Applications of Advanced Nondestructive Measurement Techniques to Address Safety of Flight Issues on NASA Spacecraft

3rd IEEE International Workshop on Metrology for Aerospace

Florence, Italy

This briefing is for status only and does not represent complete engineering data analysis
Outline

• NASA Spaceflight Programs
  – Human
  – Robotic

• NESC and the NESC NDE TDT

• Examples of Critical Safety of Flight Issues Resolved by NESC NDE TDT
  – Shuttle
  – ISS
  – Orion
  – Commercial Crew/Cargo

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NASA Human Spaceflight Programs
Low Earth Orbit

ISS Crew Transportation

ISS

Russian Soyuz
US ISS Cargo Delivery

SpaceX Dragon

Future

Boeing CST-100

Future

Sierra Nevada Dream Chaser

OSC Antares/Cygnus SpaceX – Falcon/Dragon
NASAA Human Spaceflight Programs
Beyond Low Earth Orbit

First Orion/SLS
Unmanned Test Flight
Scheduled for 2018

Orion Spacecraft –
Successful Unmanned
Test Flight – December
2014

SLS – To Be
Most Powerful
Rocket Ever Ever Built
NASA Robotic Missions

James Webb Space Telescope - 2018

Asteroid Redirect Mission


Soil Moisture Active Passive 2015

New Horizons – Pluto flyby in 2015

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• NESC created in wake of Columbia accident to provide independent assessment of technical issues for NASA programs and projects

• Scope
  – Independent in-depth technical assessments
  – Independent trend analysis
  – Independent systems engineering analysis
  – Mishap Investigations
  – Design and Flight Readiness Reviews

• Technical Discipline Teams
  – Nationally recognized experts
  – NASA, University, Industry, Gov’t Agencies

Space Shuttle on Mobile Launch Platform
Columbia Accident

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RCC Panel 8 Acoustic Signals

Impact on Panel #8: Broken Panel

Acoustic Emission Sensor Data

Peak g’s

Accelerometers

AE Sensors

Bill Prosser
June 22, 2016
This briefing is for status only and does not represent complete engineering data analysis
• Installed on all Shuttles
• Successfully flown on all flights after *Columbia*
• Detected small impacts during ascent
  – Small amplitude, nondamaging
  – Likely popcorn foam
• Detected several small MMOD impacts
Shuttle Improvements After Columbia

- Improved launch/ascent monitoring – video, radar
- Wing leading edge impact detection system (WLEIDS)
- Orbiter boom sensing system (OBSS)
- On-orbit thermography for damage assessment

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On-Orbit Thermography

Images of wing leading edge

Illustrations of on-orbit thermal camera deployment

Images of RCC samples in payload bay

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• ET TPS (foam) inspection identified as critical need after Columbia accident

• Foam proved very difficult to inspect
  – Low density and highly porous
  – High attenuation for acoustic waves
  – Poor thermal conductor

• NESC funded effort to develop and validate new NDE inspection methods
  – Backscatter Radiography
  – Terahertz Imaging
  – Shearography

Foam Loss on STS-114
Backscatter Radiography

- Collimated beam of x-rays interact with sample molecules
- Backscattered x-rays are emitted (Compton Scattering), possibly after multiple subsequent scattering events, and detected by collimated detectors
- The collimated detectors provide some preferential sensitivity to selected depth
- The x-ray beam and detectors are scanned across the part to generate a 2-D presentation of the internal features of the foam
Defect Indications with BSX

IFR test panel

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Terahertz Imaging

- Terahertz inspection uses high frequency RF energy in the band between microwave and infrared
- Terahertz beam is transmitted through object and reflects off the aluminum substrate
- The terahertz beam is scanned across the part to generate a 2-D presentation of the internal features of the foam
- Due to foam attenuation and system losses, received pulse is around 0.2 THz (2 – 3 THZ transmitted)
- Presence of defects produces changes in amplitude, phase and power spectral density of received beam
- Less attenuation can indicate less material such as the presence of a void but in reality there are complex refracting effects occurring in the foam, making interpretation more challenging

Terahertz Transceiver

Each pixel in the Terahertz image corresponds to an individual waveform
ET Inspection System

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- Overhead Crane
- LOX Feed Line
- LH₂ Tank
- ET
- Scanner
Other Shuttle Inspection Problems

High Pressure Hydrogen Valve Poppet Failure

Radiator Flex Hose Cracking

Crawler-Transporter Shoe Failure

RCS Thruster Cracking

Launch Pad Flame Trench Damage

Shuttle ET Stringer Cracks

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Current accelerometer count on ISS is 81 (SDMS: 33  EWIS: 30  IWIS: 18)
Used to monitor docking/undocking, reboost, crew exercise/activity

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• IWIS data alerted Loads Team to occurrence of anomaly during reboost
• Data from near reboost thrusters used to simulate analytical forcing function to calculate loads used for structural strength and life assessments

Final calculated loads were cleared for upcoming events and 15-year life despite exceeding limit loads
• No impact detection capability available
• Limited leak detection capability
  - Pressure sensors and hatch closing procedure
  - Handheld ultrasonic leak detector
• Distributed Impact Detection System (DIDS)
  • Multiple structure borne (AE) sensors
  • Battery powered data acquisition with wireless data transmission
• Ground testing on ISS Node 1 Structural Test Article, Flight Nodes 2 and 3, and Soyuz
  – Leak signal and background noise assessment
  – Wave propagation studies
• Background ultrasonic noise measurements obtained on ISS
  - Noise levels below required threshold for leak detection
  - Successfully located noise sources

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Note 1: Location Estimates for Sounds Recorded between 12 AM and 3 AM GMT on May 15, 2013. Crew was active during this time period.

