NASA/TM–2020-220568/Volume II/Part 1

Nondestructive Evaluation (NDE) Methods and Capabilities Handbook

Volume II Appendices —Appendix A – Appendix D

Patricia A. Howell, Editor
Langley Research Center, Hampton, Virginia

APPROVED FOR PUBLIC RELEASE

February 2020

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National Aeronautics and
Space Administration

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Nomenclature

μA	Microampere
μm	Micrometer/Micron
μs	Microseconds
1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
ABS	Acrylonitrile Butadiene Styrene
ACAD	Air Coupled Acoustic Drive
ACC	Advanced Composites Consortium
ACP	Advanced Composites Project
ACT	Air Coupled Transducer
ADR	Assisted Defect Recognition
AFP	Automated fiber placement
AISI	American Iron and Steel Institution
AMT	Active Microwave Thermography
ANSI	American National Standards Institute
APF	Automated Fiber Placement
ARC	Ames Research Center
ASME	American Society of Mechanical Engineers
ASNT	American Society of Nondestructive Testing
ASTM	American Society for Testing and Materials
ATL	Automated Tape Lay-Up
AWG	Arbitrary Waveform Generator
AWS	American Welding Society
BMS	Boeing Material Specification
BSI	British Standards Institution
BVID	Barely Visible Impact Damage
BW	Back Wall
C	Celsius
CAD	Computer-Aided Design
CAFA	Combined Analytical Finite Element Approach
CCD	Charge-coupled Device
CDRH	Center for Devices and Radiological Health
CFRP	Carbon Fiber Reinforced Polymer
CMOS	complementary metal oxide semiconductor
CNN	Convolutional Neural Network
CO_2	Carbon Dioxide
COPV	Composite Over-Wrap Pressure Vessel
CPV	Composite Pressure Vessel
CR	Computed Radiography
CST	Charge Simulation Technique
CT	Computed Tomography
CTE	Coefficient of Thermal Expansion
DAQ	Data Acquisition
dB	Decibel
dB/in	Decibels Per Inch
DDA	Digital Detector Array
DOF	Degree of Freedom
DR	Digital Radiography
DRC	Digital Radiography Center
ECT	Eddy Current Thermography
EFIT	Elastodynamic Finite Integration Technique

FBH	Flat-bottom holes
FD	Finite Difference
FDA	Food and Drug Administration
FEA	Finite Element Analysis
FEM	Finite Element Method
FEP	Fluorinated Ethylene Propylene
FLIR	Forward-looking Infrared
FMC	Full Matrix Capture
FOD	Foreign Object Debris
FOV	Field of View
ft-lbs	Foot Pounds
GE	General Electric
GHz	Gigahertz
GN_2	Gaseous Nitrogen
gsm	Grams per square meter
GWUT	Guided Wave Ultrasound
Hz	Hertz
ID	Inner Diameter
IDIQ	Indefinite Delivery/Indefinite Quantity
IEC	International Electrotechnical Commission
IML	Inner Mold Line
in	Inch
in/min	Inches per Minute
InSb	Indium Antimonide
ipm	Images per Minute
IR	Infrared
IRT	Infrared Thermography
ISTIS	*In Situ* Thermal Inspection System
J/cm^2	Joules Per Square Centimeter
K	Kelvin
KeV	Kiloelectron Volt
kg	Kilograms
kg/cm^2	kilogram per square centimeter
kHz	Kilohertz
kV	Kilovolts
kW	kilowatt
LaRC	Langley Research Center
LBI	Laser Bond Inspection
LMCO	Lockheed-Martin Company
LPS	Local Positioning System
LST	Line Scanning Thermography
LT	Lock-In Thermography
m^2	Square Meter
m^2/hr	Meters Square per Hour
mA	Miliampere
MECAD	Mechanically Coupled Acoustic Drive
MGBM	Multi-Gaussian Beam Model
MHz	Megahertz
mHz	Millihertz
mK	Millikelvin
mm	Millimeter
MPa	Megapascals
ms	Meter per Second
MS/s	Megasamples/second

