NASA Nondestructive Evaluation (NDE) Technical Program

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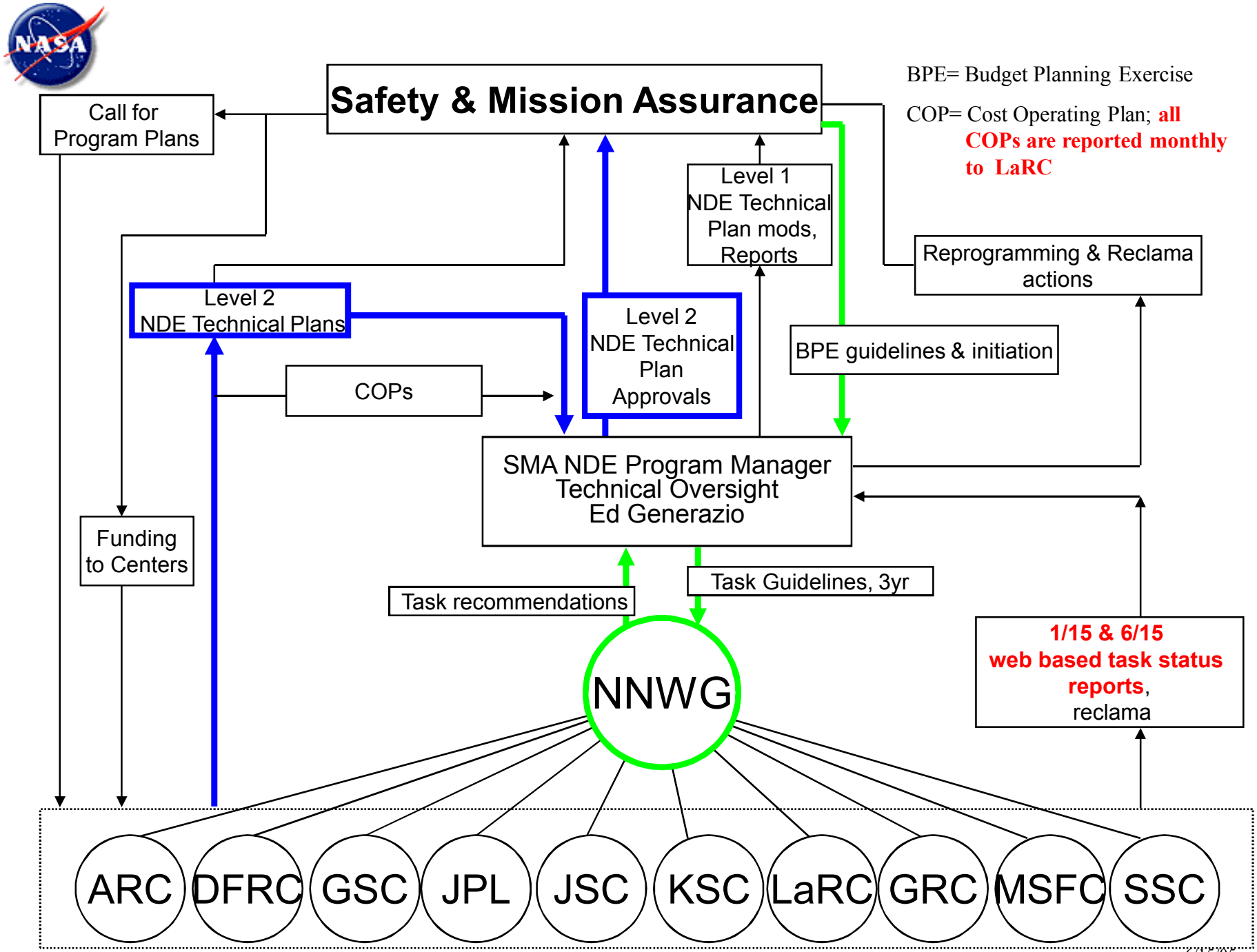
Nondestructive Evaluation Communication Group Meeting 2010
NDECM
June 2-3, 2010
Washington, DC

Outline

- **The NDE Team –NASA NDE Working Group**
- **Budget Strategy**
- **Current Activities**
- **New Technical Content FY11+**
- **Summary**


Safety & Mission Assurance
BPE= Budget Planning Exercise
COP= Cost Operating Plan; all COPs are reported monthly to LaRC
Call for Program Plans
Level 1 NDE Technical Plan mods, Reports
Reprogramming & Reclama actions
Level 2 NDE Technical Plans
Level 2 NDE Technical Plan Approvals
BPE guidelines & initiation
COPs
SMA NDE Program Manager Technical Oversight Ed Generazio
Funding to Centers
Task recommendations
Task Guidelines, 3yr
1/15 & 6/15 web based task status reports, reclama
NNWG
ARC
DFRC
GSC
JPL
JSC
KSC
LaRC
GRC
MSFC
SSC

Budget Strategy

The NDE Program is developed to meet the NASA NDE Working Group Strategic Plan and Charter:

- **Strengthen the visibility and influence of the NNWG in the conduct of the NASA flight and research programs (present and future).**
- **Develop and maintain an NDE infrastructure to meet NASA program requirements.**
- **Develop and maintain Standards and Specifications, as required, for aerospace applications whenever technical societies/industry standards or specifications are not available. Broaden the use of industry standards within NASA.**
- **Develop programmatic-relevant, cost effective NDE methodology/instruments, and transfer them to NASA implementers and industry.**
  - **Strengthen cooperative NDE efforts among the NASA Centers and NASA Programs.**
  - **Establish a certification process for space hardware NDE to ensure the implementation of cost-effective technology.**
  - **Identify long-range potential safety/reliability areas of concern for follow-on NDE Planning.**
  - **Establish a mechanism for communication of NASA Field Installations and Contractors concerns and alert of potential problems related to inspection of flight hardware. The NNWG critically reviews and ranks all proposals in priority.**

Budget is structure to meet immediate (60%), near term-within three years (30%), longer term (10%) NDE needs to assure safe and reliable operations.

- **The budget is developed by detailed justification of resource requirements, and review by all Centers.**
- **The budget estimates are from historical experience or actual costs.**

The performance metrics are: The number new NDE technologies adapted or developed and now used in the filed. Timely development or adapting of NDE technologies. Number of publications and reports. Meeting cost metrics.

