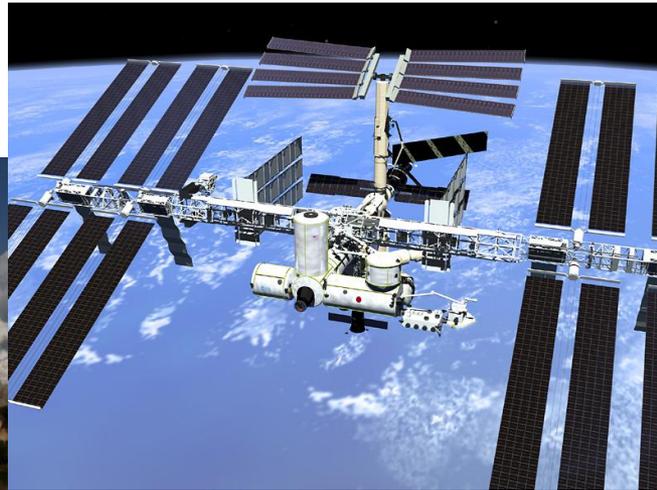


Applications of Advanced Nondestructive Measurement Techniques to Address Safety of Flight Issues on NASA Spacecraft



3rd IEEE International Workshop on Metrology for Aerospace
Florence, Italy

Outline

Bill Prosser

June 22, 2016

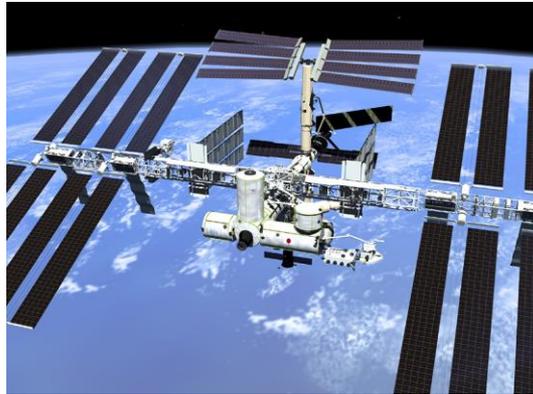
- NASA Spaceflight Programs
 - Human
 - Robotic
- NESC and the NESC NDE TDT
- Examples of Critical Safety of Flight Issues Resolved by NESC NDE TDT
 - Shuttle
 - ISS
 - Orion
 - Commercial Crew/Cargo

NASA Human Spaceflight Programs

Low Earth Orbit

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ISS

ISS Crew Transportation



Russian
Soyuz



SpaceX
Dragon



Future
Boeing
CST-100



OSC

Antares/Cygnus SpaceX – Falcon/Dragon

US ISS Cargo Delivery



Future



Sierra Nevada Dream Chaser

NASA Human Spaceflight Programs Beyond Low Earth Orbit

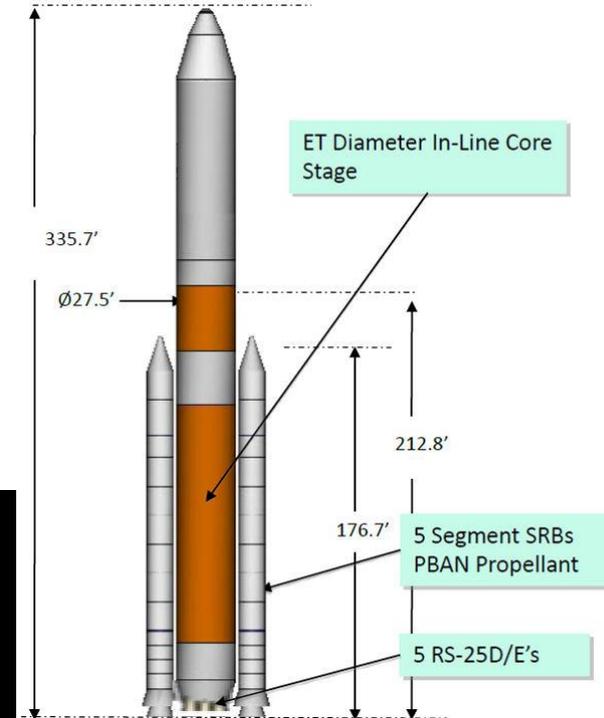
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Orion Spacecraft –
Successful Unmanned
Test Flight – December
2014

First Orion/SLS
Unmanned Test Flight
Scheduled for 2018

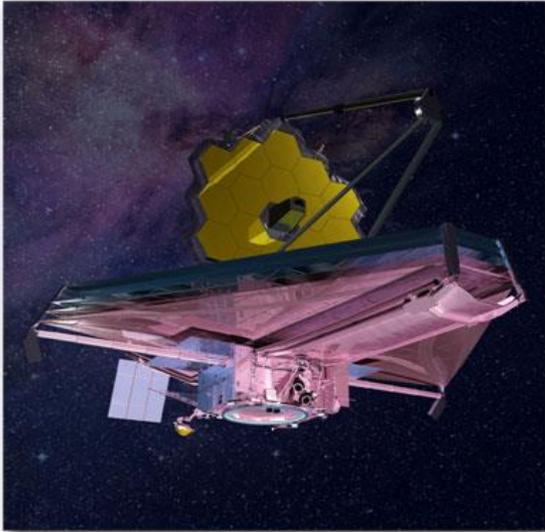


SLS – To Be
Most Powerful
Rocket Ever Built

NASA Robotic Missions

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James Webb Space Telescope
- 2018



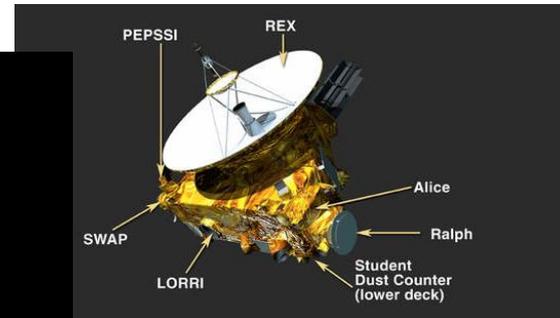
Asteroid Redirect
Mission



Juno – Jupiter Arrival
in 2016



Soil Moisture
Active Passive
2015



New Horizons – Pluto
flyby in 2015

NASA Engineering and Safety Center

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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

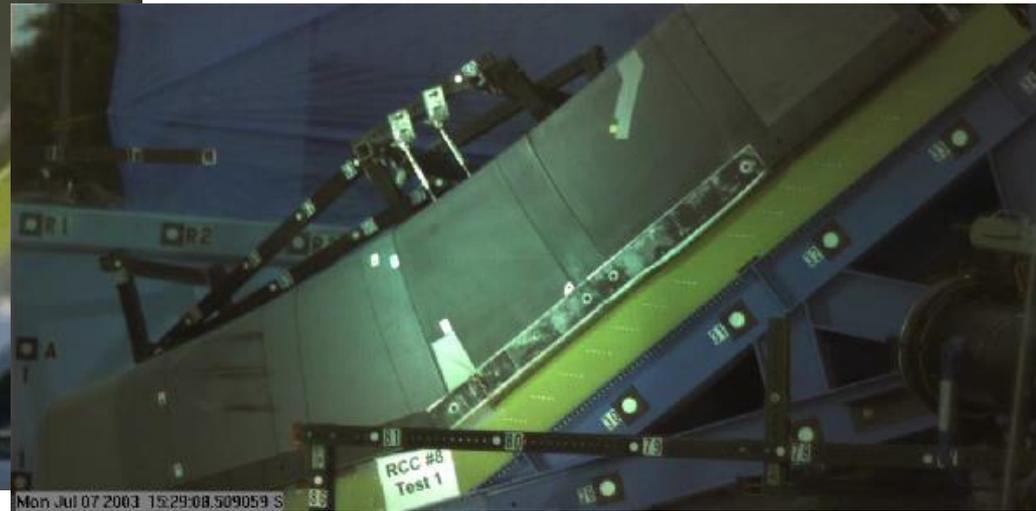


Space Shuttle on Mobile
Launch Platform

Columbia Accident Investigation

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RCC Panel 8 Acoustic Signals

