Laboratory-Based Satellite Impact Experiments for Better Characterization of the Orbital Debris Populations

J.-C. Liou, PhD
NASA Orbital Debris Program Office
Outline

• DebriSat Project Motivations and Team
• Design and Fabrication of DebrisLV and DebriSat
• Hypervelocity Impact Tests at AF/AEDC
• Post-Impact Activities
• Forward Plan
Motivations (1/3)

• Collision fragments are expected to dominate the future orbital debris (OD) environment in low Earth orbit (LEO)
  – The accidental collision between Iridium 33 and Cosmos 2251 in 2009 generated 2000+ trackable fragments and tens of thousands of small untrackable-yet-potentially-damaging/lethal debris (as small as 1 mm)
  – Collisions involving intact objects are expected to occur every 5 to 9 years

• A high fidelity breakup model capable of describing the outcome of satellite collisions is needed for
  – Good Space Situational Awareness (SSA) and OD environment definition
  – Reliable short- and long-term impact risk and survivability assessments for critical U.S. space assets

• Laboratory-based satellite impact tests are necessary to fully characterize breakup fragments
  – Fragment size, mass, area-to-mass ratio, shape, composition, optical/radar properties, etc.
Motivations (2/3)

- The need for laboratory-based impact tests was recognized by DoD and NASA decades ago

- A key laboratory-based test, SOCIT*, supporting the development of the DoD and NASA satellite breakup models was conducted by DNA at AEDC in 1992
  - Target satellite: A U.S. Navy Transit navigation satellite
    - Dimensions and mass: 46 cm (dia) × 30 cm (ht), 34.5 kg
    - No Multi-layer Insulation (MLI), no solar panel
    - Was built in the early 1960's
  - Projectile: 4.7 cm Al sphere @ 6.1 km/s
  - Breakup models based on SOCIT have supported many applications and matched on-orbit events reasonably well over the years

*SOCIT: Satellite Orbital debris Characterization Impact Test
Motivations (3/3)

- As new materials and construction techniques are developed for modern satellites, there is a need for new laboratory-based tests to acquire data to improve the existing DoD and NASA breakup models.

A/M Comparison (fragments between 10 and 20 cm)

A/M Distribution of Iridium 33 Fragments

Iridium 33 (560 kg)

NASA model predictions are noticeably different from fragments generated by modern satellites, such as FY-1C (left) and Iridium (right).
DebriSat Project Goals

• Design and fabricate a 60-cm/56-kg satellite ("DebriSat"), including MLI and solar panels, to be representative of modern payloads in LEO

• Carry out a hypervelocity impact test with sufficient kinetic energy to completely breakup DebriSat

• Collect and characterize the physical properties of fragments down to ~2 mm in size

• Analyze the data to improve the existing DoD and NASA satellite breakup models

• Benefits of improved satellite breakup models
  – Better Space Situational Awareness (SSA) and OD environment definition
  – More reliable short- and long-term impact risk and survivability assessments for critical U.S. space assets
The DebriSat Team

- **NASA Orbital Debris Program Office (ODPO)**

- **AF Space and Missile Systems Center (SMC)**
  - Co-sponsor, technical oversight: D. Davis, T. Huynh, J. Guenther, *et al.*

- **The Aerospace Corporation**
  - Design of DebriSat, design/fabrication of DebrisLV, data collection, data analyses, DoD model improvements: M. Sorge, C. Griffice, P. Sheaffer, *et al.*

- **University of Florida (UF)**
  - Design/fabrication of DebriSat, data collection, fragment processing and characterization: N. Fitz-Coy and the student team

- **AF Arnold Engineering Development Complex (AEDC)**
DebriSat versus SOCIT/Transit

- DebriSat has a modern design and is 63% more massive than Transit
- DebriSat is covered with MLI and equipped with solar panels

<table>
<thead>
<tr>
<th></th>
<th>SOCIT/Transit</th>
<th>DebriSat</th>
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<tbody>
<tr>
<td><strong>Target body dimensions</strong></td>
<td>46 cm (dia) × 30 cm (ht)</td>
<td>60 cm (dia) × 50 cm (ht)</td>
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<tr>
<td><strong>Target mass</strong></td>
<td>34.5 kg</td>
<td>56 kg</td>
</tr>
<tr>
<td><strong>MLI and solar panel</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Projectile material</strong></td>
<td>Al sphere</td>
<td>Hollow Al cylinder</td>
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<tr>
<td><strong>Projectile dimension/mass</strong></td>
<td>4.7 cm diameter, 150 g</td>
<td>8.6 cm × 9 cm, 570 g</td>
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<td><strong>Impact speed</strong></td>
<td>6.1 km/sec</td>
<td>6.8 km/sec</td>
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<tr>
<td><strong>Impact Energy to Target Mass ratio (EMR)</strong></td>
<td>78 J/g (2.7 MJ total)</td>
<td>235 J/g (13.2 MJ total)</td>
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DebriSat Design (1/3)