All Proposals Reviewed and Ranked by Priority by All Centers

Proposals for Consideration: FY11

Proposal No	Center-*	Filename	Rankings											Totals	Avg Score	Std Dev	Rank
			ARC	DFRC	GRC	GSFC	JPL	JSC	KSC	LaRC	MSFC	SSC	WSTF				
2	GRC	GRC NNWGFY11-Xray-THz-CT_Final.doc	2	1	X	4	4	2	8	5	2	6	5	39	3.9	2.2	1
1	DFRC	DFRC Tunable_laser_proposal_FINAL.docx	1	X	1	8	5	11	3	6	3	2	1	41	4.1	3.4	2
12	MSFC-1	MSFC-1.docx	3	3	3	2	8	7	2	8	X	3	4	43	4.3	2.4	3
6	JSC-1	JSC-1 Development_of_IR_Flash_Thermography_for_Graphite_EpoxyFINAL.docx	8	5	7	3	3	X	1	3	5	14	3	52	5.2	3.7	4
3	GSFC	GSFC FY11.doc	7	6	4	X	13	3	7	2	1	11	6	60	6.0	3.8	5
8	KSC-1	KSC-1 Microflow_Final.doc	13	2	2	1	1	10	X	7	15	1	11	63	6.3	5.6	6
16	WSTF-1	WSTF-1 Stress_Rupture_NDE_Proposal_restore_funding_to_complete_2yr_FINAL.doc	4	4	10	5	6	8	14	1	10	4	X	66	6.6	3.9	7
4	JPL-1	JPL-1 Heat_Sheild_Materials_FINAL.doc	6	7	6	7	X	14	6	9	4	12	12	83	8.3	3.3	8
14	SSC-1	SSC-1 Inspection_of_Underground_Pipes_(2).docx	5	10	8	9	2	12	9	4	14	X	13	86	8.6	3.9	9
9	KSC-2	KSC-2 Lamb_Waves_Final.doc	14	9	15	10	6	1	X	13	8	5	9	90	9.0	4.3	10
7	JSC-2	JSC-2 NDE_Characterization_of_MMOD_Strike_for_Composite_Materials_FINAL.doc	10	15	16	15	12	X	5	11	6	10	2	102	10.2	4.7	11
10	LaRC-1	LaRC-1 NDE_nanosensor_characterization.doc	12	8	13	6	9	13	12	X	9	15	7	104	10.4	3.0	12
13	MSFC-2	MSFC-2 Microwave_Camera_Development.docx	9	13	14	14	11	9	4	15	X	9	8	106	10.6	3.4	13
11	LaRC-2	LaRC-2 Wireless_Hi_Temp_Strain_Sensors.doc	16	16	12	12	7	4	13	X	11	8	10	109	10.9	3.8	14
17	WSTF-2	WSTF-2 NDE_for_Acceptance_of_COPV_for_NASA_Spacecraft_FINAL.doc	11	14	5	16	10	6	15	12	7	13	X	109	10.9	3.8	14
5	JPL-2	JPL-2 Counterfeit_EEE_Parts_FINAL.doc	17	12	9	11	X	5	10	14	12	7	14	111	11.1	3.5	16
15	SSC-2	SSC-2 Figueroa-02-04-2010.docx	15	11	11	13	14	15	11	10	13	X	15	128	12.8	1.9	17

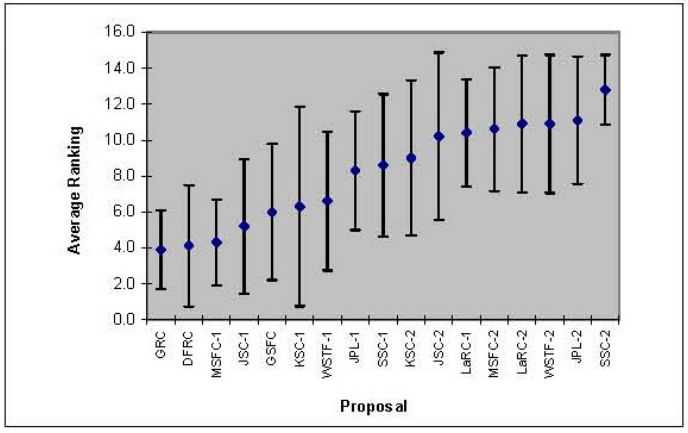
X represents that center cannot vote on its own proposals

Location of Files: http://secureworkgroups.grc.nasa.gov/nnwg?go=z60297

Task Guidelines for FY11:

- needs to be NDE or IVHM for integrity for fitness for service
- is 3 yrs or less (or 1 yr augmentation)
- has technical and programmatic synergy across the agency
- has good probability of being adopted by the program(s)
- addresses current flight or near term projected inspection issues
- has co-funding at 15% or greater by the potential customer
- maybe a bridge activity for 1 yr
- has deliverables & milestones are reasonable and are likely to be met
- has major potential benefits to safe and reliable operations
- Center's status reports have been delivered on time and are acceptable (posted on web)
- teamed efforts are a good thing
- there are no endowments in the NDE Program
- Show connectivity to findings/recommendations from the NASA Exploration Safety Study (NESS) and

ASAP available on website and at: http://www.hq.nasa.gov/office/oer/asap/index.html



Alternate method (eliminate extreme scores			
Min	Max	Revised Total	Revised Rank
1	8	30	2
1	11	29	1
2	8	33	3
1	14	37	4
1	13	46	5
1	15	47	6
1	14	51	7
4	14	65	8
2	14	70	9
1	15	74	10
2	16	84	12
6	15	83	11
4	15	87	13
4	16	89	15
5	16	88	14
5	17	89	15
10	15	103	17



Overview of NDE Program

This program addresses critical inspection needs of multiple Programs. Including **Space Station, Space Shuttle, Exploration, Aviation Safety, Stirling Engine, Flexible Path Vehicle Thermal Protection System, Predator-B Uninhabited Aerial Vehicle, Special Operations Command Global Observer, NASA F-18, Stratospheric Observer for Infrared Astronomy, Composite Crew Vehicle, James Webb Space Telescope, Global Precipitation Measurement Mission, Orion Service Module, Mars Science Laboratory, pressure systems certification NASA STD-8719.17.** This program also addresses deficiencies in NDE highlighted in the NASA Exploration Safety Study (**NESS**) and the Aerospace Safety Advisory Panel (**ASAP**). For the latter, the Panel provides a summary of key safety-related issues that the Agency confronts at this time. The most important relate to the future of the Nation's human space flight program and this program tackles inspection issues with novel methods related to current and future space components including thermal protection systems (TPS), composite materials, and nickel-based superalloy materials for the next-generation space nuclear power systems. Several NDE tasks support both in-situ and post characterization micrometeoroid and orbital debris (**MMOD**) that constitutes the leading risk to NASA missions as highlighted by **ASAP**. ***NDE is a key element supporting NESS*** *having alignment with reliability/maintainability & quality assurance, providing direct input to risk management strategies, providing Standards for personnel certification, providing top level development Chair positions for NDE personnel to rotate into, providing NNWG weekly Standards meetings that serve as awareness and training forums producing and updating NDE Standards, providing on the job training knowledge & tools for uncertainty quantification via Standards and probability of detection tasks.*

NASA NDE Program

Current Activities:

- **Composite Materials/Systems** (ISS, Orbiter, Aviation Safety, Exploration)
  - **Profilometer for Composite Pressure Vessels**
  - **In-Situ NDE Characterization of Composite Material Micromechanics**
  - **Induction Thermography / Shearography of Composite Structures**
  - **Carbon Composite Stress Rupture NDE Development**
  - **NDE of Composite Honeycomb Face Sheet Bonding**
  - **Acousto-Optic Measurement with Fiber Bragg Gratings**
  - **Impedance Measurement NDE System Development for COPV testing**
- **Micro-Focus X-ray Computed Tomography for Exploration Component Inspections**
- **Arc Weld NDE for Exploration Components with Emphasis on Portable Phased Array Ultrasonics**
- **Monitoring of Thermal Protection Systems using Robust Self-Organizing Optical Fiber**
- **Fracture Critical POD Process Validation** (all Enterprises)
- **Effect of Liquid Penetrant Sensitivity on Probability of Detection** (all Enterprises)
- **Validation of POD Methodologies** (all Enterprises)
- **Intelligent Sensors for NDE**
- **Propulsion Health Monitoring System Development and Instrumentation** (all rotating machinery)
- **Inventory of an Replacement of JSC/NASA Probability of Detection (POD) Certification Specimens**
- **Upgrade of Dryden NDI Test Equipment**
- **NASA NDE Working Group (NNWG) website http://nnwg.org/ - NNWG Ranks all NDE proposals**

NASA NDE Program (continued)

New Start Planned Activities:

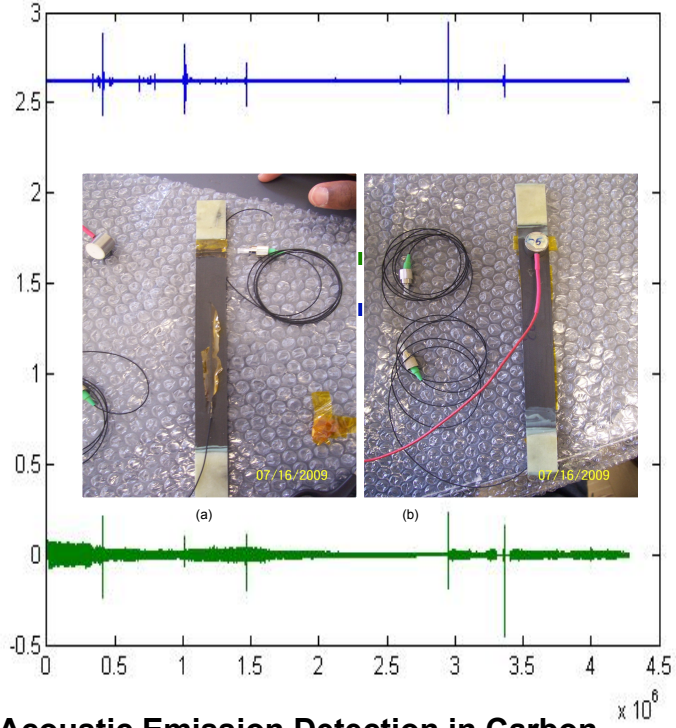
- X-ray & Terahertz studies (including 3D Computed Tomography) for Complex Aerospace Structures
- Tunable Laser Development for In-flight OFDR Structural Health Monitoring Systems
- Graphics Processing Unit Assisted Thermographic Compositing
- Development of IR Contrast Data Analysis Application for Characterizing Delaminations in Graphite-Epoxy Structures
- Probability of Detection (POD) Demonstration of Transferability: Phase II
- The Development of NDI Hypergolic Micro-Flow Sensors for the Orion Spacecraft
- Augmentation to complete Carbon Composite Stress Rupture NDE Development
- NDE of Ablative Heat Shield Materials and Structures
- Non-Intrusive Integrity Assessment of Underground Pipes

NDE of Composites

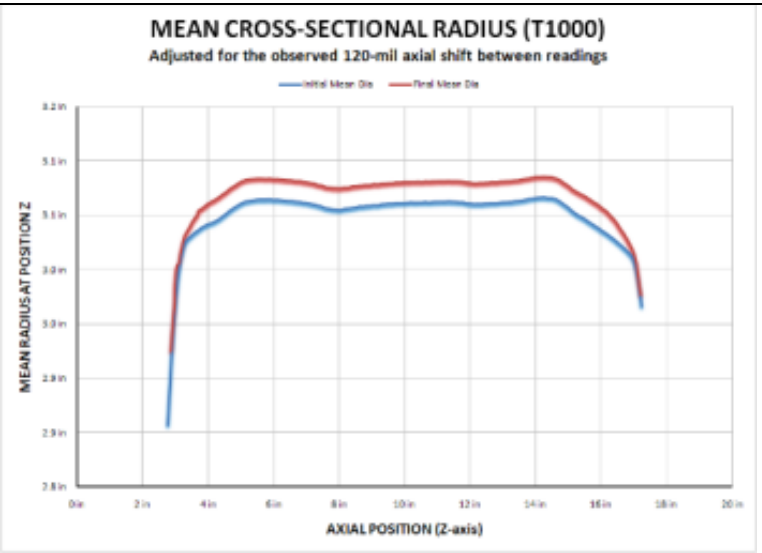




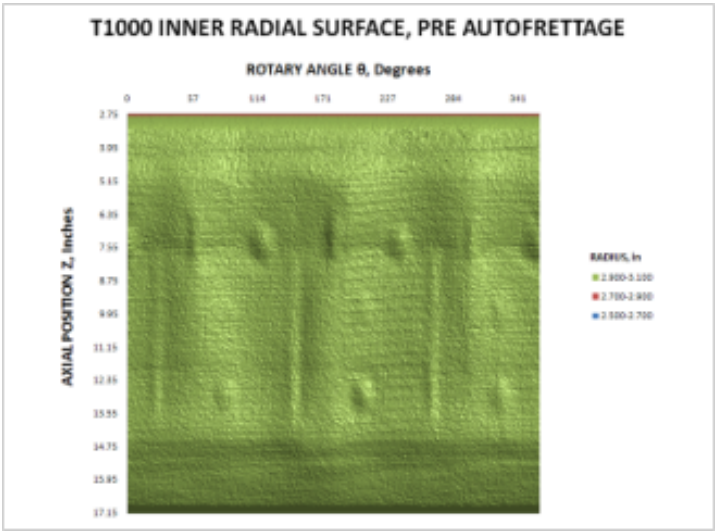
Conventional strain gauges next to Fiber Bragg Gratings, relative to point of interest on an NNWG developed Laser Profilometry map.



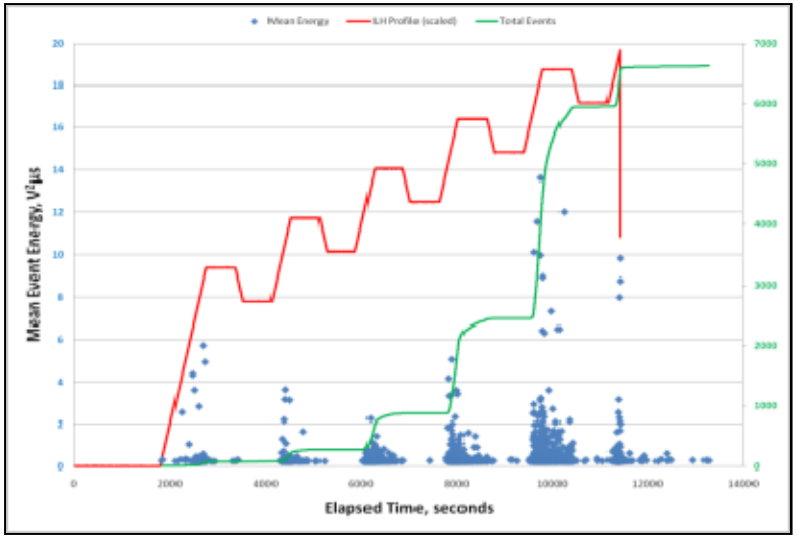
Acoustic Emission Detection in Carbon Fiber Composite Using Fiber Bragg Grating Sensors





