

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

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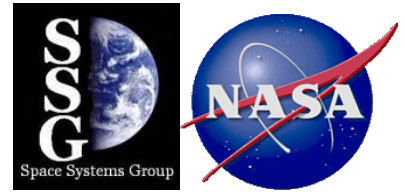
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This paper summarizes the process and methodologies used in the design of a small-satellite, DebrisSat, that represents materials and construction methods used in modern day Low Earth Orbit (LEO) satellites. This satellite will be used in a future 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 DebrisSat will focus on designing and building a "next-generation" satellite to more accurately portray modern satellites. The design of DebrisSat 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 DebrisSat. This paper discusses the processes and procedures utilized in developing DebrisSat.



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

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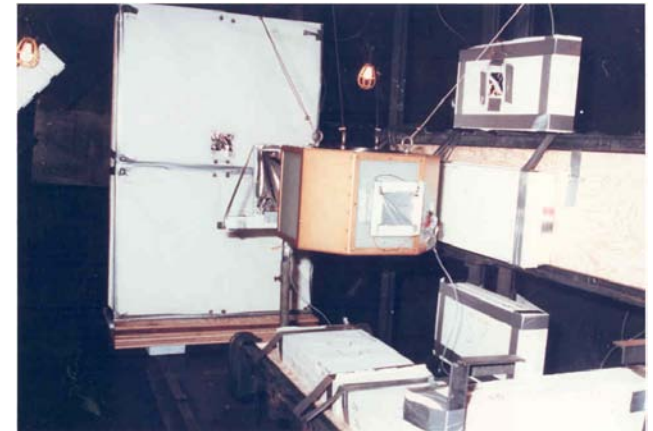


## Motivations (1/3)

- **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)

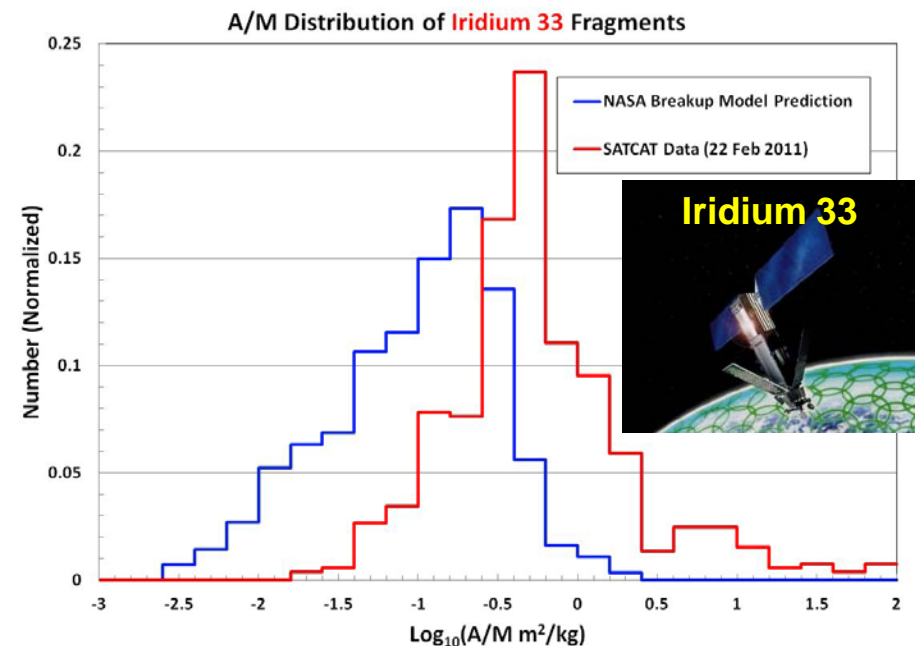
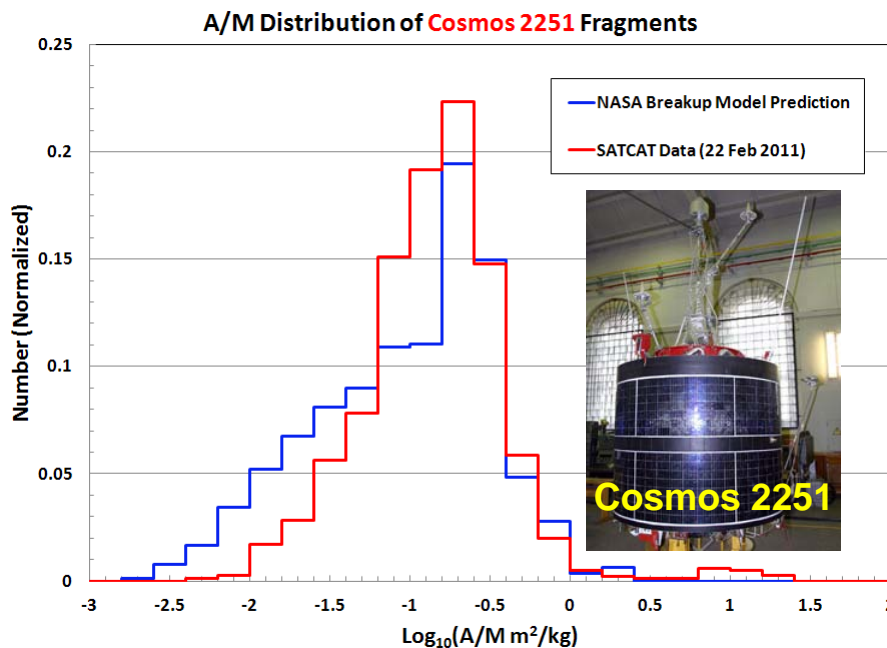
- **A key laboratory-based test, SOCIT\*, supporting the development of the DoD and NASA satellite breakup models was conducted in 1992**
  - Target satellite: A U.S. Navy Transit Navigation satellite
    - Dimensions and mass: 46 cm (dia) × 30 cm (ht), 34.5 kg
    - **No Multi-layer Insulation (MLI)**
    - 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).

