



DRAFT



Considerations for IVA NDE Instrumentation for ISS On-Orbit NDE Applications

In-space Inspection Workshop

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Summary



- Need for ISS On-orbit NDE Equipment
- Inspection Cases
- Damage Detection Requirements
- Assessment of NDE equipment for Use on ISS
 - Ultrasonic Testing and Eddy Current Testing
- NDE Test Protocols
- Ultrasonic and Eddy Current Scan Demonstration Examples
- Engineering Assessment Considerations



Need for On-Orbit NDE Equipment



- There is a high risk of module damage/penetration from MMOD impact to the ISS over the life of the program.
 - At present, there is a greater than 33 percent probability of ISS penetration from MMOD over a ten year period.
 - MMOD debris threats have been changing as more debris is being created and additional modules are being manifested.
- Although on-orbit leak repair kits are available for pressure loss mitigation, these kits do not address structural repair needs.
- The needed quantitative NDE damage assessment tools to support the evaluation and repair of structural damage are not on-orbit.



Mitigation Steps for ISS Risk 4669 Requirements for NDE Inspection



Mitigation steps status for Risk 4669 “Pressurized Module Leak Detection and Repair“

Mitigation Step	Onboard ISS	Hardware status	Developer	New CR Req
1. IVA Leak Repair PWRK	Yes	USOS Cert completed RS Cert in work	US	No
2a. IVA Leak location ULD, “BAR” Set	Yes	Completed	US, RSC E	No
3. Autonomous leak detection system UBNT Hdwe option	No	On hold pending completion of step 8	US	Yes
4. NDE inspection IVA GFE option	No	Planning and Draft CR in work	US	Yes
6. EVA Leak repair hardware “Pressurizer”	Yes	RS Cert completed USOS Cert planning in work	RSC E	No
7. Permanent repair Structural repair with bonded or welded doublers	No	Planning and Draft CR in work	US	Yes
8a. Environment characterization tests, ground UBNT Phase I	No	Completed	US	No
8b. Environment characterization tests, ground UBNT Phase II	No	Planning in progress with RSCE and Khrunichev	US	Yes
8c. Environment characterization tests, ISS on-orbit UBNT Phase I UBNT Phase II	Yes No	Pending available crewtime Planning in progress with RSCE and Khrunichev	US	Yes



Inspection Cases

Provide Capability for the Following Inspection Cases

- Case 1: Damage to pressure wall with **leak**
 - NDE after pressure repair (flexible patch or rigid dome)
 - Ultrasonic sensor will contact pressure wall outside the repair due to inability to sense damage through repair patch (Tape or dome)
 - Shear wave scan
- Case 2: EVA Epoxy and Other Repair (future capability)
 - Ultrasonic inspection of bondline, zero degree scan
- Case 3: Suspect impact damage on ISS pressure wall with **no leak**
 - Zero degree scan and/or shear wave scan
- Case 4: Corrosion
 - Zero degree scan

See “Draft of Con-ops Document” for additional information.



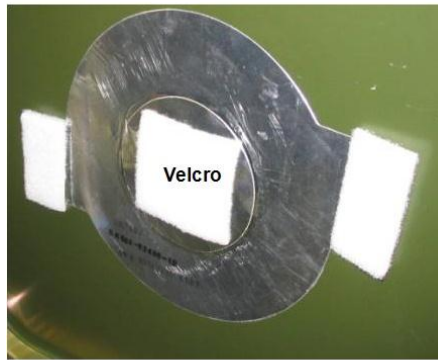
Inspection Case 1

Damaged area may be blocked by the leak repair patch

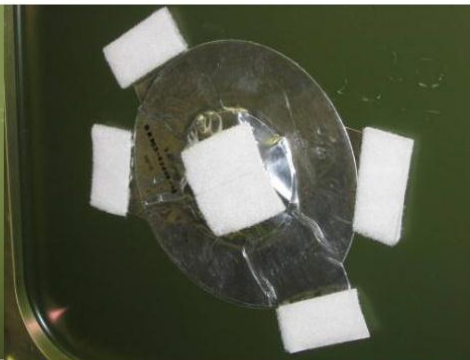
- Flexible Patch - Single and double thickness aluminum tape
- Rigid Patch - Dome-shaped aluminum plate with flexible seal

Flexible Patch

Single



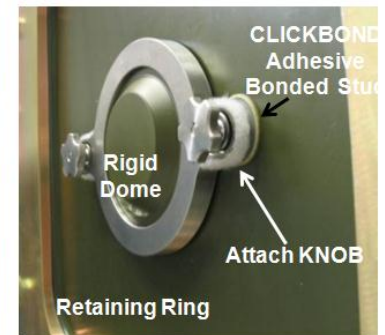
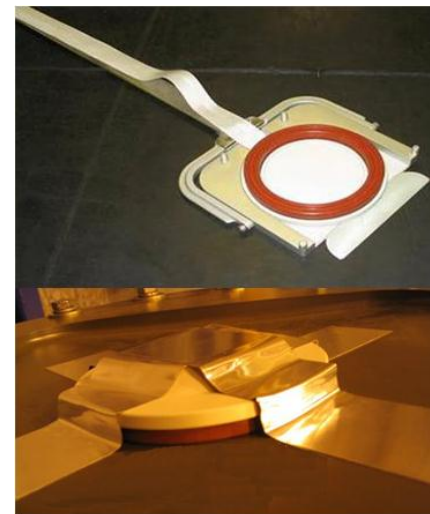
Double



Potential NDE Solution:

- Scan using ultrasonic shear wave from outside the patch
- Scan using low frequency eddy current array probe

Rigid Patch



Potential NDE Solution:

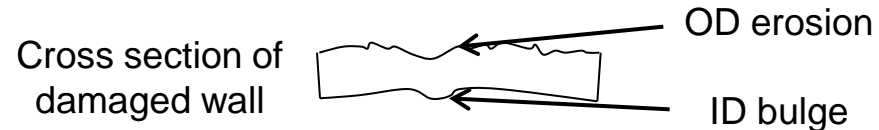
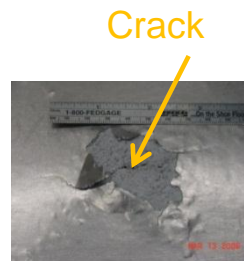
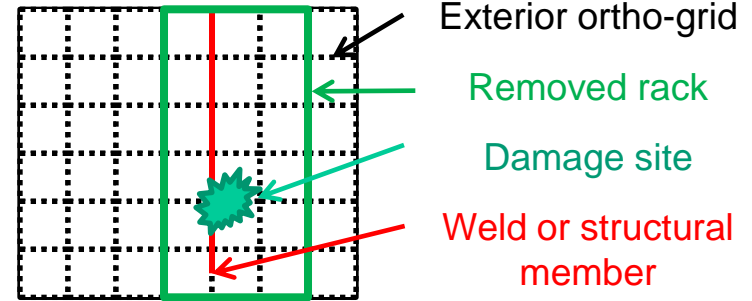
- Scan using ultrasonic shear wave from outside the patch before the second tape is applied



Damage Detection Requirements



- Boundary Map: Location & orientation of damage with respect to the vehicle
- Bulge Map: Shape and orientation of any bulges due to impact
- Thickness Map: Erosion, corrosion, and pitting
- Crack Map: Crack location, orientation, length and depth



See Draft of “Structures Memo” for additional information.



Assessment of NDE Equipment for Use on ISS



The assessment focus is to recommend the optimal COTS NDE instrument for IVA applications.

- Manufactured a range of relevant test samples
- Demonstrated/evaluated how well different instruments can detect critical flaw types.
 - Evaluated six different portable instruments.
 - Three ultrasonic array systems, three eddy current systems.
- Evaluate on-orbit operational capabilities of each device.
- Evaluate potential certifiability of possible on-orbit instruments.



Photo of Astronaut Don Pettit scanning a curved machined plate with artificial flaws.



COTS Definition per SSP 50835, Revision D, Appendix M

- COTS is defined as commercially available hardware or software procured directly from a vendor or authorized distributor. COTS must meet the following criteria:
 1. Is portable (is not structurally mounted). Items mounted via a Bogen Arm are not considered structurally mounted.
 2. Has no design modifications to vendor configuration
 3. Has no reliability requirements
 4. Will be soft stowed for launch
 5. Is non-critical (2N, 2NR and 3)
 6. Contains only previously certified alkaline (maximum 12 volts / 60 watts) and/or coin cell batteries.
- Assessment
 - Ultrasonic Flaw Detector is considered to be “COTS”



NDE Test Articles and Standards

1. Ten Manufactured Standards plates*:
 - a. Flaws: partial through the thickness holes (pits) and EDM notches (cracks)
 - b. Single flaws and multi-site flaws.
 - c. Flat with 1/16" and 3/16" thicknesses
 - d. Waffle (FGB and SM)
 - e. Curved at 80" and 25" radii of curvature.
2. Five Hypervelocity Impacted Plates*:
 - a. Flat (1/8" to 1/4" in thickness)
 - b. Waffle (FGB and SM)
3. Four bonded plates
 - a. Flat

*Scanned with and without repairs



Impact Test Samples



SM



FGB



US Lab

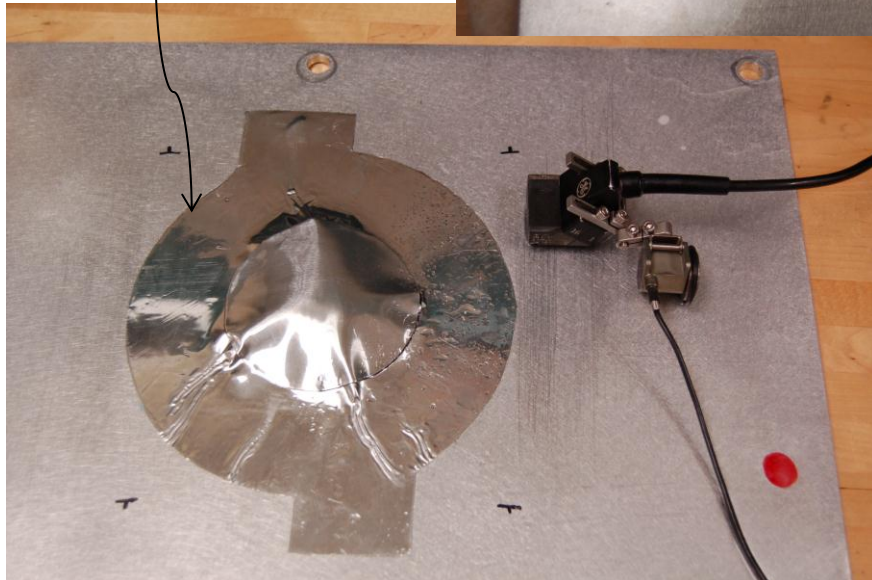


Test Sample With and Without Repairs



Unrepaired surface

PWRK tape repair



PWRK plate repair



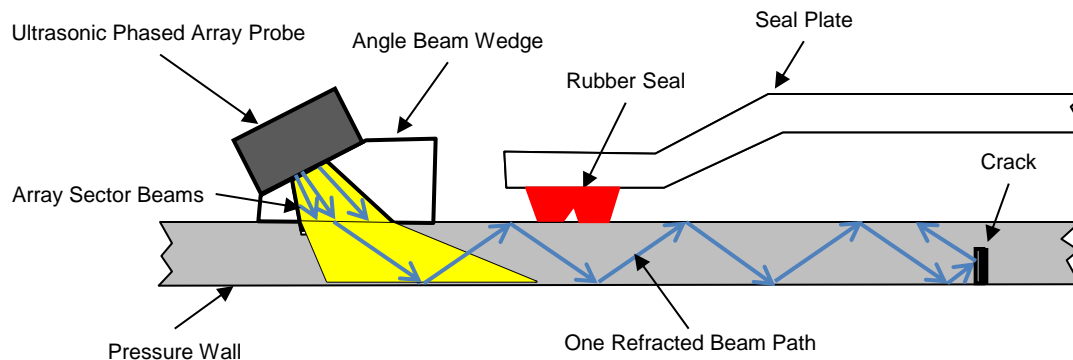


NDE Test Protocols

1. Ultrasonic Phased Array:

a. Angle Beam Wedge

- Bends the ultrasound at an angle into the plates.
- Can penetrate along the plate under the PWRK patches.
- Simple, quick, natural way to make a two dimensional image.
 - Mechanical scanner (encoder) in one direction.
 - Time in the second direction.
- Used on the manufactured standard plates and impacted plates.



