Orbital Debris and Future Environment Remediation

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Outline (1/2)

• Part 1: The Near-Earth Orbital Debris Environment
  – Overview of the orbital debris populations
  – Optical, radar, and in-situ measurements
  – Orbital debris modeling

• Part 2: Orbital Debris Modeling
  – The NASA OD engineering model
  – The NASA OD evolutionary model
  – The NASA standard satellite breakup model
Part 3: Options and Challenges for Environment Remediation

- Target the root cause of the population growth
- Target the main threat to operational satellites
- Prevent major debris generating collisions
- The challenges
Part 1: The Near-Earth Orbital Debris Environment
Overview of the Orbital Debris Environment
Only objects in the US Space Surveillance Network (SSN) catalog are shown.
Sizes of the dots are not to scale.
What Is Orbital Debris?

• Orbital debris is any man-made object in orbit about the Earth that no longer serves a useful purpose

• Examples
  – Intact objects: spent rocket bodies (R/Bs, i.e., upper stages) and retired spacecraft (S/C, i.e., payloads)
  – Breakup fragments (via explosions or collisions)
  – Mission-related debris: objects released during normal mission operations (engine covers, yo-yo de-spin weights, etc.)
  – Solid rocket motor effluents (Al₂O₃ slag and dust particles)
  – NaK droplets (coolant leaked from Russian nuclear reactors)
  – Surface degradation debris (paint flakes, etc.)
The Orbital Debris Family

Objects in the Near-Earth Environment

- R/Bs, S/C
- Breakup Fragments
- Mission-related Debris
  - NaK
  - Al₂O₃
  - Al₂O₃ (slag)
  - Paint Flakes
  - MLI Pieces
  - Meteoroids

Size (diameter):
- 10 μm
- 100 μm
- 1 mm
- 1 cm
- 10 cm
- 1 m
- 10 m
How Much Junk Is Currently Up There?

Softball size or larger (≥10 cm): ~22,000 (tracked by the Space Surveillance Network)

Marble size or larger (≥1 cm): ~500,000

Dot or larger (≥1 mm): ~100,000,000 (a grain of salt)

- Total mass: ~6300 tons LEO-to-GEO (~2700 tons in LEO)
- Due to high impact speed in space (~10 km/s in LEO), even sub-mm debris pose a realistic threat to human spaceflight and robotic missions
>22,000 objects tracked by US Space Surveillance Network (SSN) in 2012

- Tracked objects are ~10 cm and larger
- Many more untracked (i.e., smaller) objects in space
The Environment

Impact Kinetic Energy:
golf ball @ 10 km/sec ≈ midsize sedan @ 120 mile/hr
Threat from Small Orbital Debris (1/2)

Crater: Dia × Dep ≈ 1.8 mm × 0.2 mm
Estimated projectile size ≈ 0.06 mm
(STS-97 window damage, Dec. 2000)

Crater: Dia × Dep ≈ 1 cm × 2 mm
Estimated projectile size ≈ 0.5 mm
(STS-92 window damage, Oct. 2000)

→ On average, two shuttle windows were replaced per mission
Entry hole, 0.27 cm diameter

0.28 mm facesheet
4.8 mm cell 3.1 Pcf Al Core

1.27 cm

Honeycomb core damaged across ~5 cells (2.5 cm diameter)

Hole, 0.8 mm
Crack, 6.8 mm

Projectile residual

(STS-115 Shuttle Radiator Damage, 2006)
Potential Shuttle Damage

Window Replacement

EVA Suit Penetration

Radiator Penetration

- Shuttle Loss of Crew and Vehicle (LOCV) risks from MMOD impact damage were in the range of 1 in 250 to 1 in 300 per mission
  - The risks vary with altitude, mission duration, and attitude
  - OD to MM is about 2:1 at ISS altitude
The Big Sky Is Getting Crowded

- U.S. Air Force’s Joint Space Operations Center (JSpOC) provides conjunction assessments for all operational S/C
  - A warning is issued for LEO S/C when (1) a miss distance is less than 1 km and (2) a radial miss distance is less than 200 m during the forecast period of 72 hours

- In 2010, JSpOC issued 10 to 30 conjunction warnings on a daily basis, and more than 100 collision avoidance maneuvers were carried out by satellite operators

- The ISS has conducted 15 Debris Avoidance Maneuvers (DAM) since 1999
  - 4 times since last April
Consequences of the Two Major Events

An increase of 117% in the region below 1000 km
Mass in Orbit

Monthly Mass of Objects in Earth Orbit by Object Type

- LEO to GEO: ~6300 tons
- LEO only: ~2700 tons

Year

Mass in Orbit (millions of kg)
Sources of the Cataloged Populations

- ~4700 launches conducted worldwide since 1957
- 211 known breakups (thru Jan 2012)
  - Major events
    - Titan Transtage (473, 1965)
    - Agena D stage (373, 1970)
    - Ariane 1 stage (489, 1986)
    - Pegasus HAPS (709, 1996)
    - Long March 4 stage (316, 2000)
    - PSLV (326, 2001)
    - Fengyun 1C (~3200, 2007)
    - Briz-M (>1000\textsuperscript{a}, 2007)
    - Cosmos 2421 (509, 2008)
    - Iridium 33 (>700, 2009)
    - Cosmos 2251 (~2000, 2009)

\textsuperscript{a}initial report

Source Breakdown

- anom. debris, 1.9%
- payloads, 25.2%
- breakup debris, 47.7%
- rocket bodies, 12.9%
- mission-related debris, 12.3%
Explosion of Briz-M