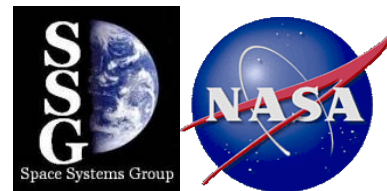


# DebriSat vs. SOCIT

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

	SOCIT	DebriSat
<b>Target dimensions</b>	46 cm (dia) × 30 cm (ht)	50 cm × 50 cm × 50 cm
<b>Target mass</b>	34.5 kg	50 kg
<b>MLI and solar panel</b>	No	Yes
<b>Projectile material</b>	Al sphere	Al sphere
<b>Projectile dimension/mass</b>	4.7 cm diameter, 150 g	5 cm diameter, 176 g
<b>Impact speed</b>	6.075 km/sec	7 km/sec
<b>Impact Energy to Target Mass ratio (EMR)</b>	78 J/g	86 J/g

National Aeronautics and Space Administration  
Space Systems Group



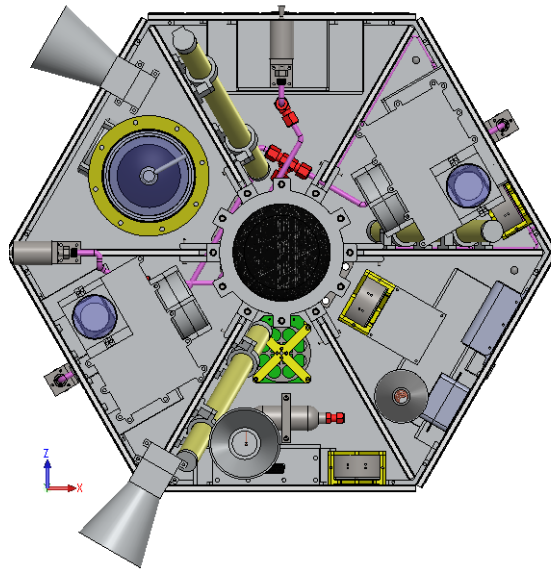


## DebrisSat Design (2/3)

- **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 reaction 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)

