Design of a Representative Low Earth Orbit Satellite to Improve Existing Debris Models

S. Clark, A. Dietrich, M. Werremeyer, N. Fitz-Coy
Department of Mechanical and Aerospace Engineering
University of Florida, Gainesville, FL 32611

J.-C. Liou
NASA Orbital Debris Program Office, NASA/JSC
Houston TX 77058

This paper summarizes the process and methodologies used in the design of a small-satellite, DebriSat, that represents materials and construction methods used in modern day Low Earth Orbit (LEO) satellites. This satellite will be used in a future hypervelocity impact test with the overall purpose to investigate the physical characteristics of modern LEO satellites after an on-orbit collision. The major ground-based satellite impact experiment used by DoD and NASA in their development of satellite breakup models was conducted in 1992. The target used for that experiment was a Navy Transit satellite (~40 cm, 35 kg) fabricated in the 1960’s. Modern satellites are very different in materials and construction techniques from a satellite built 40 years ago. Therefore, there is a need to conduct a similar experiment using a modern target satellite to improve the fidelity of the satellite breakup models.

The design of DebriSat will focus on designing and building a “next-generation” satellite to more accurately portray modern satellites. The design of DebriSat included a comprehensive study of historical LEO satellite designs and missions within the past 15 years for satellites ranging from 10 kg to 5000 kg. This study identified modern trends in hardware, material, and construction practices utilized in recent LEO missions, and helped direct the design of DebriSat. This paper discusses the processes and procedures utilized in developing DebriSat.
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M. Werremeyer¹, S. Clark², N. Fitz-Coy², J.-C. Liou²
¹University of Florida, ²NASA Orbital Debris Program Office

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Motivations (1/3)

• Collision fragments are expected to dominate the future orbital debris environment (i.e., the Kessler Syndrome)

• A higher fidelity breakup model to describe the outcome of satellite collisions is needed for
  – Good orbital debris environment definition
  – Reliable short- and long-term impact risk assessments (from debris as small as 1 mm) for critical space assets

• Laboratory-based satellite impact tests are necessary to characterize fragments smaller than 10 cm
  – Size, mass, area-to-mass ratio, shape, composition, optical/radar properties, etc.
Motivations (2/3)

- A key laboratory-based test, SOCIT*, supporting the development of the DoD and NASA satellite breakup models was conducted 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)
    - Was built in the early 1960’s
    - Was selected because of its availability
  - Projectile: 4.7 cm diameter Al sphere
  - Impact speed: 6 km/sec
  - Post-test analysis
    - Only ~10% of the fragments were measured (4761 in total)
      - Many were sieved and bagged together (up to 260 per group) to estimate the average properties of the groups
    - The results were scaled up by a factor of 10 to represent the distribution of the entire fragment set

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

- As new materials and new construction techniques are developed for modern satellites, there is a need to conduct additional laboratory-based tests and use the data to further enhance the breakup models.

NASA model predictions match well with fragments generated from an “old” satellite (left), but are significantly different from fragments of a more modern satellite (right).
DebriSat vs. SOCIT

- The planned impact test on a representative modern LEO satellite is a collaboration among academia, DoD, and NASA

<table>
<thead>
<tr>
<th></th>
<th>SOCIT</th>
<th>DebriSat</th>
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</thead>
<tbody>
<tr>
<td><strong>Target dimensions</strong></td>
<td>46 cm (dia) × 30 cm (ht)</td>
<td>50 cm × 50 cm × 50 cm</td>
</tr>
<tr>
<td><strong>Target mass</strong></td>
<td>34.5 kg</td>
<td>50 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>Al sphere</td>
</tr>
<tr>
<td><strong>Projectile dimension/mass</strong></td>
<td>4.7 cm diameter, 150 g</td>
<td>5 cm diameter, 176 g</td>
</tr>
<tr>
<td><strong>Impact speed</strong></td>
<td>6.075 km/sec</td>
<td>7 km/sec</td>
</tr>
<tr>
<td><strong>Impact Energy to Target Mass ratio (EMR)</strong></td>
<td>78 J/g</td>
<td>86 J/g</td>
</tr>
</tbody>
</table>
National Aeronautics and Space Administration
Space Systems Group
DebriSat Design (2/3)

• Match historical mass fractions for subsystems. Component emulation utilized for some subsystems.
  – **Electrical Power System** (Li-ion batteries, shielded battery and avionics boxes, CIC solar panels)
  – **Command and Data Handling** (shielded electronics boxes)
  – **Telemetry Tracking and Command** (2 UHF/VHF whip antenna, X-band horn antenna, S-band helical antenna, shielded electronics box)
  – **Attitude Determination and Control System** (4 reactions wheels, 3 magnetorquers, sun sensors, 2 star trackers, 3-axis magnetometer, IMU)
  – **Propulsion** (Composite overwrapped pressure vessel (COPV), 6 thrusters, stainless steel piping, shielded electronics unit)
  – **Structure** (aluminum hexagonal top and bottom panels, carbon fiber with aluminum honeycomb core side panels, aluminum struts and ribs)
DebriSat Design (3/3)