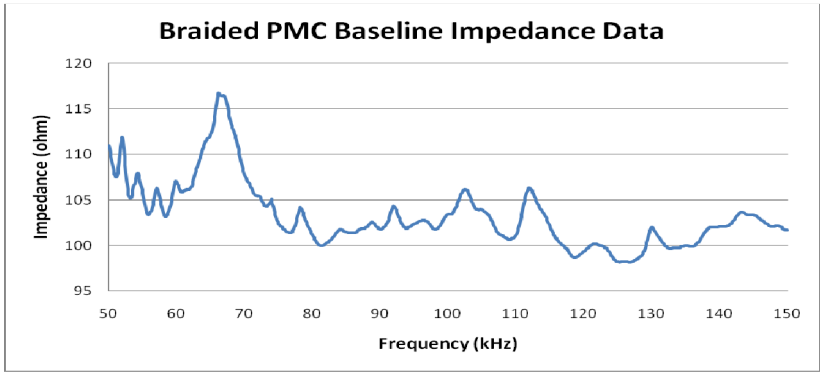


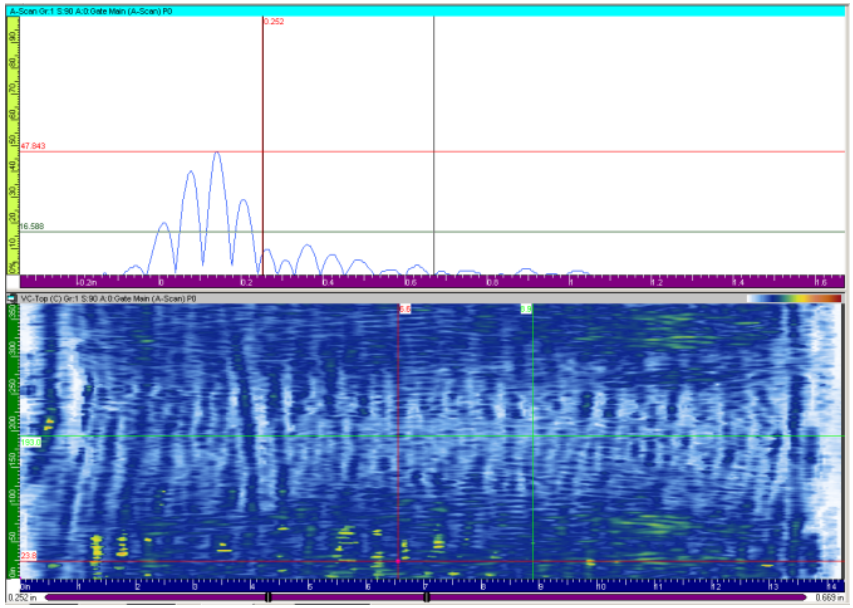
NDE of Composites



• Monitor AE hits and energy (blue data), and cumulative AE (green line), during intermittent load hold stress schedule (red line) (IM-7).

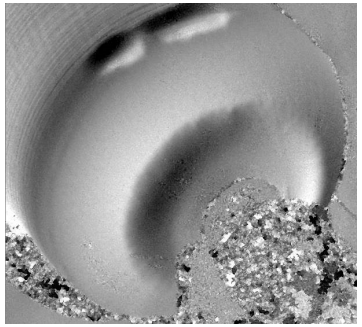
• Felicity Ratio = Stress level where AE begins in load cycle / Maximum previous stress. FR<1.0 Kaiser effect breakdown= damage.





• MSFC measured and performed UT scanned COPV
• Measured velocity on Carbon COPV.
• Changes in the modulus is an indication of fiber/tow breakage that lead to stress rupture.



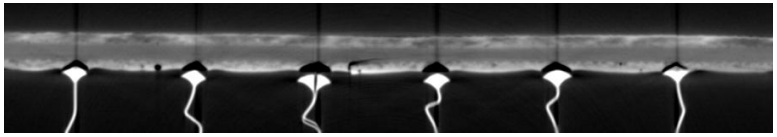


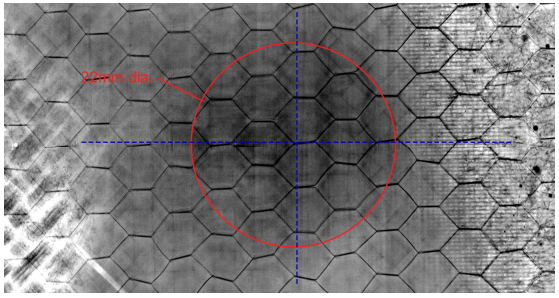
Delamination

• Flexture Wave for liner crack detection.
• Mapped defects in carbon fiber COPVs with laser shearography.

NDE of Hybrid Composites

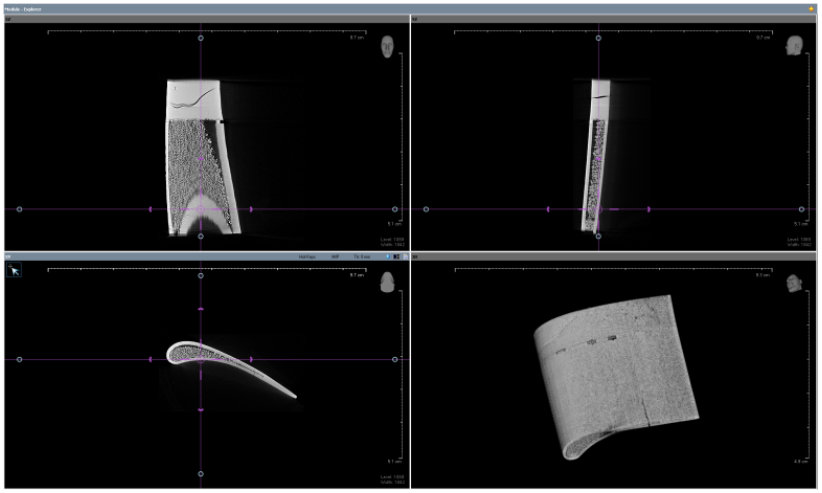
Computed X-Ray Tomography of Impacted Honeycomb Specimen



