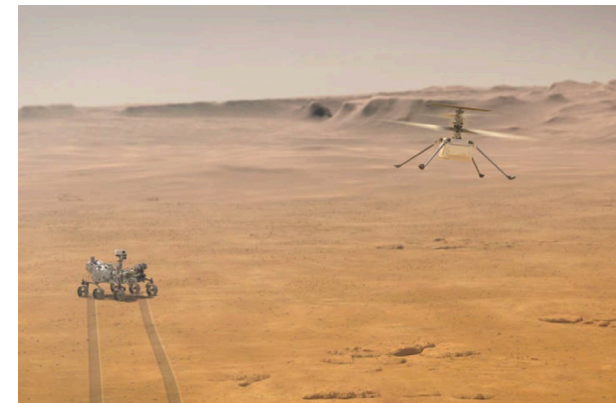
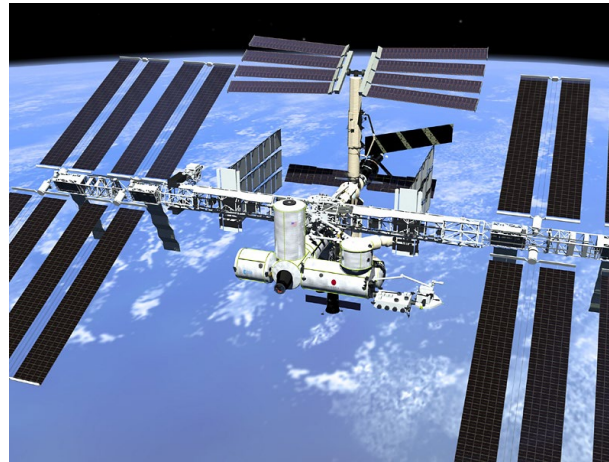




NDE Engineering for Improved Reliability and Safety of Launch Vehicles and Spacecraft

Bill Prosser

November 2, 2022



2022 ASNT Fall Conference



35 Years of NASA NDE Engineering

Bill Prosser

November 2, 2022

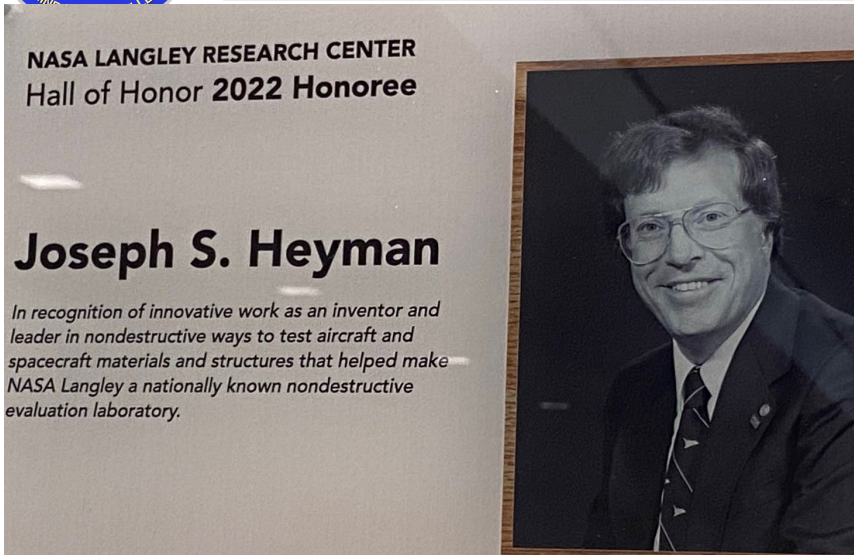
- Outstanding People
 - Leading NDE experts from NASA and other Government Agencies, Industry and Academia
 - Mentors, colleagues, collaborators and most importantly, life-long friends!
- Incredible Opportunities
 - More than 150 NDE issues, many critical safety of flight
 - All NASA Missions and Programs
 - Human Spaceflight
 - Robotic Spaceflight
 - Aeronautics Programs



Introduction to NDE

Bill Prosser

November 2, 2022



- Founded NASA Langley NDE Lab
 - One of Nations leading NDE labs
- W&M Senior Physics Project – Introduction to UT Lab Manual
- Founded JHU Materials Science Dept. and CNDE
 - List of former students is “Who’s who in NDE”!
- Master’s Project – Characterization of Nonlinear Properties of Composites



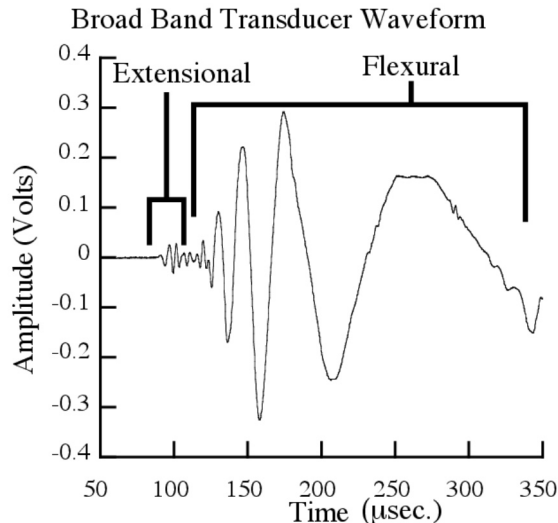
PhD Research

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- Mike Gorman (and fellow student Steve Ziola)
 - Professor at Nebraska and NPS
 - Founded Digital Wave Corporation (DWC)
- Plate mode AE propagation in aluminum plates and composite plates and tubes
 - Contributed to the founding of the field of “Modal Acoustic Emission (MAE)”
 - DWC led the development of MAE instrumentation and applications
 - DOT tube trailers, composite SCBA vessels, MMOD impact detection on spacecraft, composite damage mode identification
 - MAE implemented by other AE vendors





