The Asteroid Environment: Knowns and Unknowns

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Outline

• What is unique about the NEO surface environment?
  – Low \( g \) environment, highly unstable orbital mechanics, extreme environments

• What do we need to carry out exploration operations?
  – Shape, morphology, spin state, gravity field, S/C model

• What close proximity exploration operations are feasible?
  – Orbiting, hovering, slow flybys

• What don’t we know & what should we worry about?
  – Strength of surface, internal stability of rubble pile, dust and small particle environment after surface disturbances
Extreme Morphologies
Extreme Spin States
Extreme Orbital Environment
Extreme Surface Environment

1 KM

View from +X

View from +Y

View from +Z

View from -X

View from -Y

View from -Z

Acceleration Magnitude (mm/s²)
Unknown Small-Scale Environment

Lunar Dust Scatter

Hayabusa Sample Dust Grains

Ponding of Material on Eros (Robinson et al. 2001)

Dynamics of Levitating Dust (Hartzell & Scheeres, 2011)
What do we need to know?
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- Tasks upon arrival include estimation of:
  - Shape model
  - Gravity field
  - Rotation dynamics
  - Density distribution
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• Methods
  – Least-squares filter
    • SRIF batch/Kalman filter
    • Smoother
    • Consider covariance analysis
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- Data acquisition
  - Doppler tracking
  - Optical measurement
  - Lidar (not always necessary)
  - Earth range (marginally important)
What can we do once we get there?

- Research has identified a range of close proximity operations options at small bodies
  - There are viable approaches across all sizes/types/morphologies

- Close proximity operations about asteroids are not analogous to rendezvous and docking in LEO!
  - Physics are significantly different
  - Naive application of LEO CPROX operations and methods will not work

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- Case in point...
Orion-Class S/C Orbiting about a ~20 meter NEO,
Orbit period ~ 24 hours, SRP+gravity+sun perturbations

• Can determine all fundamental mass, spin state, and shape parameters with slow flybys of $V_{\infty} < \sim 10$ cm/s
• Entire missions, including deployment of landers, can be carried out without either entering orbit or hovering
Orbital Dynamics

Example: Range of possible orbits for the Hayabusa S/C about asteroid Itokawa

- Human-rated S/C are heavy enough to orbit almost any NEO
  - Orbits must generally lie in the terminator plane of the body
  - Fundamental limits are due to the size and geometry of the vehicle
- Practically, every NEO has a “range” of semi-major axes within which it can be orbited
Hovering Trajectories

“Inertial” Hovering  
Carried out by Hayabusa as main mission trajectory

Body-Fixed Hovering  
Necessary for descent and landing

Additional research still required to further develop these technologies

D.J. Scheeres, A. Richard Seebass Chair, University of Colorado at Boulder
What don’t we know & what should we worry about?

• The mechanics of the NEO/asteroid surface environment lies in a realm of physics totally foreign to us
  – Surface accelerations range to less than micro-G’s, due combined low gravity and rapid spin rates

• At these extreme environments cohesive van der Waals forces between regolith particles can exceed their weight for regolith grains from millimeter to larger sizes
  – Regolith on asteroids may have similar properties to “bread flour”
Comparison of Weight and Cohesion

Bond Number = Ratio of Cohesion Force with Weight
= 1 for equality
= 10-100 for macroscopic granular effects
> 100 leads to formation of larger-sized aggregates
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~ 1 cm grains

Ambient Gravitational Acceleration (Gs)
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~ 1 cm grains
~ 1 mm grains

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Comparison of Weight and Cohesion

Asteroid Regolith is Analogous to Cohesive Powders on Earth

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~ 1 cm grains
~ 1 mm grains

Table:

<table>
<thead>
<tr>
<th>Ambient Gravitational Acceleration (Gs)</th>
<th>Particle Radius (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eros Range</td>
<td>1e-08 to 1e-06</td>
</tr>
<tr>
<td>Itokawa Range</td>
<td>1e-08 to 1e-05</td>
</tr>
<tr>
<td>1999 KW4 Range</td>
<td>1e-08 to 1e-05</td>
</tr>
</tbody>
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Thursday, February 24, 2011
Rapidly rotating asteroids can be held together by van der Waals cohesion forces between ~ mm -> cm sized grains. Minimum particle size required increases as asteroid radius decreases.

The internal geophysics of cohesive granular piles is relatively unstudied and is a significant factor for surface exploration.
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Conclusions

• The NEO environment is uniquely extreme
  – Low g environment, highly unstable orbital mechanics, extreme environments

• The necessary parameters for close proximity operations bodies can be estimated with existing technology
  – Shape, morphology, spin state, gravity field, S/C model

• For any NEO, there is a viable approach for engagement
  – Orbiting, hovering, slow flybys

• We know virtually nothing about the mechanical properties of asteroids and their small scale morphology
  – Crucial data for the design of exploration missions
  – Unknowns include the surface strength, internal stability, dust and small particle environment after surface disturbances