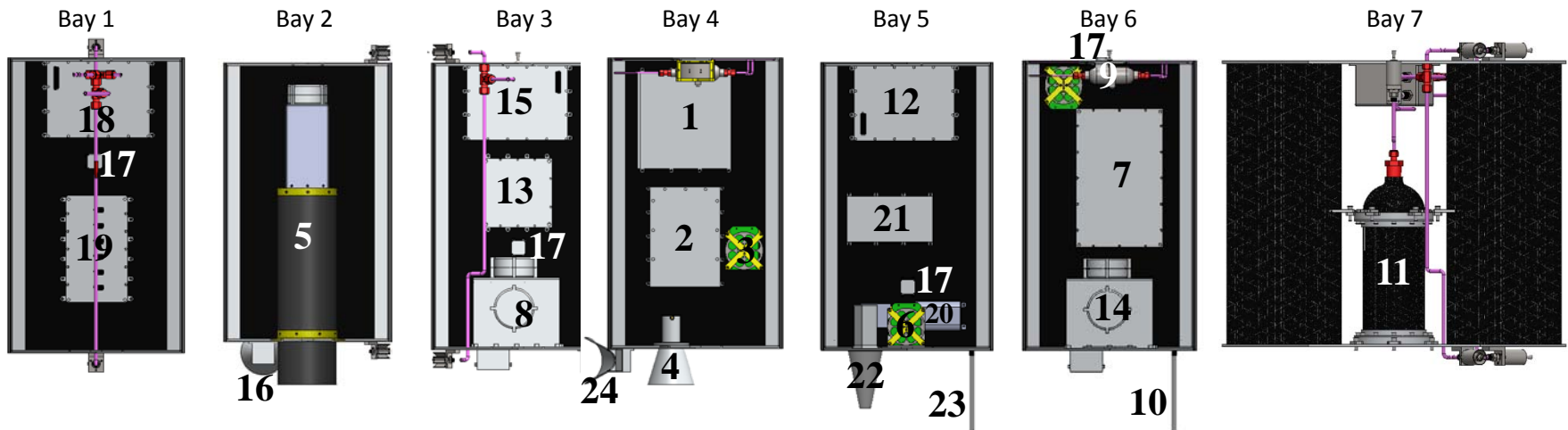


# DebrisSat Design (3/3)



### Component Identification

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

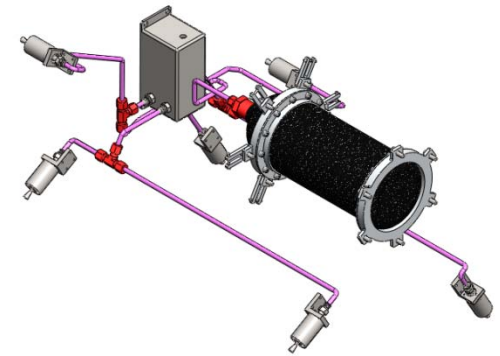


# Emulated Components

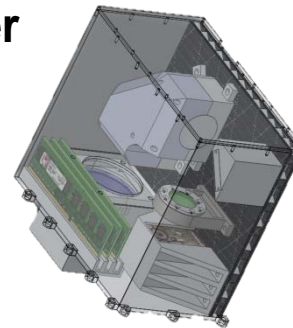
- **Emulated to reduce cost**
- **Based on existing designs**
  - Surrey and Sinclair
  - Input from subject-matter experts
- **Emulated components:**
  - **Propulsion system**
  - **Payload: near-infrared spectrometer, imager**
  - **ADCS: reaction wheels, star trackers, magnetorquers, 3-axis magnetometer**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