Bill Prosser

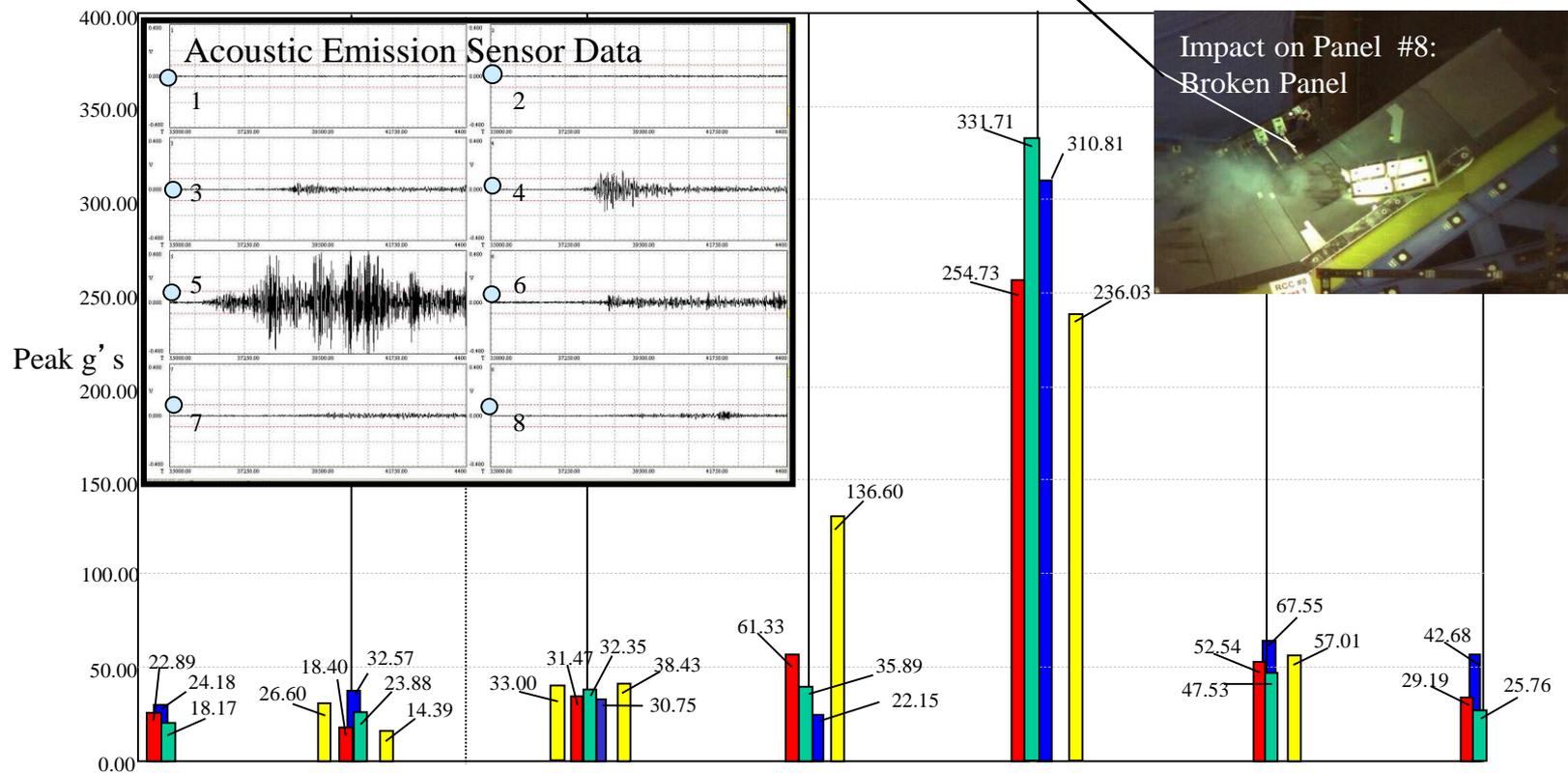
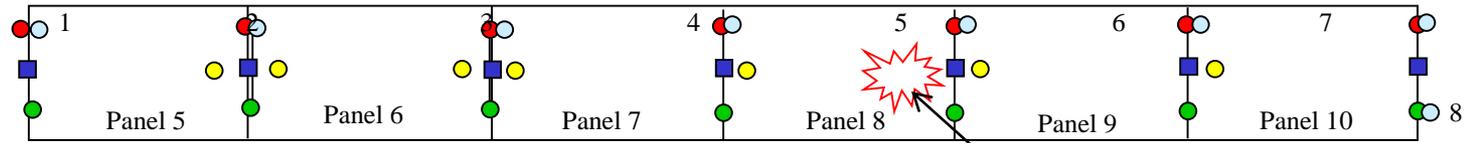
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AE Sensors

Accelerometers



- J1
- J2
- J3
- Triax

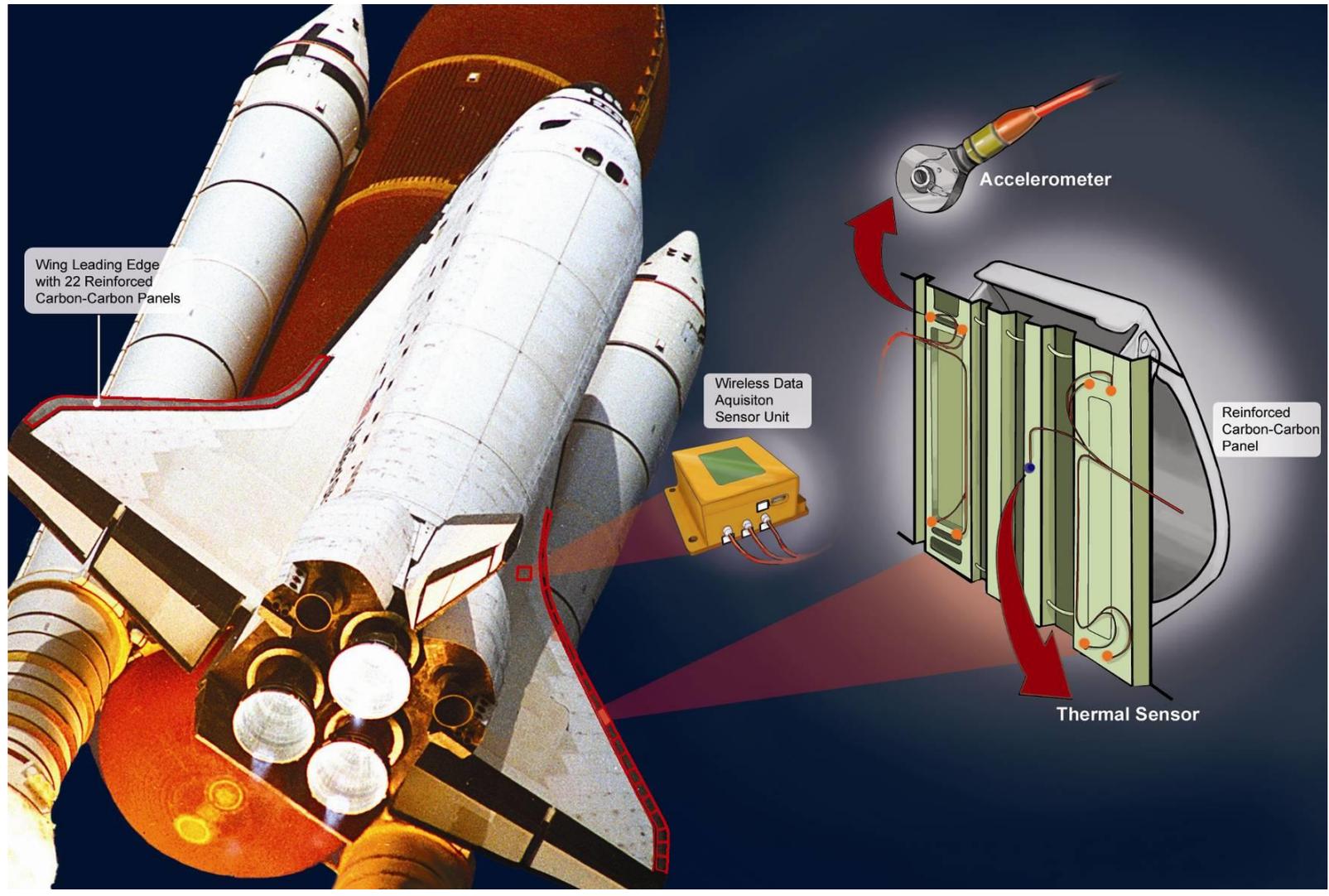


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WLEIDS

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WLEIDS Operations

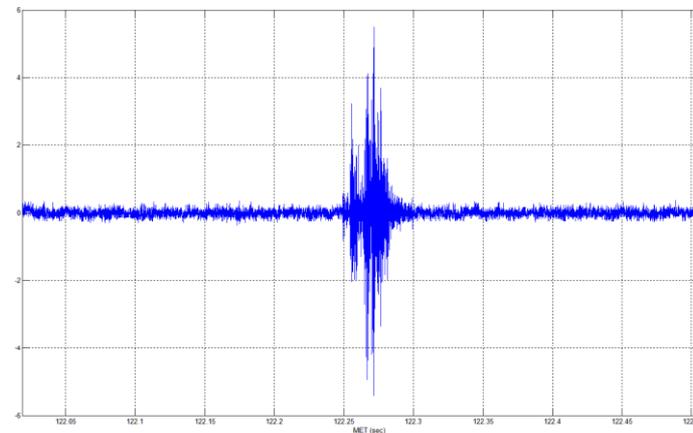
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- Installed on all Shuttles
- Successfully flown on all flights after *Columbia*
- Detected small impacts during ascent
 - Small amplitude, nondamaging
 - Likely popcorn foam
- Detected several small MMOD impacts