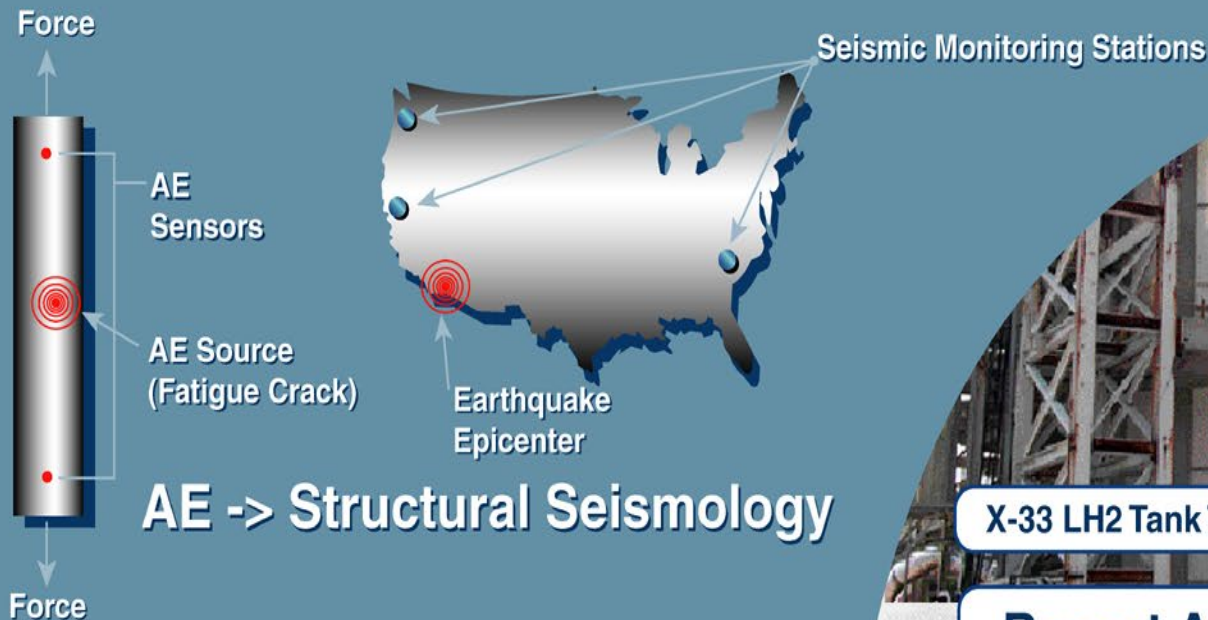
Many, Many Collaborators to Follow

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Marv Hamstad, Karen Downs, Eric Madaras, Ajit Mal, John Dorigi, Bob Rogowski, Leland Melvin, Mark Froggatt, Brooks Childers, Jason Moore, Dan Perey, John Bakuckas, Jeff Hinkley, Mike Seale, Barry Smith, Karen Jackson, Meng Chou Wu, Ron Reightler, Don Humes, John Gary, Abby O'Gallagher, Lance Richards, Jack Duke, Ed Baroth, Gary Hunter, Anindya Ghoshal, Tim Brown, Stan Woodard, Sid Allison, Stan DeHaven, Mark Shulz, S. Banerjee, Bill Winfree, Buzz Wincheski, George Studor, Eric Burke, Ajay Koshti, Dave Stanley, Warren Ussery, Shant Kenderian, Toby Case, Jeff Seebo, Reza Zoughi, Boro Djordjevic, Tom Yolken, George Matzkanin, Glen Washer, Pete Parker, Dave Forsyth, Floyd Spencer, James Walker, Sam Russell, Justin Jones, Brad Parker, Patty Howell, Elliott Cramer, Warren Ussery, Ken Hodges, Tony Corak, Bence Bartha, Regor Saulsberry, Charles Nichols, Ward Rummel, Dave Dawicke, and many, many others!

Acoustic Emission (AE) Sensing for IVHM



Sound Generated By Structural Damage

- Fatigue cracking, delamination, impact, etc.

Analysis

- Damage detection
- Location by triangulation
- Identification and assessment

Advantages for IVHM

- In-situ rather than post-flight inspection
- Global monitoring rather than point scanning

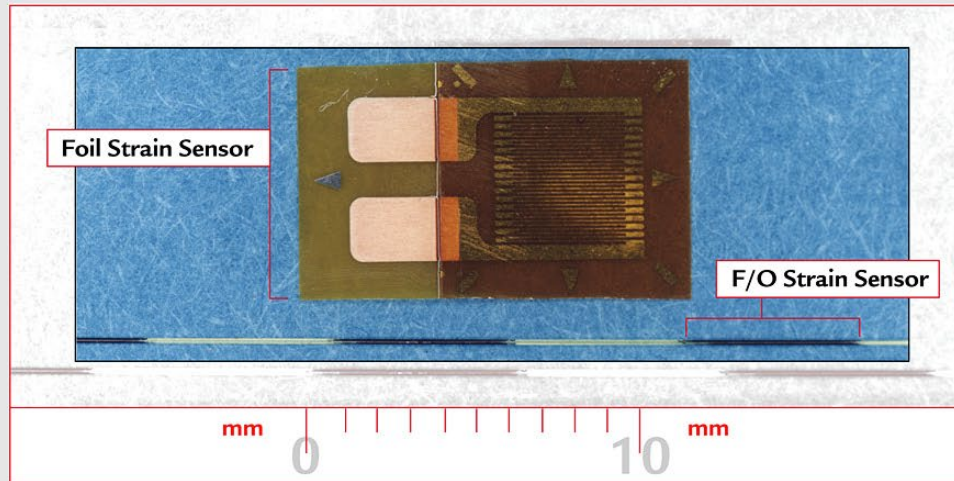
X-33 LH2 Tank Testing

Recent Aerospace Applications

F-16 Testing

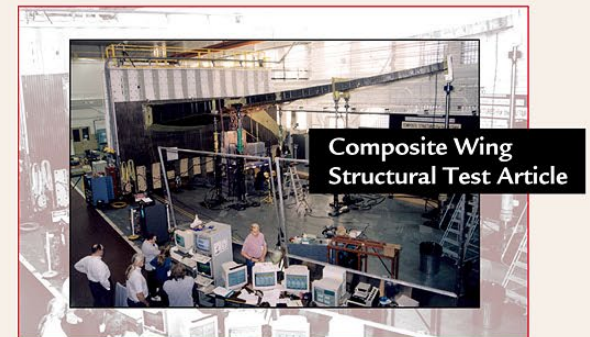
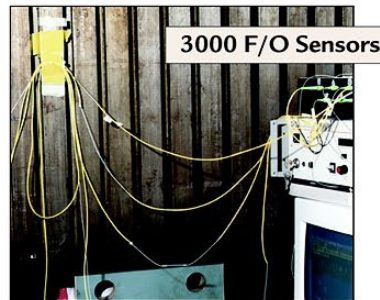
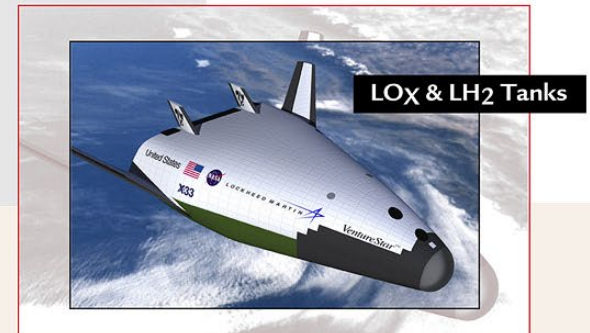