Surrey microsatellite  
propulsion system



Emulated propulsion  
system



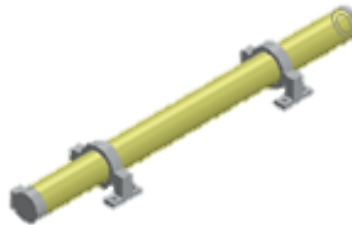
Emulated  
spectrometer



Emulated  
optical imager

# 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**



Emulated magnetorquer



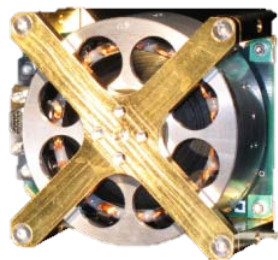
Sinclair magnetorquer



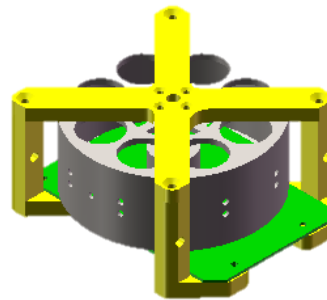
Emulated sun sensor



Sinclair sun sensor



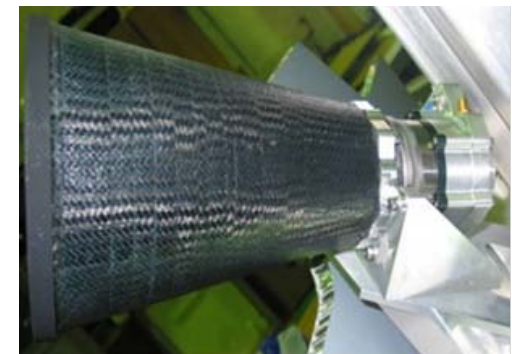
Sinclair  
reaction wheel



Emulated  
reaction wheel



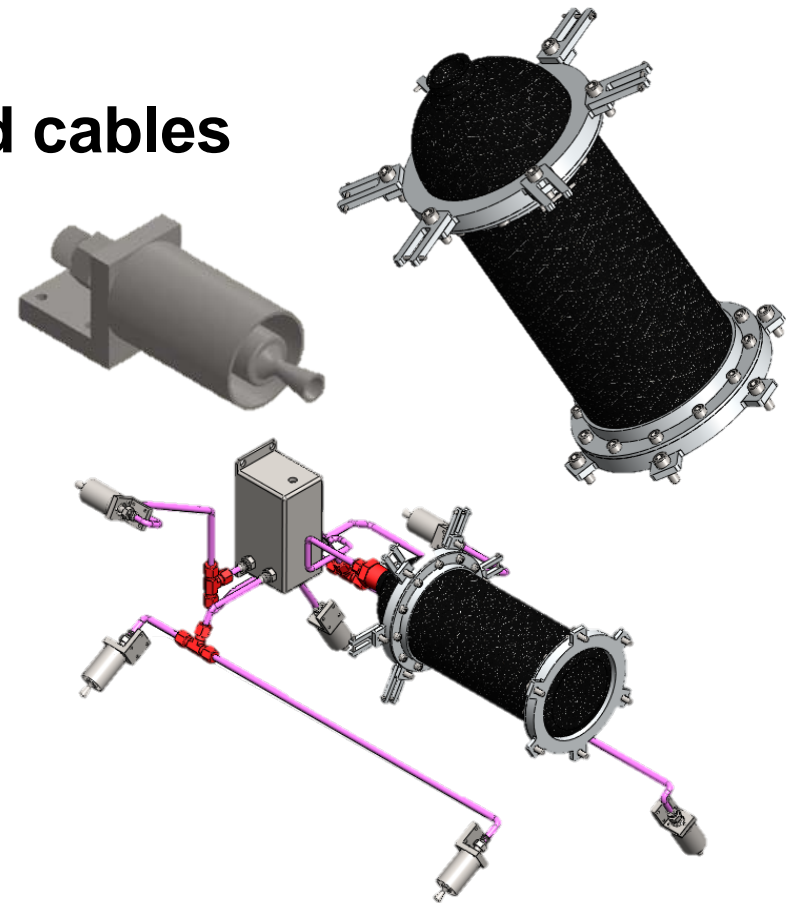
Emulated star tracker



Surrey star tracker

# 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 DebrisSat**

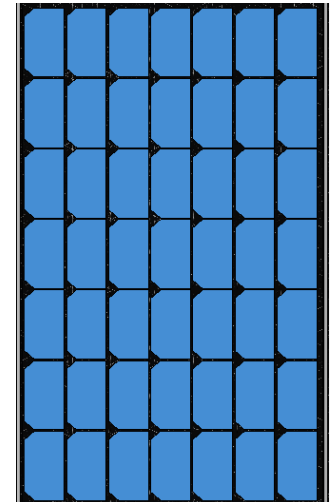


Emulated propulsion system

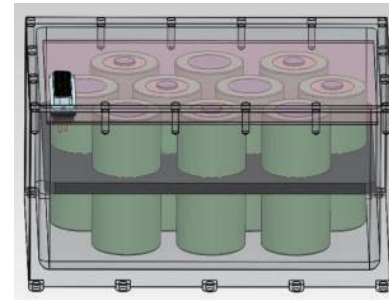


# Electrical Power System

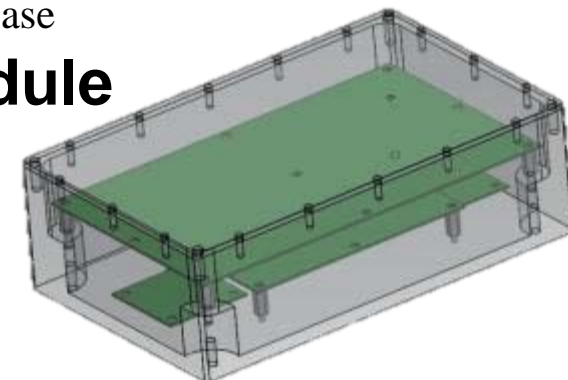
- **Solar Panels**
  - Body-mounted panels
  - Coverglass-interconnect-cells (CIC)