Sensors and Data Recorder in Wing



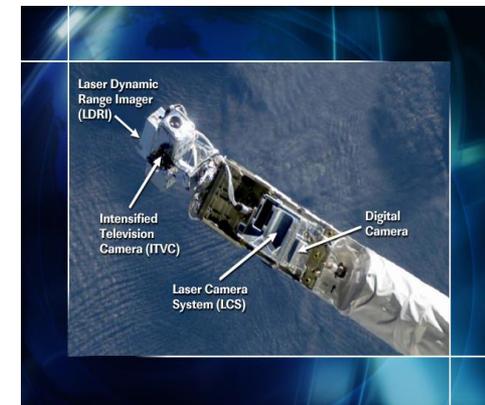
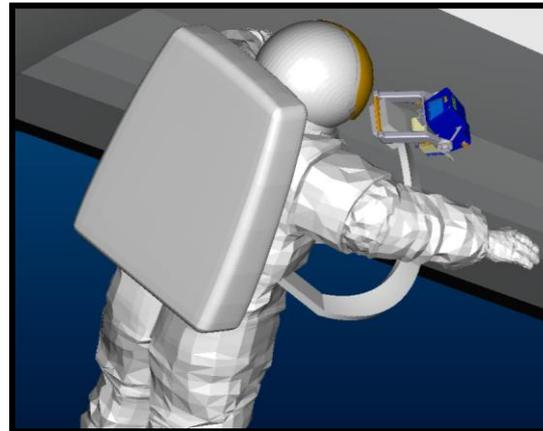
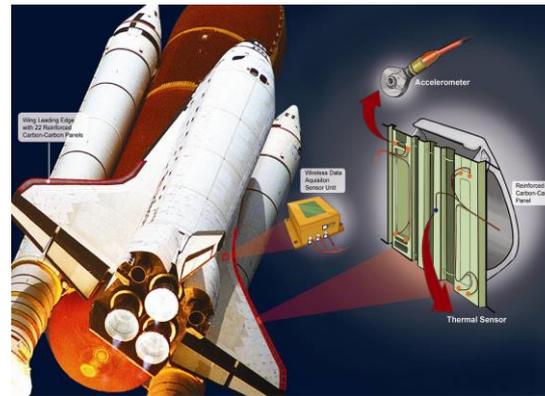
WLEIDS probable impact signal

Shuttle Improvements After Columbia

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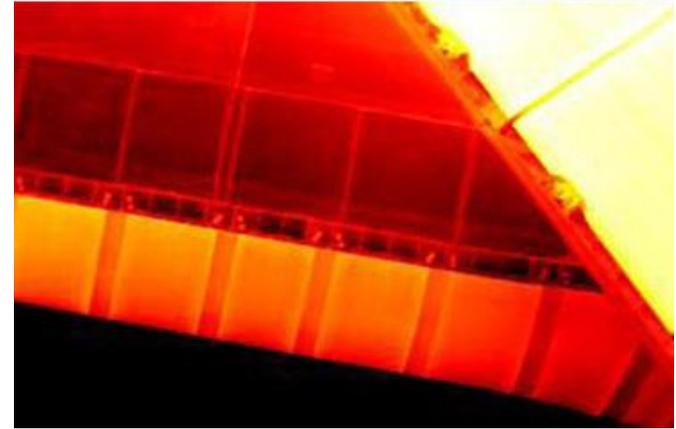
- Improved launch/ascent monitoring
 - video, radar
- Wing leading edge impact detection system (WLEIDS)
- Orbiter boom sensing system (OBSS)
- On-orbit thermography for damage assessment



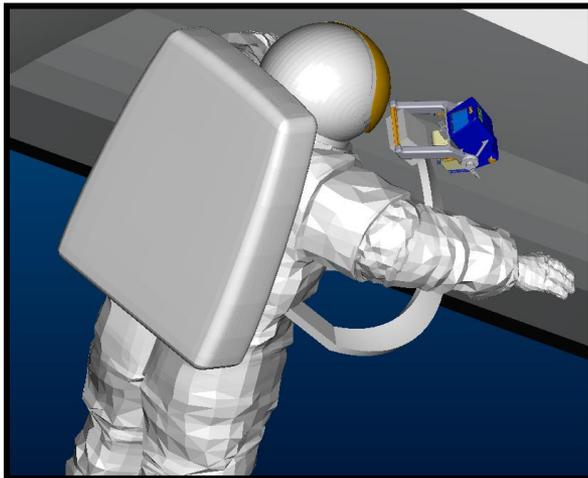
On-Orbit Thermography

Bill Prosser

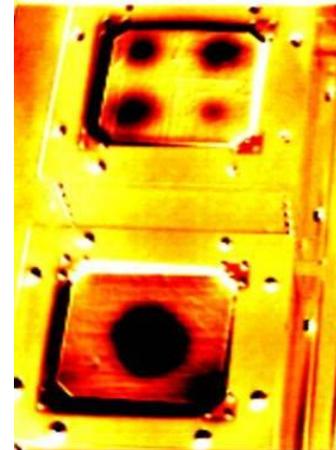
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Images of wing leading edge



Illustrations
of on-orbit
thermal
camera
deployment



Images
of RCC
samples in
payload bay

Shuttle External Tank TPS NDE

Bill Prosser

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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



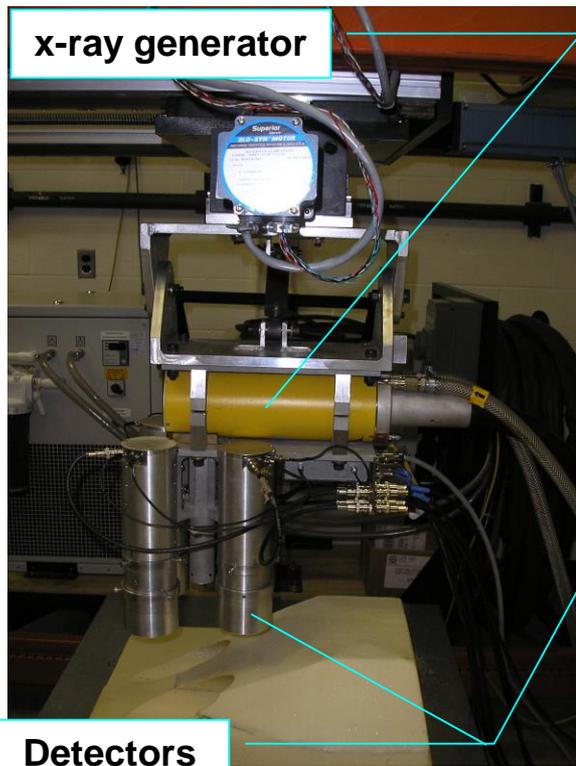
Foam Loss on STS-114

Backscatter Radiography

Bill Prosser

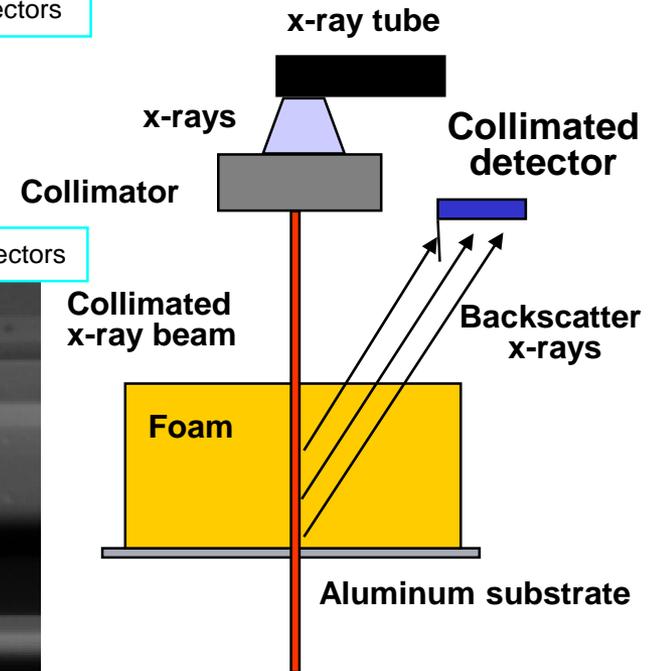
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- Collimated beam of x-rays interact with sample molecules
- Backscattered x-rays are emitted (Compton Scattering), possibly after multiple subsequent scattering events, and detected by collimated detectors
- The collimated detectors provide some preferential 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