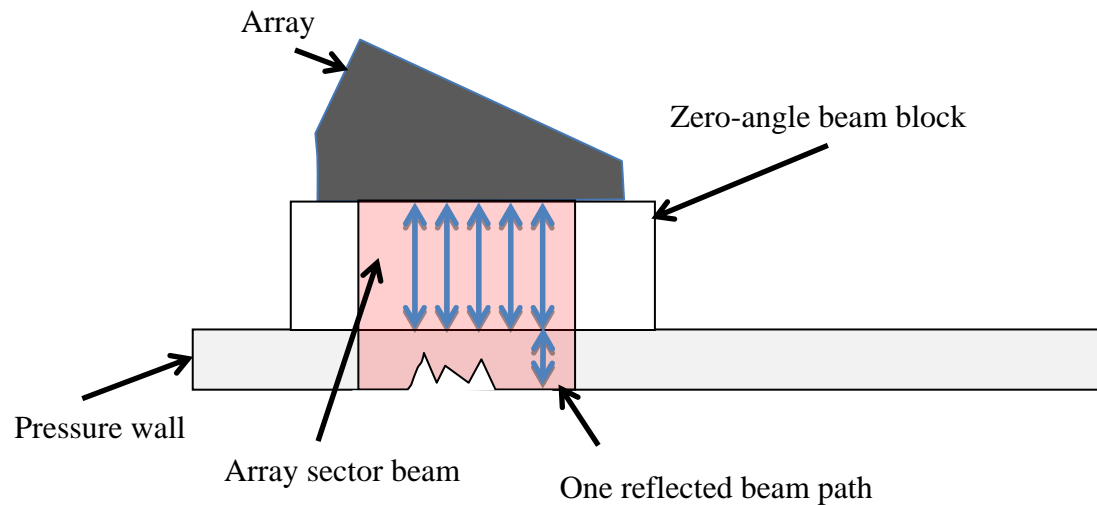


NDE Test Protocols

1. Ultrasonic Phased Array:

b. 90° Wedge

- b. Used for bondline plates
- c. Useful when there is no PWRK patch to deal with
- d. Can measure thickness of a plate.

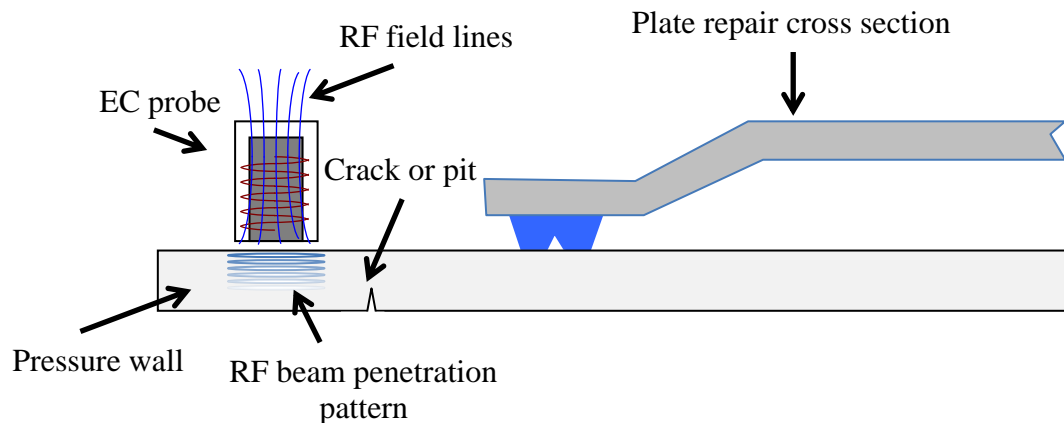




NDE Test Protocols

2. Eddy Current Scanners:

- a. Required that the probe penetrate through the aluminum to detect hidden damage
 - Probe had to be very, very low frequency to work (skin depth limited)
 - Couldn't work through the PWRK plate patch.

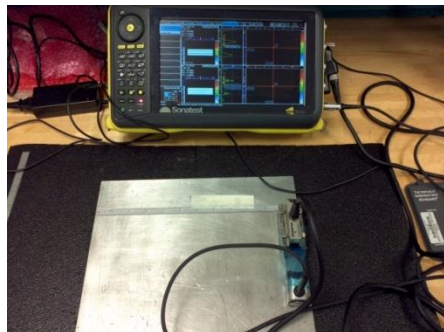




Examples of Ultrasonic Scans: Zero Degree and Shear Wave



Zero Degree Scan

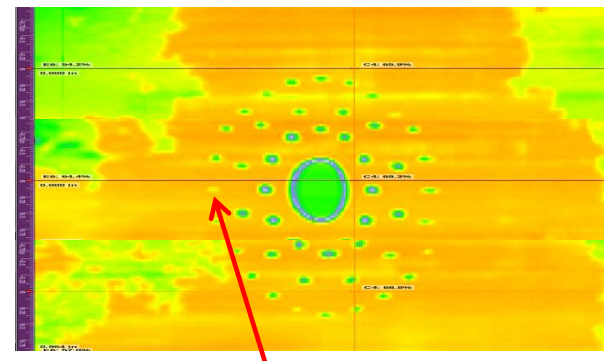


Sonatest Veo with
5L64 Transducer



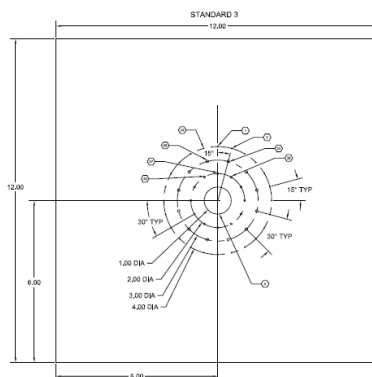
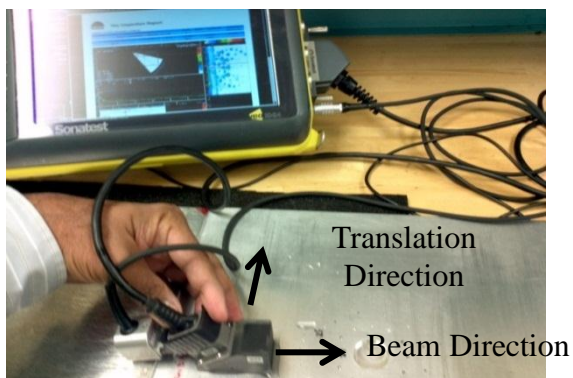
Standard 3