Distributed Fiber-Optic (F/O) Sensing for Structures IVHM



High Density Structural Sensors

- 10,000 Sensors < 1 pound
- Strain, Temperature, & Hydrogen (Propellant Leaks)
- Future Research - Vibration, Shape, Acoustic Emission, Chemistry (Corrosion)
- < \$10/Sensor



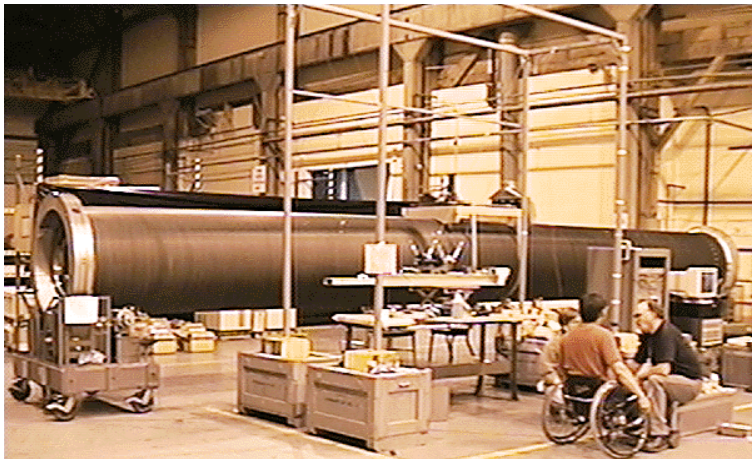
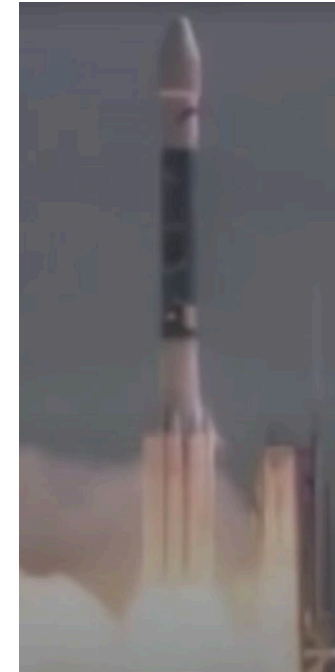


1997 Delta II Accident Investigation

Bill Prosser

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- Air Force, Alliant Tech Systems, Aerospace Corporation, and NASA
- 20 inch diameter ring specimen
 - EDM holes through ply
 - Ply wrinkles
- Impacted full scale rocket motors





Columbia Accident

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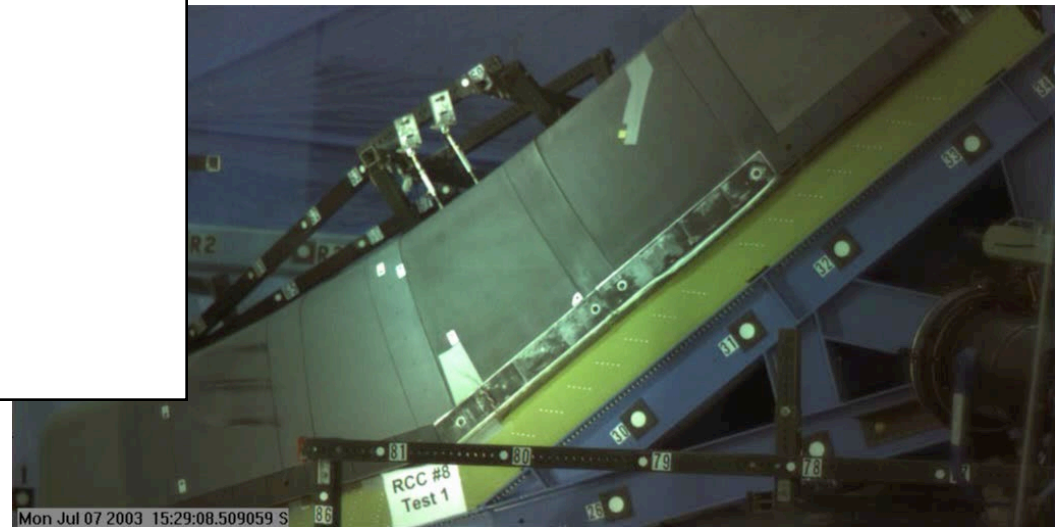




Columbia Accident Investigation

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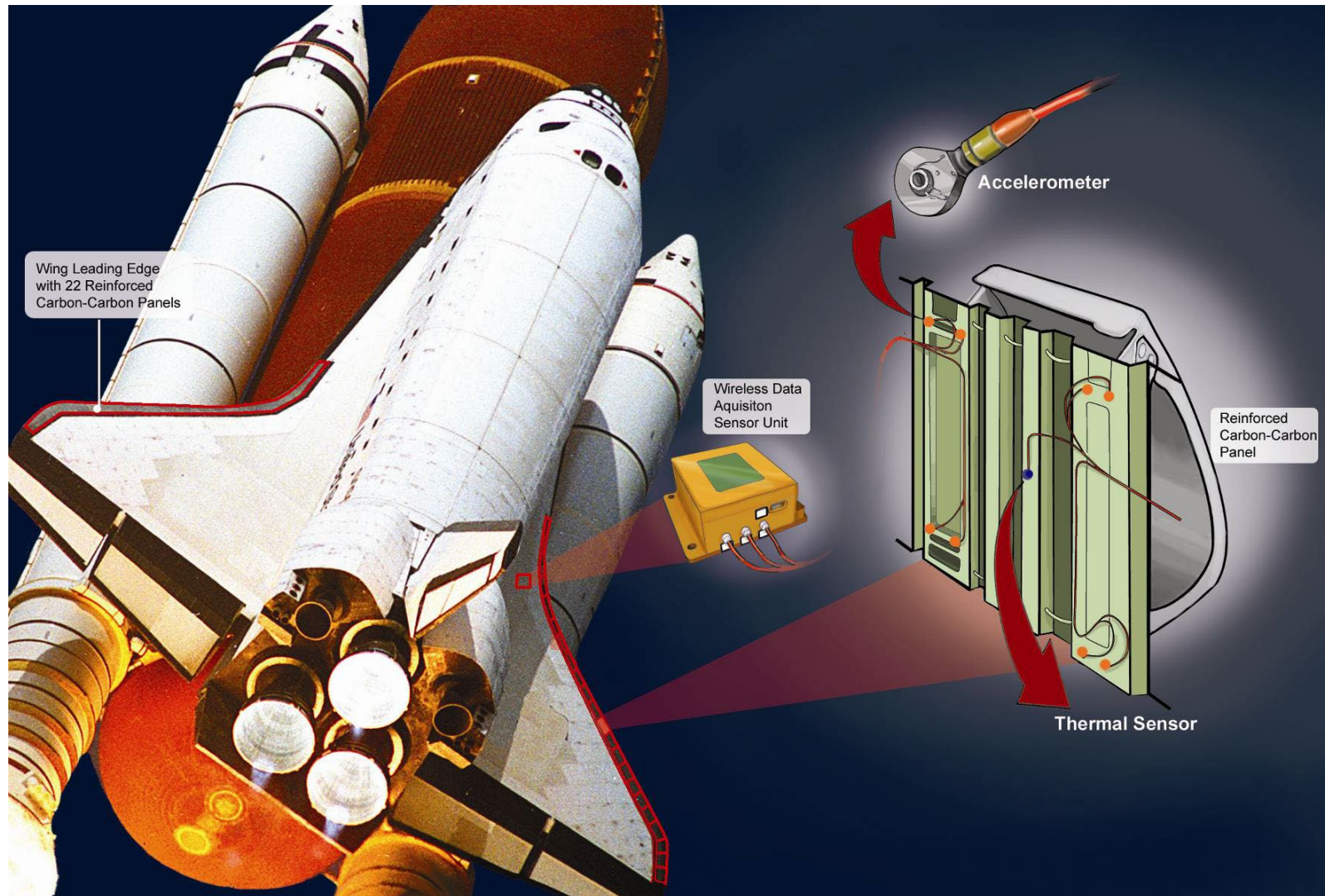




