National Aeronautics and Space Administration

New Laboratory-Based Satellite Impact Experiments for Breakup Fragment Characterization

J.-C. Liou[1], N. Fitz-Coy[2], R. Dikova[2], M. Wilson[2], T. Huynh[3], C. Griffice[4], M. Sorge[4], P. Sheaffer[4], G. Radhakrishnan[4], J. Opiela[5], H. Cowardin[5], P. Krisko[5], R. Rushing[6], M. Nolen[6], B. Roebuck[6]

[1]NASA, [2]UF, [3]AF/SMC, [4]Aerospace, [5]Jacobs, [6]AF/AEDC

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The DebriSat Team

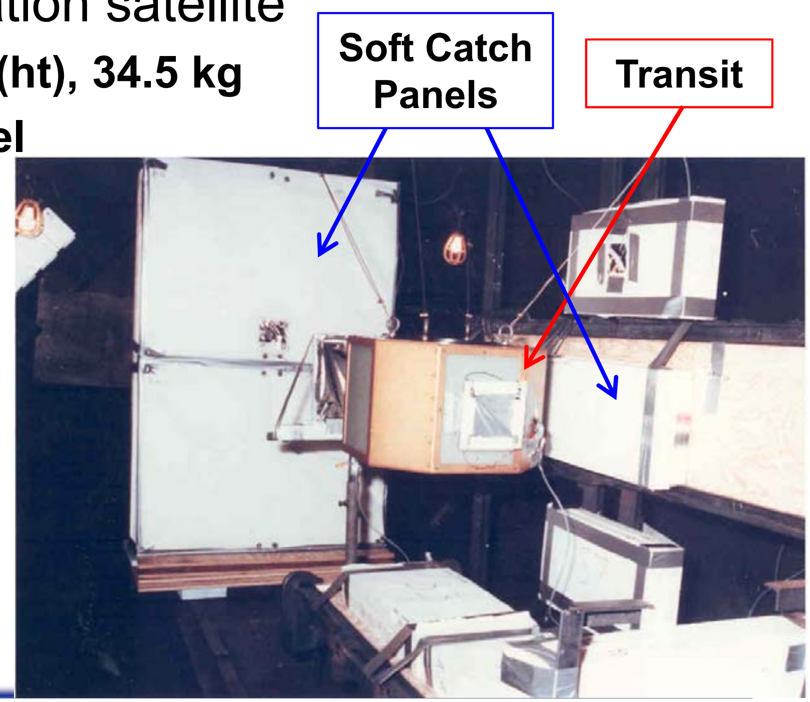
- **NASA Orbital Debris Program Office (ODPO)**
  - Co-sponsor, project and technical oversight, data collection, data analyses, NASA model improvements: J.-C. Liou, J. Opiela, H. Cowardin, *et al.*
- **AF Space and Missile Systems Center (SMC)**
  - Co-sponsor, technical oversight: D. Davis, T. Huynh, 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)**
  - Hypervelocity impact tests: R. Rushing, B. Hoff, M. Nolen, B. Roebuck, D. Woods, M. Polk, *et al.*

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)
  - Similar collisions 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)