NaI detectors

YSO detectors

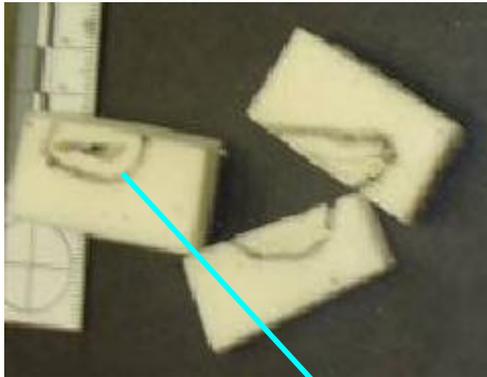


BSX Image

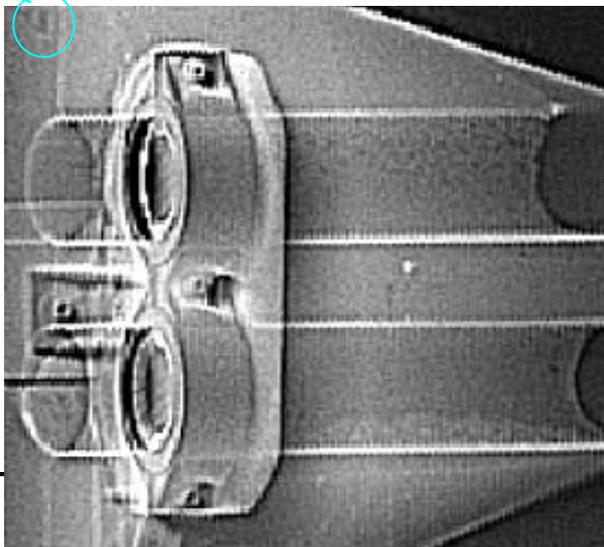
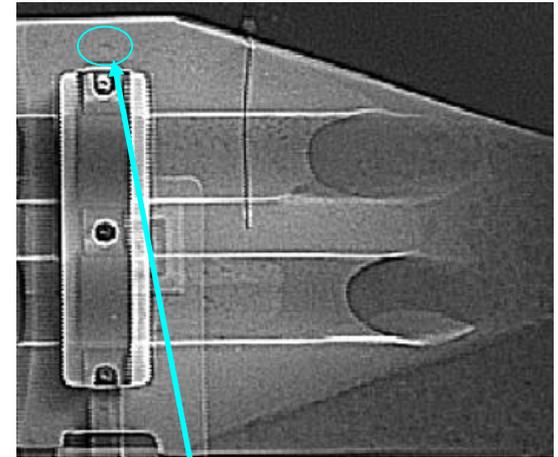
Defect Indications with BSX

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IFR test panel



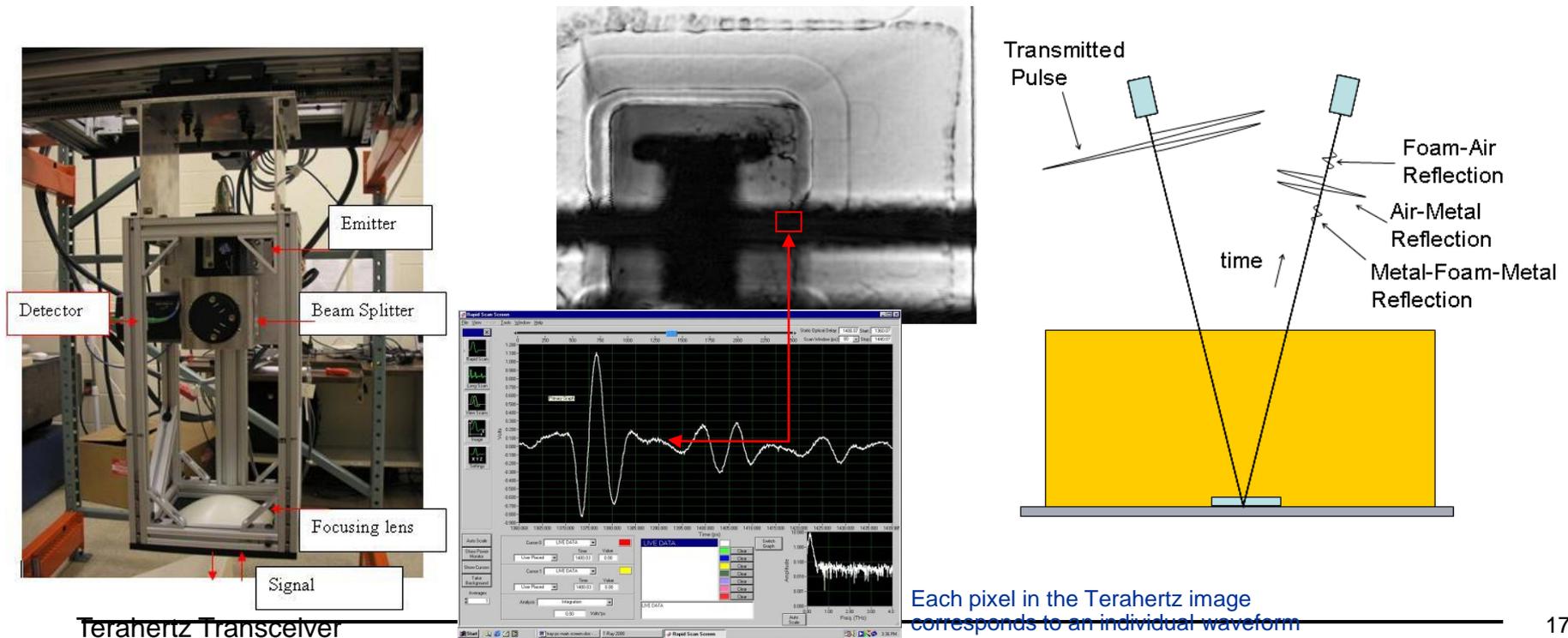
represent complete engineering data analysis

Terahertz Imaging

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- 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