Wing Leading Edge Impact Detection System (WLEIDS)

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Shuttle External Tank TPS NDE

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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
- NASA funded effort to develop and validate new NDE inspection methods
 - Backscatter Radiography
 - Terahertz Imaging
 - Shearography



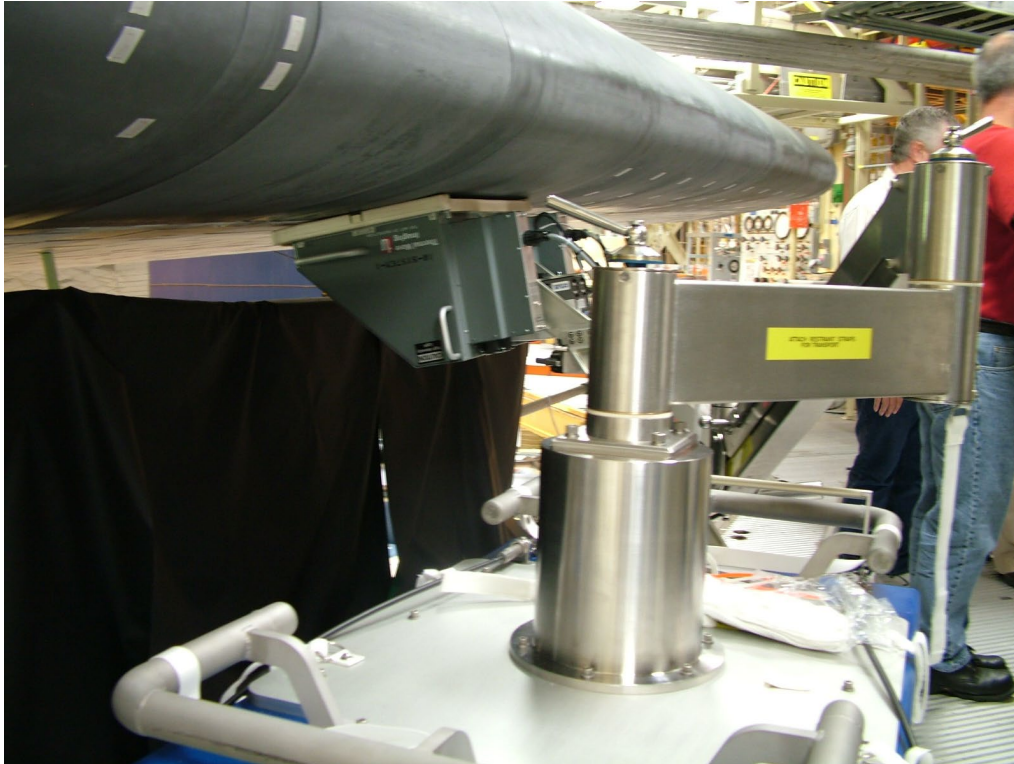
Foam Loss on STS-114



Thermographic Inspection of Shuttle RCC Wing Leading Edge and Nose Cone

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LaRC and United Space Alliance developing inspection procedure and analysis protocol

- Pre and post flight inspection
- On-orbit system also developed and tested

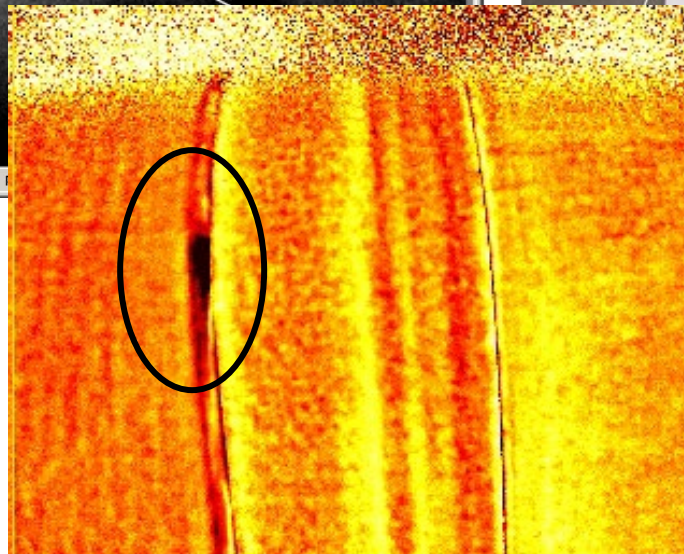
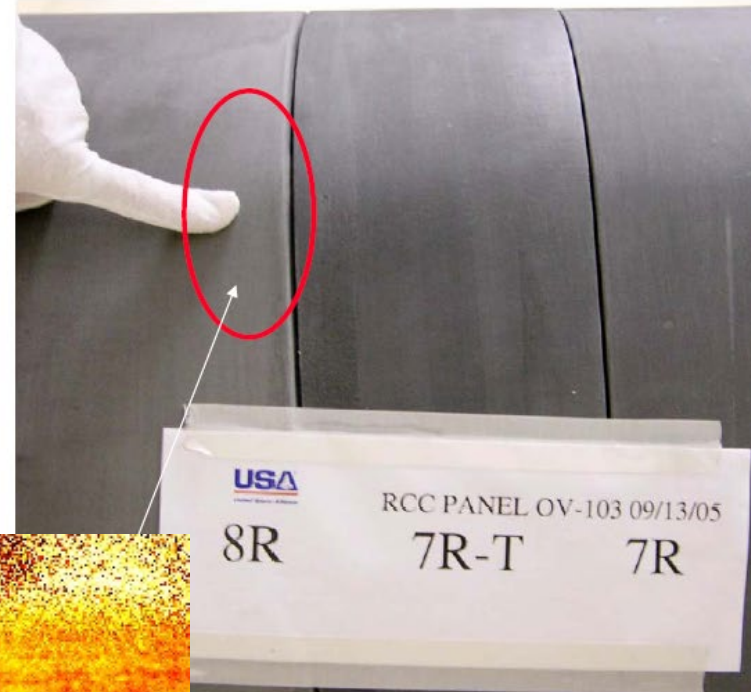
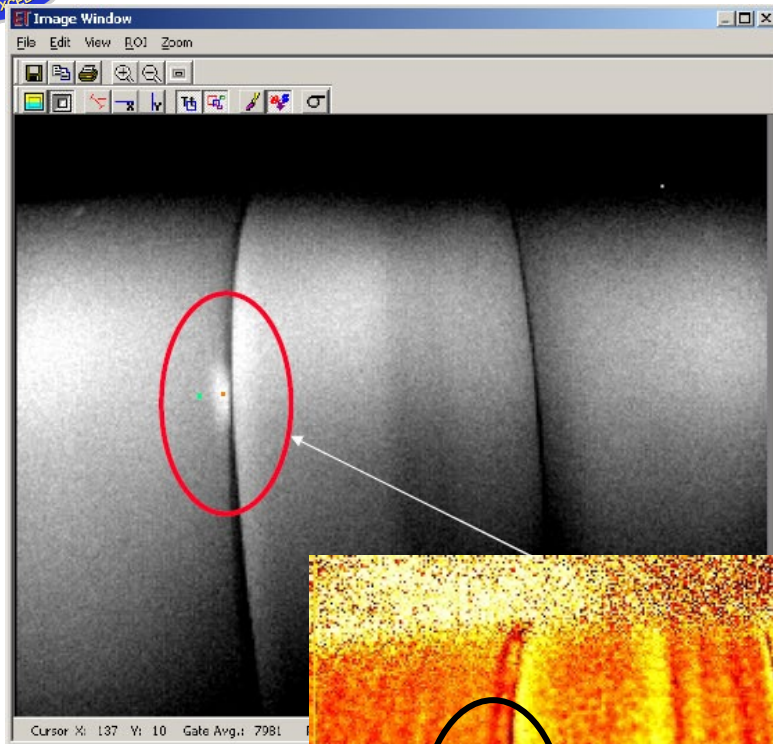