C-scan Display



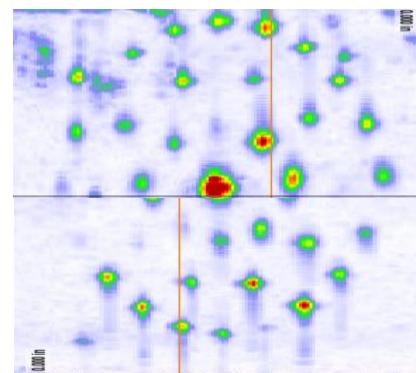
Smallest and shallowest hole
All holes were detected.

Shear Wave Scan

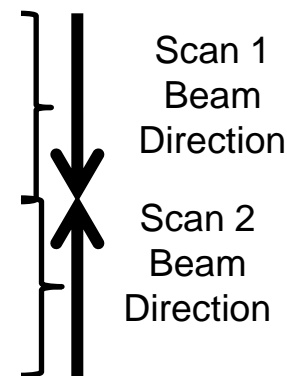


Standard 3

Top Scan Display

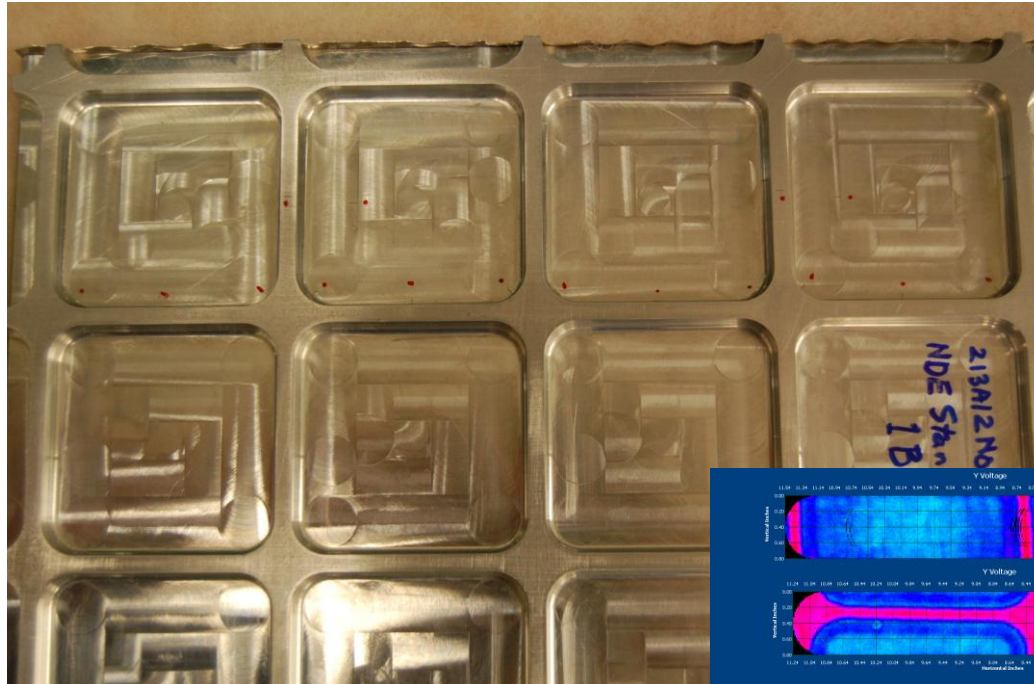


Mosaic of
Two Scans

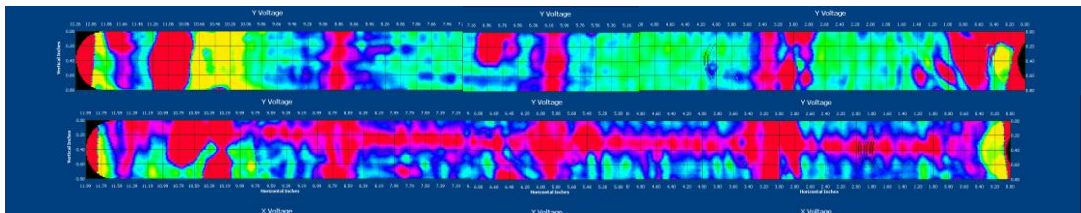
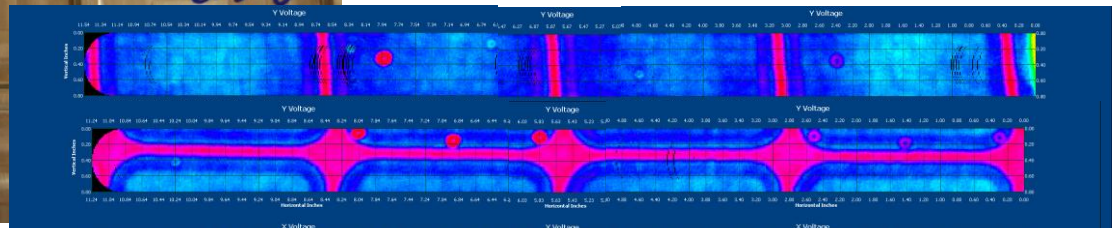




Eddy Current Scans on FGB NDE Test Standard with EDM Notches



EC scans made from IVA side without patches



Scans made from IVA side with tape patch

UniWest 454A ECS3 scans with and without PWRK tape attached.



NDE Engineering Assessment Considerations



Only the leading NDE instrument candidates are being evaluated.