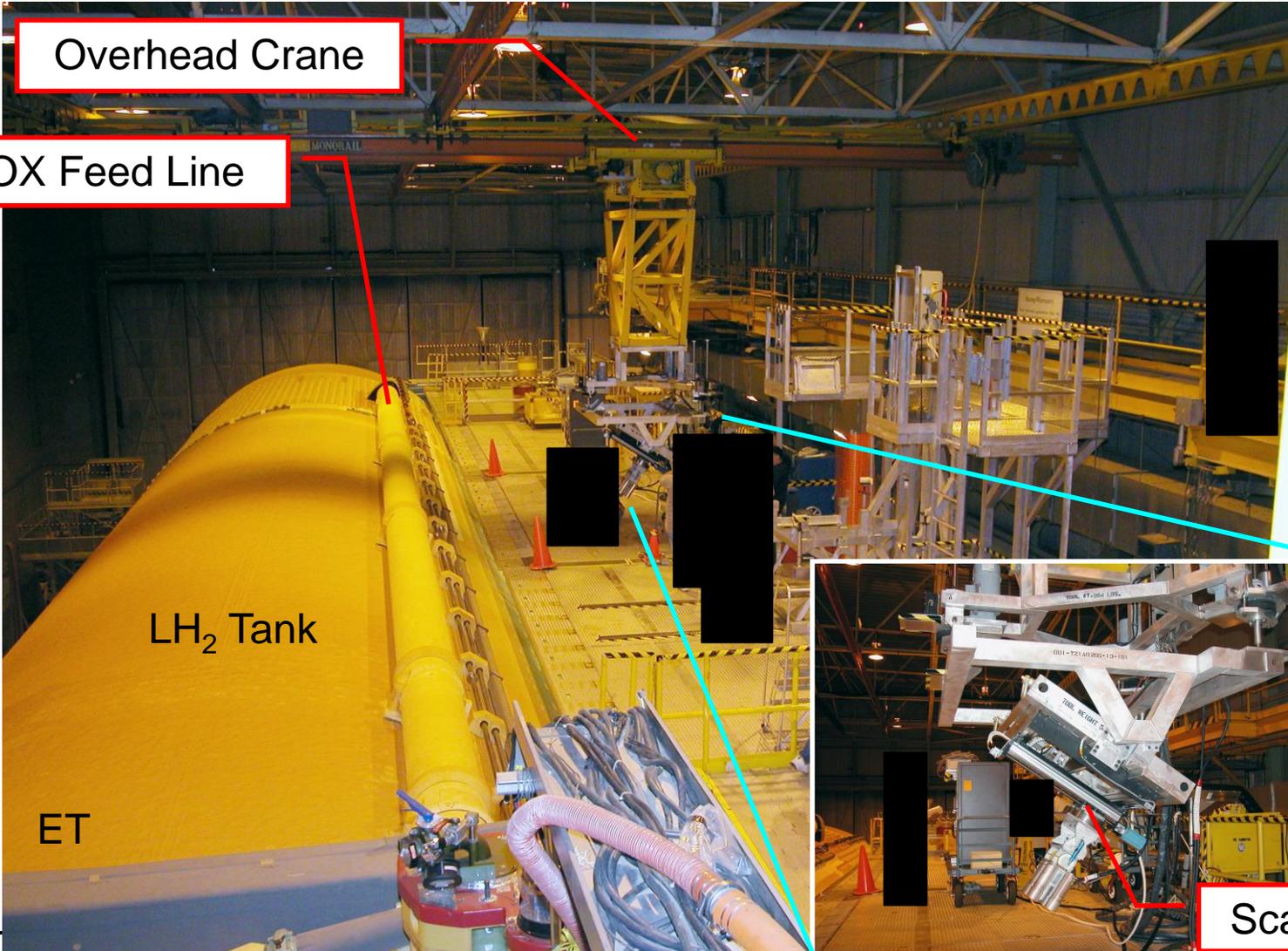


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ET Inspection System

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Overhead Crane

LOX Feed Line

LH₂ Tank

ET

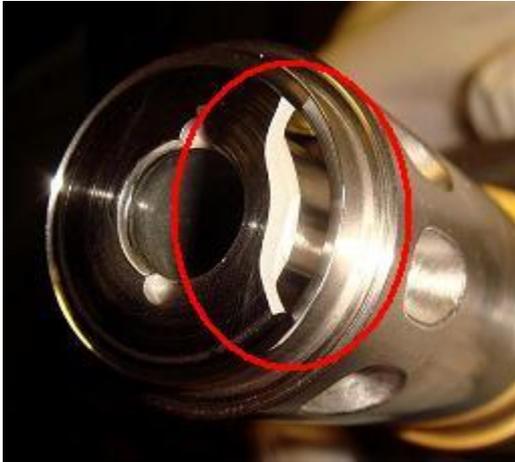
Scanner

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Other Shuttle Inspection Problems

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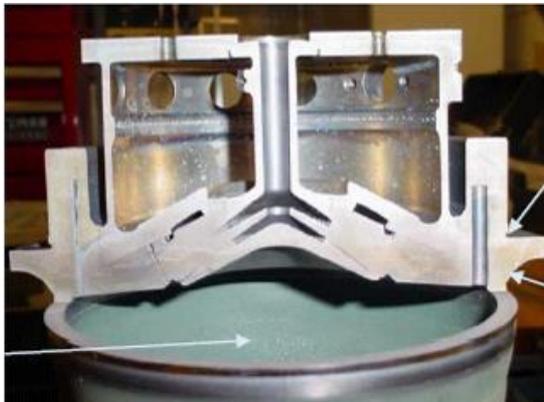
High Pressure Hydrogen
Valve Poppet Failure