RCC Inspection Results Space Shuttle Discovery (Post STS-114)

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Processed PCA
Thermal Image



Shuttle Critical NDE Issues Resolved

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ET Foam Inspection



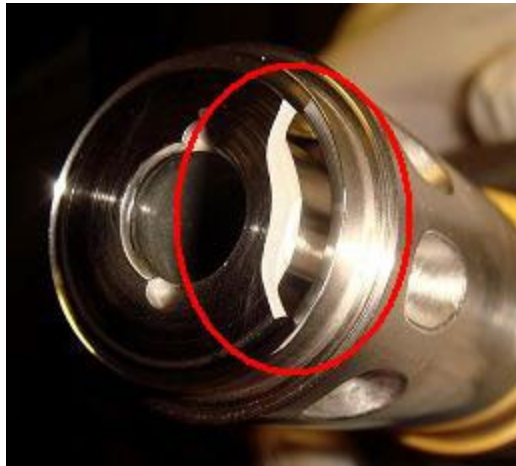
Radiator Flex Hose Cracking



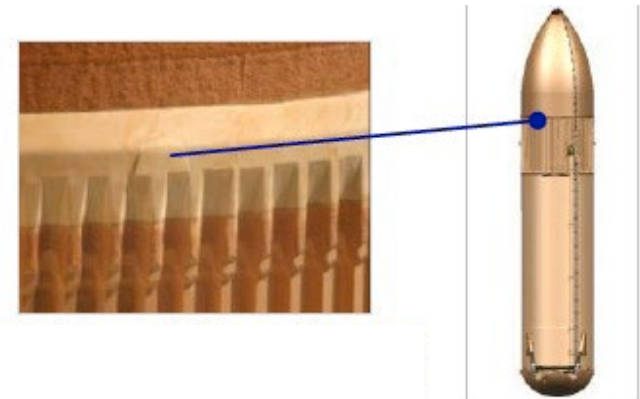
Launch Pad Flame Trench Damage



Crawler-Transporter Shoe Failure



High Pressure Hydrogen
Valve Poppet Failure



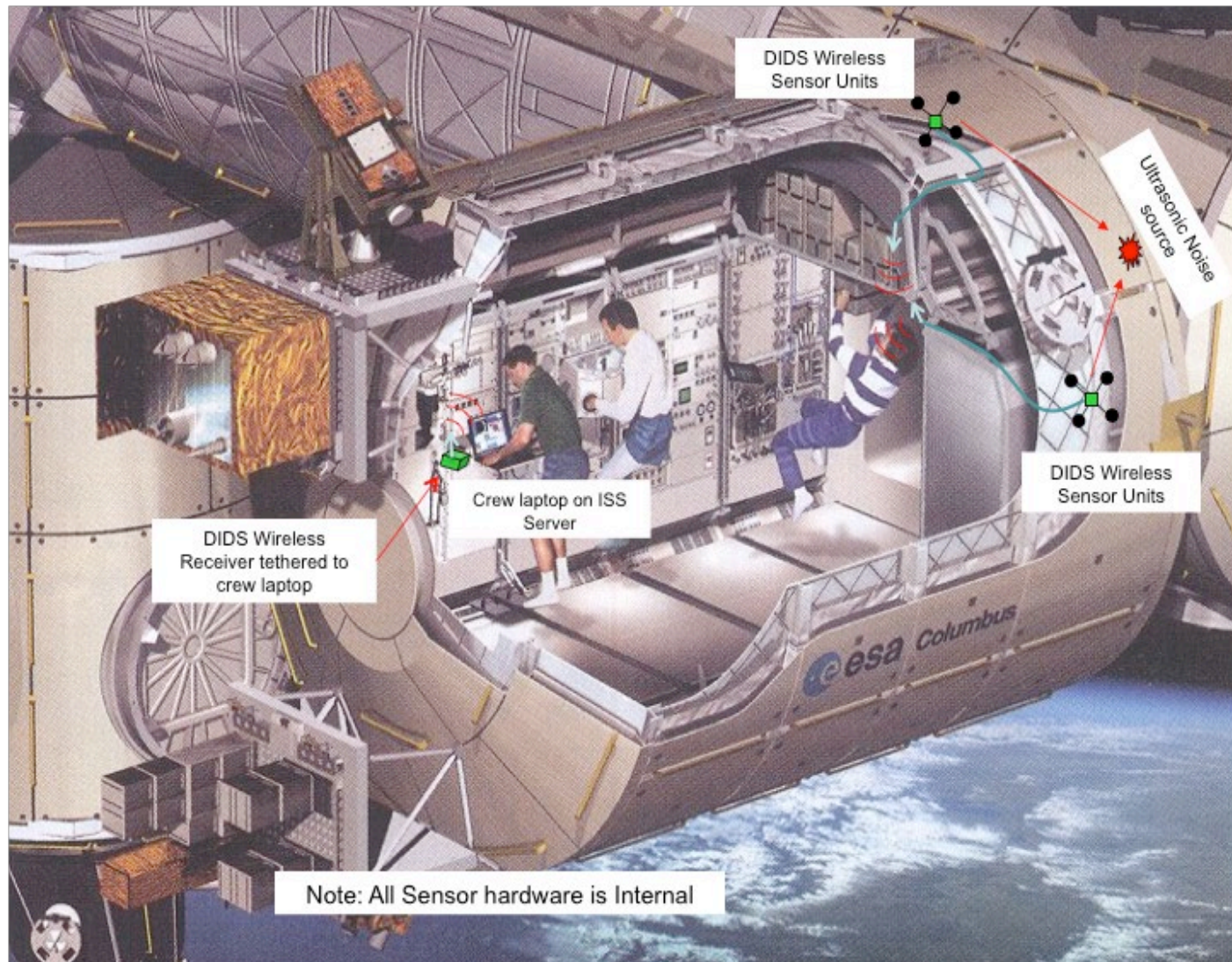
Shuttle ET Stringer Cracks



ISS Impact/Leak Detection System Development

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ISS Leak

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- Increase in background leak rate first detected in September 2019
- Initial attempts to detect with ULD unsuccessful
- Eventually isolated to PRK Chamber of Zvezda Service Module through hatch closing/pressure monitoring
- Tea leaves tracked with cameras eventually used to locate a leaking crack
- Crack temporarily patched with work ongoing to effect permanent structural repair
- Leak rate not entirely reduced so possible additional cracks still being investigated



Zvezda Service Module as seen from an approaching vehicle



Astronaut with ULD in Search for Leak



NDE/SHM Tools Provided to ISS

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- Repliset and eddy current to accurately size crack and investigate crack origin
- Advanced Array ULD to detect any additional/future leak sources
- IWIS to assess cyclic loading in region of crack to help assess root cause as well as expected growth and critical crack size