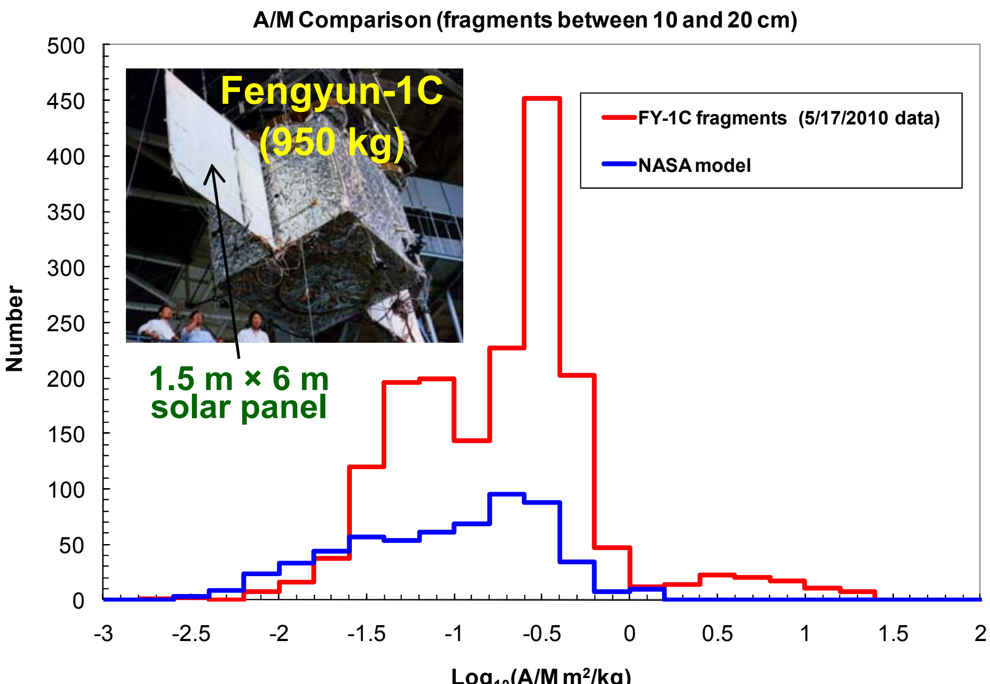
- **The need for laboratory-based impact tests was recognized by DoD and NASA decades ago**
- **A key laboratory-based test, SOCIT*, supporting the development of the DoD and NASA satellite breakup models was conducted by DNA at AEDC in 1992**
  - Target satellite: A U.S. Navy Transit navigation satellite
    - **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

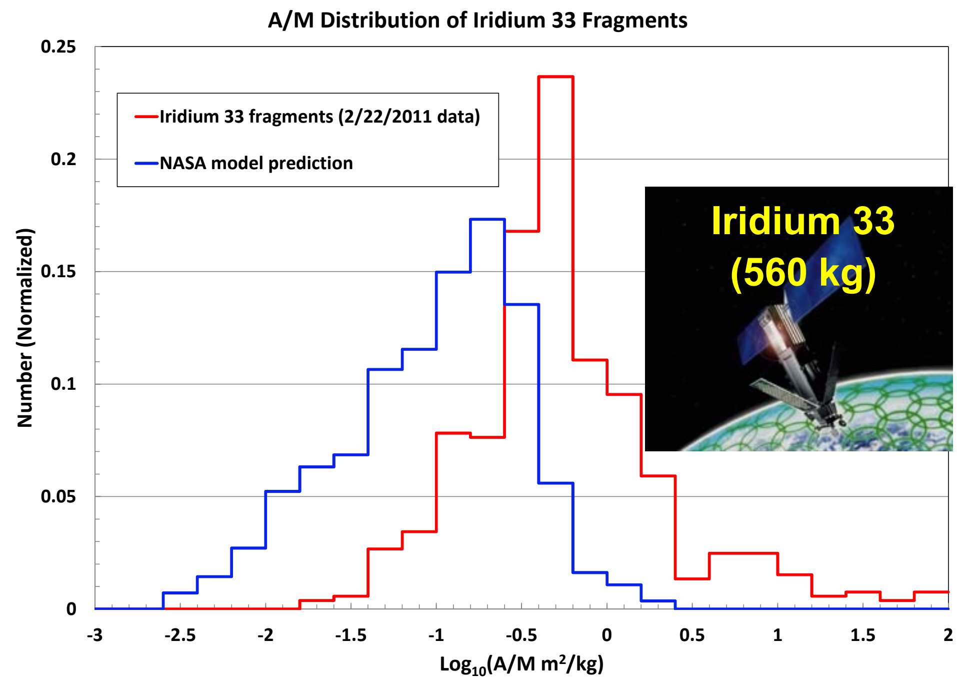


*SOCIT: Satellite Orbital debris Characterization Impact Test

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.**





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/50-kg class 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