1. Electromagnetic Interference for On-orbit
2. EMI susceptibility
3. DC Magnetic Fields for Russian Launch Vehicles
4. Power Inverter interface requirements.
5. Thermal requirements
6. Materials and Processes Use and Selection, Off-gassing
7. Other
 - Sharp Edges and Corners Protection, Coin Battery Tracking, Cleanliness and Identification Labeling



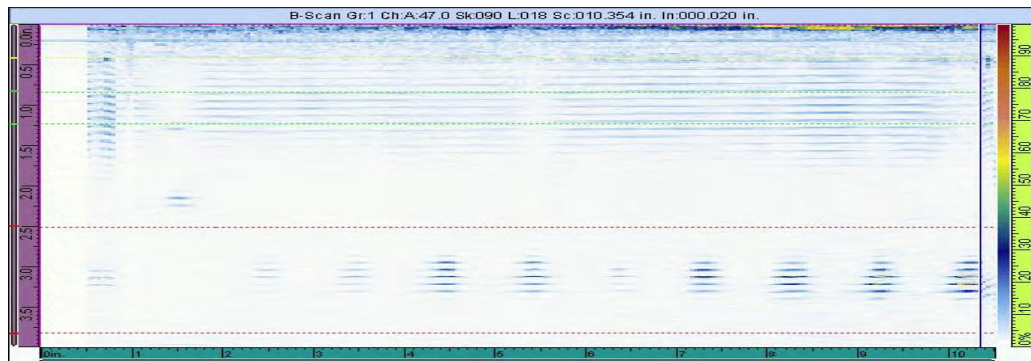
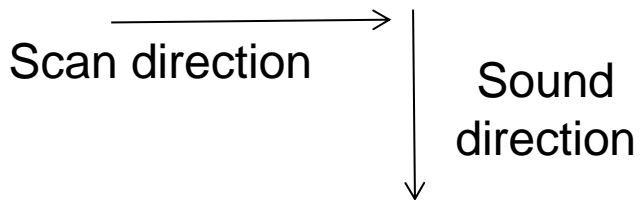
Conclusions from On-Orbit COTS NDE Equipment Assessment



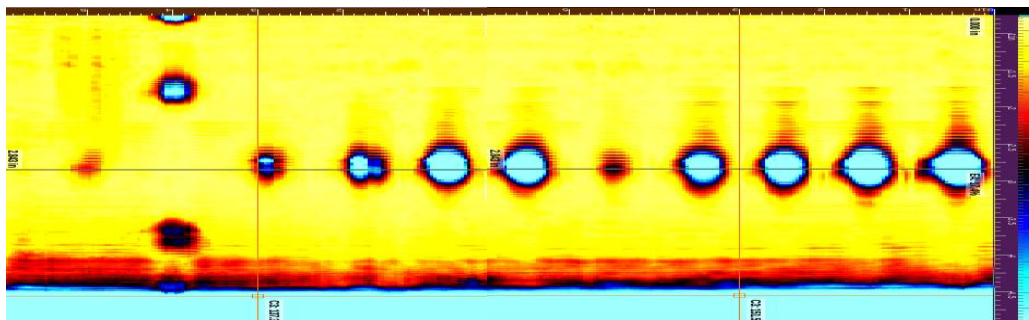
1. NDE systems evaluated were sensitive to detecting structural features such as isogrid webs.
2. The systems evaluated were unable to detect damage directly adjacent to the isogrid web under a PWRK patch
3. Ultrasonic Phased Array systems were more capable than eddy current array/scanner systems in detecting and assessing damage from all the manufactured test plates and simulated MMOD impacts with the PWRK patches in place on ISS pressure wall specimens.
 - i. The Sonatest Veo and Olympus Omniscan MX-UT systems performed equally, while the GE Phasor had software limitation.
4. The Sonatest Veo "Top-scan" process saves the data from the different inspection angles, allowing additional analysis of the results on the ground



On-Orbit COTS NDE Equipment Assessment B-Scan vs. Top-Scan Advantage



Omniscan MX
B-Scan Image
2 Mb per scan.
Only one ray direction



Sonatest Veo
Top-Scan Image
26 Mb per scan.
Multiple ray directions



On-Orbit COTS NDE Equipment Assessment Astronaut/Operations Testing Findings



5. ISS crew, without any additional training, were able to quickly assemble and operate the NDE instruments evaluated using only simple one-page procedures.
6. The need for an additional computer for image display, as required by the UniWest 454A Eddy Current system with the ECS3 scanner was deemed more complicated than desirable for on-orbit operations.
7. Spring-loaded position encoders used in a zero-G environment will require a reaction force to keep the sensor in contact with the part undergoing inspection, which will complicate operations.
8. The probes/scanning components of NDE systems evaluated are too large (i.e. diameter and height) to permit inspections underneath racks and fixed structure and behind panels, which limit inspection regions (i.e. approximately 70 percent of U.S. module surface area and 30 percent of Russian module surface area)
9. All NDE systems evaluated were deemed usable, but a preference for the Sonatest Veo system was identified because of its simpler operating controls and computer-human interface, and the visual display.



On-Orbit COTS NDE Equipment Assessment Observations



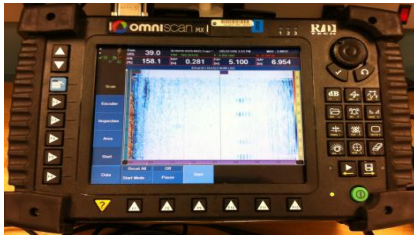
1. The development of non-standard methods and procedures were required to enable quantitative damage measurements under PWRK patch.
2. The ISS crew would prefer water as an ultrasonic couplant instead of ultrasonic gel.
3. The HRF (Human Research Facility) operations model for conducting body ultrasound was identified as a guide for development of NDE on-orbit module inspection procedures.
4. The Olympus Omniscan MX-UT system has been replaced by the MX2-UT system.



