

ANSI/AIAA s-081A Pressure Vessel Standards Implementation Guidelines August 6-7, 2009



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Composite Overwrapped Pressure Vessel NDE

ANSI/AIAA S0-81A NDE Outline

5.2.9 - Stress Rupture Life

5.2.10 - Mechanical Damage Control Requirements

5.4.1 Liner Fabrication and Process Control

5.5.2 - Inspection Techniques

5.5.3 Inspector Certification Program

5.6.4 - Inspection and Maintenance

5.6.5 - Repair and Refurbishment

6.1.3 - Damage-Tolerance Life (Safe-Life) Analysis

6.3.1 - Non-Destructive Inspection

5.2.9 - Stress Rupture Life

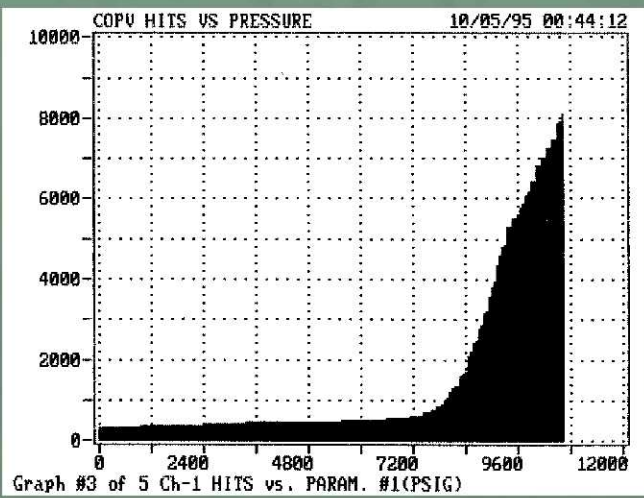
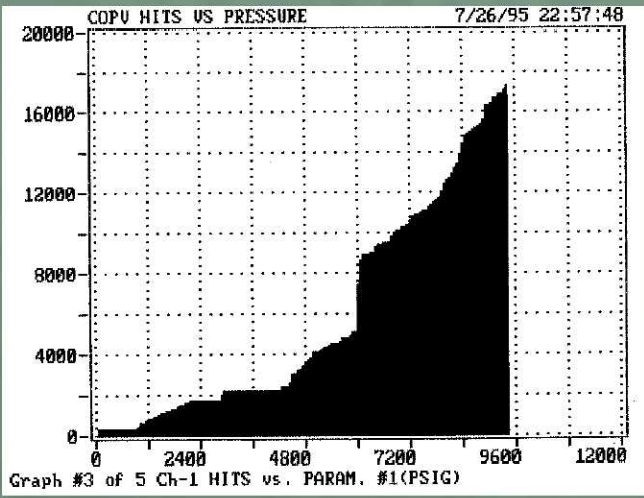
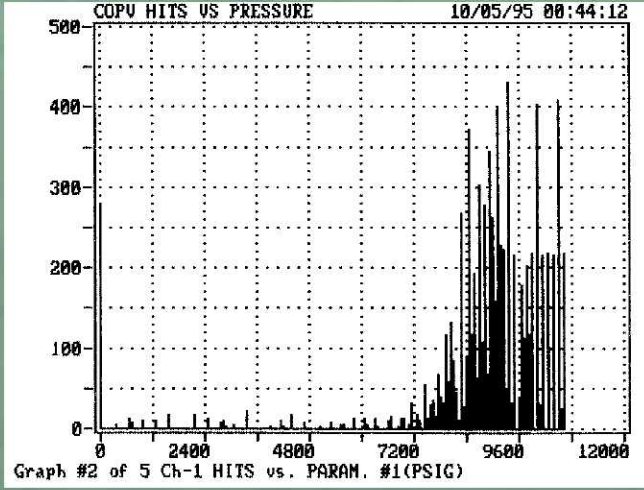
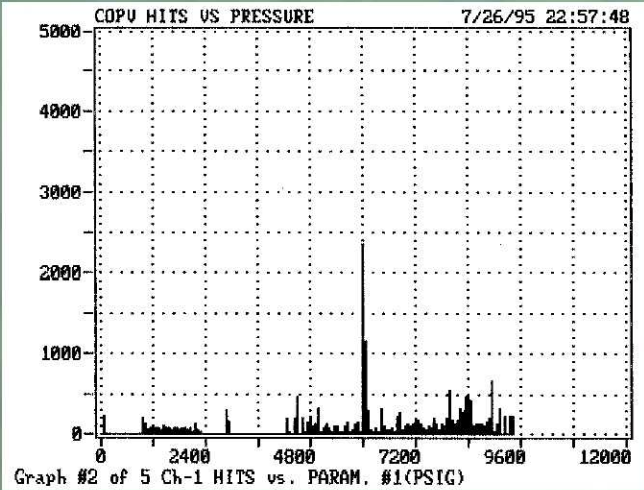
The composite shell of a COPV shall be designed to meet the design life considering the time it is under sustained load. For the specified mission duration, there shall be no credible stress rupture failure modes based on the stress rupture data for the specified probability of survival. The probability of survival shall be selected by the user for the intended application. For vessels pressurized at the launch site, the stress rupture requirements for one year at 0.999 probability of survival shall be met.