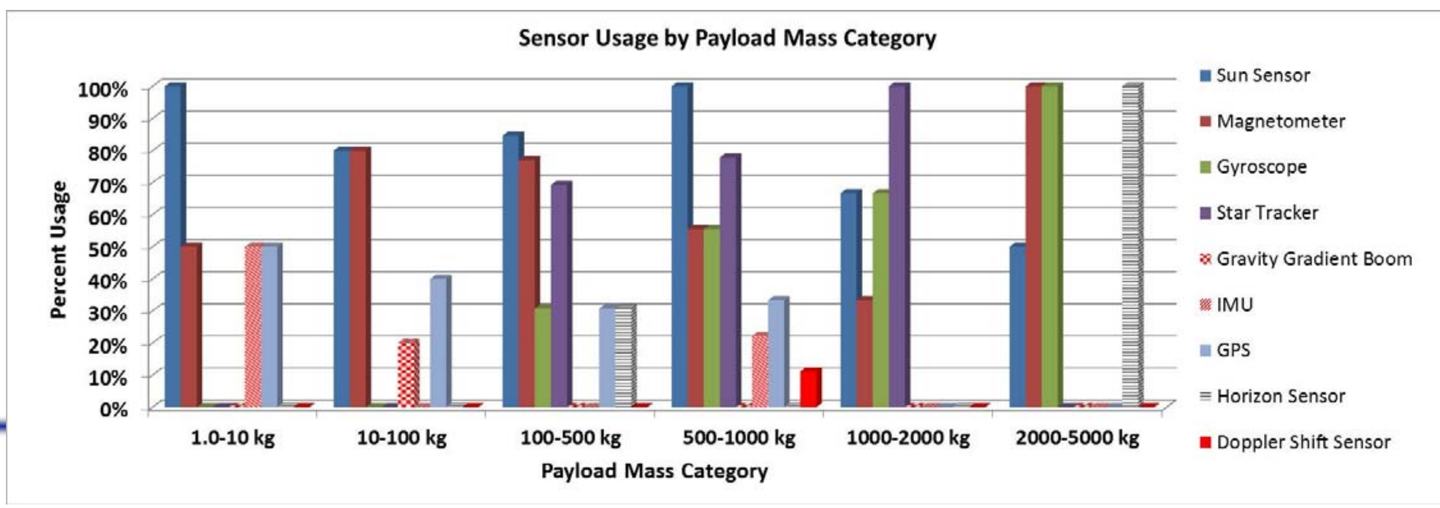
DebriSat versus SOCIT/Transit

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

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

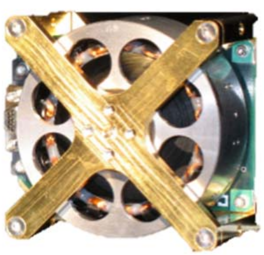
DebriSat Design (1/3)

- **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

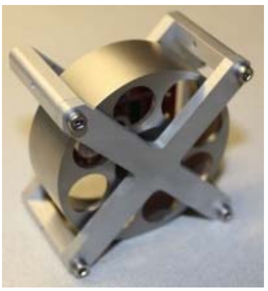


DebriSat Design (2/3)

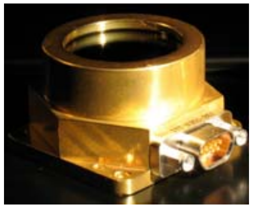
- **DebriSat includes 7 major subsystems**
  - Attitude determination and control system (ADCS), command and data handling (C&DH), electrical power system (EPS), payload, propulsion, telemetry tracking and command (TT&C), and thermal management
  - Each subsystem contains standard components, such as 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



Reaction wheel (Credit: Sinclair Interplanetary)