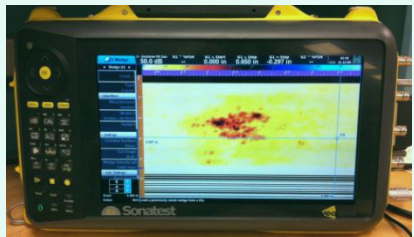
Assessment of NDE Instrumentation for ISS-On-Orbit NDE Application

Ultrasonic Phased Array Flaw Detectors

1. Olympus Omniscan MX UT



2. Sonatest Veo

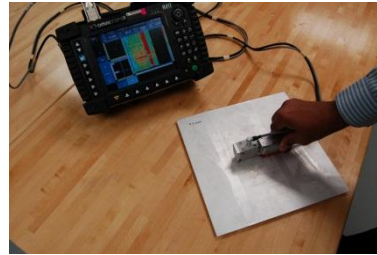


3. GE Phasor



Eddy Current Systems

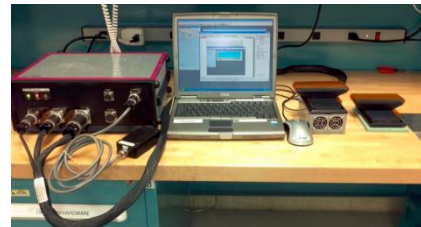
1. Olympus Omniscan MX EC Linear Array



2. UniWest 454A with ECS3 Eddy Current Rotating Probe Scanner



3. Jentek Sensors Grid Station, Linear Array



Six astronauts participated in the assessment and gave opinions on operations and suggestions for modifications

- Pettit, Walker, Metcalf-Linenburger, Fincke, Yui, Aunon
- Suggestions:
 - Try system out on zero-G flights.
 - Didn't like a spring loaded encoder (use an optical encoder?).
 - Want an edge guide to help with scanning.
 - Like water for a couplant (easy clean up).
 - Want simple procedures.
 - Emulate Human Research Facility (HRF) team's process.

Operations criteria:

1. NDE Crew Time for measurements
2. # Crew required
3. Setup/Tear Down Time
4. NDE Expertise/Training Required by Crew
5. Preventive/Calibration/Upkeep actions
6. Access Requirements
7. ISS Interfaces
8. Size (Storage and Access impacts)

Instrument Model	NDE Score 0 to 2	Ops/Astro. Score 0 to 5	Eng. Score 0 to 5	Net Score 0 to 20
Olympus Omniscan MX UT	1.62	3.15	3.95	11.5
Sonatest Veo	1.62	3.5	3.95	12.07
GE Phasor XS	0.98	2.7	N/A	2.65
Olympus Omniscan MX EC	0.2	2.45	N/A	0.49
UniWest 454A ECS3	0.07	2.2	2	0.29
Jentek GridStation	0.04	N/A	N/A	0

Sonatest Veo was selected by NESCC Team based on the comparative evaluation of these instruments



On-Orbit COTS NDE Equipment Assessment Recommendations



The following NESC recommendations are directed to the ISS Program if a decision is made to utilize commercial field portable NDE instrumentation aboard the ISS to mitigate IRMA risk 4669.

1. Select the Sonatest Veo Ultrasonic Phased Array system for further testing, modification, and eventual certification for flight



Objectives in Phase 1 and Later Phases



- Provide capability to inspect ISS pressure wall for MMOD impact damage before and after leak repair
 - Phase 1: Ultrasonic Flaw Detector for ISS
 - Provide NDE capability in pressurized IVA environment to inspect areas where direct hand access is available in U.S. and Russian modules (70% of U.S. modules)
 - Provide 2-D scanning capability on U.S. modules (not a requirement for Russian modules due to interior ortho-grid but some coverage is possible)
 - Later Phases
 - Provide IVA coverage for areas within a reach of a ~3 ft. long custom reach tool
 - ♦ Custom scanner at the end of reach tool with attachment/hold-down mechanism
 - ♦ Scanner should work within the 1" gap underneath U.S. module stand-off areas and over the Russian module ortho-grid structure
 - ♦ Wireless encoder to improve ease of scanning operation



Ultrasonic Flaw Detector System Application Requirements and Performance Characteristics



- Ultrasonic Flaw Detector Application Requirements
 - **Capable of performing ultrasonic zero degree and shear wave scans on flat or slightly contoured (radius > 25') ISS aluminum pressure shell wall to provide evaluation of suspect MMOD damage and repair of the same. Ultrasonic Flaw Detector is not meant for detecting leak due to MMOD damage.**
 - Provide NDE capability in pressurized IVA environment to inspect areas where direct hand access is available in U.S. (estimated 70% area) and Russian modules
 - Capable of producing 2D scans on approximately 8" x 8" areas in presence or absence of a dome or tape patch repair.
 - See "inspection cases" and "damage detection requirements" for more details
 - Verify written procedures by scanning NDE Standard 3 and 5 on ground and on ISS (DTO)
- Veo Performance Characteristics
 - USB port on Veo and USB memory stick for data storage and file transfer
 - Verify on qualification unit
 - Other instrument performance characteristics per Veo (16:128) specifications
 - See "Veo specification" by Sonatest Inc.
 - Ethernet and VGA ports are available on Veo but are not planned to be used.
 - Verify on qualification unit