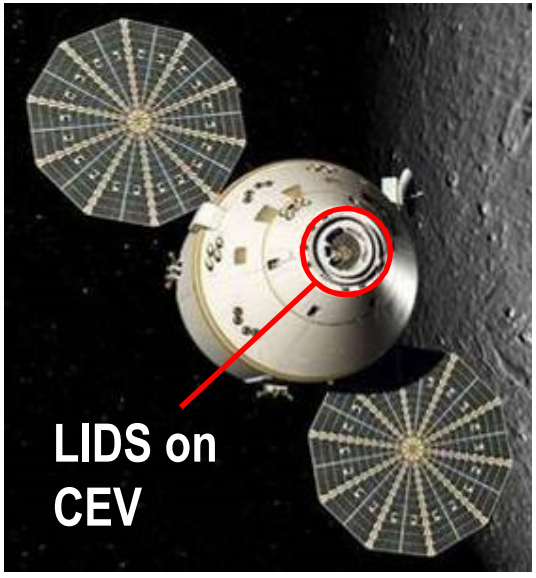


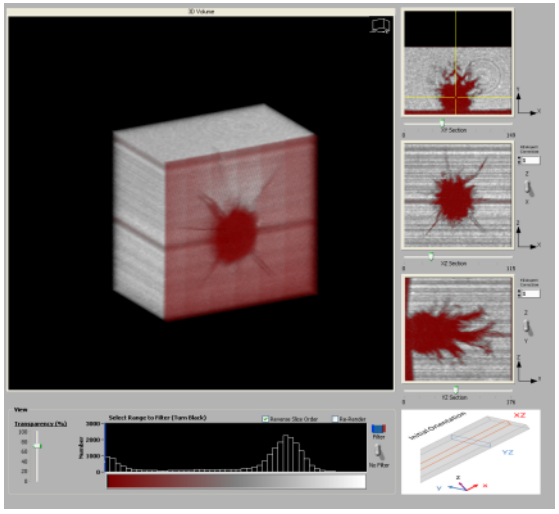
Estimated Region of Disbond

X-ray Tomography Upgrade



- **Ceramic Vane showing small crack: Prior CT system could not detect this crack**

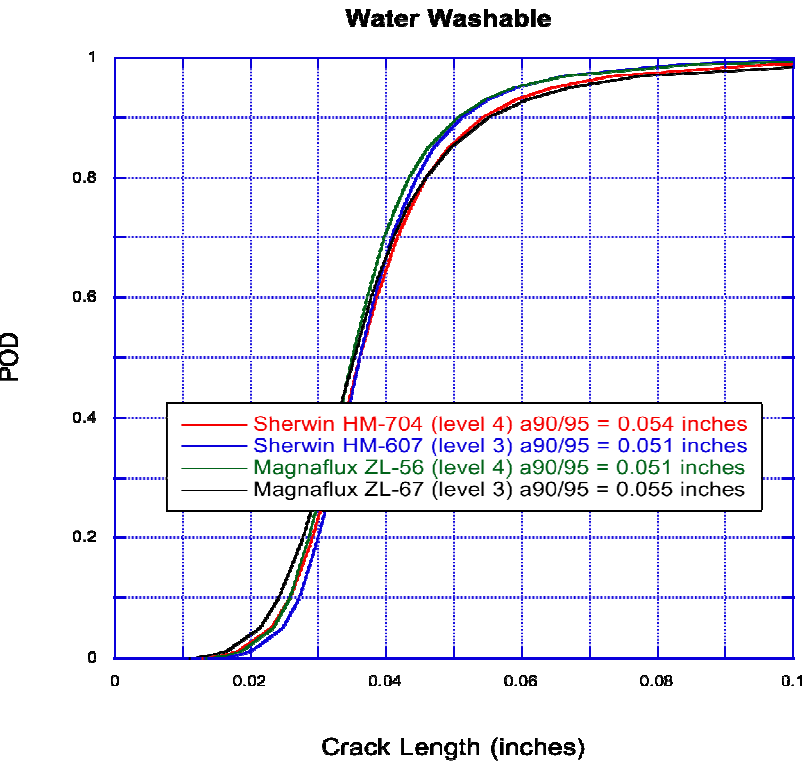




- **X-ray CT for CEV Low Impact Docking System (LIDS) Seals micrometeoroids and orbital debris (MMOD) testing**

Probability of Detection (POD)

Comparing L3 and L4 Penetrants & POD Transferability

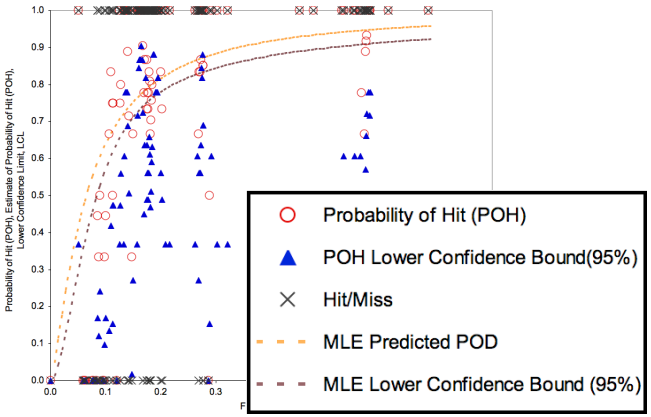


The matrix of penetrant inspection demonstration tests on aluminum crack panels is complete.

These finding support the use of sensitivity level 3 penetrants for NASA Standard Level penetrant inspections.

POD Demonstration Transferability - A procedure for production of low aspect ratio (0.1) cracks in aluminum has been established. Over 100 cracks have been grown in 32 crack panels.

Fracture Critical POD Process Validation

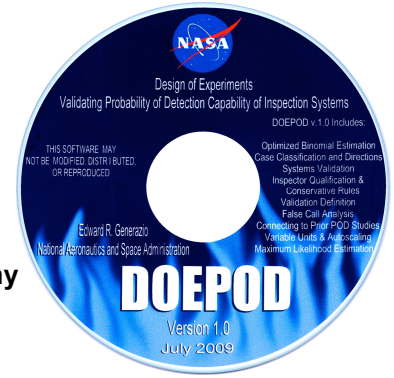


800 flaws specimens -Flaws 0.010”- 0.250”

Plates & Welded Tubes
Stainless Steel
Aluminum
Titaium
Inconel

Ultrasonic, Eddy Current, Penetrant, Visual, Radiography, Digital Radiography

Flaws 0.010”- 0.250”
Replenish JSC POD specimen library

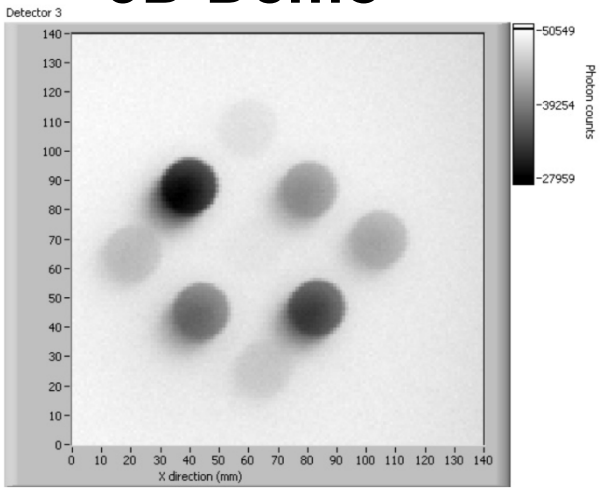


Cryo Tank NDE Project



Sensor installed at Pad B LH2 Tank

X-ray Backscatter 3D Demo



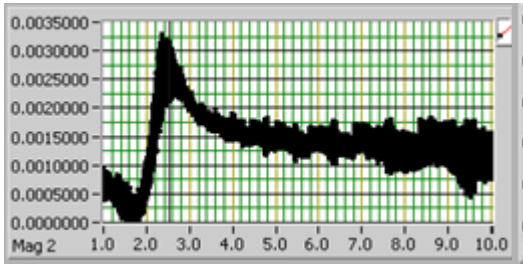
Single-sided measurement

Image of one test block consisting of pennies under various layers of AL sheet. One goal will be to demonstrate that we can determine the depth of each penny.