5.2.9 - Stress Rupture Life



5.2.9 - Stress Rupture Life

AE Spectra

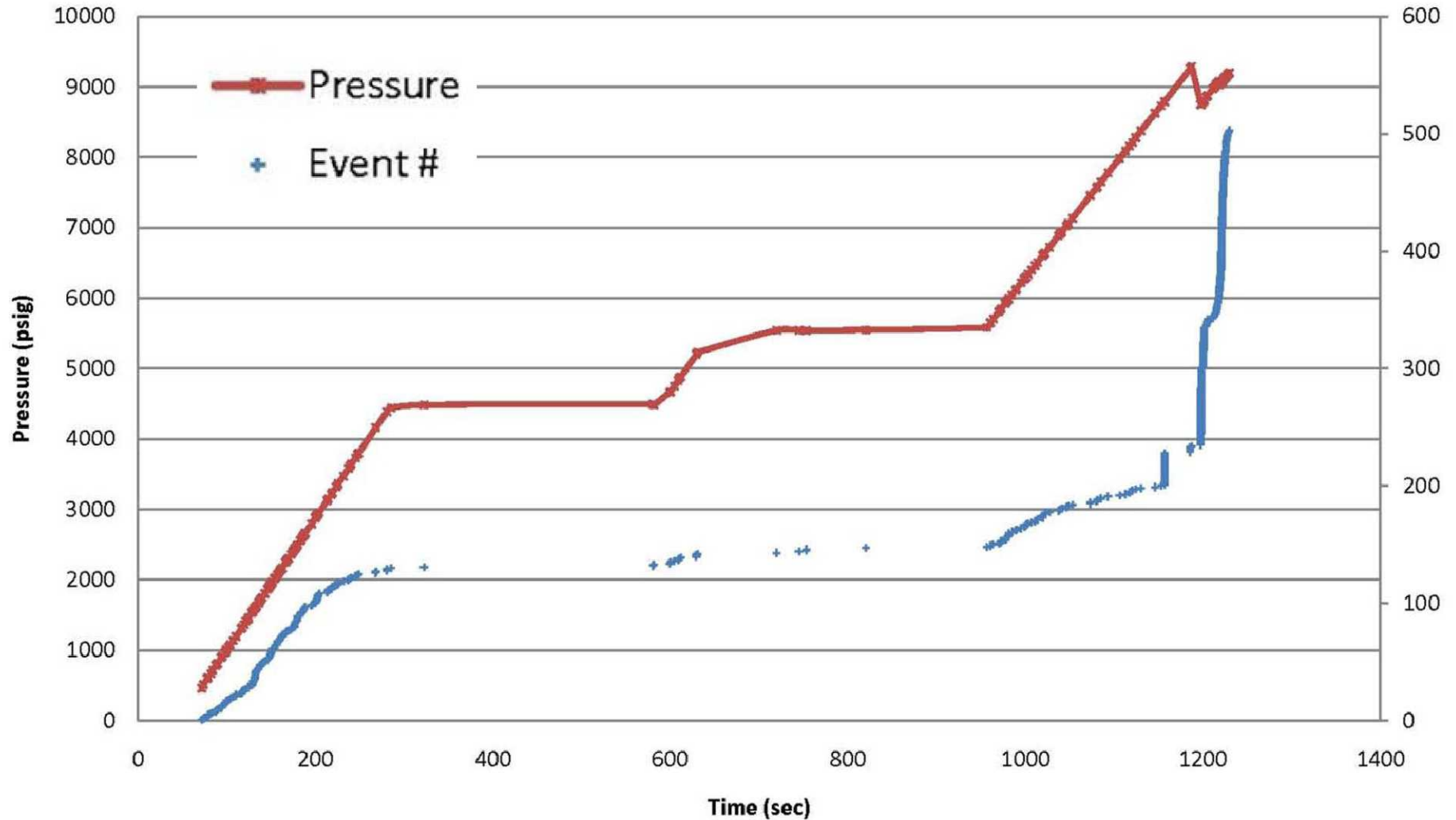


Impact-damaged COPV

Undamaged COPV

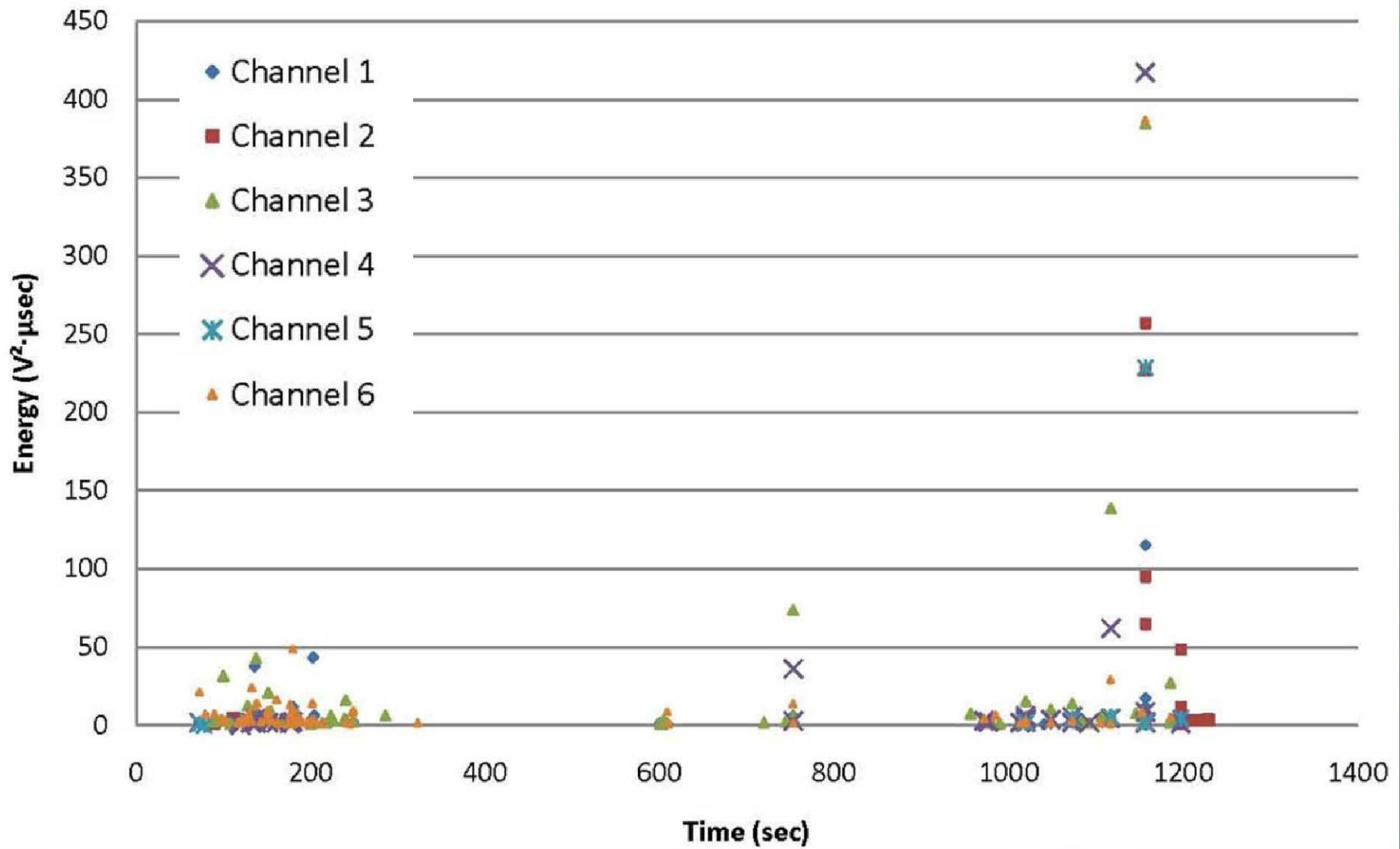
5.2.9 - Stress Rupture Life

Pressure and Events vs. Time



5.2.9 - Stress Rupture Life

Energy of Events vs. Time



5.2.10 - Mechanical Damage Control Requirements

A Mechanical Damage Control Plan (MDCP) shall be created and implemented that assures the COPV will not fail due to mechanical damage during manufacturing, testing, shipping, installation, or flight. The plan shall identify all credible mechanical damage threats starting from manufacture to the end-of-service life. Mechanical damage mitigation plans, procedures, and inspection points shall be defined. Comprehensive operating/handling/shipping procedures shall be prepared to ensure the COPV does not receive critical mechanical damage. These procedures shall be included or referenced in the MDCP.

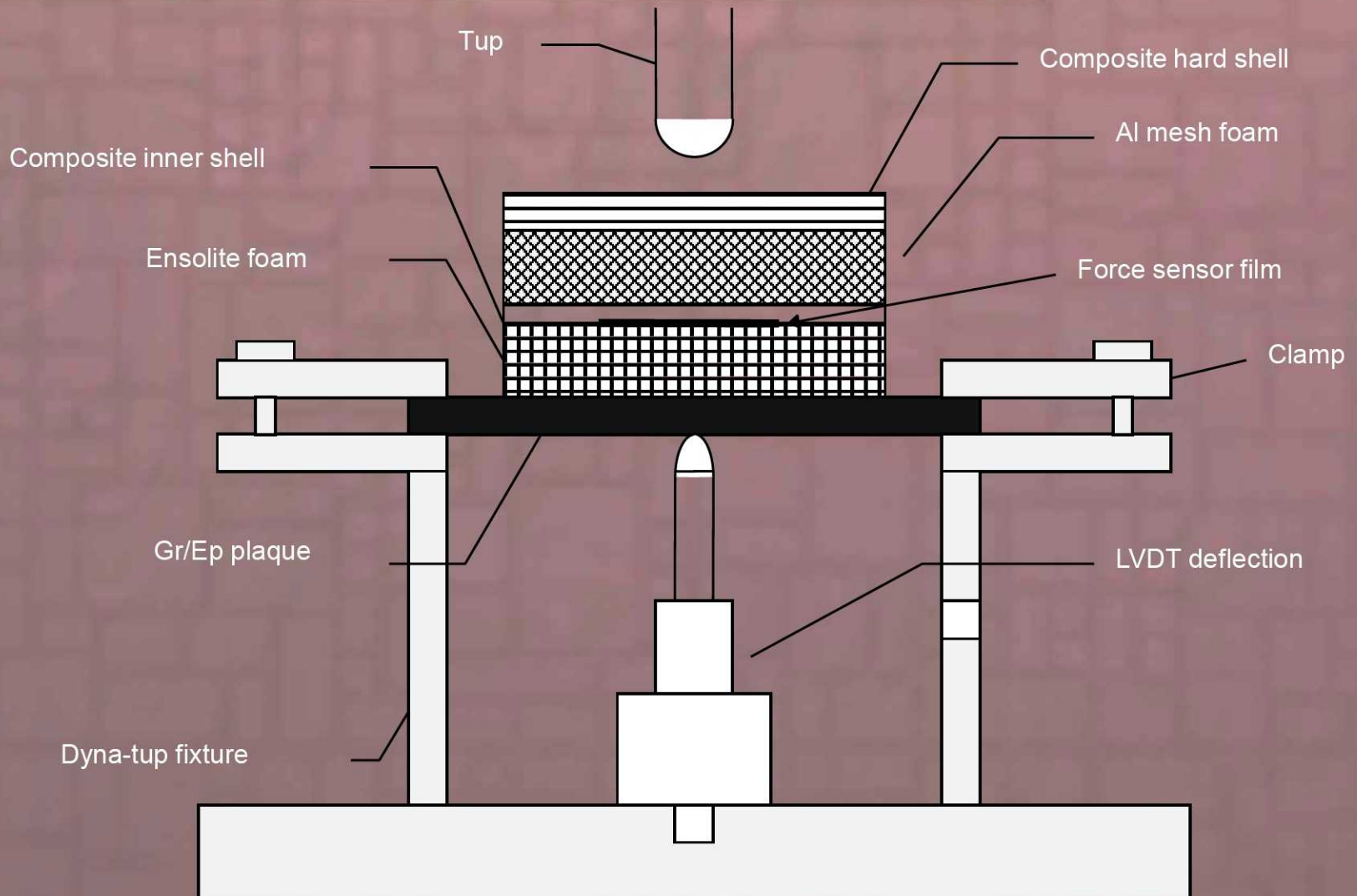
- [Protective Covers](#)
 - Covers may be used to isolate and protect the COPV. This approach requires that the cover be tested to demonstrate that the worst-case credible mechanical damage threat results in 5 ft-lb or less energy imparted to the COPV. If the energy imparted to the COPV is greater than 5 ft-lbs, then an impacted dedicated test article vessel must be pressure tested to demonstrate that the burst factor requirement of Section 5.2.2 is met.