Radiator Flex Hose Cracking



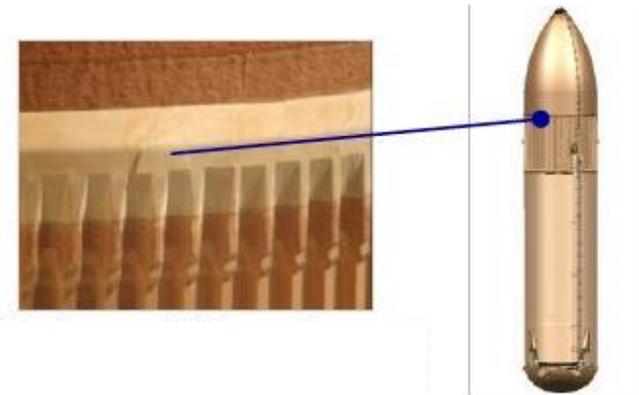
Crawler-Transporter Shoe Failure



RCS Thruster Cracking



Launch Pad Flame Trench Damage

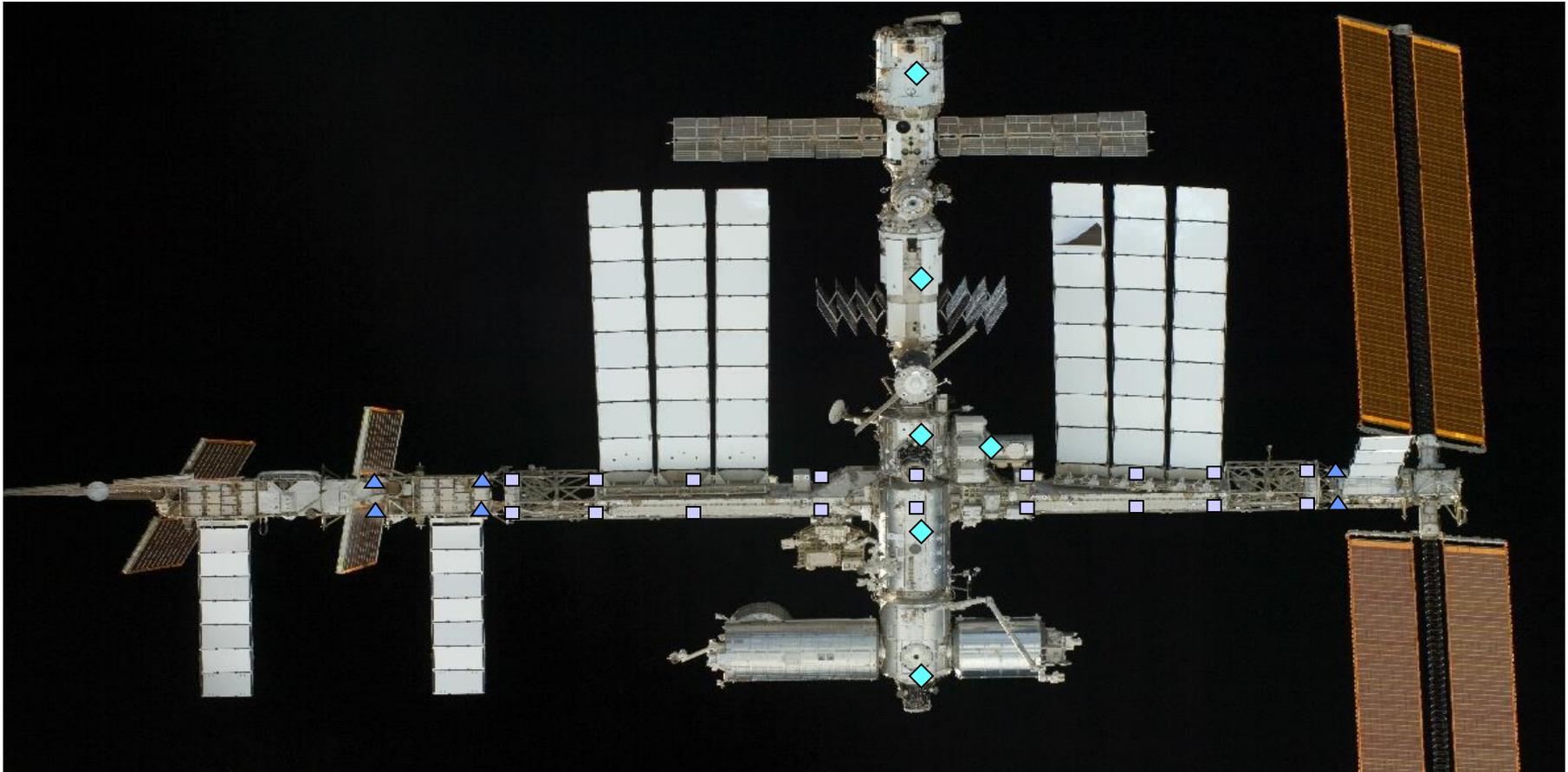


Shuttle ET Stringer Cracks

International Space Station Structural Health Monitoring

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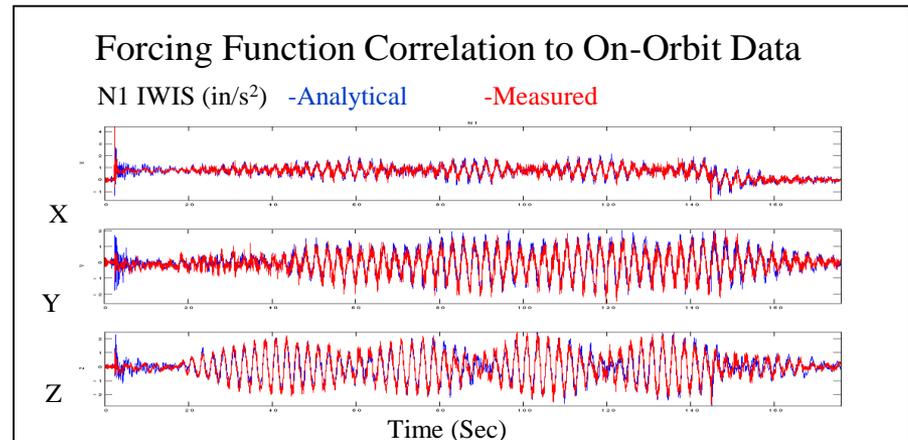
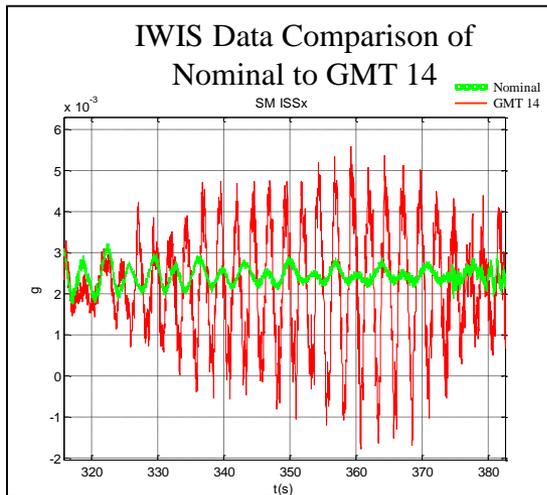
◆ IWIS □ SDMS ▲ EWIS
Current accelerometer count on ISS is 81 (SDMS: 33 EWIS: 30 IWIS: 18)
Used to monitor docking/undocking, reboost, crew exercise/activity

ISS Reboost Anomaly

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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



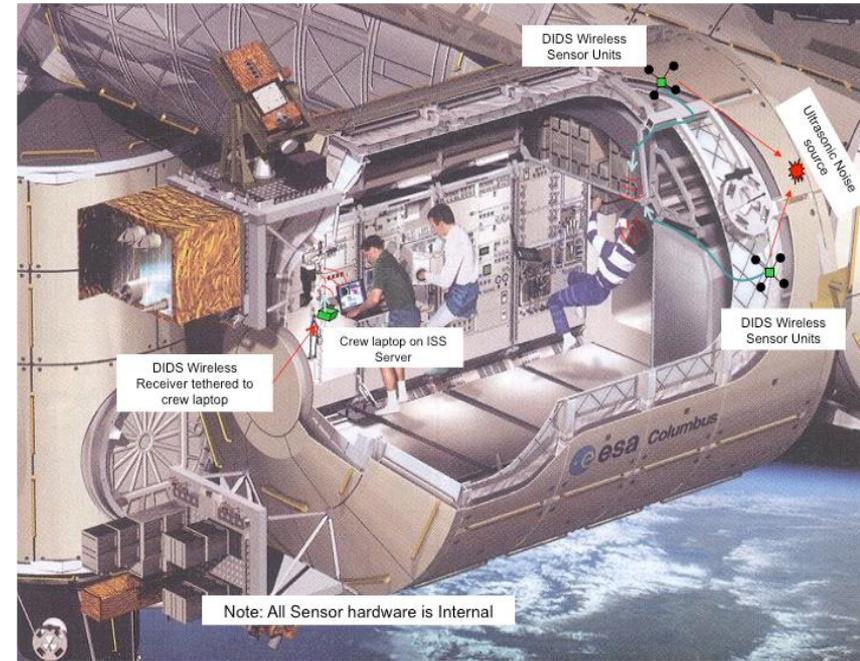
Final calculated loads were cleared
for upcoming events and 15-year life
despite exceeding limit loads

ISS MMOD Impact and Leak Detection

Bill Prosser

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- 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

Bill Prosser

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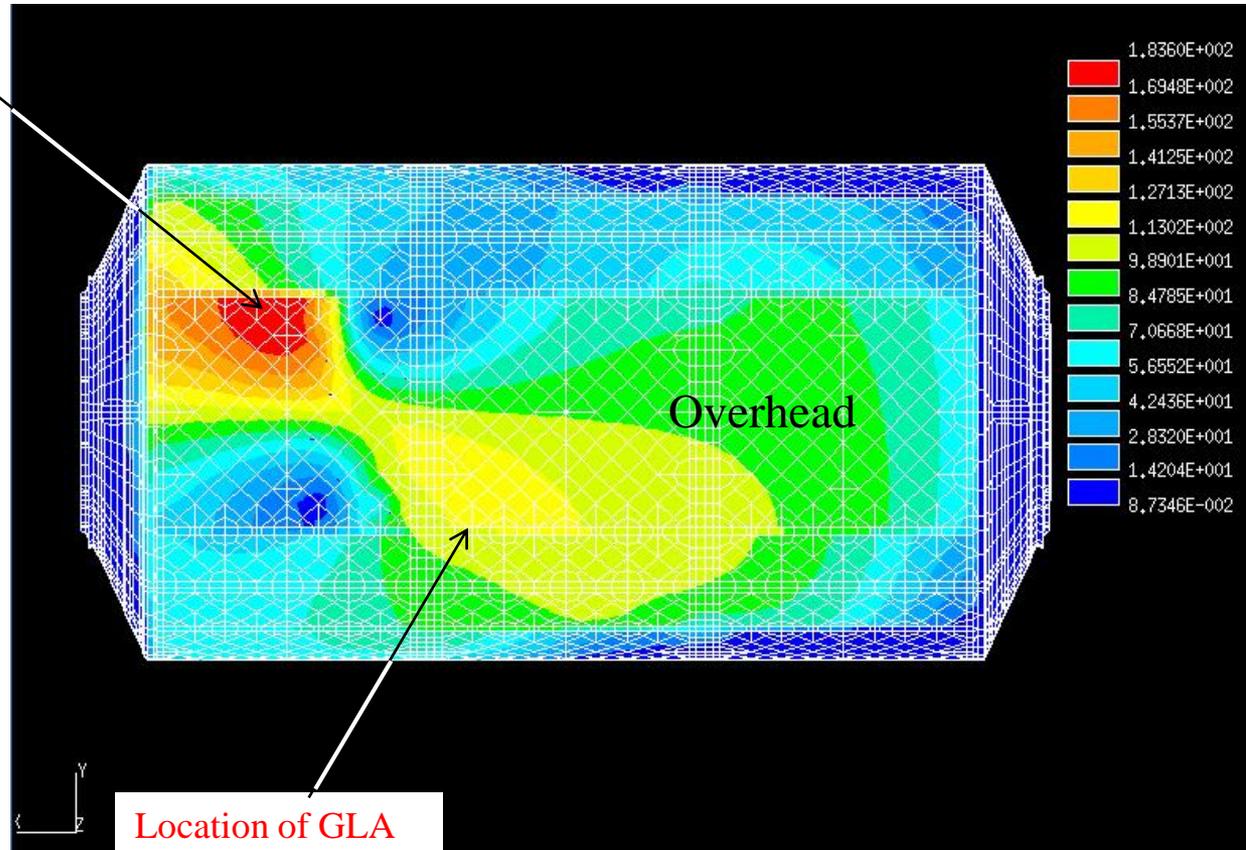
Note 1: Location Estimates for Sounds Recorded between 12 AM and 3 AM GMT on May 15, 2013
Crew was active during this time period.