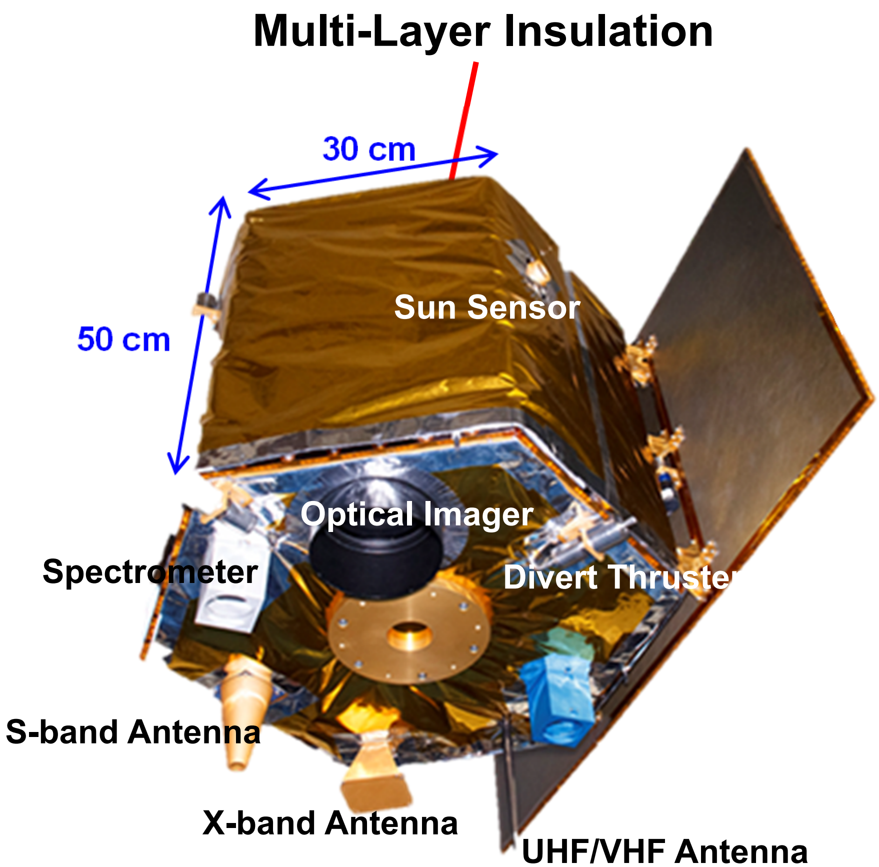
Emulated reaction wheel

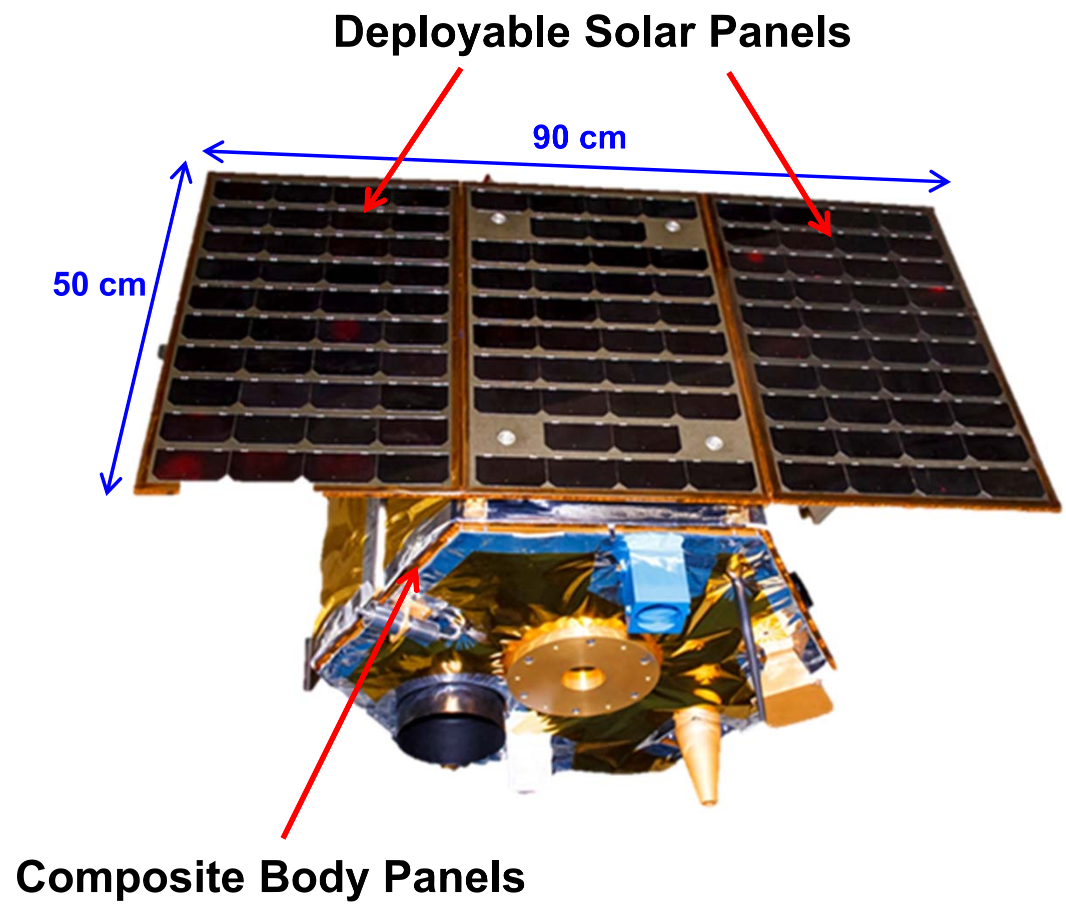


Sun sensor (Credit: Surrey)

Emulated sun sensor

DebriSat Design (3/3)