  - Cells bonded to M55J face sheets (side panels)
  - 327 UTJ CIC cells total
    - EDUs from Spectrolab
- **Batteries**
  - 3 Li-ion battery cases
  - 10 batteries per case
- **Power conditioning and distribution module**
  - BCR for each battery case
  - Power conditioning PCB
  - Power distribution PCB
- **D-sub connectors with shielded cables**



Solar panel assembly



Battery case



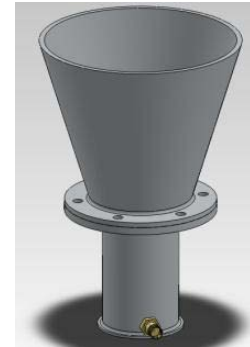
Power conditioning and distribution module



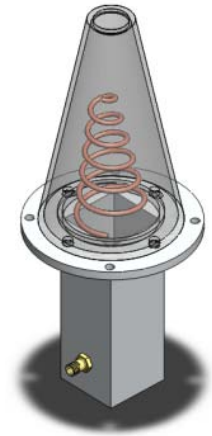


# Telemetry, Tracking, and Command

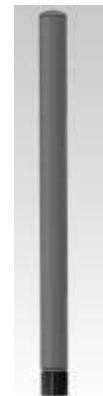
- **Emulated S-band helical antenna**
  - Based on Surrey S-band design
- **Emulated X-band antenna**
  - Based on Surrey X-band design
- **VHF/UHF omni-directional antenna**
  - COTS DigiKey antenna
- **Emulated TT&C avionics boxes**
  - Shielded aluminum boxes
  - COTS signal switch and divider
  -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