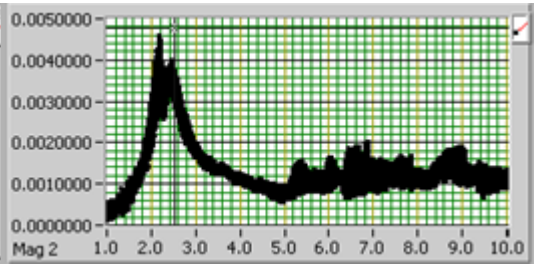
Propulsion Health Monitoring System Development and Instrumentation

•Capacitive Sensor Results for Spinning Disks

No Notch (Phase vs. kRPM)



Notched (Phase vs. kRPM)

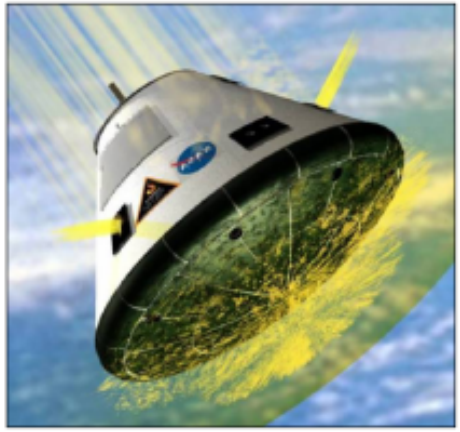


Conducted precision controlled spin tests evaluate various sensing technologies for in situ detection of rotor damage

NDE Techniques for Orion

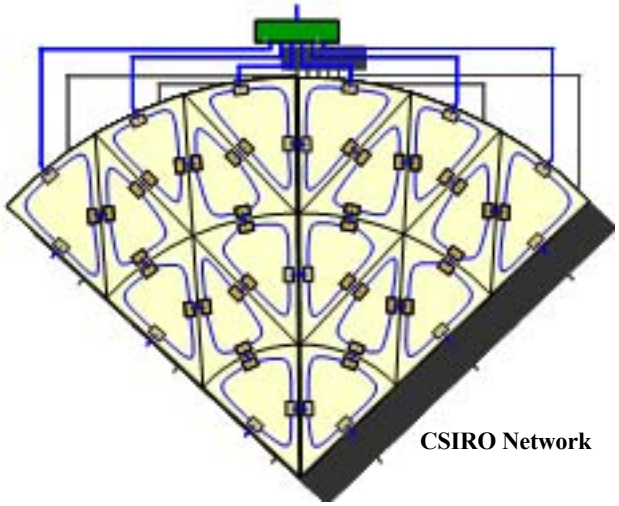
NDE techniques are needed for welded tube joints performed by an Orbital Arc Welding method.

Monitoring of Thermal Protection Systems using Robust Self-Organizing Optical Fiber Sensors.



NASA / CSIRO
Concept Demonstrator





CSIRO Network

Develop structural health monitoring system technology that incorporates advanced sensors to detect damage on thermal protection systems



DFRC Heat Shield Tests

X-Ray CT

National Aeronautics and Space Administration

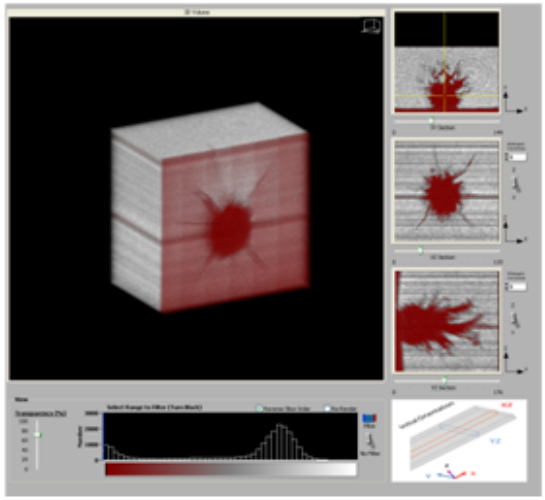
New NASA Glenn State of the art Computed Tomography System: Control Room

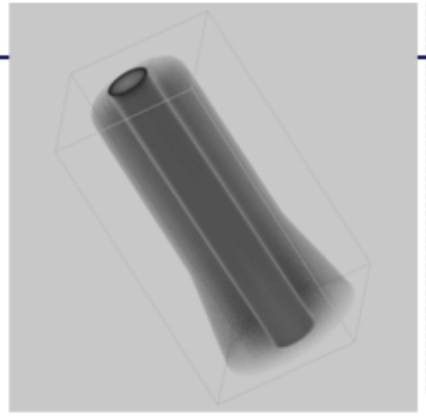
Imtec power supply and motion controller