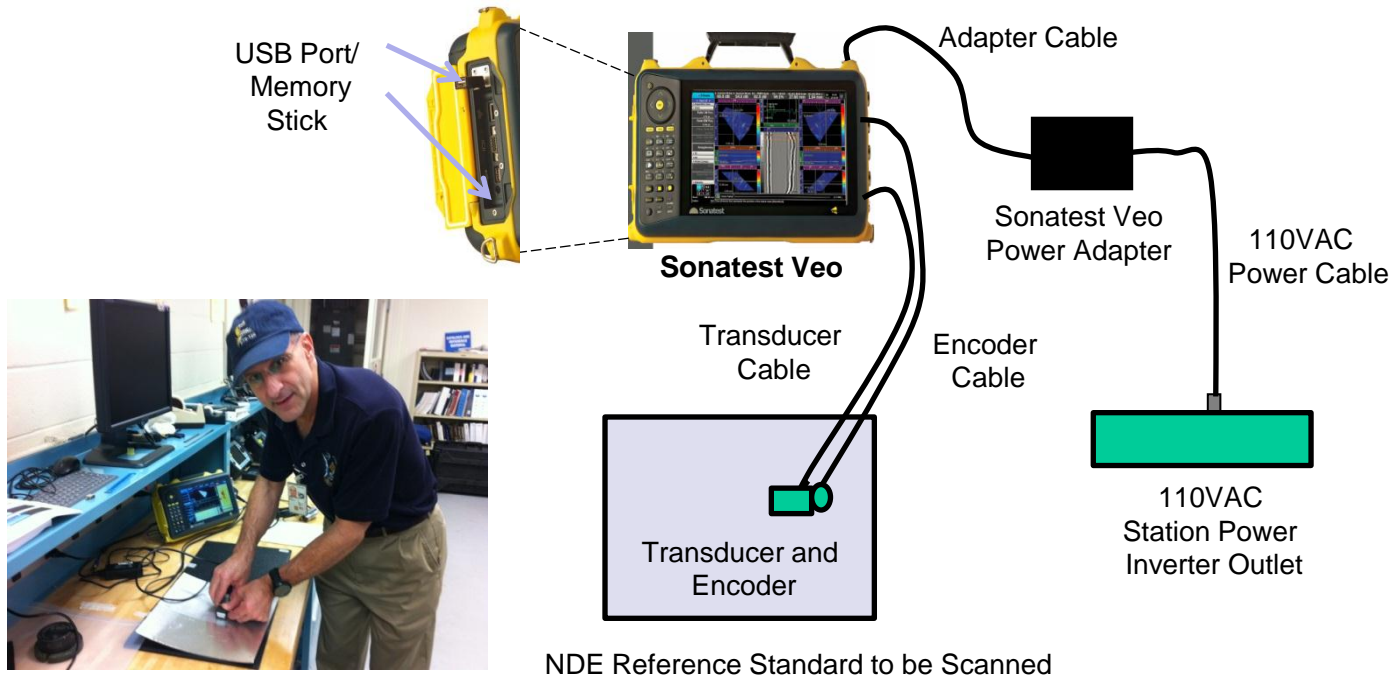
Physical Interface Requirements



- Restrained on-orbit by a Nylon hook-and-loop fastening system, “Velcro”™
 - Use Velcro on Veo, NDE standards, transducer cables, encoder cables, soft cases etc.
 - USB memory stick is used for data storage and file transfer
 - Interface to the power inverter in USOS providing 110 VAC output for Ultrasonic Flaw Detector. * Battery is not used to power the instrument.
 - An ultrasonic transducer would contact the inspection surface. Potable water (approx. 1 teaspoon) is used as a couplant. Use water from crew drinking water bag. Water is preferred by crew over gel type medical ultrasound couplant Aquasonic 100 which is available on the ISS.
 - An encoder (wheel) would contact the inspected surface during scanning.
 - A 300mm steel ruler would be taped to the surface to act as a guide for scanning and to provide scale in photographs of the inspected area.
 - A crew member would hold the transducer/encoder assembly in one or two hands and scan the part surface. A second crew member may be needed to operate the Veo instrument and assist the first crew member as needed. One crew member may be sufficient for the ISS demonstration of ultrasonic scanning on test pieces but if used in actual inspection of the pressure wall, two crew members would likely be needed.
- * Intravehicular Activity Non-Destructive Evaluation Tool Evaluation Test, Report: ESCG-4270-13-AS&T-DOC-0001, Revision: Baseline, Feb. 2013.



Ultrasonic Flaw Detector System Configuration



Astronaut Don Pettit
Scanning an NDE Standard

Hardware Criticality: 3
Software Classification: C

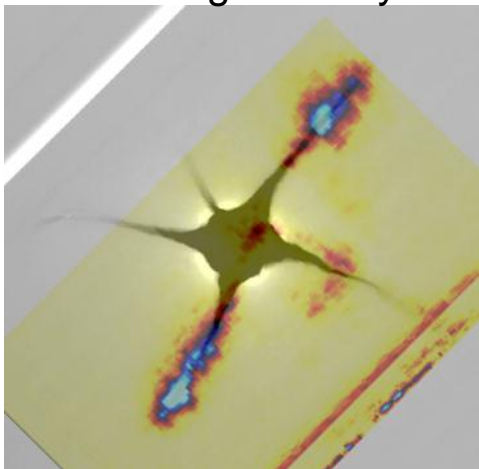
Software is contained within the Sonatest Veo instrument. There is no requirement to communicate with a laptop.



