Multi-Spectral Measurements for Detection, Location, and Evaluation of Impacts to Space Structures

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Overview

- The Challenge
- Hypervelocity Impact (HVI) Background
- Previous Work – Detection, Location, and Evaluation
  - Civilian
  - Military
- Future Work
  - Impact/Leak Location
  - New Approach for Impact Evaluation
The Challenge

- The smallest of particles or debris can cause significant damage to spacecraft
- Impacts can compromise spacecraft operation or cause catastrophic failure
- Understanding hypervelocity impact (HVI) events (i.e. collisions greater than a few kilometers per second) will help to improve spacecraft reliability
- An understanding of impacts includes:
  - Detection – An awareness of what happened
  - Location – An awareness of where it happened
  - Evaluation – An awareness of how bad it is
Spacecraft Environment

- Meteoroids
- Solar Wind
- Debris
- Ionosphere
- Geomagnetic field
- Spacecraft plasma sheath
- Thruster plume
- Differential surface charging
- Power distribution

Image courtesy of Stanford University

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Hypervelocity Particles

• Meteoroids
  – Speeds
    • 11 to 72.8 km/s (interplanetary)
    • 30-60 km/s (average)
  – Densities
    • ≤1 g/cm$^3$ (icy)
    • > 1 g/cm$^3$ (rocky/stony)
  – Sizes
    • < 0.3 m (meteoroid)
    • < 62 μm (dust)

• Space Debris
  – Speeds in LEO
    • < 12 km/s
    • 7-10 km/s (average)
  – Densities
    • > 2 g/cm$^3$
  – Sizes
    • < 10 cm (small)

Probability of Impact?  Effects from Impact?

Courtesy of Stanford University
Flux

Should we worry about the small particles?

Courtesy of Stanford University
Spacecraft Anomalies

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Year</th>
<th>Agency</th>
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</thead>
<tbody>
<tr>
<td>Olympus</td>
<td>1993</td>
<td>ESA</td>
</tr>
<tr>
<td>Landsat 5</td>
<td>2009</td>
<td>NASA</td>
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<td>JASON-1</td>
<td>2005</td>
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<tr>
<td>ADEOS II</td>
<td>2003</td>
<td>JAXA</td>
</tr>
<tr>
<td>ALOS</td>
<td>2011</td>
<td>JAXA</td>
</tr>
</tbody>
</table>

NGDC Database: Anomaly Diagnosis

- Electron Caused EM Pulse (Deep Dielectric Charging) - 490
- Electrostatic Discharge (Surface Charging) – 1072
- Single Event Upset - 822
- Radio Frequency Interference – 8
- Unknown – 2587

Courtesy of Stanford University
Recommendation: The NASA meteoroid and orbital debris programs should establish a baseline effort to evaluate major uncertainties in the Meteoroid Environment Model regarding the meteoroid environment in the following areas:

1) meteoroid velocity distributions as a function of mass;
2) flux of meteoroids of larger sizes (>100 microns);
3) effects of plasma during impacts, including impacts of very small but high-velocity particles; and
4) variations in meteoroid bulk density with impact velocity.”
Research Objective

• Spacecraft are routinely impacted by hypervelocity particles with possibility of damage
  – Mechanical: “well-known”, larger (> 120 microns), rare
  – Electrical: “unknown”, smaller, more numerous
    • Electrostatic Discharge (ESD)
    • Electromagnetic Pulse (EMP)

• **Objective**: *characterize plasma, radio frequency (RF) emission, acoustic emissions, acceleration, and light from impacts to assess possibility of spacecraft damage*
Previous Work

- Impact Detection and Location
  - Already accomplished using various modes/spectra

- Impact Evaluation (**Real-time, In-situ**)
  - In its infancy
  - Have conducted studies using
    - Vibration
    - Acoustic emissions
    - Conducted RF
    - Radiated RF
    - Plasma
Impact AE/RF/Plasma Emissions Testing
NASA White Sands Test Facility (WSTF)