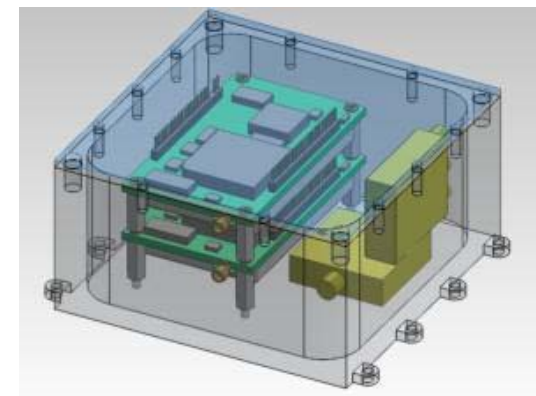
Emulated X-band antenna



Emulated S-band antenna



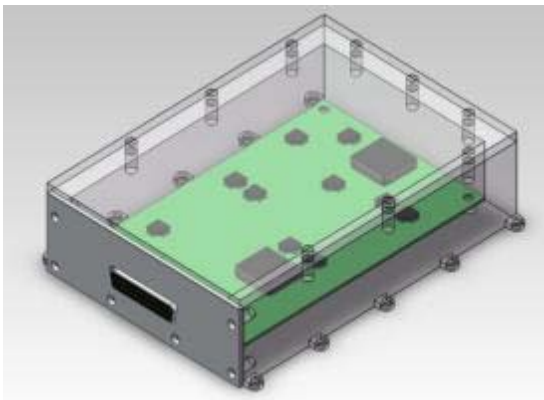
UHF/VFH omni-directional antenna



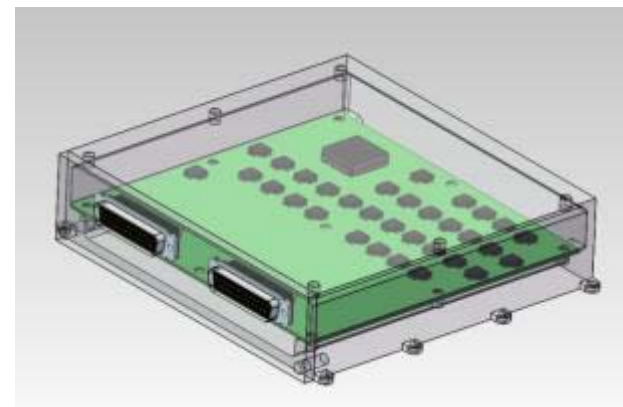
Emulated TT&C avionics

# 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**



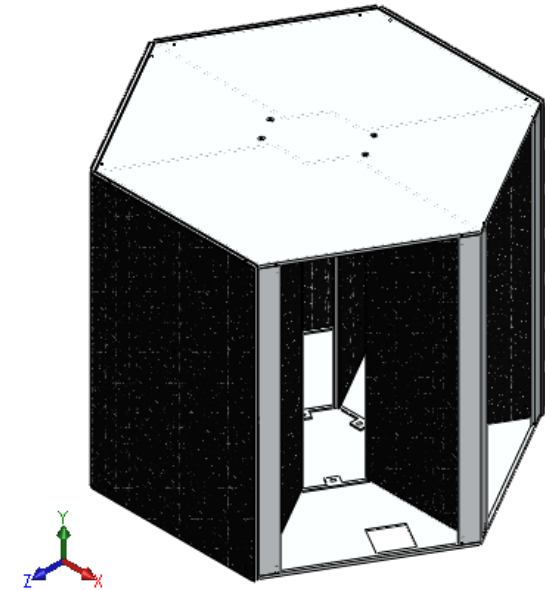
Emulated flight computer



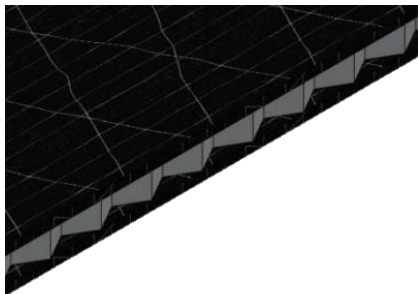
Emulated data recorder

# Structure

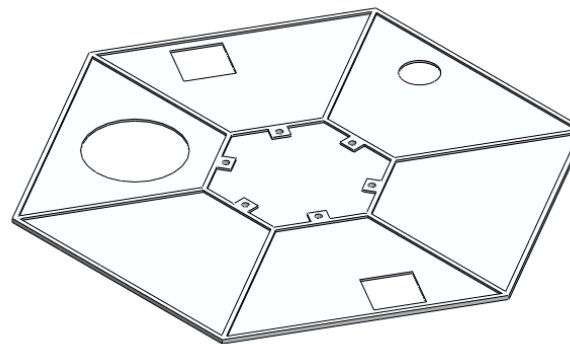
- **Hexagonal prism**
- **Aluminum hexagonal panels**
- **Webbed design**
  - Reduced mass
  - Increased rigidity
- **Composite side panels and ribs**
  - M55J carbon fiber face sheets
  - Aluminum honeycomb cores
- **Aluminum longerons**