5.2.10 - Mechanical Damage Control Requirements

- Damage Indicators
 - Indicators may be used to clearly show whether a COPV has received critical damage. This approach requires that the indicators be tested to demonstrate that they can sense and indicate a mechanical damage event over the range of 5 ft-lbs to the maximum credible threat level. If the indicator's minimum sensing energy is above 5 ft-lbs, then a dedicated test article COPV must be impacted at that energy level and pressure tested to demonstrate that the burst factor requirement of Section 5.2.2 is met.
- Worst-case Threat Damage Tolerance
 - A dedicated test article COPV may be tested to demonstrate it can withstand 1.25 x the worst-case credible mechanical damage and still meet the burst factor requirement of Section 5.2.2. If this approach is used, no covers or indicators are needed.
- Visual Mechanical Damage Threshold Testing
 - A dedicated test article COPV may be tested to demonstrate that the mechanical damage threshold energy creates a visually detectable damage indication that will survive the pressure test for the burst factor requirement of Section 5.2.2. If this approach is used, the COPV must be visually inspected after the threat exposure and prior to pressurization.

5.2.10 - Mechanical Damage Control Requirements

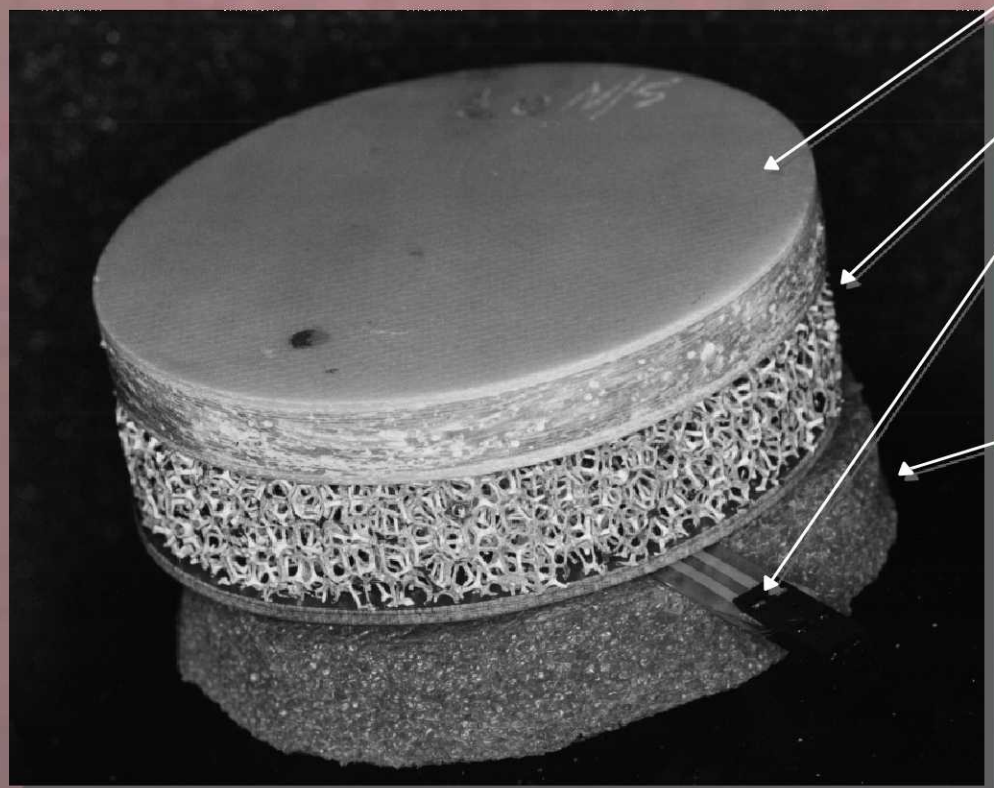
Impact Indicator/Protector Test Fixture



5.2.10 - Mechanical Damage Control Requirements

Overview of Impact Protectors

Hard-shell laminate cover shield



Fiberglass/epoxy composite
hardshell

Aluminum mesh foam

Resistive force sensor
mounted on thin
fiberglass board

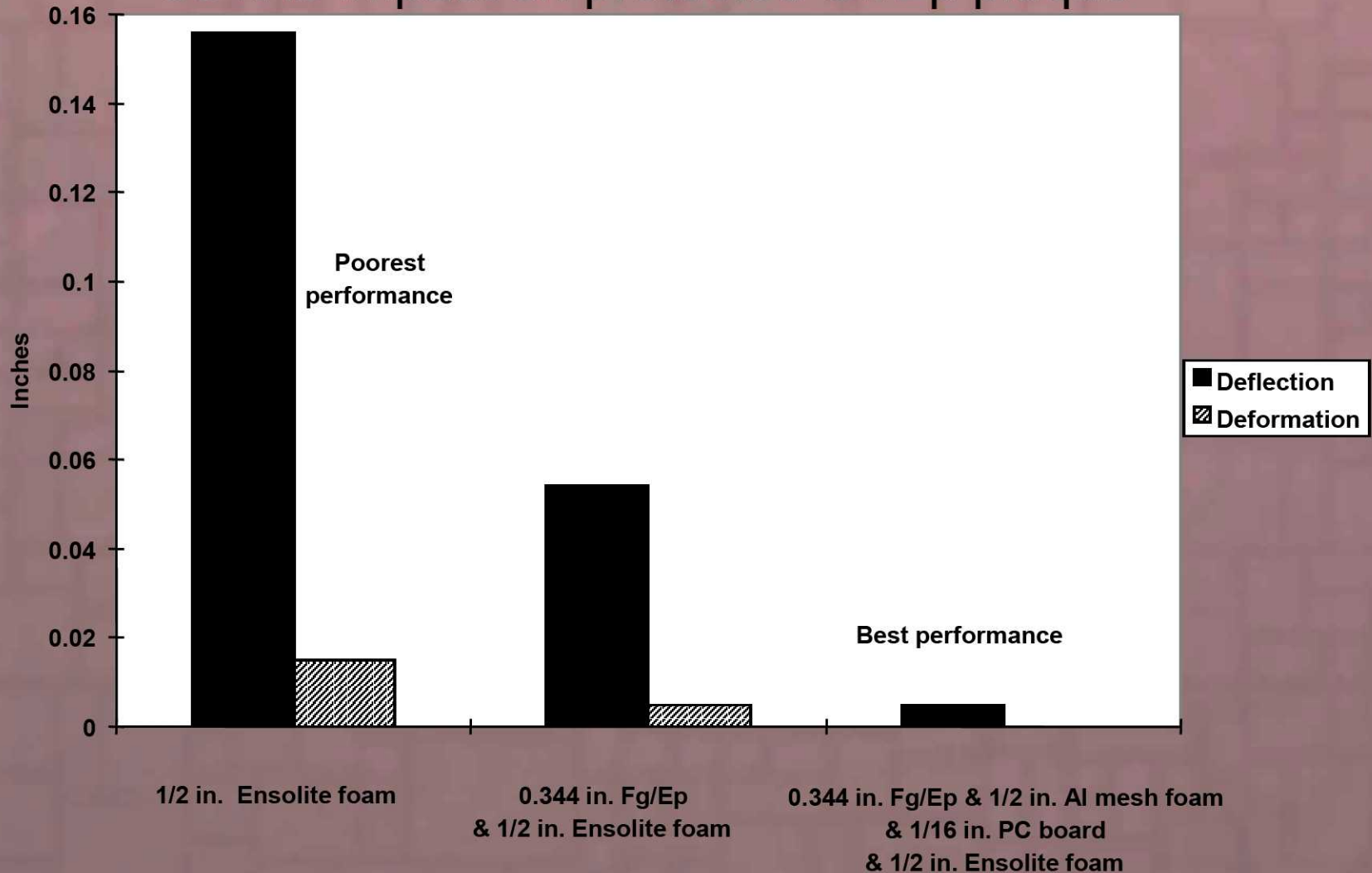
Ensolite[®] high-density foam

Impact indicator/protector cross section

5.2.10 - Mechanical Damage Control Requirements

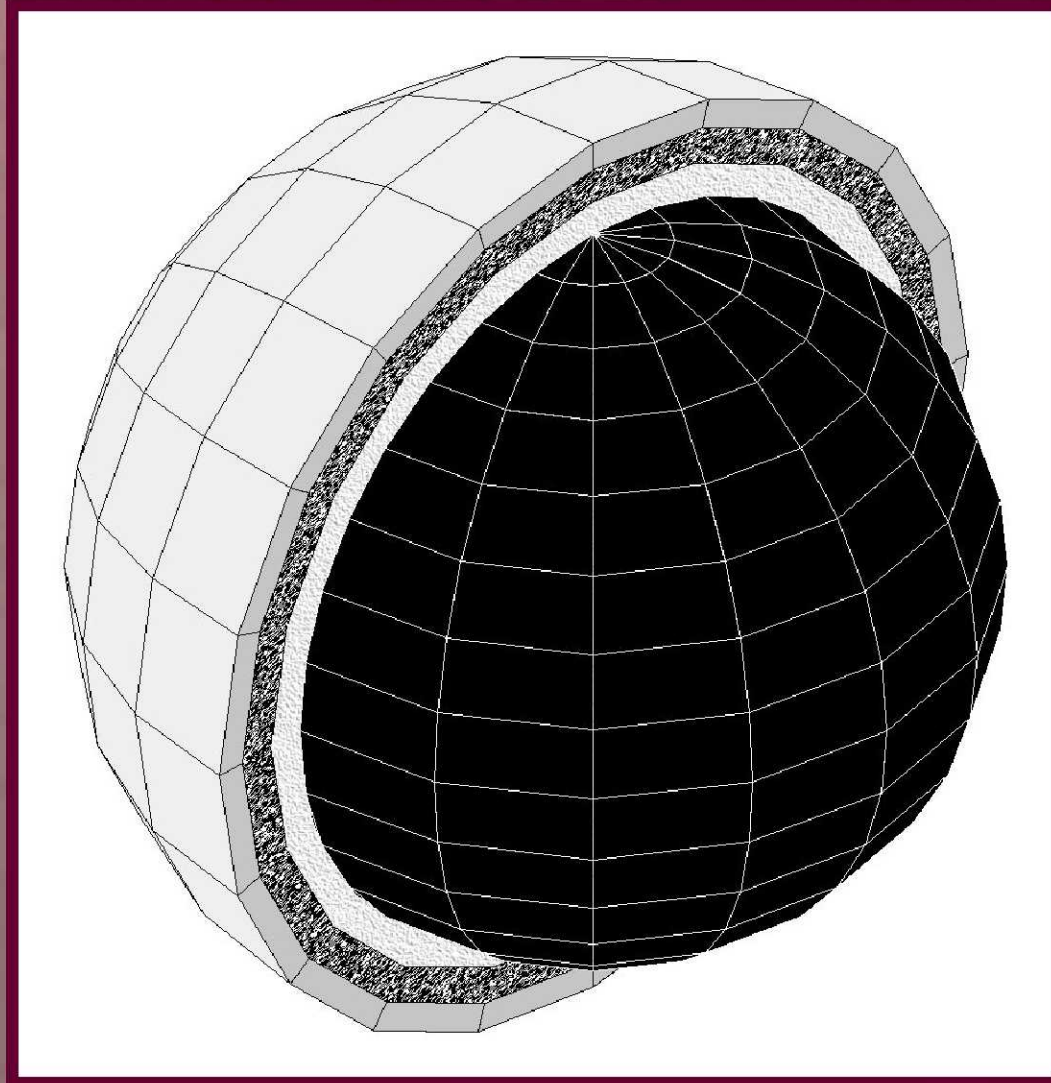
Protector Mechanical Performance

35 ft-lb impact on protected Gr/Ep plaque



5.2.10 - Mechanical Damage Control Requirements

Spherical Protective Cover



5.2.10 - Mechanical Damage Control Requirements

