GRASP: An Asteroid Lander/Rover for Asteroid Surface Gravity Surveying

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Microsats Beyond LEO

- Microsats and nanosats are (finally!) revolutionizing how some types of space missions are carried out
- Their leading benefit: much lower cost, for those missions they suit
- Characterized by “Microspace Approach” to development
- To date, these have been confined to Low Earth Orbit (LEO) missions
- To date, deep-space planetary exploration missions have been very expensive “bigsats” --- too expensive for all but the large space agencies to afford, and even for them not very often
- We believe that there are at least some niche exploration missions that can be done using much-lower-cost, microsat/nanosat-class spacecraft
- GRASP is one such: a highly capable asteroid surface geophysical exploration “microsat”, which would cost far less than traditional planetary exploration missions
• Located near Toronto, Canada
• Core business:
  – Airborne geophysics instrument development and exploration
  – Developing world’s most sensitive airborne gravity gradiometer
• Senior technical staff led development of Canada’s first microsat missions
• Now also developing space geophysics instruments
• Bridging terrestrial and space exploration communities
Space Flight Laboratory, Micro/Nanosatellites

<table>
<thead>
<tr>
<th>Service Area</th>
<th>SFL Capability</th>
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<tbody>
<tr>
<td>Satellite development</td>
<td>18+ years, 22 satellites, 50+ yrs on-orbit heritage</td>
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<tr>
<td>Payload integration</td>
<td>Extensive</td>
</tr>
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<td>Release mechanisms</td>
<td>XPODs, 23 missions</td>
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<tr>
<td>Software (space/ground)</td>
<td>Extensive</td>
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<tr>
<td>Launch arrangements</td>
<td>26 satellites for 10 countries, 12 clusters</td>
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<tr>
<td>Commissioning</td>
<td>At both SFL MCC and client locations</td>
</tr>
<tr>
<td>Operations Handover</td>
<td>Delivery after commissioning</td>
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<tr>
<td>Operations</td>
<td>At both SFL MCC and remote stations</td>
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<tr>
<td>Ground stations / Mission Control Centers</td>
<td>Worldwide, installation and access</td>
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- Professional staff, professional missions.
- High-end quality, low-end cost.
- Highly capable yet compact missions.
- High performance smaller satellites.
- Built for customers around the world.
- Canada’s premier microspace organization.
Asteroid Interiors

?
Ways of Investigating Interiors

Few sensing methods (short of drilling etc.!) penetrate:

- Magnetometry
- Radar sounders (and related electromagnetic methods)
- Seismometry
- Gravity measurement
Nothing stops gravity...

- But...it’s terribly weak!
- Spacecraft radio tracking works poorly for small asteroids
- Altimetry has to calibrate out other forces, e.g. light pressure
- Gravity gradiometry, someday...
- Gravimetry is promising
Enabling Technology: VEGA Instrument (Vector Gravimeter/Accelerometer)

- Developed by Gedex
  - Innovative (patented) design
  - Spun off from airborne gravity gradiometer system technology
- Measures absolute (gravity + acceleration) vector
  - Vector: All 3 components measured
  - Absolute: No bias or gain-factor drift
- Operating Principle
  - 2 gimbal-mounted accelerometers
  - Make measurements in several orientations
  - Process to eliminate time-varying bias and scale factor variations
- Accuracy
  - Relative accuracy: long-term accuracy of differences in measurements at stations with similar gravity magnitudes
  - On Earth (measured): close to 1 milliGal (1 microG)
  - Error model predicts accuracy improvement as local gravity decreases
  - On a small asteroid: with a local gravity magnitude of 1-100 microG, relative accuracy 1-10 nanoG predicted
  - Equivalent to the short-term accuracy of the best terrestrial exploration gravimeters
“Weighing” An Asteroid Using VEGA