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**

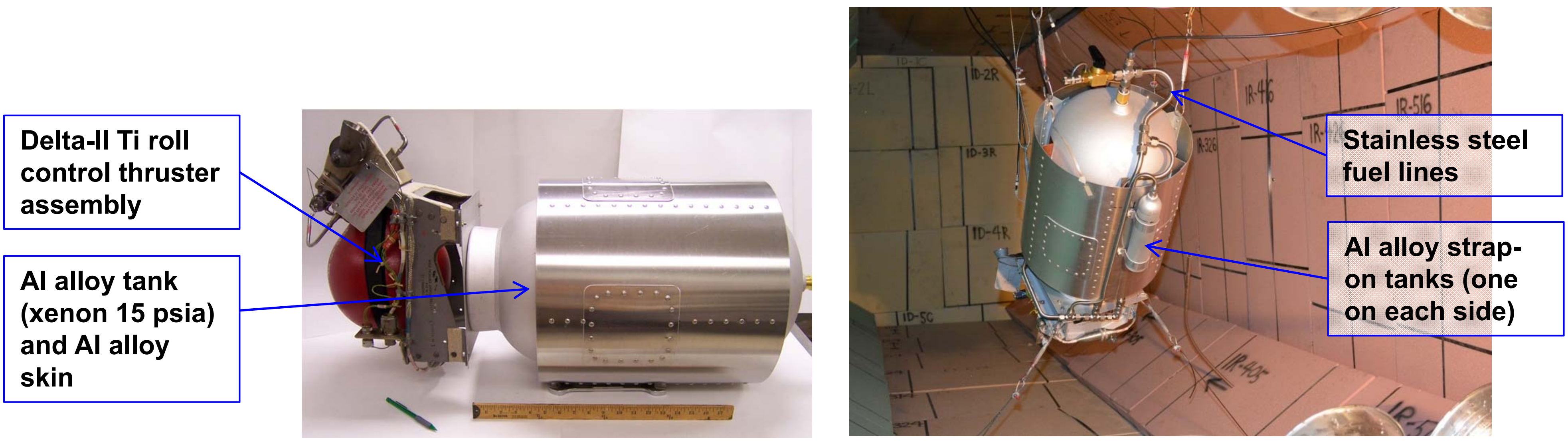
Examples of the before (without target) and after impact views of the target chamber (10 ft × 20 ft).