Damage Indicators

- Indicators tested to demonstrate sense of damage over range of 5 ft-lb to the maximum credible threat level
- If the minimum sensing energy is above 5 ft-lb, then a dedicated COPV must be impacted at that energy level and pressure tested to demonstrate the burst factor requirement is met



5.2.10 - Mechanical Damage Control Requirements

Overview of Impact Indicators

- Plexiglass/glass covers (foam-lined metal)
 - Provides protection for 5 ft-lbf impacts
 - Indicates COPV impact by failed cover
- Ensolite[®] foam with force-sensing films
 - Provides protection for <1 ft-lbf impacts
 - Indicates COPV impact by electronic alarm
- Micro-spheres
 - Burst/break during impact event



5.2.10 - Mechanical Damage Control Requirements

Worst-Case Threat Damage Tolerance Testing

- Dedicated COPV may be tested to demonstrate it can withstand 1.25 x the worst-case damage and still meet the burst factor requirement.
- If this approach is used, no covers or indicator are needed.
 - Visual inspection points should be identified in the Mechanical Damage Control Plan



5.2.10 - Mechanical Damage Control Requirements

Visual Mechanical Damage Threshold Testing

- Dedicated COPV may be tested to demonstrate damage energy creates visually detectable damage that will survive the pressure test and still meet the burst factor requirement.
- If this approach is used, the COPV must be visually inspected after the threat exposure and prior to pressurization.
 - Visual inspection points pre-determined in ICP



5.4.1 Liner Fabrication and Process Control

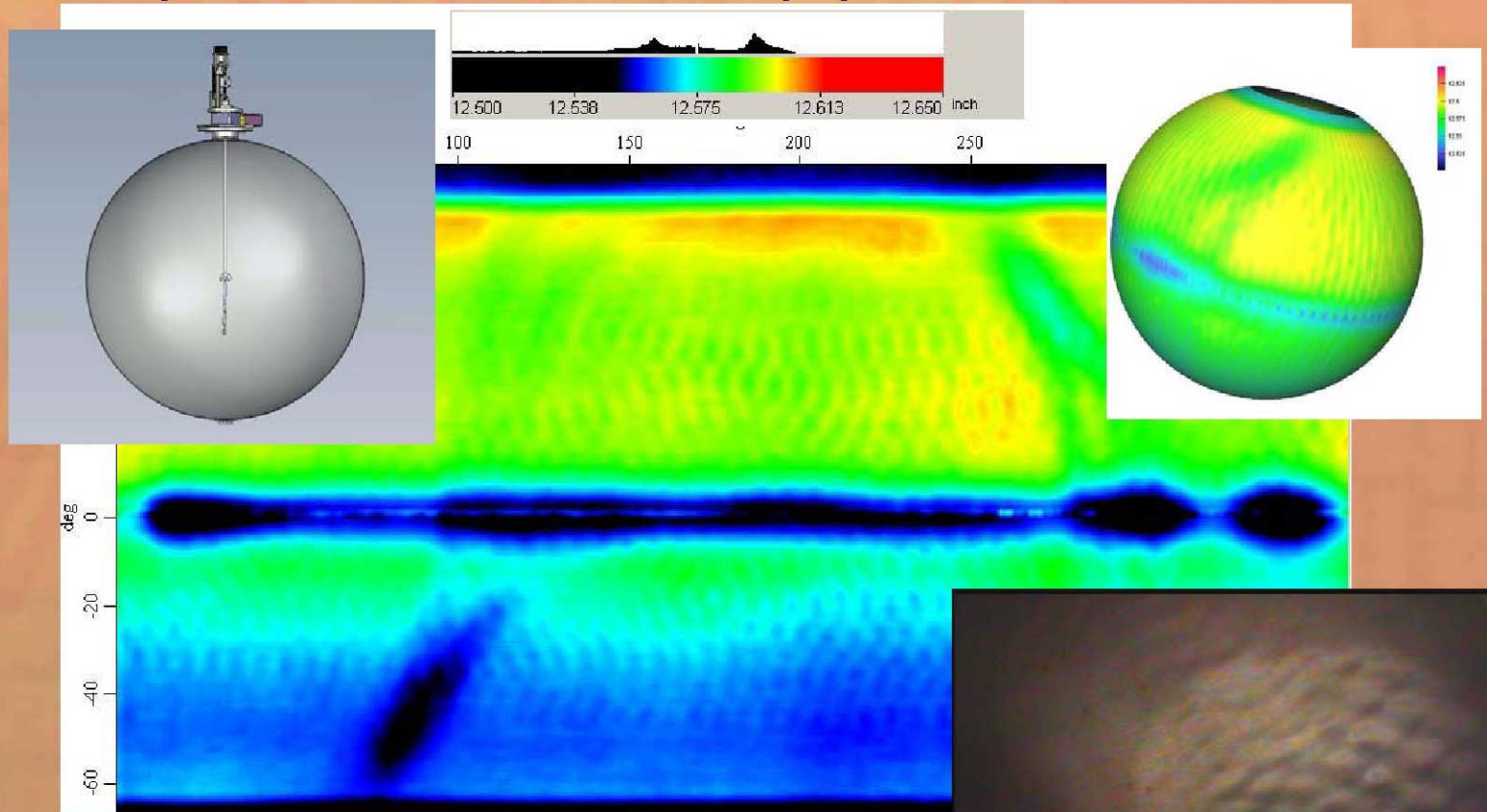
Proven processes and procedures for fabrication and repair shall be used to preclude damage or material degradation during material processing, manufacturing operations, and refurbishment.

Special attention shall be given to ascertain that the melt process, thermal treatment, welding process, forming, joining, machining, drilling, grinding, and repair operations are state-of-the-art and have been used on similar items.