Structural assembly



Composite panel

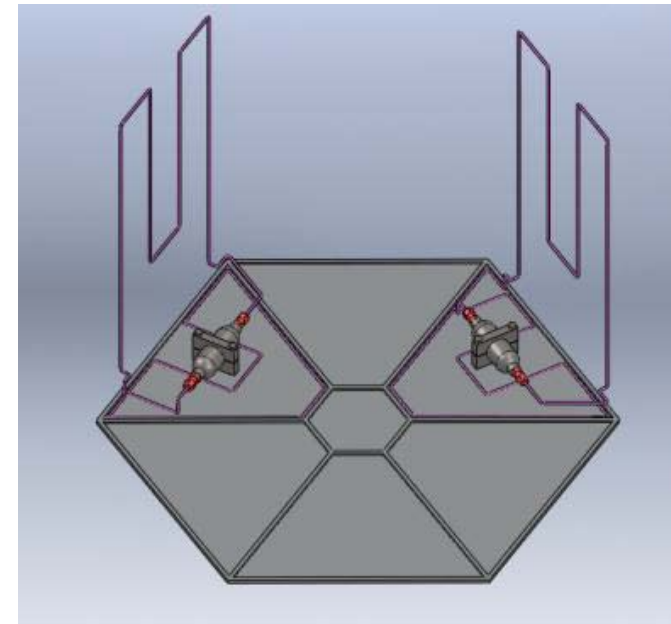


Aluminum “webbed” panel



# Thermal Management

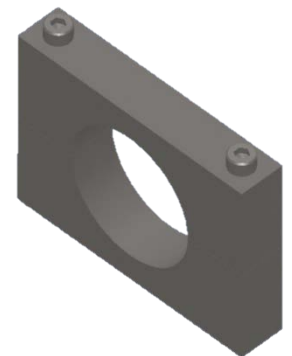
- Emulated based on capillary pump loop (CPL) designs
- Two independent loops
- Stainless steel plumbing
- Side panels have internal plumbing
- Zenith hexagonal panel as radiator
- Kapton heaters on avionics boxes/thermal shielded cables
- Multi-layer insulation
  - External faces in areas without solar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



CPL loops with radiator



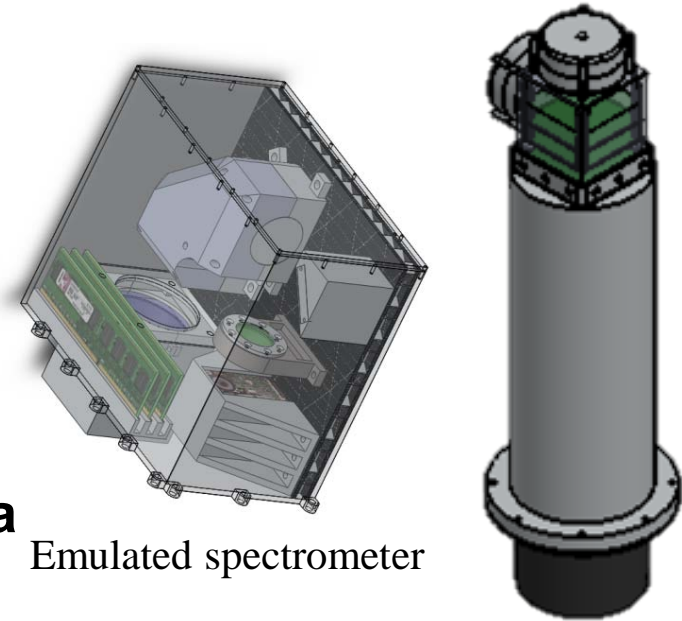
CPL reservoir



Reservoir mount

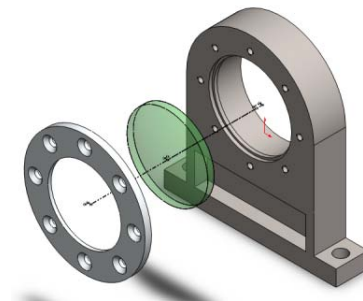
# Payload

- **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



Emulated spectrometer

Emulated optical imager



Titanium lens mount



## Status of DebrisSat

- **Project kickoff – Sep 2011**
- **Final design**
  - LEO study completed
  - Detailed design submitted to JSC – July 2012
- **Fabrication of the target satellite – Sep 2013\***
  - DebrisSat 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\***

\*Contingent upon available funding, collaboration/contributions



# Acknowledgements

## Organizations:

- **NASA Orbital Debris Programs Office**
- **USAF Space and Missile Systems Center**
- **Aerospace Corporation**
- **University of Florida Space Systems Group**

## Subject-Matter Experts:

- **Scott Peck, spacecraft structures and FEA**
- **Peter Thomas, spacecraft payloads**
- **Geoff Reber, spacecraft propulsion**
- **Andrew Tretten, spacecraft attitude determination and control**
- **Jeff Cha, spacecraft thermal control**

## Donations:

- **Sinclair Interplanetary, reaction wheel and torque rod cores**
- **Micro Aerospace Solutions, inertial measurement unit**