- DebriSat is intended to be representative of modern LEO satellites
  - A survey of recent LEO payloads was conducted
  - 50 satellites were selected for detailed analysis
  - Common subsystems, materials, mass fractions, structure, and construction methods were identified
  - Sub-system mass fraction analysis performed by Aerospace CDC group using ~150 satellites
  - Major design decisions were reviewed and approved by Aerospace subject matter experts from different disciplines

![Sensor Usage by Payload Mass Category](chart.png)
DebriSat includes 7 major subsystems

- Attitude determination and control system (ADCS), command and data handling (C&DH), electrical power system (EPS), payload, propulsion, telemetry tracking and command (TT&C), and thermal management
- Each subsystem contains standard components, such as star trackers, reaction wheels, flight computer, data recorder, thrusters, antennas, avionics boxes, heat pipes, cables, harnesses, etc.
- To reduce cost, most components are emulated based on existing design of flight hardware and fabricated with the same materials
DebriSat Design (3/3)

- Multi-Layer Insulation
- Sun Sensor
- Optical Imager
- Spectrometer
- S-band Antenna
- X-band Antenna
- UHF/VHF Antenna
- Divert Thruster
- Deployable Solar Panels
- 90 cm
- 50 cm
- 30 cm
- Composite Body Panels
Hypervelocity Impact Tests at AEDC

- Range-G operates the largest two-stage light gas gun in the U.S.
- Standard diagnostic instruments include X-rays, high-speed Phantom cameras, and lasers
  - With additional IR cameras, piezoelectric sensors, and witness plates
- Low-density polyurethane foam panels are installed inside target chamber to “soft catch” fragments

Color-coded soft-catch low density foam panels
Projectile Design

- To maximize the projectile mass at the 7 km/sec impact speed without a sabot, a special projectile was designed featuring a hollow aluminum cylinder embedded in a nylon cap
  - The nylon cap served as a bore rider for the aluminum cylinder to prevent hydrogen leakage and also to protect the barrel
Pre-test Shot DebrisLV Design

• To further increase the benefits of the project, Aerospace built a target resembling a launch vehicle upper stage ("DebrisLV") for the pre-test shot
  – DebrisLV: 17.1 kg, body dimensions ~ 88 cm (length) × 35 cm (diameter)

• Pre-test shot was successfully conducted on 1 April 2014
  – Projectile impacted DebrisLV at 6.9 km/sec and completed fragmented DebrisLV
DebrisLV Impact Sequences

598 g projectile @ 6.9 km/sec
Target Chamber Before and After Impact

DebrisLV before impact  DebrisLV after impact
DebriSat Impact Sequences

- DebriSat shot was successfully conducted on 15 April 2014
  - Projectile impacted DebriSat at 6.8 km/sec and completely fragmented the target

570 g projectile @ 6.8 km/sec
DebriSat Impact Video

DebriSat
Laboratory-Based
Hypervelocity Impact Test
Post-Impact Fragment Collection

- After each impact, all intact foam panels, broken foam pieces, loose fragments, and dust were carefully collected, documented, and stored
  - 41 pallets of $\sim 2 \text{ m} \times 2 \text{ m} \times 2 \text{ m}$ boxes were packed
  - Estimated $\geq 2 \text{ mm}$ DebriSat fragments are on the order of 85,000
Current Activities and Forward Plan (1/2)

- Process foam panels, collect/document/store loose fragments
- Conduct x-ray scanning of foam panels/pieces to identify locations of $\geq 2$ mm fragments
- Extract $\geq 2$ mm fragments from foam panels/pieces
- Measure fragments individually
  - Dimensions, mass, shape, density, composition, photos

UF X-ray facility

X-ray image projected on panel to identify fragments

Sorting small loose fragments
Current Activities and Forward Plan (2/2)

- Obtain 3D scan data for large fragments
  - Estimate cross-sectional area, area-to-mass ratio, and bulk density
- Conduct laboratory radar, photometric, and spectral measurements for selected fragments
  - Support improvements to the NASA radar RCS-to-size estimation model
  - Establish a database for the development of an optical magnitude-to-size estimation model
  - Characterize space environment effects on the optical and spectral properties of impact fragments

Sample fragments and data from a 2008 cubesat impact test.
Questions?