5.4.1 Liner Fabrication and Process Control

Laser Profilometry

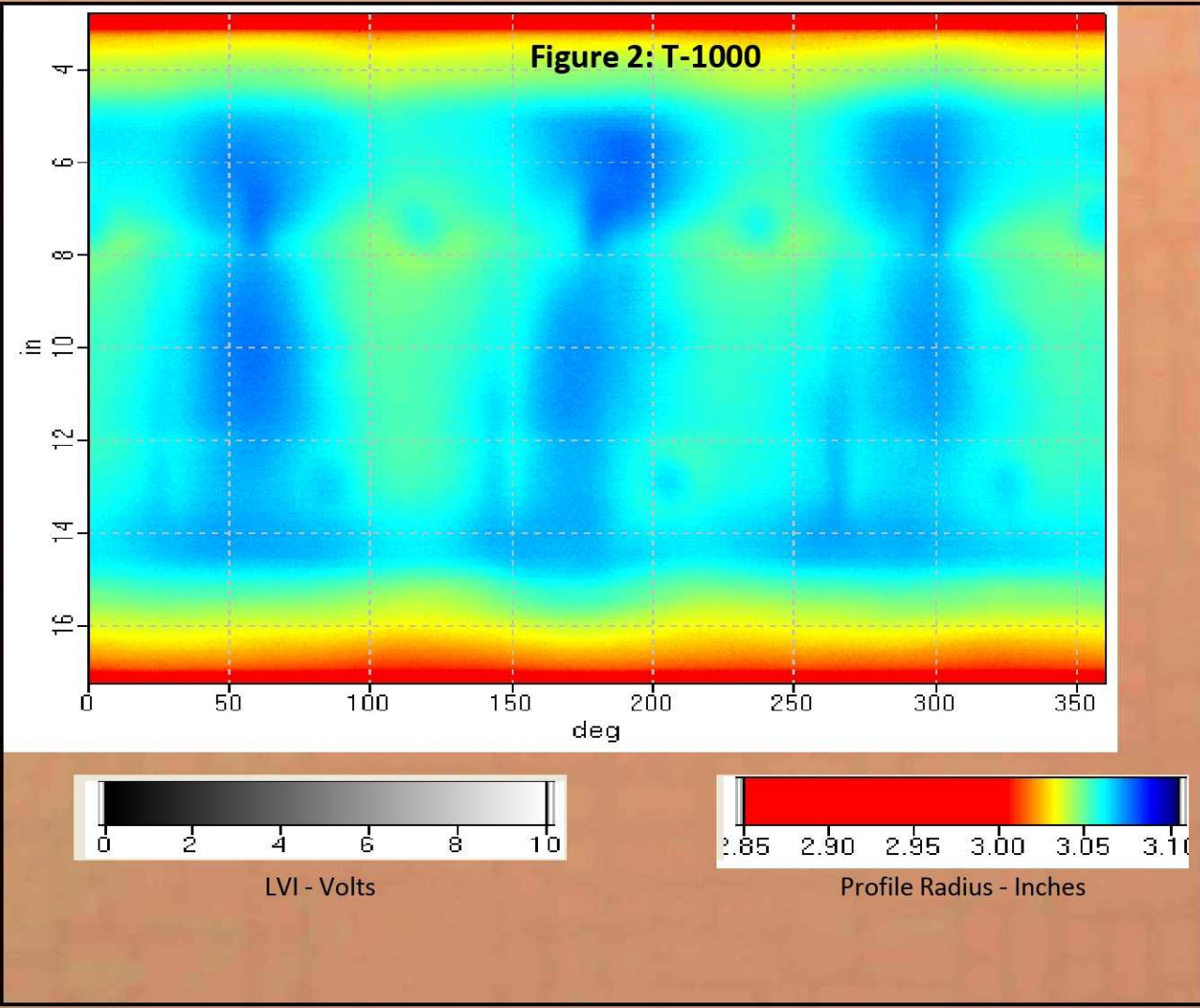
Laser Profilometry of COPV's interior surface quantifies liner buckling not inspectable by other methods and mirrors physical observation



Calibration traceable to National Standard and demonstrated better than 0.001 accuracy/repeatability on 26-in. and better than 0.002 accuracy/ repeatability on 40-in.

5.4.1 Liner Fabrication and Process Control Con't

Cylindrical Laser Profilometry Scan



5.5.2 - Inspection Techniques

- The selected NDI techniques for the liner and/or boss(es) shall be performed before overwrapping with composite materials.
- NDI techniques for liners shall have the capability to determine the size, geometry, location, and orientation of all significant flaws. The detection capability of each selected NDI technique shall be capable of detecting initial flaw sizes corresponding to 90% probability of detection at 95% confidence level.
- After composite overwrapping and curing, the COPV shall be visually inspected by a trained COPV inspector per 5.5.3 at the points defined by the damage control plan.

5.5.2 - Inspection Techniques

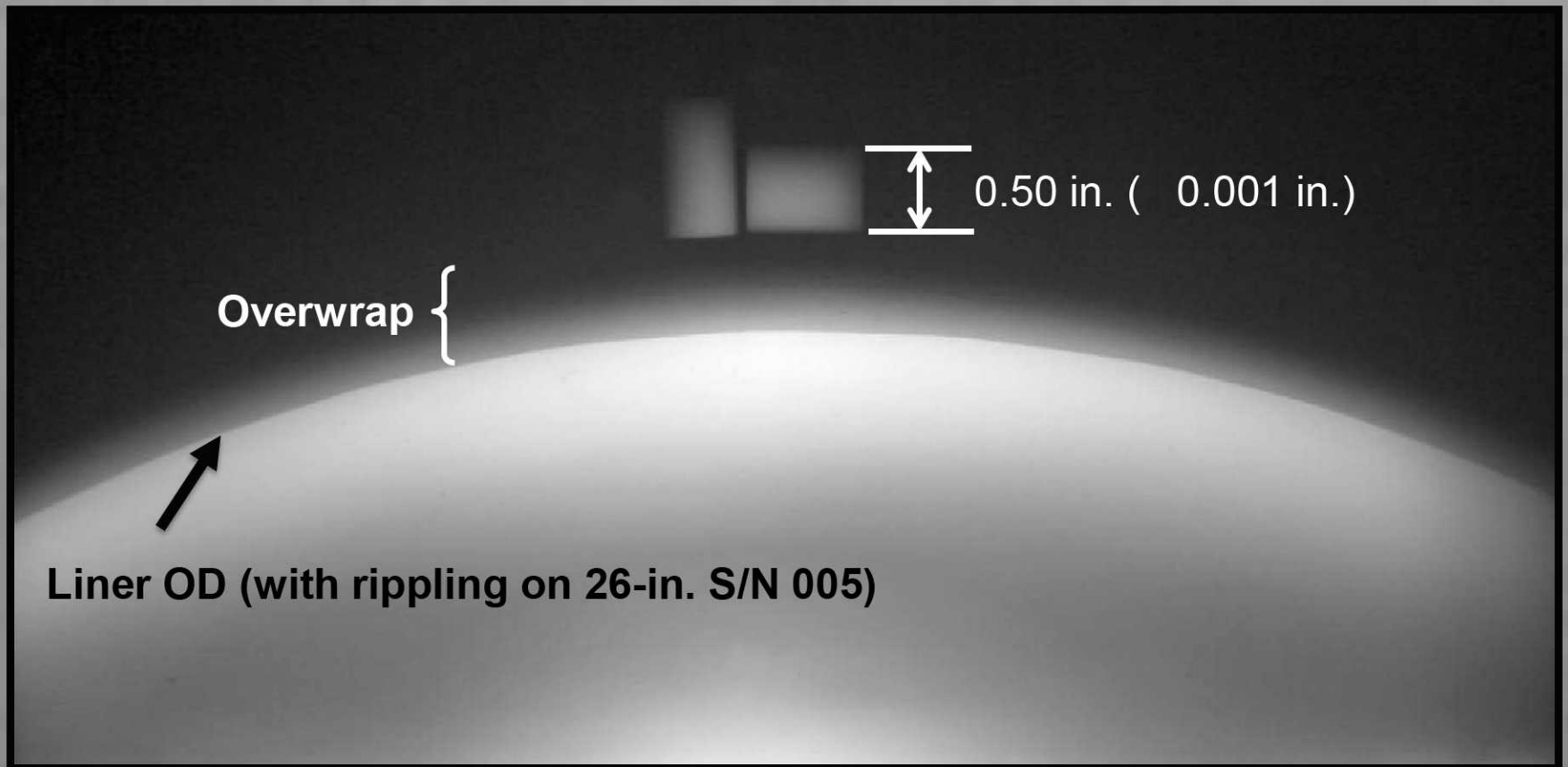
Radiography

- Radiographic examination
 - Identify cracks in liner
 - Image discontinuities in the weldments
 - Thickness of the weldment heat-affected zones
- Identify Liner buckles or ripples



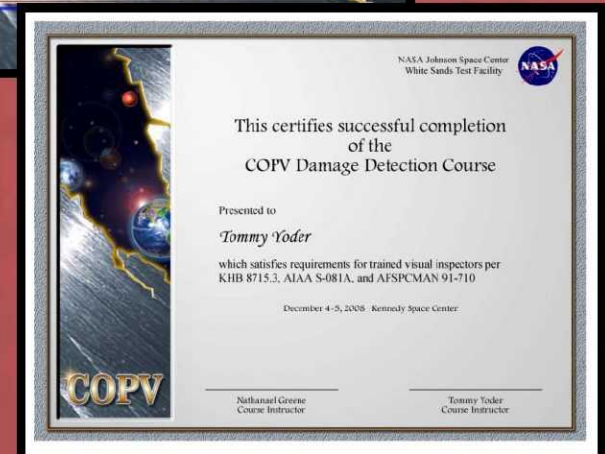
5.5.2 - Inspection Techniques

Example Radiographs of S/N 001 26-in.



5.5.3 Inspector Certification Program

- WSTF Training Course fulfills training requirements.
- Company is responsible for ensuring that trained personnel have been certified. A trained inspector's skills should be comparable to a Level II visual inspector.



5.6.4 - Inspection and Maintenance

- NDE shall be performed per the mechanical damage control plan.
- Allowable damage limits shall be used to determine inspection frequency.
- Records of inspection shall be collected and maintained.