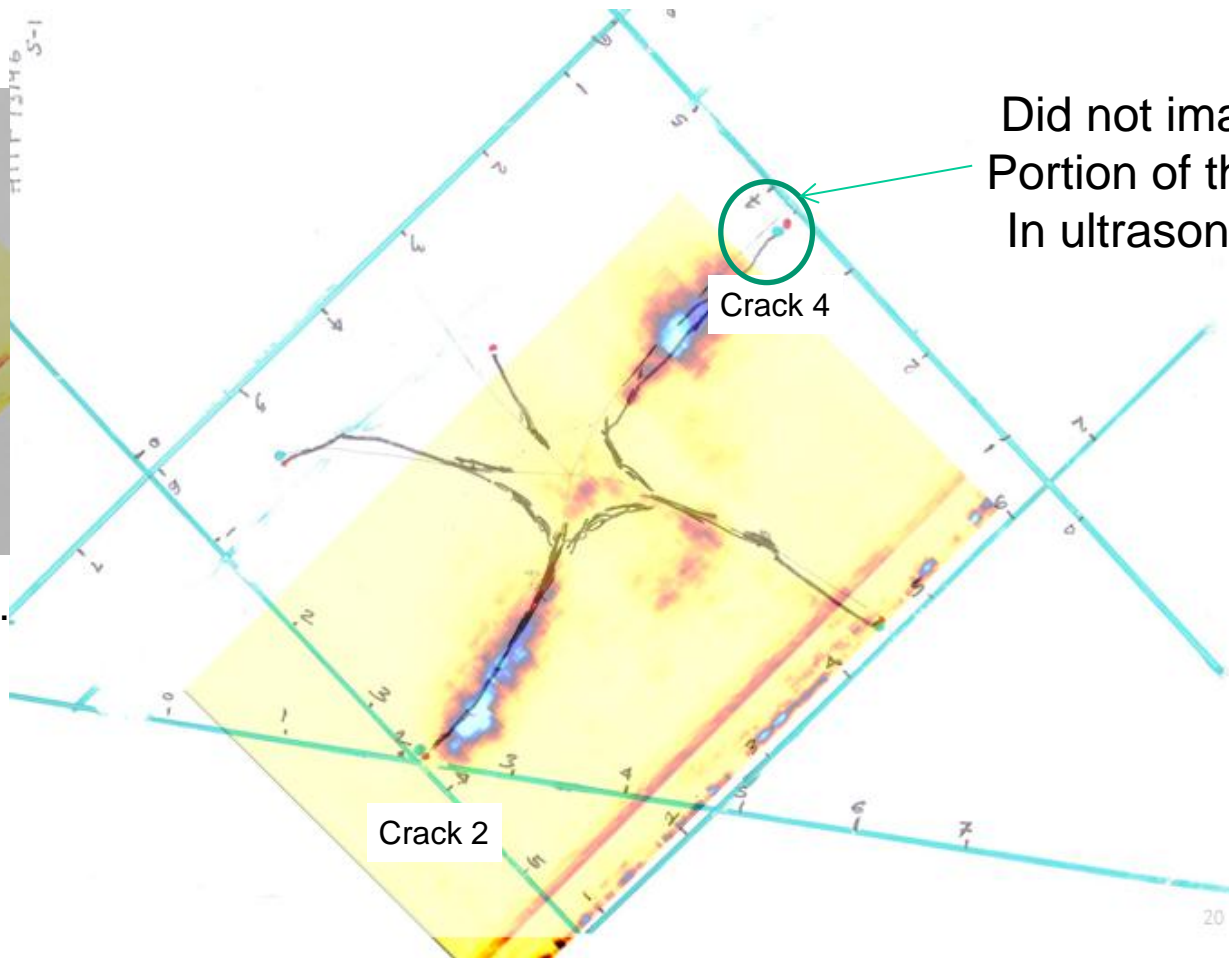
Scan Superimposed on the Scan Template



Scan D7 Superimposed
on Digital X-ray



Cracks 2 and 4 Detected.



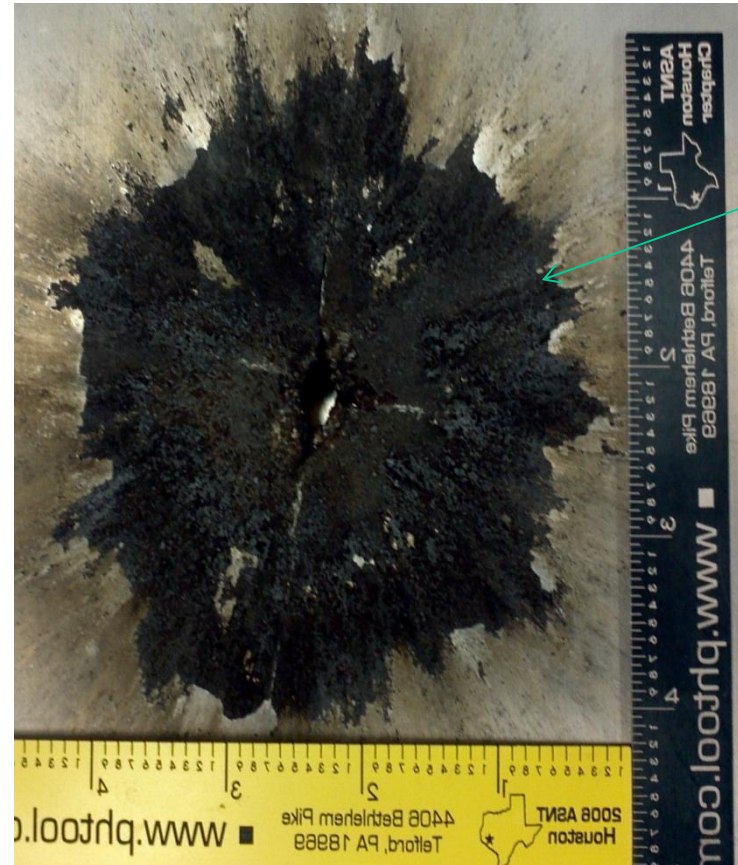
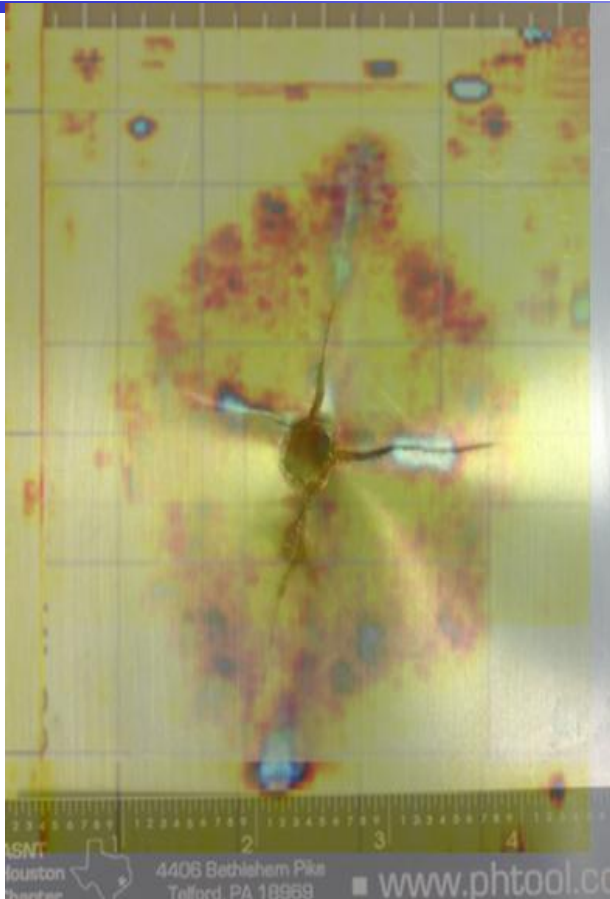


Example of C-scan Image Comparison With Damage Photo



Superimposed Scans

Mirror Image of Impact Side Photo



Dark region

The photo image matches with the superimposed scan image approximately. Ultrasonic scan shows considerable variation in the signal response from the cracks. Crack orientation, depth and other damage in the path of ultrasonic beam influences the ultrasonic signal amplitude from cracks. Overall damage area given by the ultrasonic scan matches (+0.0, -0.4") with the visually observed dark soot region.