Projectile Design

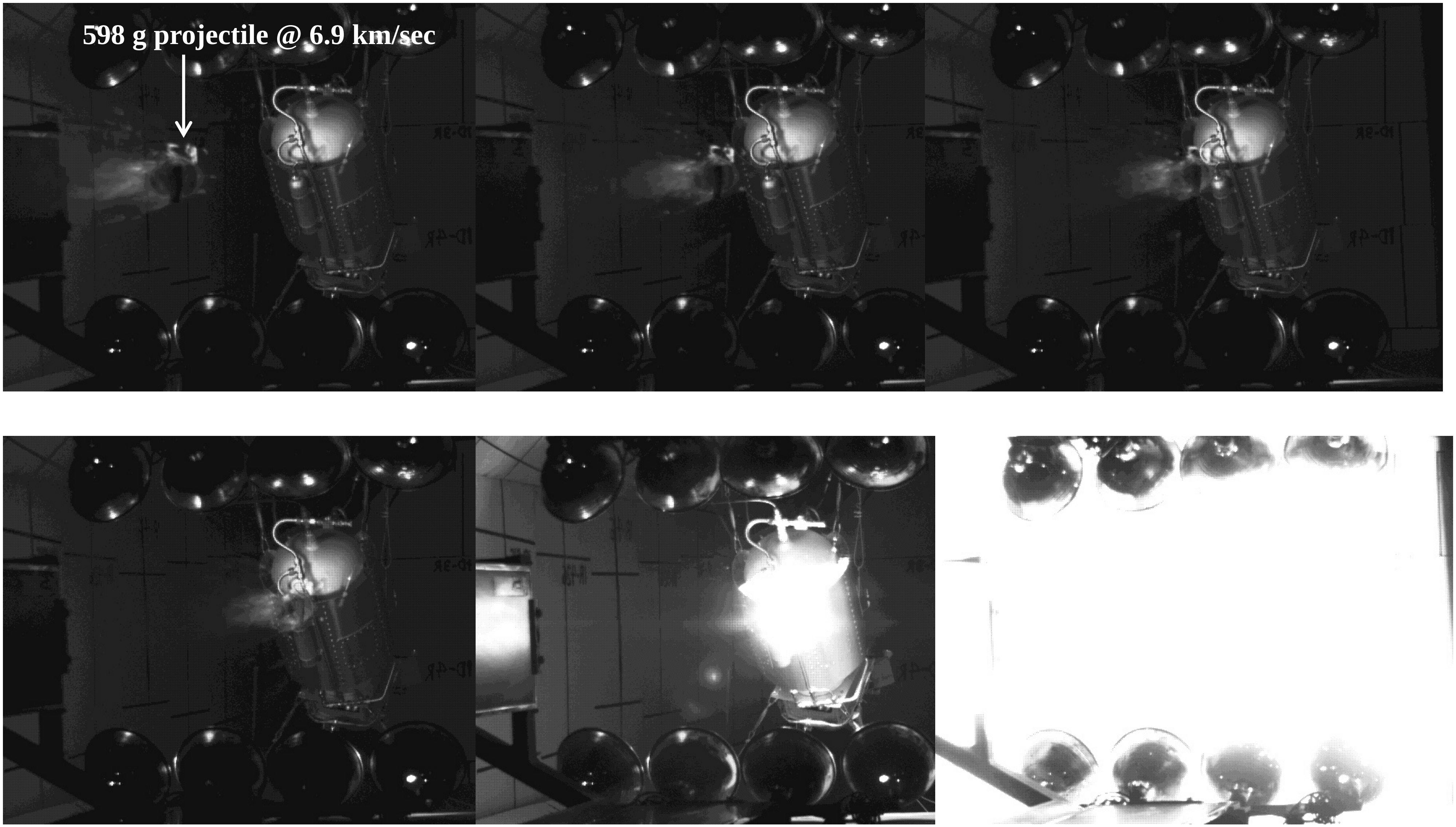
- **To maximize the projectile mass at the 7 km/sec impact speed without a sabot, a special projectile was designed featuring a hollow aluminum cylinder embedded in a nylon cap**
  - The nylon cap served as a bore rider for the aluminum cylinder to prevent hydrogen leakage and also to protect the barrel

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 April 1st**
  - Projectile impacted DebrisLV at 6.9 km/sec and completed fragmented DebrisLV