5.6.4 - Inspection and Maintenance

Sample WSTF VT Report

- Date
- COPV description
- VT observations
- Key observations
- Sketch
- Digital photo(s)
- Signature/stamp

**WHITE SANDS TEST FACILITY
COPY VISUAL INSPECTION REPORT**


Date 03/11/97 AKM7-Pressure

COPY DESCRIPTION			
Manufacturer	<u>Lincoln Corp.</u>	F/N <u>220125-1</u>	S/N <u>903</u>
Configuration	<u>Cylindrical</u>	Dimensions	<u>12" x 36"</u>
Test Sequence	<u>N/A</u>	WSTF No.	<u>N/A</u>

VT OBSERVATIONS				
No.	Size	Location Long. (in)	Int/Ext	Comments/Observations
<u>1</u>	<u>270-300°</u>	<u>28.5-37</u>	<u>Ext</u>	<u>Scuff on broken fiber-surround</u>
<u>2</u>	<u>±250°</u>	<u>51</u>	<u>Ext</u>	<u>Transition zone fiber cracking</u>
<u>3</u>	<u>0°</u>	<u>41.5-43</u>	<u>Ext</u>	<u>Surface Scuff</u>
<u>4</u>			<u>Ext</u>	<u>Fiber bridge on blind boss</u>
<u>5</u>			<u>Ext</u>	<u>Fiber bridge on port boss</u>
<u>6</u>	<u>270°</u>	<u>12" from</u>	<u>Ext</u>	<u>Scuff on surface</u>
		<u>transition</u>		<u>band</u>

Sketch: As Required

Note: Key from Part 1 label
and clockwise from port



KEY OBSERVATIONS
Cracking
Cuts (fiber breakage)
Discoloration
Impacts (dents)
Ply disorientations
Surface bubbles (ground)
Voids
Other

Examined by: _____

Reported by: _____

Approved by: Michael Brown Paul J. ...

5.6.5 - Repair and Refurbishment

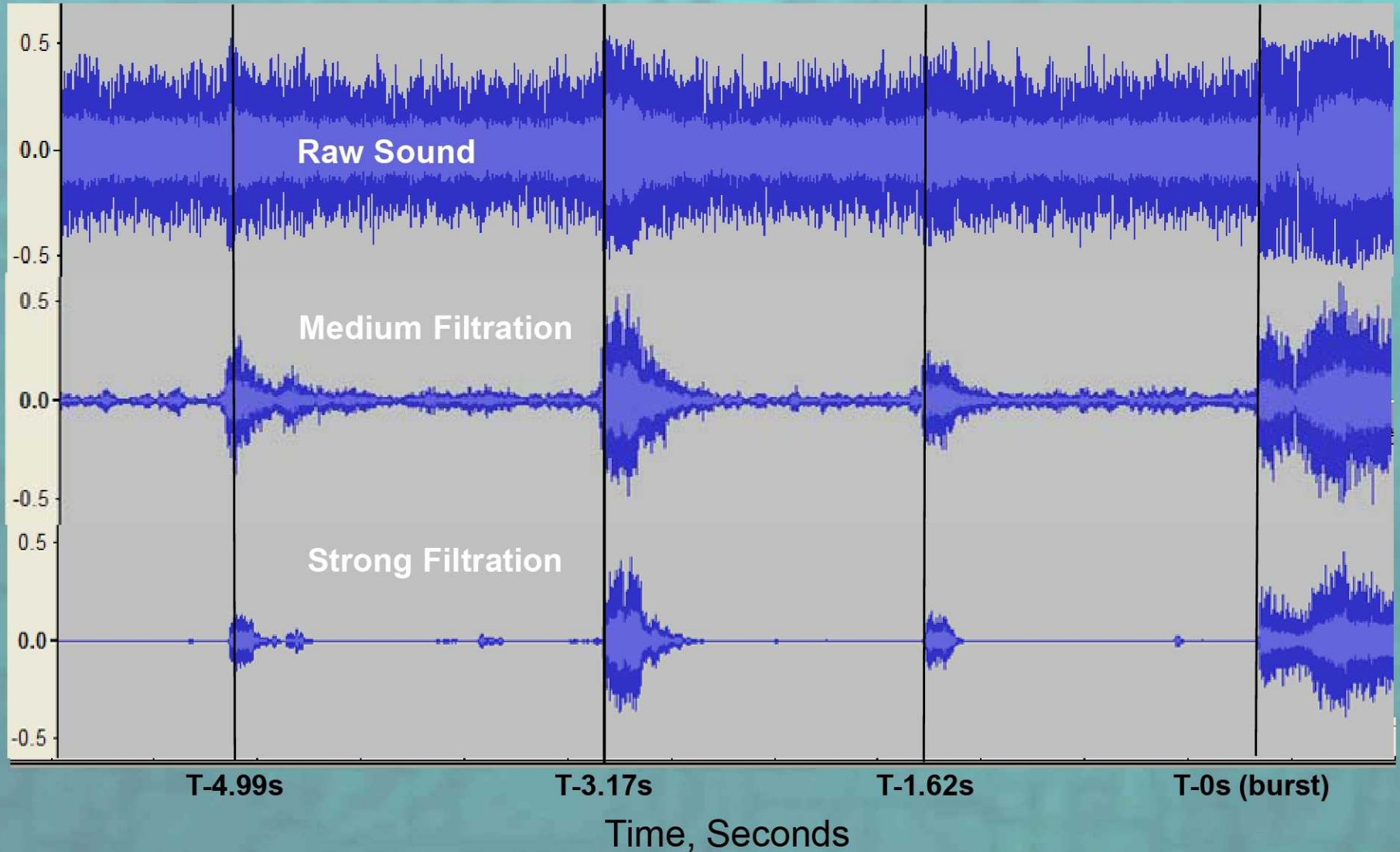
- When visual inspection reveals mechanical damage or defects exceeding manufacturing specification levels (and standard repair procedures), the damaged COPV shall be submitted to a material review board (MRB) for disposition.
- If repair or refurbishment is allowed by the procuring authority, any repaired or refurbished COPV shall be recertified afterward by the applicable acceptance test procedure for new COPVs to verify structural integrity and establish suitability for continued service.

5.6.5 - Repair and Refurbishment

- To determine if vessel is acceptable for reuse due to mechanical damage (MRB required)
 - COPV manufacturer should be involved in MRB
 - Qualified materials representatives
 - Recertification by acceptance testing
 - AHJ (procuring authority)
- Health checks may be required

5.6.5 - Repair and Refurbishment

Passive Listening - Burst Sound File

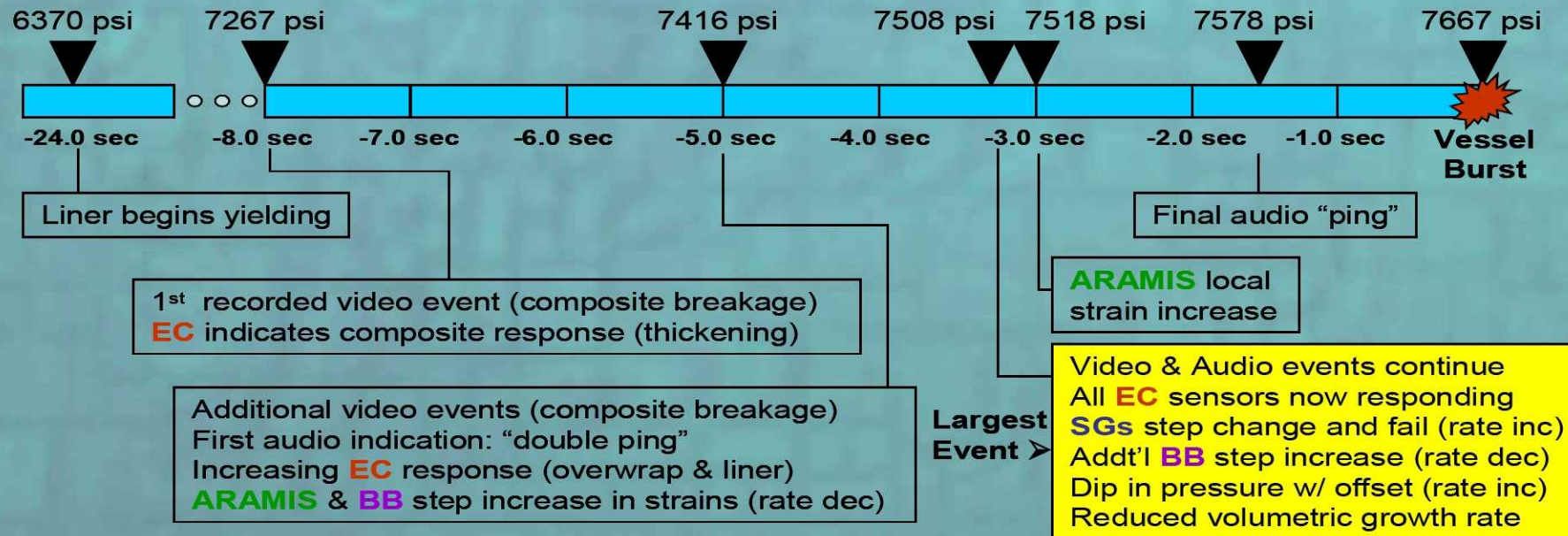


5.6.5 - Repair and Refurbishment

Chronological Mapping of Tank Failure

Team mapped all the instrumentation data to the video record to determine the chronological sequence of the burst events

- Found that all data were consistent
- Acoustic emission system became saturated and was not usable late in the burst
- At T-8 sec, visual evidence of fiber failure at the outer surface with minimal response from other onboard instrumentation
- The timeline from T-5 onward was a flurry of activity from most of the onboard instrumentation



EC = Eddy Current
ARAMIS = Digital Image
SG = Strain Gauge
BB = Belly Bands

t-5 thru t-3.2 sec
NOTE: Steady tow breakage on video towards burst point.