Note 2: Ultrasonic Background Noise Levels in the US Lab are below critical leak sound levels.
Spacesuit Water Leak
Italian Astronaut (Luca Parmitano)

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NDE of Spacesuit Components

Nuclear Reactor Neutron Ray Source

Neutron CT image of spacesuit component showing contamination

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Orion Heatshield Bond Verification

• New Orion Heatshield Architecture Comprised of Bonded Blocks of TPS Material

• Integrity of Bondline Critical

• Proposed Approach Includes Process Control, Proof Testing, and NDE

• Multiple NDE Methods
  – THz for missing adhesive material
  – UT for disbonds
  – BSX for gap filler voids
Orion Window Inspection

- Verification of Minimal Distortion of Spacecraft Windows
- Optical Interferometer Based Distortion Measurement System
- Custom Scanning System

Forward window composed of two fused silica panes and one acrylic pane.
COPV Liner Inspection

• On pad failure of COPV during engine test
• Need to inspect liners for smaller flaws and to be able to inspect post wrapping/autofrettage/proof testing
• Scanning eddy current system capable of external and internal liner inspection
  – Thickness mapping
  – Flaw detection
• Coupled with pre-existing laser profilometry inspection system
• System development and preliminary evaluation complete
• POD for flaw detection underway
Maximum Height: 162 in. (including sensor)

ID Vertical Stage
Travel increased to 72 in

New OD Vertical Stage
60 in travel

Up to 22 inch dia. liner

Liner Rotation Stage

Liner Thickness Mapping

Flaw Detection
ISS Visiting Vehicle Inspection

• TPS damage due to prolonged exposure to MMOD while docked at ISS is the number one contributor to LOC risk for Soyuz, and future SpaceX Dragon and Boeing CST-100 Commercial Crew vehicles

• Assessing approaches to minimize risk
  – Development of Damage Assessment and Decision Plan
  – Evaluating various inspection/detection methodologies
    • On-board impact detection
    • Survey inspection using currently available ISS assets
    • New technologies for focused inspections
# Soyuz Focused Inspection Assessment

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<th>Improved Sensors:</th>
<th>Risk Addressed</th>
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<th>Other Applications</th>
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<tr>
<td>- Wrist/elbow add-on HD</td>
<td>MLI Thru Hole</td>
<td>Too far away</td>
<td>Use EHDC?</td>
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<tr>
<td>- CSA – DDVS on SSRMS</td>
<td>IR and LIDAR</td>
<td>Need BXray</td>
<td>SSRMS Ops</td>
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<tr>
<td>- AS&amp;E Mini-Z Xray BXray</td>
<td>Testing Needed</td>
<td>Thru hole in substrate - size needs to be Validated</td>
<td>SSRMS Integ</td>
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<tr>
<td>- TEK-84 BXray System</td>
<td>-</td>
<td>COTS - needs interface dev</td>
<td>ISS &amp; C. Crew</td>
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<tr>
<td>- Nuexact BXray - NAVAIR</td>
<td>-</td>
<td>Miniaturize Scanner cert</td>
<td></td>
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<tr>
<td>- POC BXay – L.A. or LaRC</td>
<td>-</td>
<td>Development Needed</td>
<td></td>
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<tr>
<td>- IR Camera</td>
<td>Tests needed - ability to find MLI thru-holes</td>
<td>Aluminized MLI Blocks Energy</td>
<td></td>
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<tr>
<td>- Millimeter Wave Image</td>
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<tr>
<td>- Terrahertz Scanner</td>
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**EVA-based**

| - Borescope | Push thru hole | COTS | ISS&C. Crew |
| - Backscatter X-ray | Hand-held | COTS | ISS&C. Crew |

**Free-flyer**

| - Japanese Robotic Arm | Too Far Away | Safety, Reliability, Comm & Nav |
| - no tether | - | New Infrastructure |

| - SSRMS-based, no tether | Too far Away | Safety |
| - SSRMS-based - tether | Mini B-Xray? | BXray Dev |
| - “Independent” Mission | Too Far Away | Ext to Int Damage |

**External Robots:**

| R2, JPL, SRI | Sensor Dependent | Long Term Investigation? |

## Bill Prosser

June 22, 2016
Summary Comments

• Nondestructive Measurement Techniques play a crucial role in NASA spaceflight programs
• Often key aspect in providing flight rationale
• Will be increasingly important as NASA moves to longer duration missions beyond low earth orbit
• Acknowledge the support of the NESC NDE TDT who provide a truly outstanding resource to the Agency to enable safe flight!
Bat-ronaut

STS-119/15A
FD 02 Execute Package

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Approved by FAO: Terry Clancy

Last updated: Mar 16 2009 12:59PM GMT
JEDI (Joint Execute package Development and Integration), v2.04.0003

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