- **Briz-M**
  - 4\textsuperscript{th} stage of a Russian Proton Launch Vehicle
  - 485 km by 14,750 km, inclination = 51.5°
  - Mass ~2000 kg
  - Possible cause of the breakup: explosion of the remaining propellant on board the stage

(R. McNaught, Feb 17, 2007)
Accidental On-Orbit Collisions

- Four accidental collisions between cataloged objects have been identified
  - 1991: Russian Sat (launched in 1988) ↔ Russian fragment
Optical, Radar, and In-Situ Measurements
Current NASA Debris Data (1/2)

- **Goldstone radars (>32.2°)**
- **Haystack radar (>30°)**
- **HAX radar (>42.6°)**

**U.S. Space Surveillance Network**

- **HST-WFPC2 (580x610 km, 93-09)**
- **STS (300x400 km, 95-11)**

![Diagram showing particle diameters and altitudes](Image)

(*Boundaries are notional*)
Current NASA Debris Data (2/2)

- **Haystack (30-m dish, X-band)**
- **HAX (12.2-m dish, Ku-band)**
- **MODEST (0.6-m, Cerro Tololo)**
- **Goldstone radars**
- **DSS-14 (70-m dish, X-band)**
- **DSS-15 (34-m dish receiver)**
- **HST-WFPC2 radiator**
- **Impact crater**

**Particle Diameter**
- 10 μm
- 100 μm
- 1 mm
- 1 cm
- 1 m

*Boundaries are notional.*

(Images of telescopes and radars, with altitudes and distances indicated.)
NASA RADAR Observations

- Signal processing
- Object detection/correlation
- Debris size estimation
- Orbit determination
- Environment definition

![Flux vs. Diameter, Year 2001, 800 to 1000km](chart.png)

*Note: a few large Haystack events were excluded because of poor statistics.*

Goldstone

Haystack and HAX
NASA Optical Observations

- Photometric and spectral measurements
- Object detection and correlation
- Optical Measurement Center (OMC)
- Surface material identification
- Orbit determination
- Environment definition
In-Situ Data From Returned Surfaces
• 685 impact features (≥300 µm) were identified
  – Recorded each impact feature’s shape, size, depth, and volume
Critical Data Gaps

HST-WFPC2 (580x610 km, 93-09)
STS (300x400 km, 95-11)

Gap 1

Goldstone radars (>32.2°)
Haystack radar (>30°)

HAX radar (>42.6°)

U.S. Space Surveillance Network

(*Boundaries are notional.)
Future NASA Debris Telescope

- **NASA Meter Class Autonomous Telescope (MCAT)**
  - 1.3 m aperture, 0.96° field of view, f/4
  - Located at Kwajalein Atoll (9°N, 168°E)
  - Target detection limits
    - GEO ~10 cm diameter (20.5 V-mag)
  - Primary objectives
    - GEO debris down to ~10 cm
    - LEO debris with low inclinations and high eccentricities
    - Simultaneous radar-optical observations
  - Expected operations ~2013
A New Particle Impact Detection Technology

- **Debris Resistive/Acoustic Grid Orbital Navy Sensor (DRAGONS)**
  - Objective: A low-cost/mass/power experiment to detect and characterize 0.1 to 1 mm MMOD particles at 800-1000 km altitude
  - Components: (1) a large surface (≥1 m²) coated with thin resistive grids, (2) acoustic sensors attached to the backside of the board/film
  - Team: USNA, NASA/ODPO, Kent (UK), NRL, VT
  - Status: Presented to the annual DoD Space Experiment Review Board (SERB) since 2007, a potential flight opportunity in 2015

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**Hypervelocity Impact Tests**
- Resistive grid width: 75 μm
- Projectile: 0.3 mm stainless steel
- Impact speed: 5.06 km/sec
- Impact angle: normal
- Two PVDF acoustic sensors attached to the board
Modeling
**General Orbital Debris Modeling (1/2)**

- **NASA DO engineering model**
  - Is a mathematical model (such as ORDEM) capable of predicting OD impact risks for critical space assets (ISS, etc.)

- **NASA OD evolutionary model**
  - Is a physical model (such as LEGEND) capable of predicting future debris environment
  - Supports the development of US/NASA debris mitigation guidelines and safety standards

- **NASA satellite breakup model**
  - Describes the outcome of a satellite breakup (explosion or collision)
General Orbital Debris Modeling (2/2)

- **Reentry risk assessments**
  - Uses Object Reentry Survival Analysis Tool (ORSAT) to evaluate satellite reentry risks
  - The risk of human casualty from surviving debris shall not exceed 1 in 10,000 (NASA Standard 8719.14)

- **NASA Debris Assessment Software (DAS)**
  - Is designed to assist NASA Programs in performing orbital debris assessments for their planned missions

![Delta II propellant tank](Image)
*Delta II propellant tank (Georgetown, TX, 1997)*

![Titanium casting of STAR-48B SRM](Image)
*Titanium casting of STAR-48B SRM (Saudi Arabia, 2001)*

![Titanium casting of STAR-48B SRM](Image)
*Titanium casting of STAR-48B SRM (Argentina, 2004)*
ODQN is a quarterly publication of the NASA Orbital Debris Program Office

- includes some of the latest events in orbital debris research, news, statistics, project reviews, meeting reports, and upcoming events
Questions?