Final 3 seconds
NOTE: EC shows steady composite thinning. Liner sensors show similar trends.

6.1.3 - Damage-Tolerance Life (Safe-Life) Analysis

- Flaw sizes shall be predetermined to ensure NDE is acceptable at Probability of Detection (POD) requirements.



6.3.1 - Non-Destructive Inspection

- Every COPV shall be subjected to visual and other non-destructive inspection (NDI), per the inspection plan of Section 5.5.1, to establish the initial condition of the fabricated vessel.
- Inspection shall include a volumetric and surface inspection by selected NDI techniques.
- An internal liner inspection for buckles or other gross internal defects shall be conducted on all COPVs after autofrettage and proof pressure cycles.

6.3.1 - Non-Destructive Inspection

Example of Visual Inspection



6.3.1 - Non-Destructive Inspection

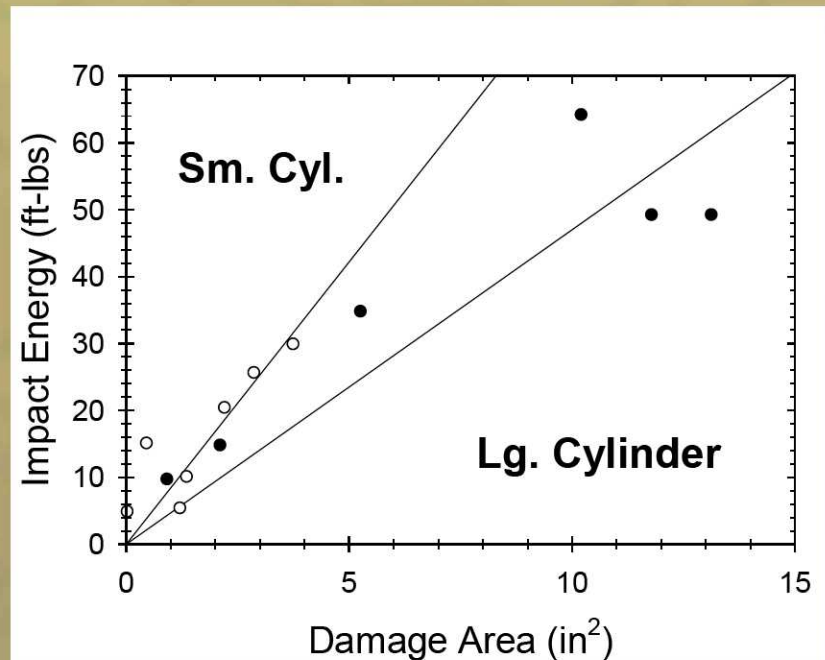
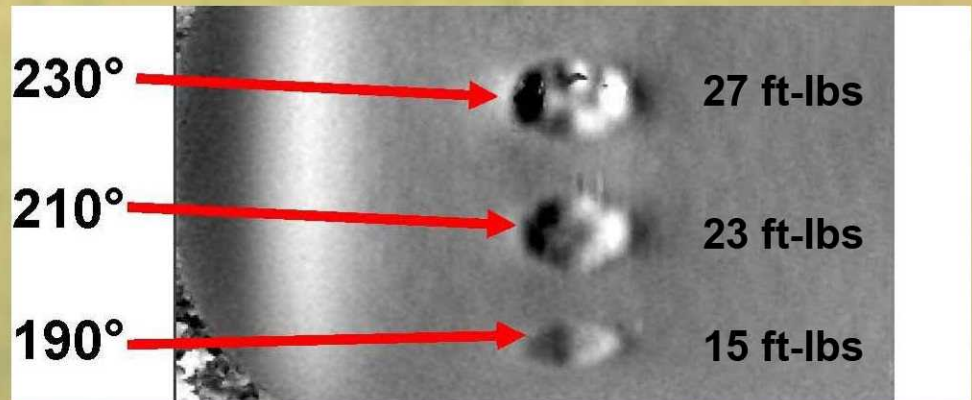
Borescope Inspection



6.3.1 - Non-Destructive Inspection

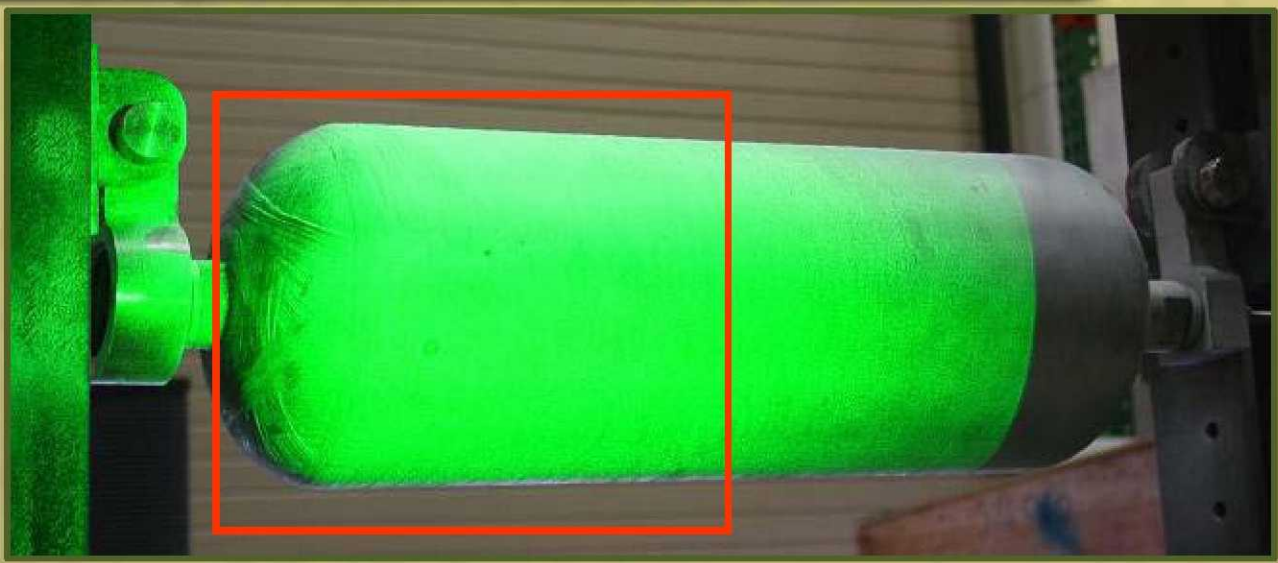
Shearography Inspection

1. Shearography detected small damage sites below the visual detection threshold
2. Shearography indicated damage much more extensive than visually evident
3. Damage area increases with impact energy for all COPVs

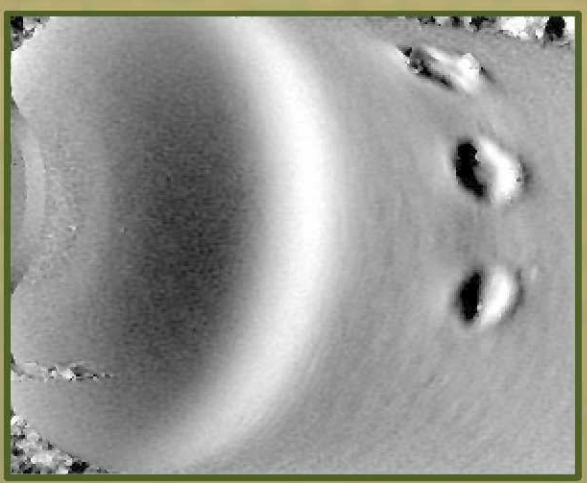


6.3.1 - Non-Destructive Inspection

6 x 22-in. Graphite COPV Shearography Inspected with 10 psid



Centered
at 30



Centered
at 60

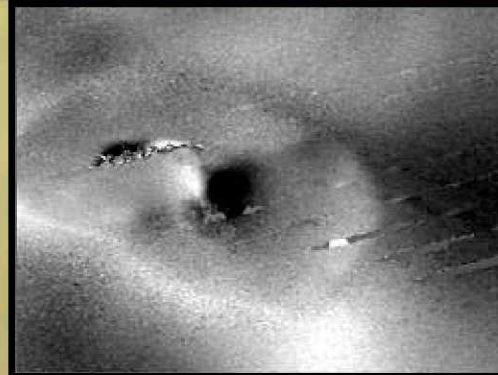


Unprogrammed Damage

6.3.1 - Non-Destructive Inspection

Carbon Fiber COPV: Impact Damage

1- 5 psi. Shows broken fibers at center with a large delamination.



20-24 psi. Shows more detail.



150-154 psi. Image of delamination not detected, broken fibers in center.