- **Relevant to ESA’s Asteroid Impact Mission (AIM)**
- Mothership arrives at asteroid.
- Mothership imagery for asteroid size, shape, spin rate and direction, tumbling state.
- Lander carrying VEGA is released, makes its way to some point on the surface.
- Make gravimetric measurement.
- Mothership imagery to locate that station in asteroid-fixed reference frame.
- In post-processing, compensate out centrifugal component of measurement (plus components due to asteroid wobble, if significant).
- Fit compensated measurement to asteroid shape model to estimate average density.
"Weighing" a Boulder on an Asteroid

Boulder to be weighed

(Asteroid surface)

(Bulk asteroid gravity vector)

(Boulder gravity vector)

(Net local gravity vector)

Vector Gravimeter

Deflection of the vertical

- Relevant to NASA’s ARRM mission
- Make measurements at multiple stations
- Compare to give deflection of the vertical
- Requires a lander capable of roving about the asteroid’s surface in a controlled manner

[Hirata & Ishiguro, 2011]
Global Gravimetry Survey

- Assuming a roving lander is used to carry VEGA instrument...
- For a small asteroid, survey at stations over the entire body
- *Use the resulting measurements to estimate a whole-body internal density distribution*
  - Using geophysical potential fields inversion techniques
- With enough measurement stations, can produce much higher-resolution gravity model than from orbit

[Saito et al., 2006]
GRASP
“GRavimetric Asteroid Surface Probe”

GRASP Ground Control Centre

Mothership
MS OBC

IOBC
S-Band Tx/Rx

GRASP-Mothership Interface
Deployer
Imagers
Oscillator

Ground Station

Communications
S-Band Tx/Rx

Structure
Fender Deployment
Panel Deployment

Solar Cells
Batteries
Power Board

Power

Propulsion
Reaction Wheels
Rate Sensors

VEGA
VEGA Heaters

Primary Payload
VOBC (OBC C)

Secondary Payloads
Imagers
LED’s
Magnetometer

ADCC (OBC B)

Thermal
Heaters

HRC (OBC A)
GRASP vis-à-vis LEO Micro/Nanosats

- **Similarities with existing LEO micro/nanosat missions:**
  - Being developed by an experienced micro/nanosat development team
  - Using well-proven “Microspace Approach” to achieve low cost
  - Uses much of the same equipment as SFL micro/nanosat missions

- **Mission differences which drive design differences:**
  - Needs to operate both free-floating “in orbit”, but also needs to get to the surface of an asteroid, and operate there, and move about on the asteroid
  - Distance from Sun varies between 0.8 and 2.0 AU, so heat input and available solar power varies by a lot, making thermal and power subsystem designs challenging
  - Heat from asteroid surface impacts GRASP temperature, and that can vary over a wide range, making thermal design yet more challenging
  - Communications: this at least is easier, only need to communicate to the Mothership, out to 50-100 km
GRASP Mission Objectives

• **Mission Capabilities**
  – Assistance to mothership’s mission
  – Global gravimetric surveying on small asteroids
  – Science, resource prospecting
  – Test surface mobility techniques

• **Specific Near-Term Missions**
  – *NASA’s Asteroid Redirect Robotic Mission*
    • Determine masses of candidate boulder targets
    • Accurately enough to meet ARRM mission needs
    • To within 10% (TBC)
  – *ESA’s Asteroid Impact Mission*
    • Determine the mass of Didymos-B (“Didymoon”)
    • Accurately enough to meet AIM mission needs
    • To within 10% (TBC)
Design Objectives/Constraints

• **Able to carry out useful asteroid surface gravimetry missions**
  – Enables exploitation of VEGA instrument’s unique capabilities
  – Position GRASP as an attractive Canadian contribution to other space agencies’ asteroid missions

• **Use Microspace approach**
  – Seek smallest useful asteroid lander/rover mission and system
  – “Deep space microsat”
  – Use microsat/nanosat engineering and management know-how to minimize costs
  – Make GRASP missions affordable by Canada’s space program

• **Learn lessons from other small-body missions**
  – Hayabusa’s MINERVA deployment issue
  – Rosetta’s Philae landing issue
GRASP Configurations

