ENAE 788X Overview and Introduction

• Course Overview
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• Group Design Project
• Overview of Planetary Robot Mobility
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Goals of ENAE 788X

• Learn the underlying fundamentals of mobility in extraterrestrial environments
• Learn the principles of mechanism design relevant to mobility systems
• Understand mobility trade-offs in the context of planetary surface robotics
• Perform an open-ended design task for a planetary surface rover
Web-based Course Content

• Data web site at http://spacecraft.ssl.umd.edu
  - Course information
  - Syllabus
  - Lecture notes
  - Problems and solutions

• Interactive web site at https://elms.umd.edu/
  - Communications for team projects
  - Lecture videos
Syllabus - Rover Hardware

- Terramechanics
- Wheel drive systems
- Wheel design
- Suspension systems
- Motors and gear trains
- Steering systems
- Tracked systems
- Legged locomotion
Syllabus - Rover Software

- Software Engineering
- Spectacular Software Failures
- Robot Control
- Sensors
- Manipulation
- Navigation and Mapping
- Obstacle Detection and Avoidance
Grading Scheme

- 20% homework and labs
- 20% midterm
- 30% team project (team grades)
- 30% final exam
Planetary Surface Simulation Facility
Term Design Project Goals

• Provide opportunity to use principles of class to perform open-ended realistic design
• Reinforce experiences with engineering in teams, making technical presentations
• Address a problem of real interest to NASA
• Provide opportunity for graduate involvement in design competitions (e.g., RASC-AL)
Design Project Statement

• Perform a detailed design of the mobility systems for a small pressurized rover
  - Chassis systems (e.g., wheels, steering, suspension...)
  - Navigation and guidance system (e.g., sensors, algorithms...)
• Design for moon, then assess feasibility of systems for Earth analogue rover
• This is not a hardware project - focus is on detailed design
• Will probably have three competing teams
Level 1 Requirements (Performance)

1. Rover shall have a maximum operating speed of at least 15 km/hour on level, flat terrain
2. Rover shall be designed to accommodate a 0.5 meter obstacle at minimal velocity
3. Rover shall be designed to accommodate a 0.1 m obstacle at a velocity of 7.5 km/hour
4. Rover shall be designed to accommodate a 20° slope in any direction at a speed of at least 5 km/hour with positive static and dynamic margins
Robotic Mobility

- Free Space
- Relative Orbital Motion
- Airless Major Bodies (moons)
- Gaseous Environments (Mars, Venus, Titan)
  - Lighter-than-“air” (balloons, dirigibles)
  - Heavier-than-“air” (aircraft, helicopters)
- Aquatic Environments (Europa)
- Subsurface Access (drills, excavation)
- Surface Mobility (wheels, legs, etc.)
von Karman - Gabrielli Diagram
# Comparison of Basic Characteristics

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Earth</th>
<th>Free Space</th>
<th>Moon</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravitational Acceleration</strong></td>
<td>9.8 m/s² (1 g)</td>
<td>-</td>
<td>1.545 m/s² (.16 g)</td>
<td>3.711 m/s² (.38 g)</td>
</tr>
<tr>
<td><strong>Atmospheric Density</strong></td>
<td>101,350 Pa (14.7 psi)</td>
<td>-</td>
<td>-</td>
<td>560 Pa (.081 psi)</td>
</tr>
<tr>
<td><strong>Atmospheric Constituents</strong></td>
<td>78% N₂ 21% O₂</td>
<td>-</td>
<td>-</td>
<td>95% CO₂ 3% N₂</td>
</tr>
<tr>
<td><strong>Temperature Range</strong></td>
<td>120°F -100°F</td>
<td>150°F -60°F</td>
<td>250°F -250°F</td>
<td>80°F -200°F</td>
</tr>
<tr>
<td><strong>Length of Day</strong></td>
<td>24 hr</td>
<td>90 min - Infinite</td>
<td>28 days</td>
<td>24h 37m 22.6s</td>
</tr>
</tbody>
</table>
Overview of Planetary Surface Systems

- Lunar
- Mars
- Venus
- Minor bodies
- Technologies in development
Surveyor

- Seven mission May 1966 - January 1968 (5 successful)
- Mass about 625 lbs
- Surveyor 6 performed a “hop”
  - November 1967
  - 4 m peak altitude, 2.5 m lateral motion
Lunakhod 1 and 2

- Soviet lunar rovers
  - 2000 lbs
  - 3 month design lifetime
- Lunakhod 1
  - November, 1970
  - 11 km in 11 months
- Lunakhod 2
  - January, 1973
  - 37 km in 2 months
Lunar Roving Vehicle

- Flown on Apollo 15, 16, 17
- Empty weight 460 lbs
- Payload 1080 lbs
- Maximum range 65 km
- Total 1 HP
- Max speed 13 kph
Mars Pathfinder

- Sojourner rover flown as engineering experiment
- 23 lbs, $25M
- Design life 1 week
- Survived for 83 sols (outlived lander vehicle)
- Total traverse ~100 m
Mars Exploration Rovers

• Two rovers landed on Mars in January 2004
• Design lifetime 90 sols, 1 km (total)
• By August, 2008:
  - Spirit 7528 m (4.61 m/sol)
  - Opportunity 11,736 m (7.24 m/sol)
Mars Science Laboratory (and MER)
MSL Mission Overview

Video shown in class
Mars Aircraft

- Deployed during EDL phase
- Glider or powered
ARES Deployment
ARES Half-Scale Dropped from 100Kft

Video shown in class
Mars Balloons

PARACHUTE DECELERATION

BALLOON DEPLOYMENT, FILLING, AND SOLAR HEATING (~8 km)

DROP HEAT SHIELD

BALLOON FILLS AND COASTS DOWN

DAWN WINDS = 10 m/sec

GENTLE, ROLLING IMPACT ANGLE

CONTROLLED DESCENT = 3 m/sec

ROLLING IMPACT

ROCKET UNLOADED FIRST PAYLOAD

BALLOON ASCENDS TO 3 km ALTITUDE FOR SURFACE IMAGING

HOT GAS VENTED

SOFT-LAND SECOND PAYLOAD
Huygens Probe

- Titan entry January 2005
- Descent imaging used to survey surface at different scales
- Wind motion provided horizontal traverse of surface
Field Trials for New Mobility Technologies
Robonaut/Centaur (JSC)
ATHLETE Driving Over Dunes

Video shown in class
ATHLETE Performing Drilling

Video shown in class
Desert RATS 2008 - Moses Lake, WA
Drill Sampling Robot - CMU
K-10 (NASA Ames)
ATHLETE (JPL)
Chariot (NASA JSC)
Chariot with Plow Blade
Chariot in Testing at NASA JSC

Video shown in class
Walking Robots

Photo by Bill Ingalls/NASA
Tetwalker (GSFC)

Video shown in class
Sub (Solid) Surface Access
Future Human Planetary Exploration

- Will involve mobility platforms at multiple levels
  - Small explorers
  - Unpressurized crew-carrying vehicles
  - Pressurized rovers
  - Specialized systems
- Need for robustness and repairability