Starboard

US Lab FEM Model

Location of GLA
(General Luminary Assembly) on LAB1OS1 panel in hallway

Forward



Location of GLA on LAB1OP3 panel in hallway

Port

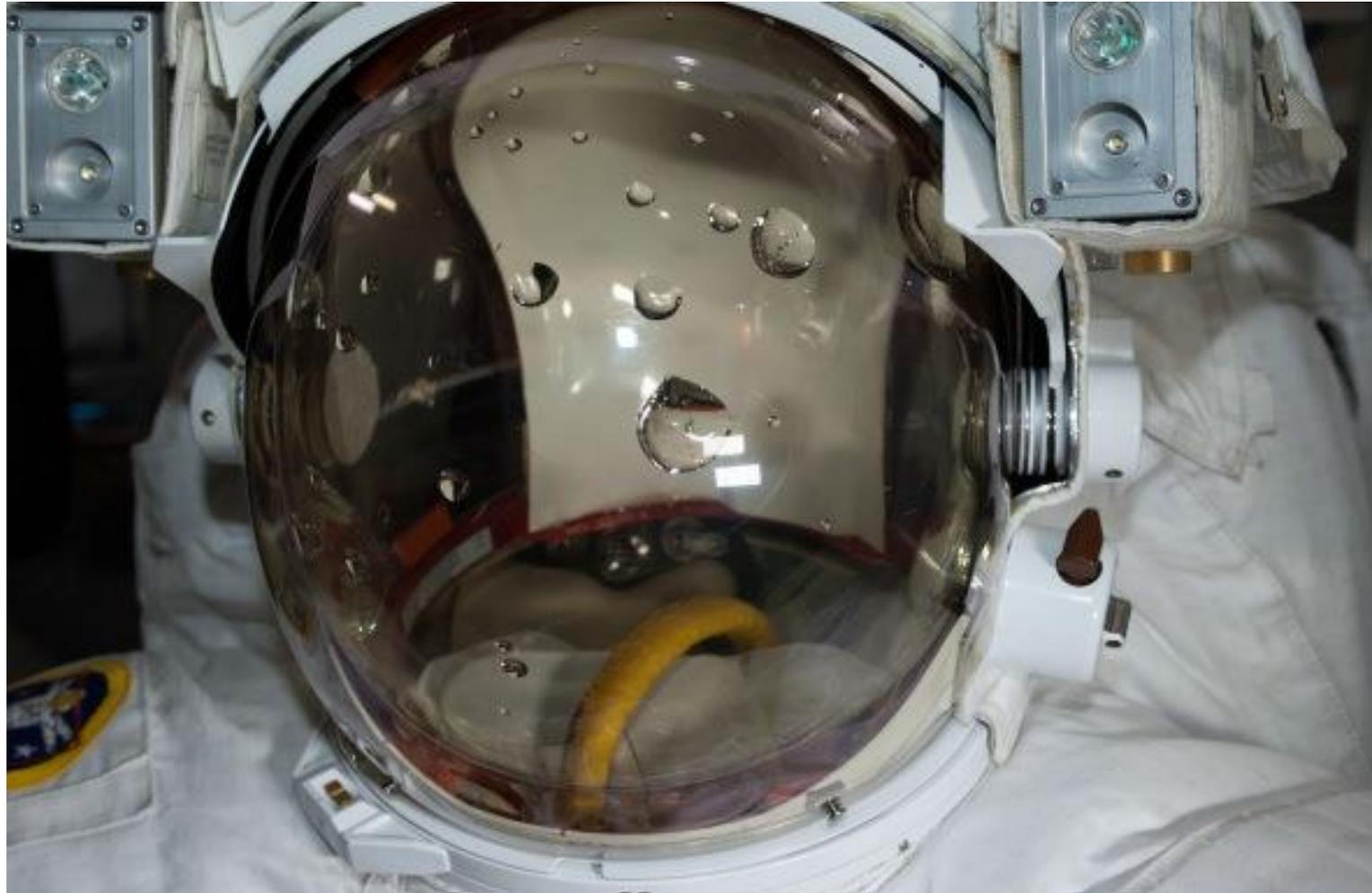
Aft

Note 2: Ultrasonic Background Noise Levels in the US Lab are below critical leak sound levels.

Spacesuit Water Leak Italian Astronaut (Luca Parmitano)

Bill Prosser

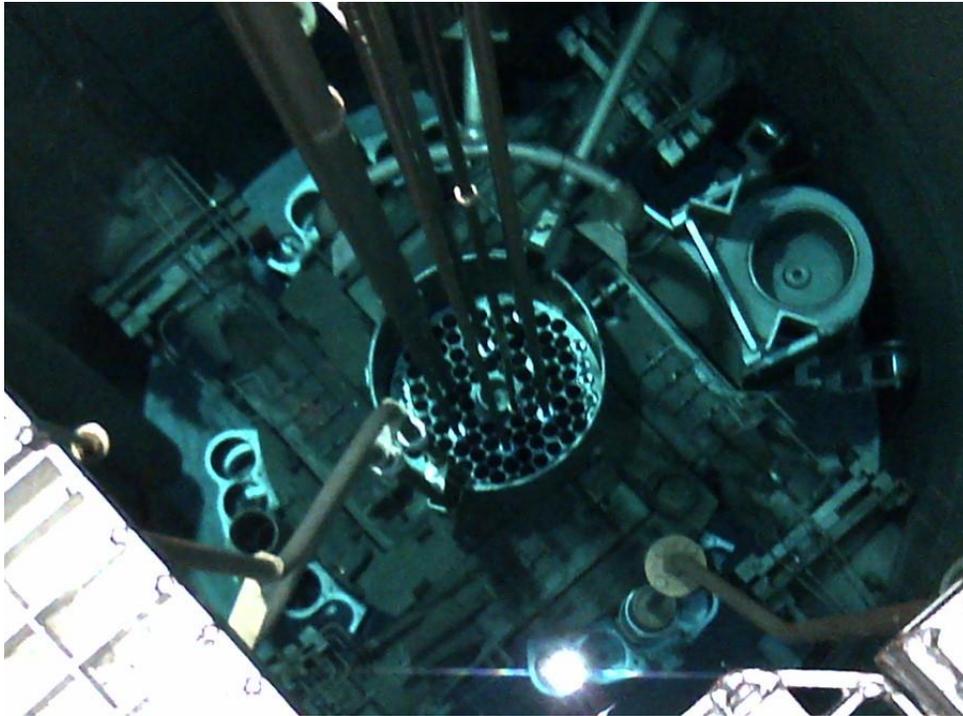
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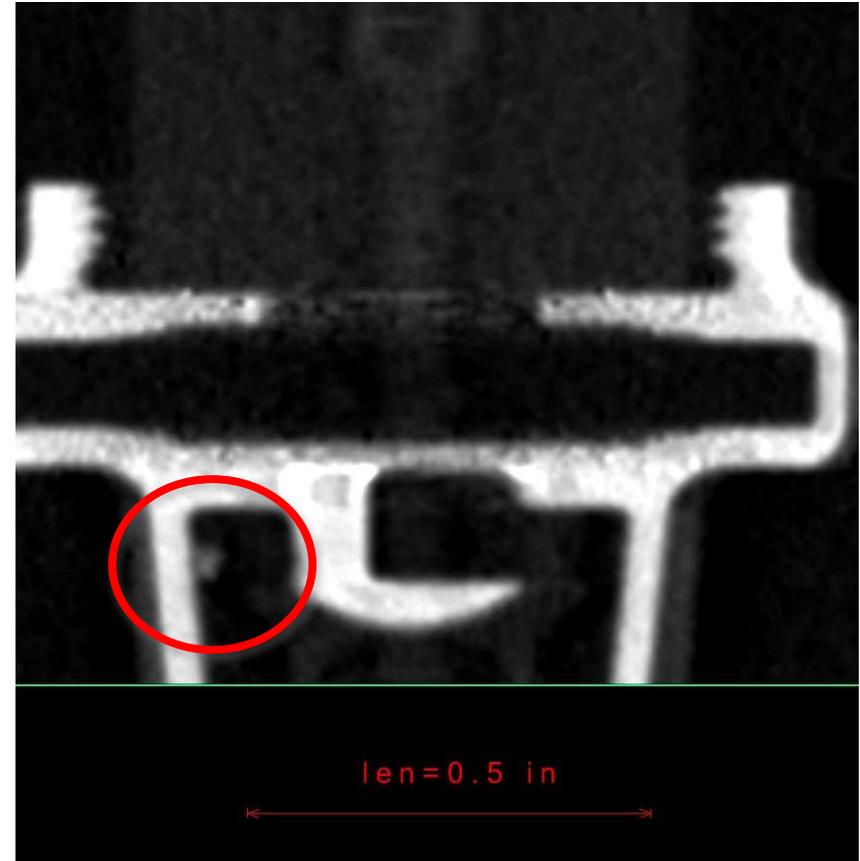
NDE of Spacesuit Components

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Nuclear Reactor Neutron Ray Source



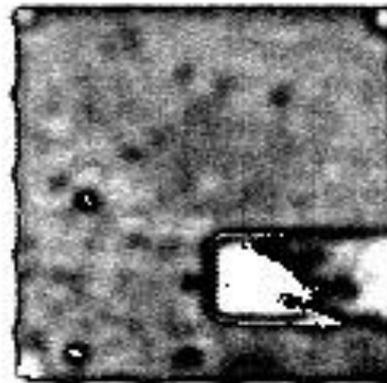
Neutron CT image of spacesuit component showing contamination