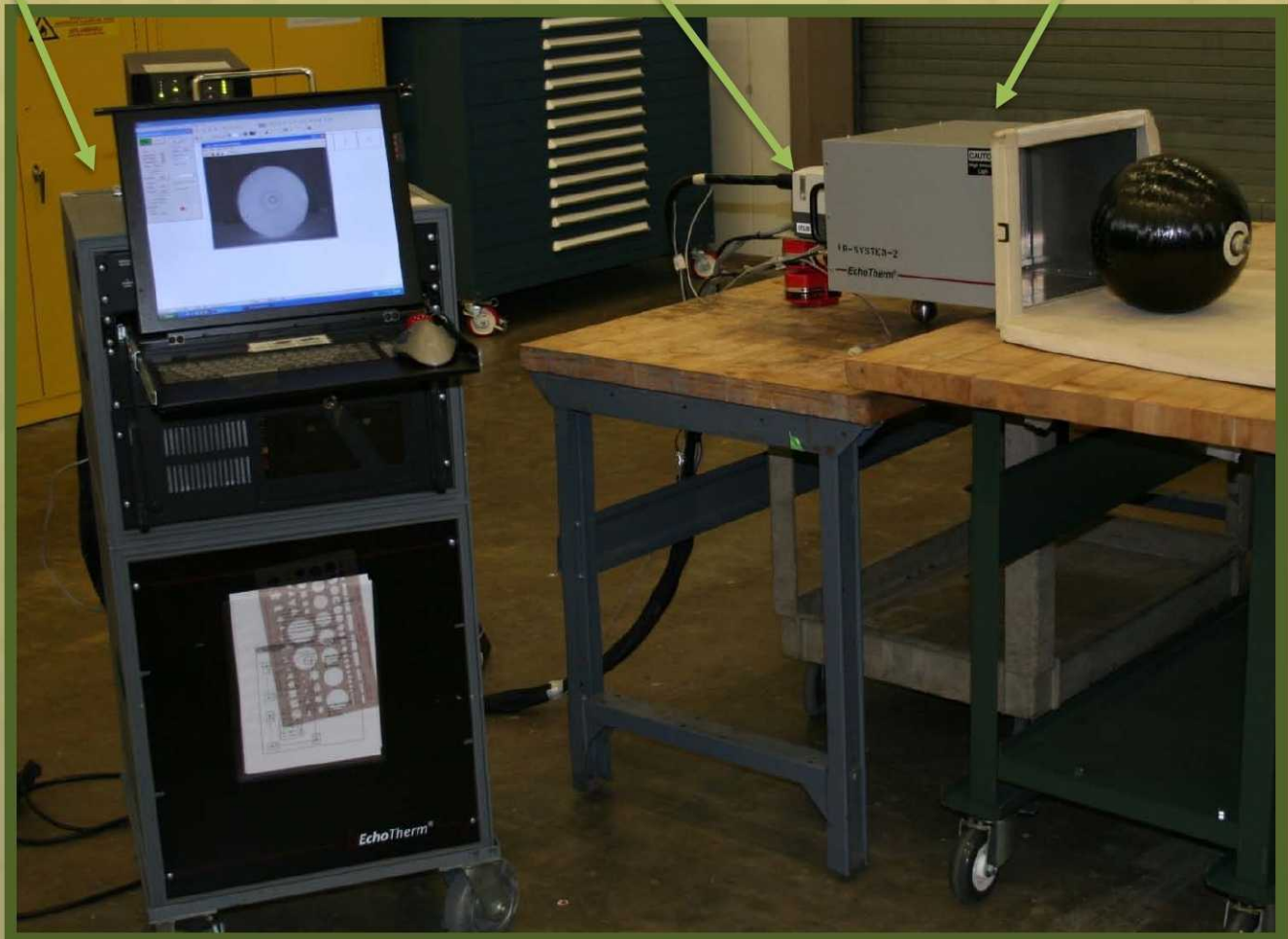
6.3.1 - Non-Destructive Inspection

Flash Thermography Setup

Data Acquisition Station

Camera

Hood containing 2 high intensity flash bulbs

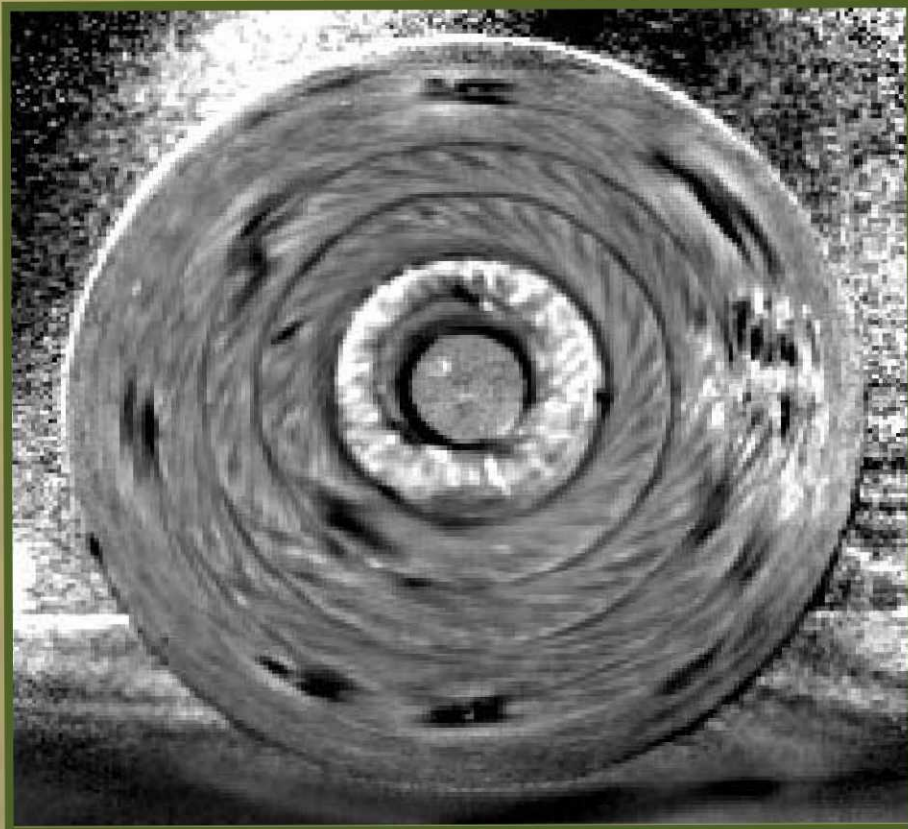


6.3.1 - Non-Destructive Inspection

Bottom Boss 0 deg TDC

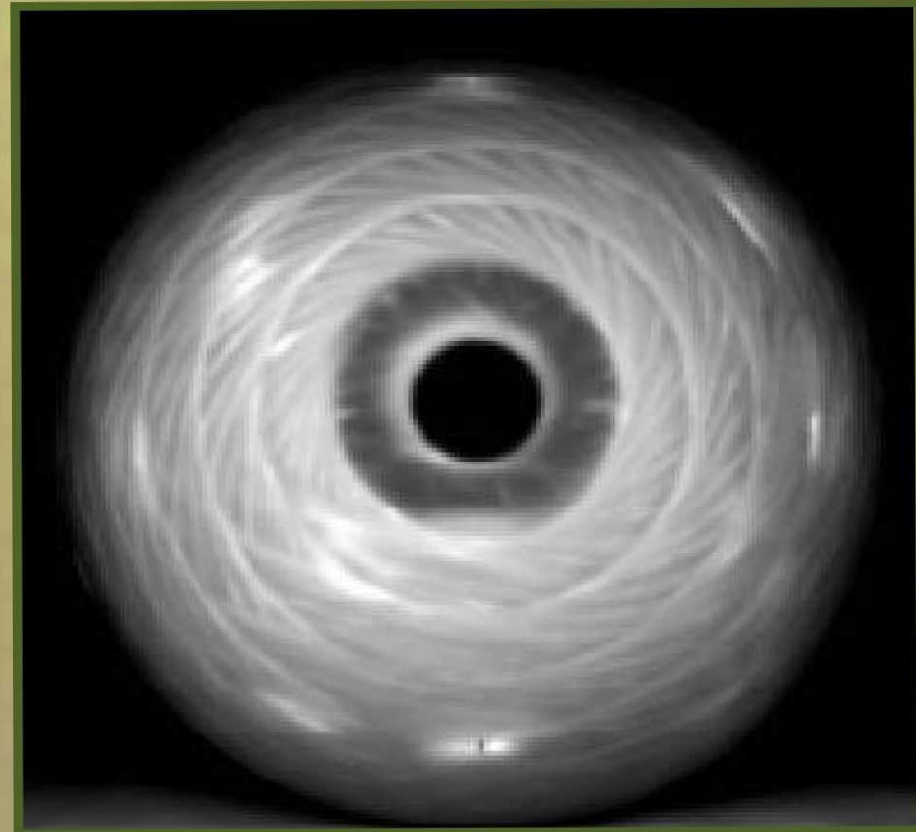
2nd Derivative

2.5 Sec.



RAW

2.5 Sec.



6.3.1 - Non-Destructive Inspection

COPV 47 at 135 , 2.5 sec, Raw, 25 mm



Questions

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