Dispensing Gun



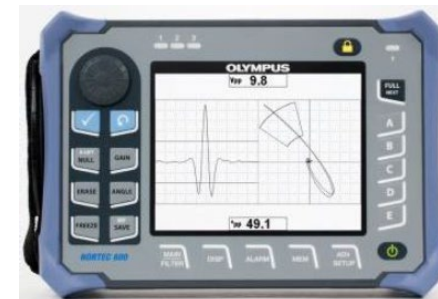
Repliset T3



Static-mixing Nozzles



AULD



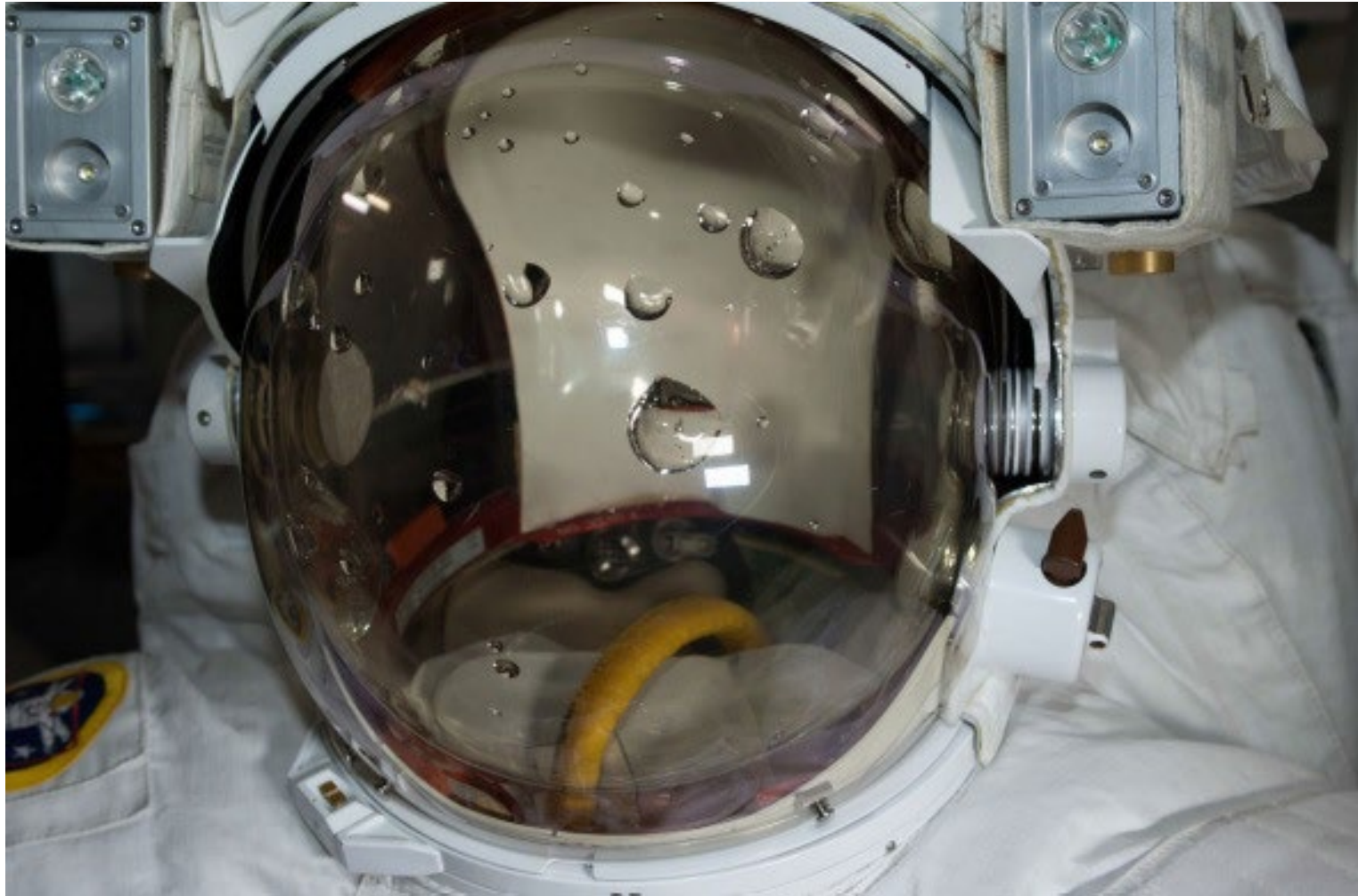
Eddy Current System



Spacesuit Water Leak

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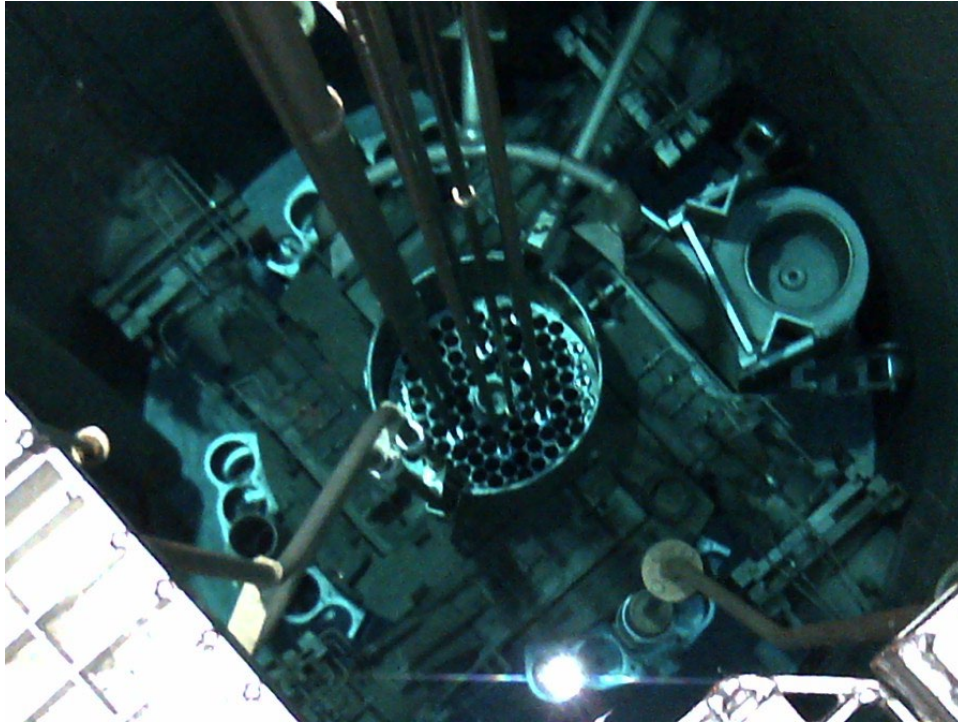




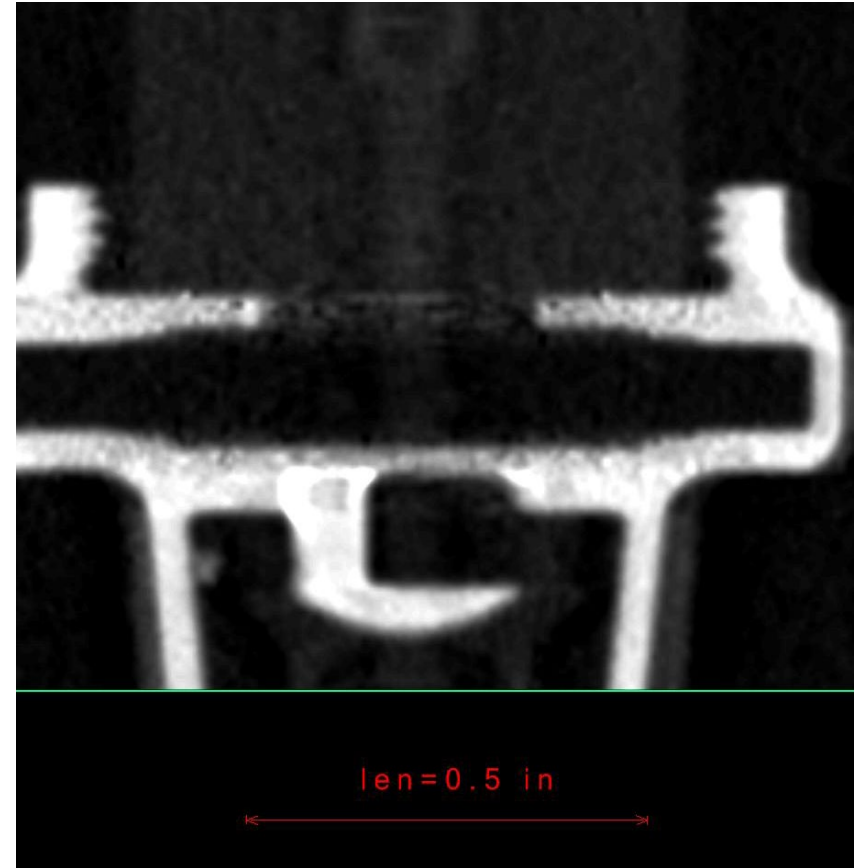
NDE of Spacesuit Components

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Nuclear Reactor Neutron Ray Source



Neutron CT image of spacesuit component showing contamination

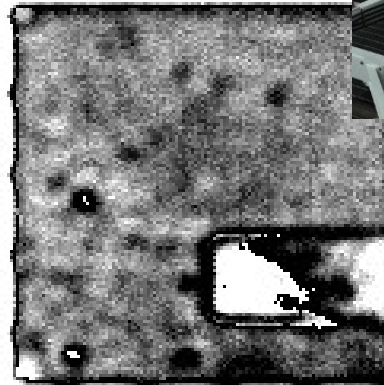


Orion Heatshield Bond Verification

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 Qualified
 - THz for missing adhesive material
 - UT and PAUT for disbonds
 - BSX for gap filler voids





Mars 2020 Heatshield Failure

Bill Prosser

November 2, 2022

- Backup heatshield composite carrier structure from MSL planned for use on Mars 2020
- Failed during qualification static load test
- IR thermography and x-ray CT used to inspect failed heatshield specimens as well as redesign test coupons
- Redesigned heat shield built, inspected and tested in time to support launch