Component Identification

1 - Flight Computer
2 - Data Recorder
3 - Reaction Wheel 1
4 - X-Band Conical Feed Horn Antenna
5 - Optical Imager
6 - Reaction Wheel 2
7 - Power Conditioning and Distribution
8 - Spectrometer 1
9 - Thermal Reservoir
10 - Omni-Directional Antenna 1
11 - Propulsion System
12 - Li-ion battery box 1
13 - Telemetry Avionics Box
14 - Spectrometer 2
15 - Li-ion Battery Box 2
16 - Star Tracker 1
17 - Sun Sensor (4)
18 - Li-ion Battery Box 3
19 - Payload Support Module
20 - Magnetometer
21 - ADCS Command Unit
22 - S-Band Helical Antenna
23 - Omni-Direction Antenna 2
24 - Star Tracker 2
Emulated Components

- Emulated to reduce cost
- Based on existing designs
  - Surrey and Sinclair
  - Input from subject-matter experts
- Emulated components:
  - Propulsion system
  - Payload: near-infrared spectrometer, imager
  - ADCS: reaction wheels, star trackers, magnetorquers, 3-axis magnetometer
  - Avionics: boxes, cables, etc.
  - C&DH
  - TT&C: x-band and s-band antennas
  - Thermal management
  - Battery cases
Attitude Determination and Control

- **Attitude Determination**
  - 2 star trackers
  - 4 sun sensors
  - 3-axis magnetometer
  - Inertial measurement unit

- **Attitude Control**
  - 4 reaction wheels
  - 3 magnetorquers

- **Single ADCS avionics box**
Propulsion System

- Composite overwrapped pressure vessel (COPV)
- Emulated resistojet thrusters
- Solenoids and thermally shielded cables
- Shielded electronics box
- Welded SS316L plumbing
- Stainless steel fittings
- Tank mounting:
  - Bonded metal ring
  - Mounting bracket
  - Axial struts
- Mounted in center of DebriSat
**Electrical Power System**

- **Solar Panels**
  - Body-mounted panels
  - Coverglass-interconnect-cells (CIC)
  - Cells bonded to M55J face sheets (side panels)
  - 327 UTJ CIC cells total
    - EDUs from Spectrolab

- **Batteries**
  - 3 Li-ion battery cases
  - 10 batteries per case

- **Power conditioning and distribution module**
  - BCR for each battery case
  - Power conditioning PCB
  - Power distribution PCB

- **D-sub connectors with shielded cables**
Telemetry, Tracking, and Command

- **Emulated S-band helical antenna**
  - Based on Surrey S-band design
- **Emulated X-band antenna**
  - Based on Surrey X-band design
- **VHF/UHF omni-directional antenna**
  - COTS DigiKey antenna
- **Emulated TT&C avionics boxes**
  - Shielded aluminum boxes
  - COTS signal switch and divider
  - Emulated RF circuitry
  - Communication and control PCBs
Command and Data Handling

- **Emulated Flight computer and data recorder**
  - COTS motherboards
  - Shielded aluminum boxes
  - D-sub connectors and shielded cables
  - Mounted to side panels near heat pipes to remove heat

Emulated flight computer

Emulated data recorder
Structure

- **Hexagonal prism**
- **Aluminum hexagonal panels**
- **Webbed design**
  - Reduced massed
  - Increased rigidity
- **Composite side panels and ribs**
  - M55J carbon fiber face sheets
  - Aluminum honeycomb cores
- **Aluminum longerons**
Thermal Management

- Emulated based on capillary pump loop (CPL) designs
- Two independent loops
- Stainless steel plumbing
- Side panels have internal plumbing
- Zenith hexagonal panel as radiator
- Kapton heaters on avionics boxes/thermal shielded cables
- Multi-layer insulation
  - External faces in areas without solar cells
  - Not on radiator
  - Wrapped on some internal components
Payload

- **Emulated spectrometers (Qty. 2)**
  - Structural housing and shielding
  - Optical bench
    - M55J face sheets
    - Aluminum honeycomb core
  - Fold and bend mirrors
  - Thor Labs optical lenses
  - Charge-coupled device (CCD) camera

- **Emulated optical imager**
  - Cassegrain reflector telescope
  - 3-arm mechanical lens brace
  - Aluminum sunshade
  - Shielded avionics module at CCD end

- **Payload support module**
  - Separate shielded avionics box
Status of DebriSat

- Project kickoff – Sep 2011
- Final design
  - LEO study completed
  - Detailed design submitted to JSC – July 2012
- Fabrication of the target satellite – Sep 2013*
  - DebriSat will be subjected to rigorous testing with the exception of functional avionics testing
- Conduct hypervelocity impact test at the AF’s Arnold Engineering and Development Center – Jan-Feb 2014*
- Complete post-test fragment measurements – Dec 2014*
- Process/analyze data for model improvements – 2015*

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• Andrew Tretten, spacecraft attitude determination and control
• Jeff Cha, spacecraft thermal control

Donations:
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• Micro Aerospace Solutions, inertial measurement unit