Orion Heatshield Bond Verification

Bill Prosser

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- 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

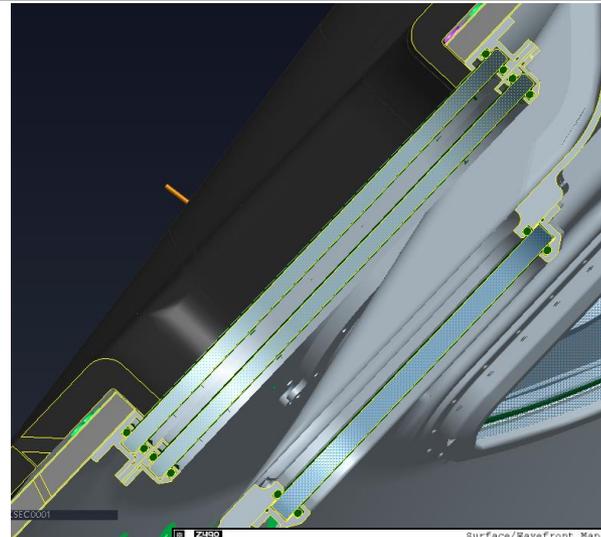


Orion Window Inspection

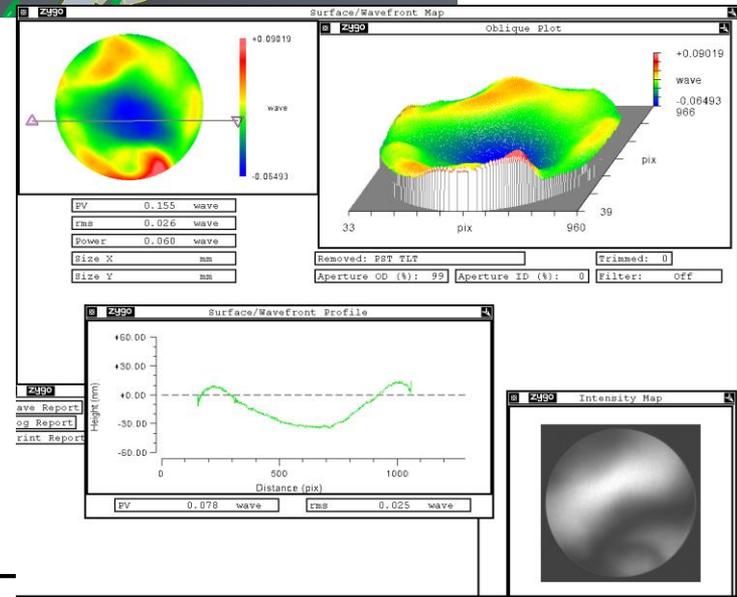
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- Verification of Minimal Distortion of Spacecraft Windows
- Optical Interferometer Based Distortion Measurement System
- Custom Scanning System



Forward window composed of two fused silica panes and one acrylic pane



COPV Liner Inspection

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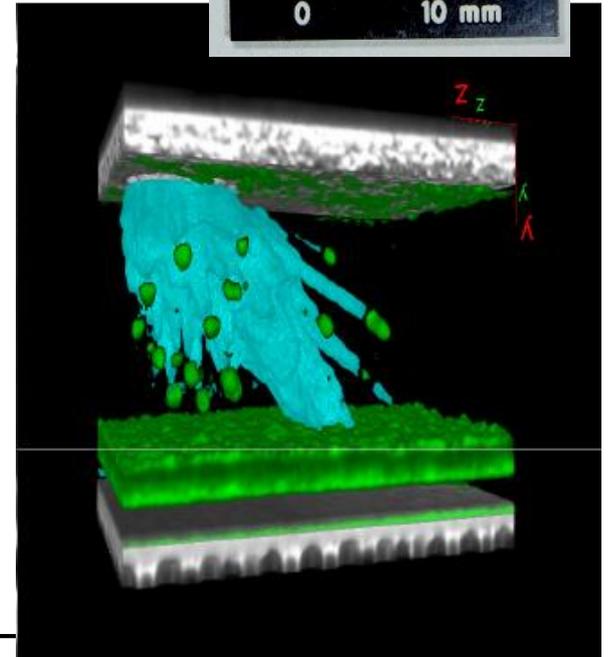
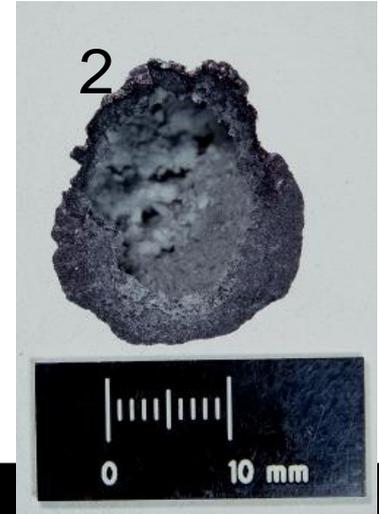
- On pad failure of COPV during engine test
 - Need to inspect liners for smaller flaws and to be able to inspect post wrapping/autofrettage/proof testing
 - Scanning eddy current system capable of external and internal liner inspection
 - Thickness mapping
 - Flaw detection
 - Coupled with pre-existing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

ISS Visiting Vehicle Inspection

Bill Prosser

June 22, 2016

- 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

Bill Prosser

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	Risk Addressed		Effort to Achieve		Other Applications
	MLI Thru Hole	Backshell	Cost & Sched	Ops Effort	
Improved Sensors:					
- Wrist/elbow add-on HD	Too far away		Use EHDC?	SSRMS Ops	Imagery
- CSA – DDVS on SSRMS	IR and LIDAR	Need BXray	2018 is late	SSRMS Integ	Comm Crew
- AS&E Mini-Z Xray BXray	Testing Needed	Thru hole in substrate - size needs to be Validated	COTS - needs interface dev	SSRMS Integration on FGB PDGF and SPDM Ops	ISS & C. Crew
- TEK-84 BXray System					
- NuSAFE BXray - NAVAIR					
- POC BXray – L.A. or LaRC					
- IR Camera					
- Millimeter Wave Image	Tests needed - ability to find MLI thru-holes	Aluminized MLI Blocks Energy	Development Needed		ISS Radiator Tiled TPS
- Terrahertz Scanner					
EVA-based					
- Borescope	Push thru hole		COTS	EVA not practical	ISS&C. Crew
- Backscatter X-ray	Hand-held		COTS		ISS&C. Crew
Free-flyer					
- Japanese Robotic Arm – no tether	Too Far Away		Safety, Reliability, Comm & Nav	New Infrastructure	Many
- 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?	Intensive Robotic Ops	Limited locations

Summary Comments

Bill Prosser

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- 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

Bill Prosser

June 22, 2016

STS-119/15A FD 02 Execute Package

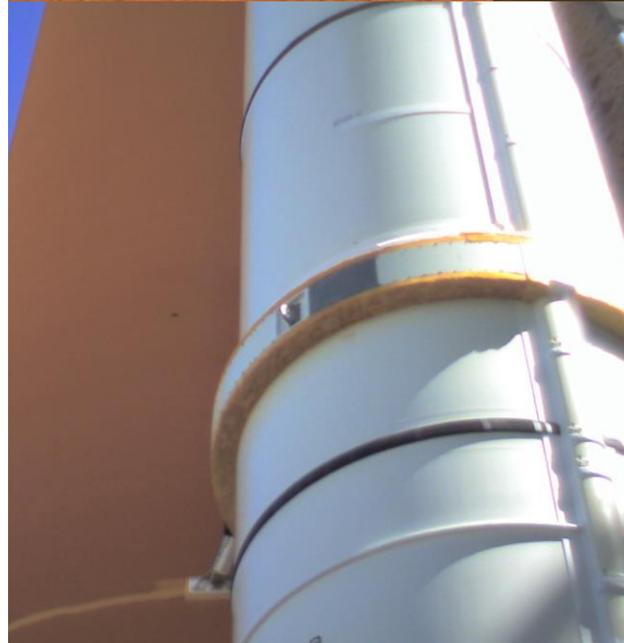


MSG	Page(s)	Title
003A	1 - 13	FD02 Flight Plan Revision (pdf)
004A	14 - 15	FD02 Mission Summary (pdf)
005	16	FD02 Transfer Prep (pdf)
006	17 - 23	T0 Umbilical Area Inspection Procedure (pdf)

Approved by FAO: Terry Clancy

Handwritten signature of Terry Clancy.

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



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