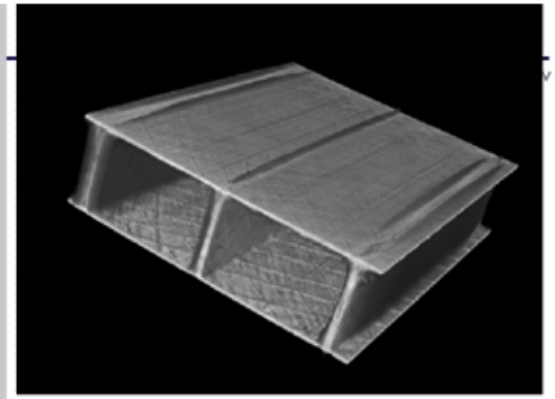
Feinfocus analog X-ray control package

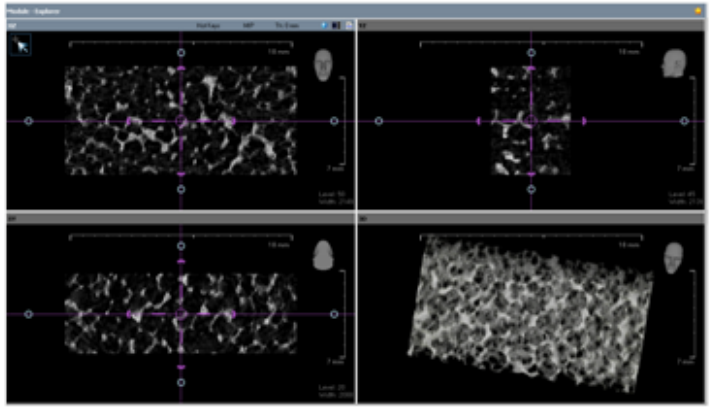


Dedicated Work Station



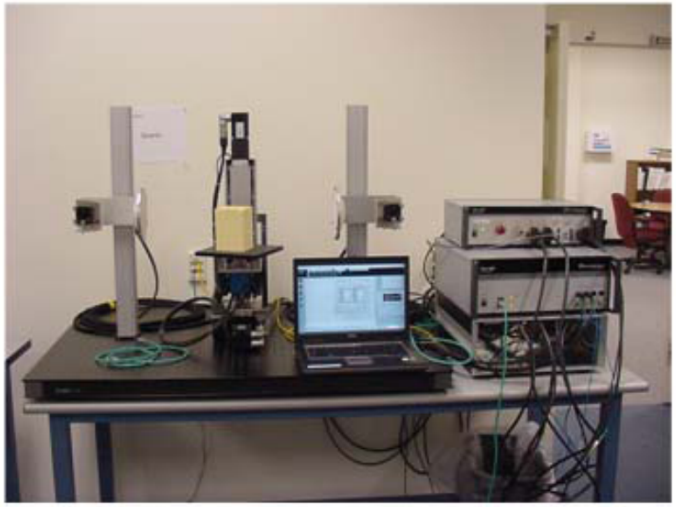




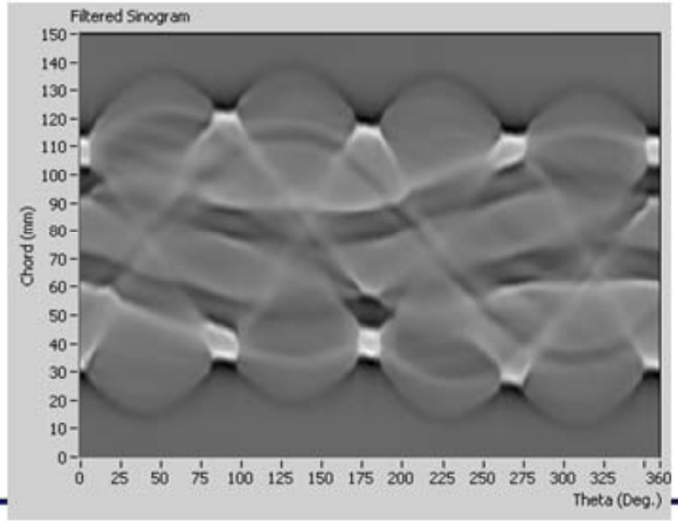


THz Computed Tomography

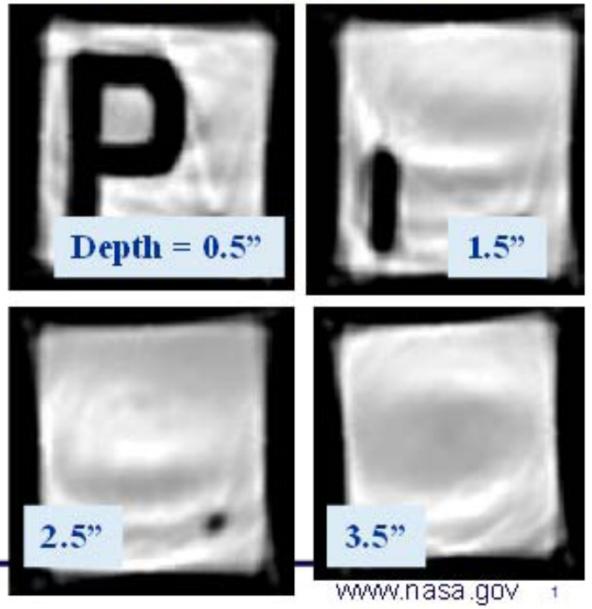




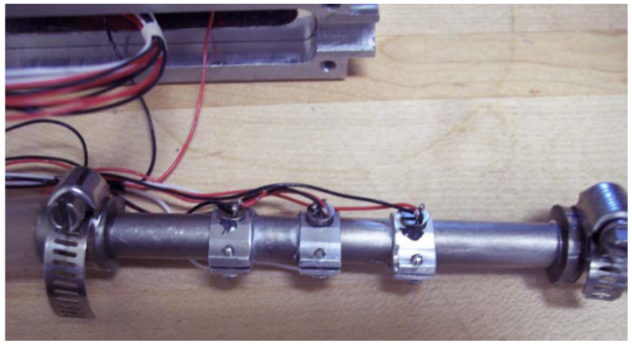


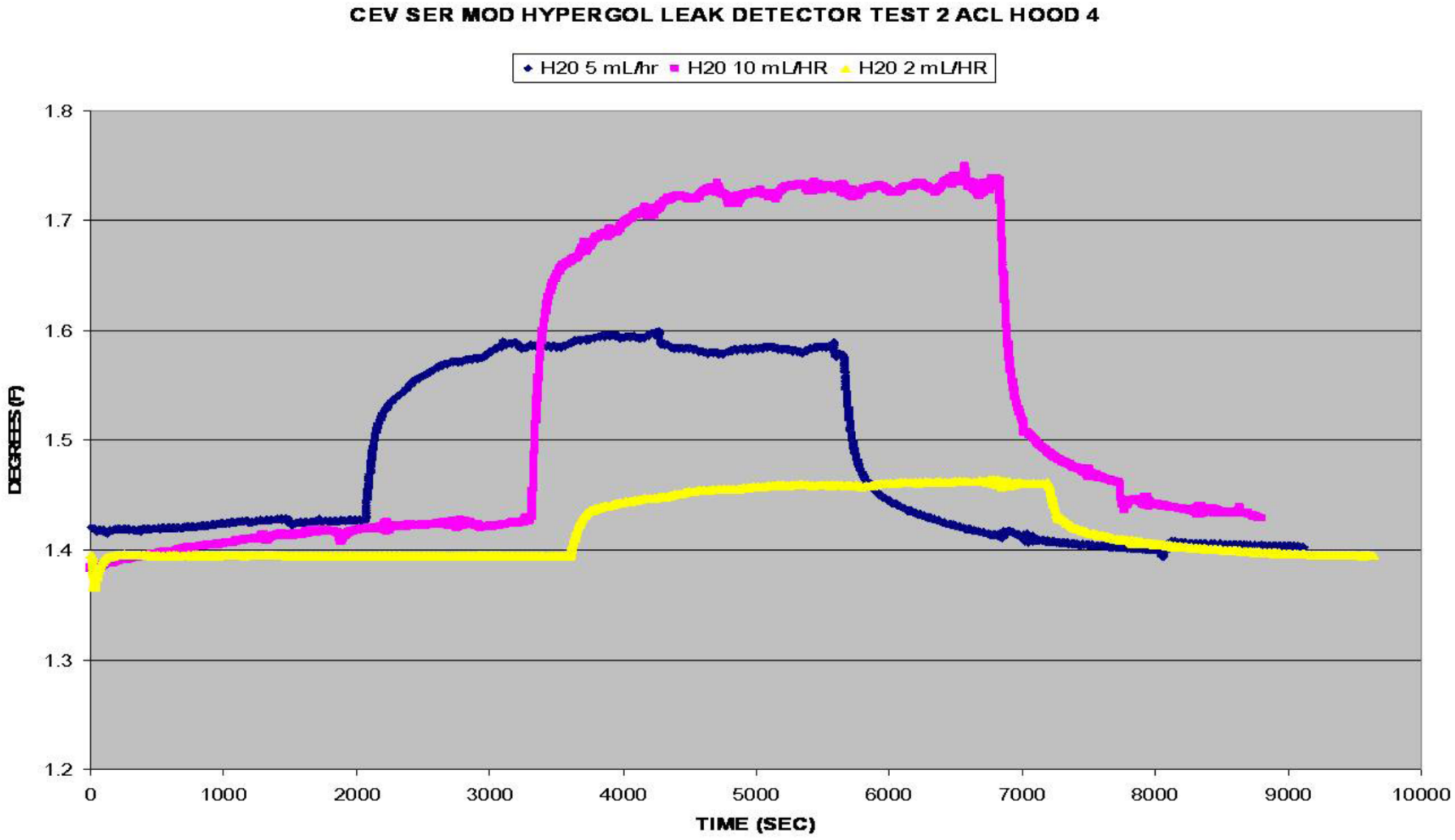


CT slices – ET Foam



Development of NDI Hypergolic Micro-Flow Sensors





- **Tunable Laser Development for In-flight OFDR Structural Health Monitoring Systems**
  - Develop a more cost effective fiber-ring laser-based tunable laser.
  - Build and demonstrate a prototype fiber-ring laser.
  - NASA Dryden F-18 tail number 853 - provide comprehensive fiber-optic sensing on the wings, along with a robust interrogation system.
  - NASA Stratospheric Observatory for Infrared Astronomy (SOFIA) -integrate fiber-optic structural health monitoring along the fuselage of the 747 and within the telescope cavity.

- **Graphics Processing Unit Assisted ThermographicCompositing**
  - Develop a software application that utilizes General Purpose Graphics Processing Units to increase the capabilities of thermogram analysis and mosaic layout for large data sets.

- **Development of IR Contrast Data Analysis Application for Characterizing Delaminations in Graphite-Epoxy Structure**
  - Current IR software can not evaluate IR response for flaw depth, size and gapping.

- **Probability of Detection (POD) Demonstration Transferability: Phase II**
  - Directly compare the POD for flat panels versus a larger part with a more complex geometry.

- **Augmentation to complete Carbon Composite Stress Rupture NDE Development** (restore project to near original funding levels)
  - Accomplish the second round of composite overwrapped pressure vessels (T1000 and IM7) stress rupture testing, NDE, analysis, and compile and report results.

- **NDE of Ablative Heat Shield Materials and Structures**
  - PICA (Phenolic Impregnated Carbon Ablator) and Avcoat.
  - Level of disbond in PICA
  - Detect partially filled AvCoat cells

- **Non-Intrusive Integrity Assessment of Underground Pipes**
  - Develop inspection methodology for buried pipe to determine the existence of defects, such as cracks, resulting from cyclic loading.

Summarizing

- Identified The NDE Team –NASA NDE Working Group
- Explained Budget Strategy
- Covered Current NDE Activities
- New NDE Technical Content FY11+
- Summarized of Current NDE Activities
  - NDE of Composites
  - NDE of Hybrid Composites
  - Computed X-ray Tomography
  - Probability of Detection
  - NDE of Cryo Tanks
  - Backscatter X-ray
  - Real-time NDE (Health Monitoring) of Propulsion Systems (turbomachinery)
  - NDE of Orbital Welds
  - Monitoring the Integrity of Thermal Insulation Systems
- Summarized New NDE Technical Content
  - Terahertz and X-ray Tomography
  - NDE of Hypergolic Micro-Flow
  - Tunable Laser Development for In-flight OFDR Structural Health Monitoring Systems
  - Graphics Processing Unit Assisted Thermographic Compositing
  - Development of IR Contrast Data Analysis Application for Characterizing Delaminations in Graphite-Epoxy Structure
  - Probability of Detection (POD) Demonstration Transferability: Phase II
  - Augmentation to complete Carbon Composite Stress Rupture NDE Development (restore funding)
  - NDE of Ablative Heat Shield Materials and Structures
  - Non-Intrusive Integrity Assessment of Underground Pipes

End

Budget Topics:

Schedule/Plan/ Milestones:

• Develop structural health monitoring system technology that incorporates advanced sensors to detect damage on thermal protection systems 9/2014
• Characterize the measurement response of fiber Bragg sensors embedded in Composite Overwrapped Pressure Vessels 8/12
• Validate the ability of smart sensors to reliably produce data 9/2011
• Assess stress-rupture related strength degradation in composite pressure vessels 8/2012
• Profilometer for Cylindrical COPVs with Ellipsoid ends of COPV 8/2010
• Determine feasibility of developing a consensus standard for in-service accept-reject for COPV 8/2010
• Nondestructive evaluation (NDE) techniques for detection of face sheet disbonds for different configurations of face sheet and honeycomb material. 10/2012
• Wireless passive corrosive environment sensor 6/2010
• NDE techniques for welded tube joints performed by an Orbital Arc Welding method. 9/2010
• Assessment of thermal imaging for Cryo Tank integrity 9/2010
• Investigate optically sensed acoustic emissions as impact monitoring system. 6/2010
• In-situ NDE methodologies for capturing strain changes, frequency variations, damage or crack pre-cursors, and crack initiations in rotating components. 9/2011
• Baseline 3D terahertz CT capability 10/2010
• Evaluate Probability of Detection (POD) Demonstration Transferability 9/2011

Significant Accomplishments:

• DFRC has completed testing of a 5-ft scaled heat shield carrier structure instrumented with fiber optic sensors using DFRC patented system technology.
• DFRC/MSFC/WSTF preliminary testing has shown excellent agreement with Fiber Bragg Gratings parallel and perpendicular to load.
• JSC/WSTF completed stress rupture aging of the second lot of 20 T1000 carbon vessels on January 29, 2010 (4 vessels failed)
• JSC titanium material acquired. Several specimens machined and slotted for fatigue cracking.
• JSC/WSTF profilometer was shipped to General Dynamic in Lincoln Nebraska (late December 2009) and was used there by the project manager through the end of January 2010 to follow 6 ISS stress rupture test vessels through the manufacturing process, providing a characterization never before obtained
• KSC Orbital Arc Welded Equipment for welded samples—equipment has been certified.
• KSC preparing 1000 Liter cryogenic tank to confirm thermal imaging results from the Pad B LH2 tank with known void sizes and inner tank temperatures
• SSC demonstrate smart sensor signal detection on composite samples with a control input signal.
• GRC tested new capacitive sensor and efforts are in progress to add the newly acquired capability by including an Eddy Current sensor system to monitor shaft/rotor displacement profile.
• GRC large numbers of voids arising from processing of composites were found, as well as large areas of matrix resin without reinforcing fiber. Features were independent of rupture life
• GSFC penetrant results show that the sensitivity level 3 penetrants performance is equal to or better than the level 4 penetrants.
• LaRC 90% of POD fatigue specimens manufactured with 50% NDI completed

Issues /Concerns:

• Late start caused by the continuing resolution caused a 4 month slip in the development schedule.

▪ Significant issue has been that the Space Station SARJ wear tests have co-opted the fatigue apparatus

▪ NDE Steering Committee chair designate in developing framework for that committee.

▪ Photolithographic fabrication of micron wide lines on PVDF (Polyvinyl Diflouride) is still an issue.