability to prototype vehicle
  - Dependent upon mission profile
Spring 2006 AFG Assignment #4

• Vehicle powertrain architecture
  – “The missing link” between requirements and vehicle design stage
  – Reading assignment
Spring 2006 AFG Continued…

• Timeline

• Further vehicle architecture background
  – Challenges of hybrid vehicles
  – “Research integration of these fuel cells with batteries and electric hybrid vehicle architectures”
  – Semester design project: Integration of motor with Ballard Nexa Fuel Cell in JMK laboratory
The Future: Summer / Fall 2006