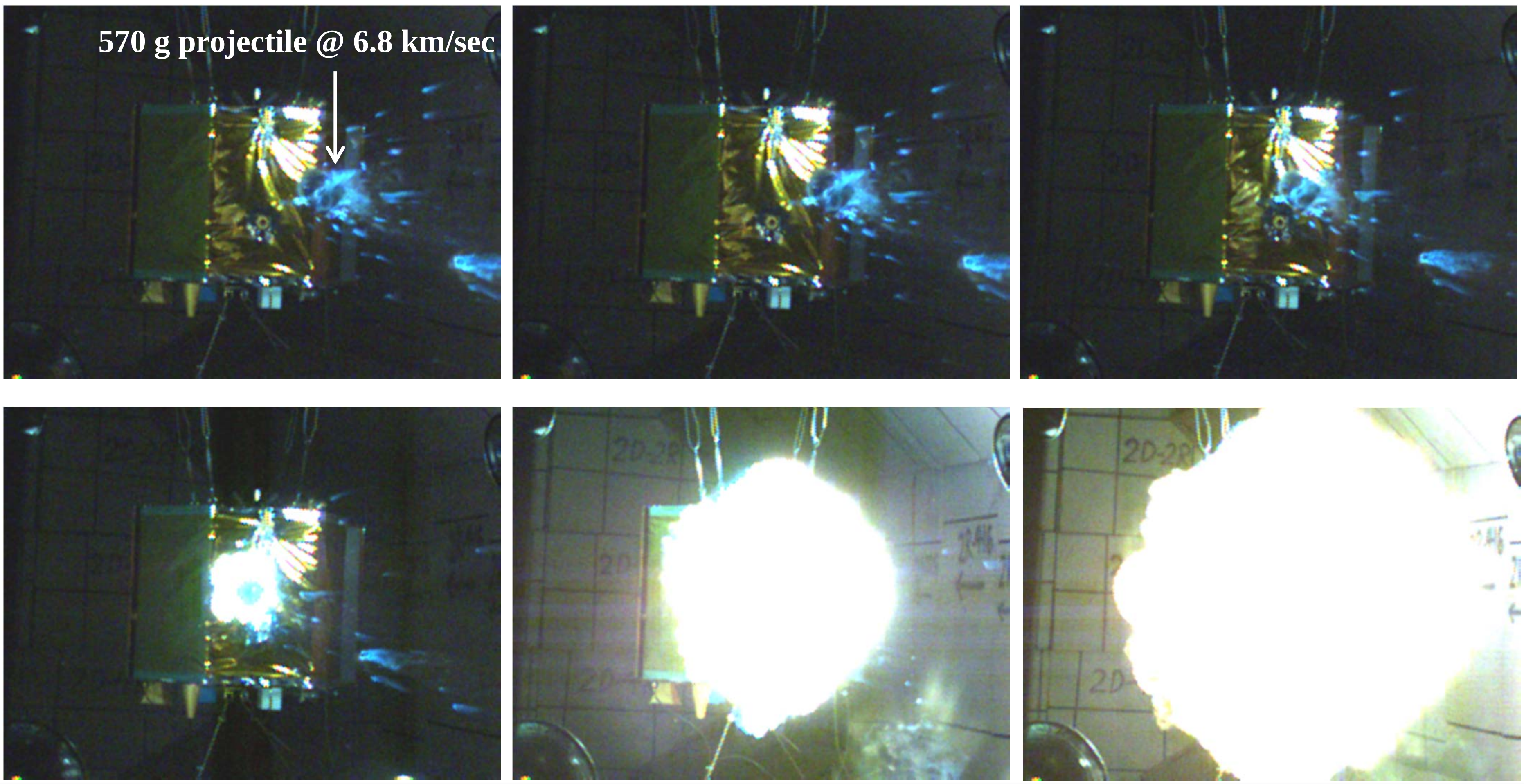


DebrisLV Impact Sequences



DebriSat Impact Sequences

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



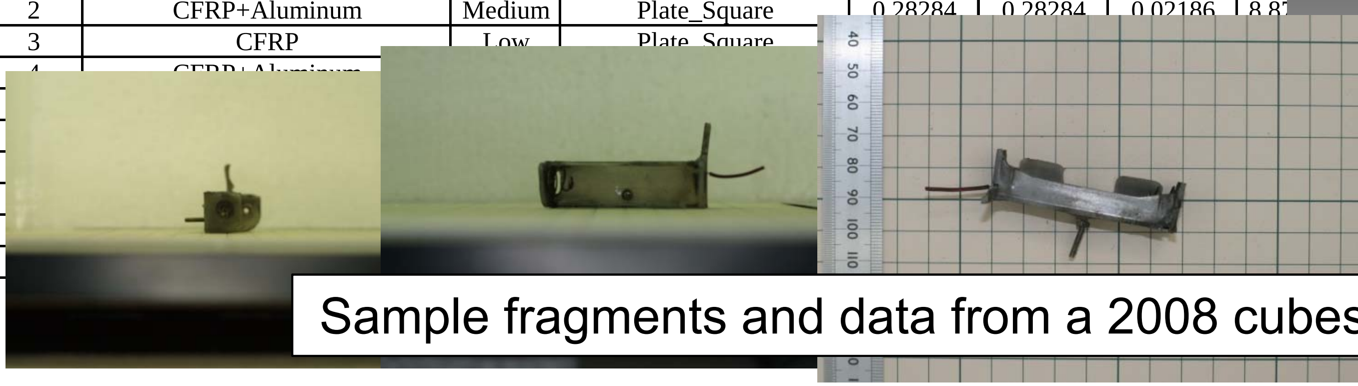
Post-Impact Fragment Collection

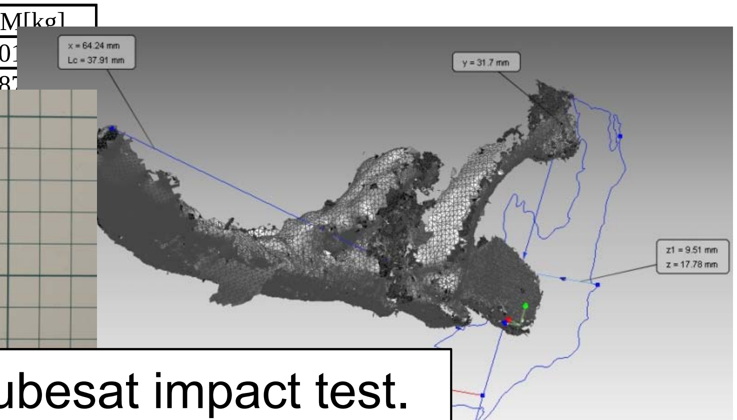
- **After each impact, all intact foam panels, broken foam pieces, loose fragments, and dust were carefully collected, documented, and stored**
  - 41 pallets of ~2 m × 2 m × 2 m boxes were packed
  - Estimated ≥2 mm DebriSat fragments are on the order of 85,000

Fragment Characterization Plan

- **Conduct x-ray scanning of foam panels/pieces to identify locations of ≥2 mm fragments**
- **Extract ≥2 mm fragments from foam panels/pieces**
- **Measure fragments individually**
  - Dimensions, mass, shape, density, composition, photos
- **Obtain 3D scanning data for selected fragments**
  - Cross-sectional area, A/M, bulk density
- **Conduct radar, photometric, and spectral measurements for selected fragments**
  - Support improvements to radar and optical size estimation models

No	Characteristic	Label	Shape	x[m]	y[m]	z[m]	M[kg]
1	CFRP+Aluminum	Medium	Plate_Square	0.28284	0.28284	0.03031	2.01
2	CFRP+Aluminum	Medium	Plate_Square	0.28284	0.28284	0.02186	8.87
3	CFRP	Low	Plate_Square	[illegible]	[illegible]	[illegible]	[illegible]
4	CFRP+Aluminum	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]





Sample fragments and data from a 2008 cubesat impact test.

Project Schedule

- **Project preparation: 2009-2011**
- **Project kickoff: Sep 2011**
- **Preliminary design: Jun 2012**
- **Final design: Jan 2013**
- **AEDC impact test plan draft: Aug 2013**
- **Complete fabrication of DebriSat: Jan 2014**
- **Vibration and thermal vacuum tests: Mar 2014**
- **Hypervelocity impacts at AEDC: April 2014**
- **Complete basic fragment measurements: Dec 2015***
- **Radar and optical measurements: 2016***
- **Process/analyze data for model improvements: 2016***

(*contingent upon available resources.)