NASA Engineering and Safety Center

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

ISS

Russian
Soyuz

US ISS Cargo Delivery

SpaceX
Dragon

Future

Boeing
CST-100

Future

OSC
Antares/Cygnus

SpaceX – Falcon/Dragon

Sierra Nevada Dream Chaser
First Orion/SLS Unmanned Test Flight Scheduled for 2018


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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NASA Engineering and Safety Center

• 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

[Image: Space Shuttle on Mobile Launch Platform]
Columbia Accident

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Columbia Accident Investigation
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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

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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 RCC samples in payload bay

Images of wing leading edge

Illustrations of on-orbit thermal camera deployment

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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
- 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

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Defect Indications with BSX

IFR test panel
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

Bill Prosser
June 22, 2016

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Other Shuttle Inspection Problems

High Pressure Hydrogen Valve Poppet Failure
Radiator Flex Hose Cracking
RCS Thruster Cracking
Launch Pad Flame Trench Damage
Crawler-Transporter Shoe Failure
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
ISS MMOD Impact and Leak Detection

- 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
**Ultrasonic Background Noise Tests**

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.

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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
COPV Liner Inspection System

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
<table>
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<th>Improved Sensors:</th>
<th>Risk Addressed</th>
<th>Cost &amp; Sched</th>
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<td>- Wrist/elbow add-on HD</td>
<td>MLI Thru Hole</td>
<td>Too far away</td>
<td>Use EHDC?</td>
<td>SSRMS Ops</td>
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<td>- CSA – DDVS on SSRMS</td>
<td>IR and LIDAR</td>
<td>Need BXray</td>
<td>2018 is late</td>
<td>SSRMS Integ</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>COTS - needs interface dev</td>
<td>SSRMS Integration on FGB PDGF and SPDM Ops</td>
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<tr>
<td>- TEK-84 BXray System</td>
<td>-</td>
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<td>ISS &amp; C. Crew</td>
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<td>- Nuisafe BXray - NAVAIR</td>
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<td>ISS Radiator</td>
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<td>- POC BXay – L.A. or LaRC</td>
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<td>Tiled TPS</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>Development Needed</td>
<td>ISS Radiator</td>
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<tr>
<td>- Millimeter Wave Image</td>
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<td>- Terrahertz Scanner</td>
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<td>ISS&amp;C. Crew</td>
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<td>EVA-based</td>
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<tr>
<td>- Borescope</td>
<td>Push thru hole</td>
<td>COTS</td>
<td>EVA not practical</td>
<td>ISS&amp;C. Crew</td>
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<td>- Backscatter X-ray</td>
<td>Hand-held</td>
<td>COTS</td>
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<td>Free-flyer</td>
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<td>- Japanese Robotic Arm</td>
<td>Too Far Away</td>
<td>Safety, Reliability, Comm &amp; Nav</td>
<td>New Infrastructure</td>
<td>Many</td>
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<td>- no tether</td>
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<tr>
<td>- SSRMS-based, no tether</td>
<td>Too far Away</td>
<td>Safety</td>
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<td>- SSRMS-based - tether</td>
<td>Mini B-Xray?</td>
<td>BXray Dev</td>
<td>-</td>
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<tr>
<td>“Independent” Mission</td>
<td>Too Far Away</td>
<td>Ext to Int Damage</td>
<td>-</td>
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<tr>
<td>External Robots: R2, JPL, SRI</td>
<td>Sensor Dependent</td>
<td>Long Term Investigation?</td>
<td>Intensive Robotic Ops</td>
<td>Limited locations</td>
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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 18 2009 12:59PM GMT
JEDI (Joint Execute package Development and Integration), v.2.04.0003

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