Target Setup in Chamber

Actual Impact Location: (-5.87, -6.25)

Triangulation Location: (-5.93, -6.27)

RF Waveforms

Sensors

Stanford Sensor
Invocon Spacecraft Measurements

- Spacecraft Test, Evaluation & Monitoring
- Structural Analysis
- Condition-Based Maintenance
- Micro-Gravity Measurement
Wing Leading Edge Impact Detection System

Monitored impacts during ascent and MMOD impacts in orbit

Relay Units

Laptop-based Receiver

Sensor Units

Note: Similar units presently used to monitor BEAM
Distributed Impact Detection System (DIDS)

- Low-power impact detection and leak location for ISS
- Acoustic Emission, Acceleration, Ultrasonic
- Continuous monitoring of impact events
- Ultra low-power trigger modes
- Sample rates to ~1 MHz
- 4 channels / device
- Presently used on BEAM

NASA photo – DIDS on ISS
Impact Monitoring on Bigelow Expandable Activity Module (BEAM)

- **BEAM**
  - Inflatable habitat attached to ISS for two-year test and evaluation
  - Preparation for future habitats – long-duration and deep space

- **Instrumentation for**
  - Deployment dynamics
  - Radiation
  - Temperature
  - **Hypervelocity Impacts**

- **Challenges of Inflatable**
  - Many diverse layers
  - Low-Frequency
  - Significant attenuation

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Launch Vehicle Instrumentation & Avionics

- Precision Control, Monitoring, & Communication Systems for Launch Vehicles & Spacecraft
- Pyrotechnic Sequencers & Timers
- Hit Grid Systems for Lethality Assessment
- Smart Batteries
- Integrated Telemetry Systems
Future Work

- Impact/Leak Detection and Location
  - Health Interrogation for Space Structures (HISS)
- Impact Detection, Location, and Evaluation
  - Optical Approach
Health Interrogation for Space Structures (HISS)

- Response to requests from NASA
- Upgraded Distributed Impact Detection System (DIDS)
  - Present system has been expanded well beyond its initial purpose
  - Adds significant additional data acquisition and processing capabilities
    - For present leak/impact detection needs
    - Generic and capable enough for expanded roles in future
- Multi-level, distributed sensing and processing
  - Transducers – multiple per Sensor Unit
  - Sensor Units – multiple per ISS module
  - Module hub – one hub per module
  - Server – one per vehicle
- User access to alerts, data, and control
  - Flight crew – Space Station Computers (SSC) & tablet computers via web browser
  - Ground crew

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An Alternate Approach

- Use Optics for Impact Evaluation
- Simplify approach to improve SWaP-C constraints
  - Assumes we know material for each layer of vehicle
  - Assumes we can continuously monitor with optics
- Monitor discrete frequencies in optical spectrum
- Witness flash from impact
- Determine materials involved in impact based on spectroscopic signature
- Determine the layers penetrated by an impact
Alternate RF Approach

- Replace AE components in WKIPS with RF analogies
- Direct line of sight not necessary
- Mount sensors inside or outside vehicle
- Conducted or radiated RF can be used (may want to add conductive layer)
- Instrumentation exists TODAY to perform this testing/monitoring
- Data already exists from this system that validates many of its capabilities
- Includes capability for impact location
Summary

- Research is ongoing for HVI effects associated with RF and Plasma
- Research has resulted in practical tools
  - Presently aboard manned and unmanned space vehicles
  - Can be applied to TPS, satellites, and other structures
  - More (complimentary) information can be obtained from multi-spectral measurements
- New approaches can improve monitoring outcomes
  - Upgrading impact/leak location will significantly increase capabilities/automation
  - Optical approach will improve impact evaluation capabilities
  - RF approach builds on present system
  - Wireless synchronization to 1ns will enable simple deployment
Acknowledgments

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