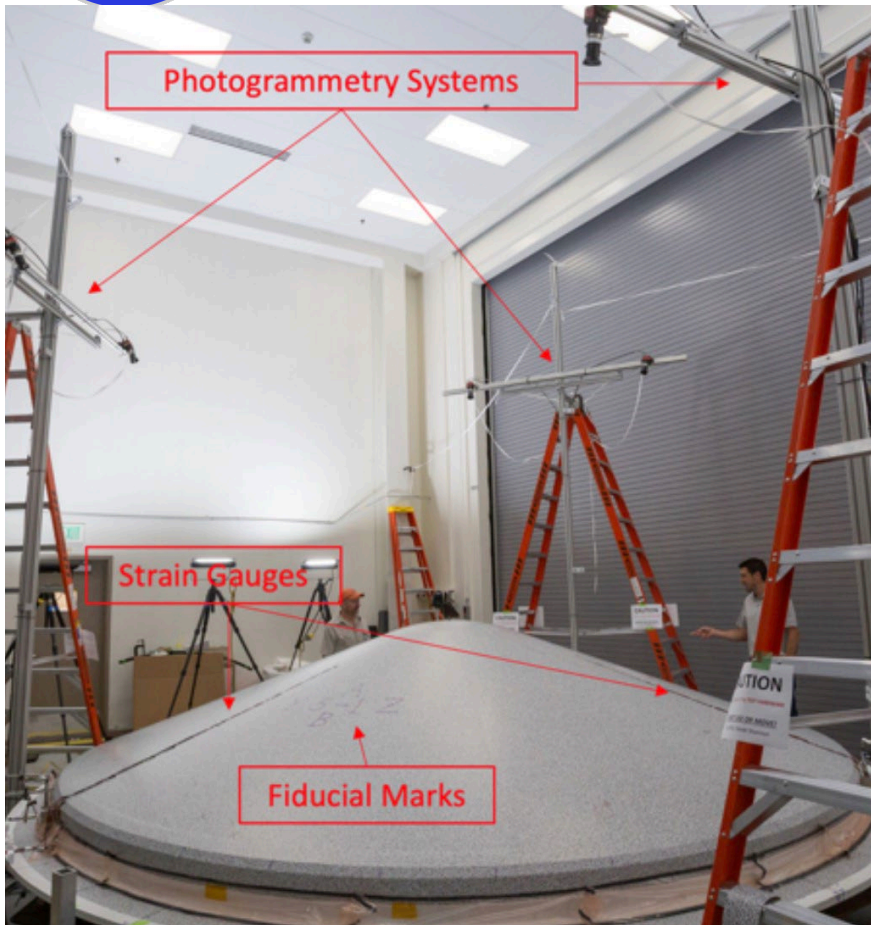




Mars 2020 Heatshield Qualification

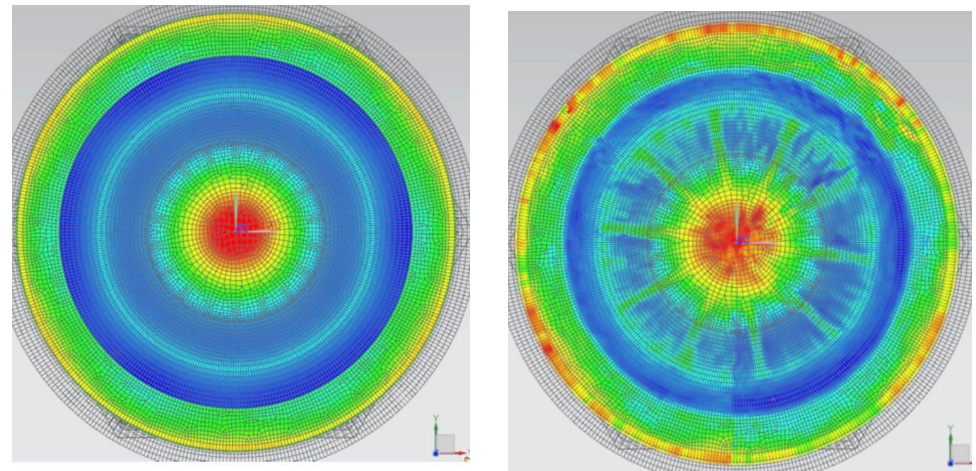
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Three DIC Systems Configured for Heatshield Qualification Test

- DIC used to monitor deformation
- Provide real time indications of any damage
- Post-test correlation to predicted strains



Predicted and Measured Strain



COPV Liner Inspection System

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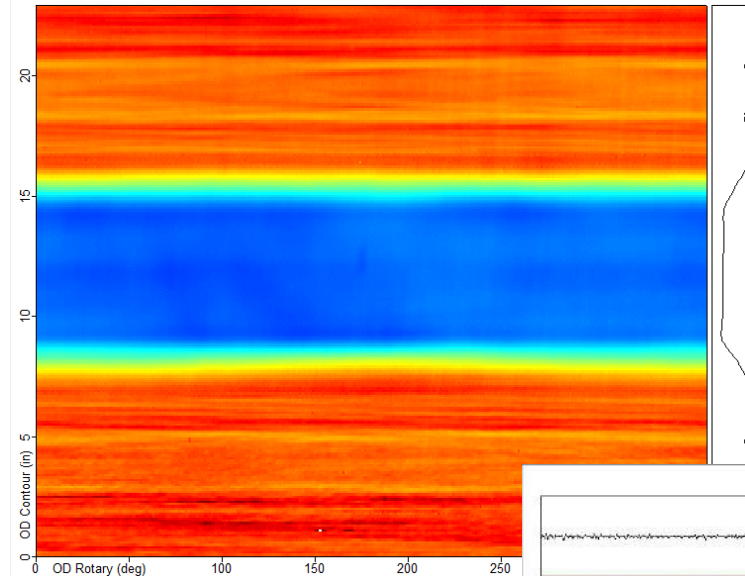
Maximum Height: 162 in.
(including sensor)

ID Vertical Stage
Travel increased to
72 in

New OD Vertical Stage
60 in travel

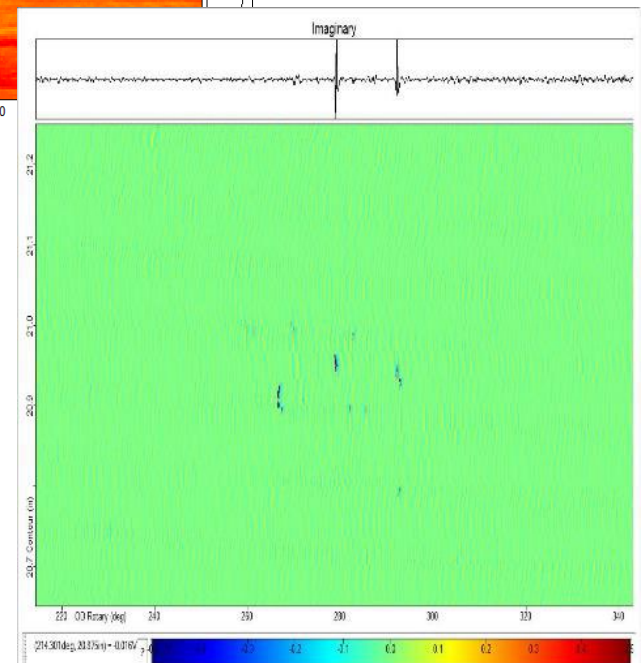
Up to 22 inch dia. liner

Liner Rotation Stage



Liner
Thickness
Mapping

Flaw
Detection





Summary Comments

Bill Prosser

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- NDE plays 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
- Extend thanks to all that support the NESC NDE TDT who provide a truly outstanding resource to the Agency to enable safe flight!