Stowed: 12U

Deployed (zoomed-in)
Some GRASP Components

- Star Tracker (x1)
- Deployable Solar Panels (x14)
- S-Band Patch Antennas (x4)
- LEDs (x6)
- Sun Sensor (x6)
- Thruster Units (x2) (5 Nozzles Each)
- Deployable Fenders & Feet (x6)
- Radiators (x2)
- Lidar (x1)
- Imagers (x26)
Orientations on Asteroid Surface

- Bounce to a landing, like Philae on Comet 67P
- End up in one of these orientations – can survive in any of them!
- Propulsively “hop, pirouette and land” for desired orientation (1A)
- Routine mobility by propulsion – independent of surface properties!
- Mobility experiments: move by tumbling between these orientations
GRASP: Surveying boulders

Typical $\Delta V = 5 \text{ cm/s}$

$\theta = 45^\circ$

0.5 m

2 m
GRASP: Global Survey Roving

Typical $\Delta V = 60$ cm/s

5 m

25 m

100 m
ARRM

- Asteroid Redirect Robotic Mission, December 2022 launch, NASA
- Rendezvous with an Itokawa-sized asteroid, using low-thrust propulsion
- Descend to surface, pick up a boulder
- Manoeuvre near asteroid for months
- Then return boulder to high Lunar orbit
- Possible VEGA roles:
  - On ARRM spacecraft:
    - **VEGA as an inertial navigation sensor**
  - On a hitch-hiker payload:
    - **Canada provide GRASP lander/rover dropped by ARRM onto asteroid surface**
    - Measure mass of target boulders before selection and pick-up
    - Rove around asteroid, with ARM acting as comms relay to Earth, conducting a global gravimetry survey
AIM

- Asteroid Impact Mission, October 2020 launch, ESA
- Rendezvous component of joint ESA/NASA AIDA (Asteroid Impact Deflection Assessment) mission
- AIM currently funded by ESA for 18-month Phase A/B1 study, ending mid-2016
- Plans to request go-ahead under GSTP
- Already planning carry one large asteroid lander (MASCOT-2 from DLR), and two 3U cubesat launchers

- Possible VEGA role:
  - Canada contribute a GRASP lander/rover: measure Didymos-B mass accurately, carry out extensive surface gravity survey, observe impact from surface
VEGA and GRASP

• Concept looks sound
• Details being filled in
• Suitable carriers exist
• Most technology is on hand or well along in development
• Practical affordable Canadian asteroid mission
Questions?
Backup Slides...
E.g., Anomalous Gravity Signal at Surface of Didymos-B [nG]

E.g., from a large (15% of total Didymos-B volume) medium-density anomaly just below the surface

Density anomaly, radius = depth to centre = 40 m, \( \Delta \rho = 1,000 \text{ kg/m}^3 \), \( m=2.7 \times 10^8 \text{ kg} \)

VEGA accuracy: 1-10 [ng]

Didymos-B, \( r=75 \text{ m} \),
Average \( \rho = 1,700 \text{ kg/m}^3 \), \( m=3 \times 10^9 \text{ kg} \), \( f_g = 3635 \text{ ng} \), assumed spherical

Gravity signature of the anomaly at the surface versus longitude

Nominal Didymos-B Surface Gravity
Surface Gravity Including Anomaly
Multiple Solar Arrays

- Ensure no “death modes”
- Enough PV area to survive 12-hour nights at 2 AU from the Sun
GRASP Operations Concept

• A: Nominal Deployment
  – Carrier S/C hovers ~ 50 m above asteroid
  – GRASP deployed at ~ 2 cm/s

• B: Missed Deployment
  – E.g., Hayabusa’s MINERVA
  – Deployed in a direction that misses asteroid

• C: Recovery Mode
  – Determine position and velocity with respect to Carrier S/C and asteroid
  – Using cameras on GRASP and Carrier, and radio tracking from GRASP to Carrier
  – Propulsively change trajectory to land on the asteroid