msec	Millisecond
MSFC	Marshall Space Flight Center
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
Nd:Glass	Neodymium Glass Laser
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Test
NEDT	Noise Equivalent Differential Temperature
NGIS	Northrop Grumman Innovation Systems
nm	Nanometer
ns	Nanosecond
OEM	Original Equipment Manufacturer
OML	Outer Mold Line
ONR	Office of Naval Research
OSHA	Occupational Safety and Health Administration
PA	Phased Array
PCA	Principal Component Analysis
PEUT	Pulse Echo Ultrasound
PMC	Polymer Matrix Composite
PML	Perfectly Matched Layer
POC	Point of Contact
PoD	Probability of Detection
PPT	Pulsed-Phase Thermography
psi	Pounds Per Square Inch
PT	Pressure-Sensitive Tape
PTFE	Polytetraflouroethylene (Teflon™)
PVDF	polyvinylidene fluoride
PWI	Plane Wave Imaging
PW-UTC	Pratt Whitney – United Technology Corporation
PZT	Piezoelectric Sensors/Transducer
R&D	Research and Development
RAH	Refresh After Heat
RBH	Refresh Before Heat
RGB	Red, Green, and Blue
RMS	Root Mean Squared
ROI	Region of Interest
RPF	Release Ply Fabric
RSG	Rotated-Staggered Grid
RVE	Representative Volume Element
s	Seconds
SAE	Society of Automotive Engineers
SAFE	Semi-Analytical Finite Element
SAR	Synthetic Aperture Radar
sec	Seconds
SHM	Structural Health Monitoring
SLDV	Scanning Laser Doppler Vibrometer
SMAAART	Structures, Materials, Aerodynamics, Aerothermodynamics, and Acoustics Research and Technology
SME	Subject Matter Expert
SNR	Signal to Noise Ratio
SOFI	Spray on Foam Insulation
SoP	State-of-Practice
sq. ft/hr	square foot per hour

SSFT	Single-Side Flash Thermography
SSIR	Single-Sided Infrared Thermography
SVD	Singular Value Decomposition
TC2	Technical Challenge 2
TDRS	Time Domain Reflectometry Systems
TFM	Total Focus Method
Tg	Glass Transition Temperature
THz	Terahertz
TPS	Thermal Protection System
TSR	Thermographic Signal Reconstruction
TT	Through Transmission
TTIR	Through-Transmission Infrared Thermography
TTUT	Through-Transmission Ultrasound
TWI	Thermal Wave Imaging System
USC	University of South Carolina
UT	Ultrasound
VaRTM	Variation Resin Transfer Molding
VSHM	Visualized Structural Health Monitoring
XCT	X-ray Computed Tomography

Appendix A NASA Advanced Composites Project NDE – State of the Practice Report[1]

A.1 Introduction

In the Advanced Composites Project (ACP), NASA is collaborating with members of the aerospace industry to reduce the timeline to develop and certify composite structure for commercial and military aeronautic vehicles. NASA and industry have identified three focus areas, or technical challenges, as having major impact on the current certification timeline. One focus area, Technical Challenge (TC2) – Rapid Inspection, is concerned with increasing the inspection throughput by the development of quantitative and practical inspection methods, data management methods, models, and modeling tools. One of the objectives in TC2 is to develop tools for rapid quantitative characterization of defects. The adoption of composite materials in aircraft manufacturing for use in structural applications continues to increase but is still relatively new to the industry and has relatively large development and certification costs in comparison to metallic structures. Traditional methods of nondestructive evaluation (NDE) used for isotropic materials such as metals may not be adequate for composite applications and is a contributing factor to the cost and complexity of developing new structural composites. Additionally, the defects of interest in composite materials are significantly different from metals.

Therefore, under the ACP, TC2, NASA initiated an assessment of the current state-of-practice (SoP) in the aerospace industry for the NDE of composite structural components and a determination of what factors influence the NDE process for composites. The survey was developed and executed as a team effort under a contract to The Boeing Company (point of contact (POC): Dr. Gary Georgeson, Boeing) with participation from General Electric (GE), Pratt Whitney-United Technology Corp. (PW-UTC) and Lockheed-Martin Company (LMCO). NASA provided technical oversite of the survey development and execution.

The goal of the survey was to assess the current SoP for NDE/nondestructive testing (NDT) of composite parts and structure, drawing from as large a cross-section of the industry as practical. Therefore, this assessment spanned the fixed-wing, rotary-wing, and propulsion segments of the aircraft industry and received input from a corresponding cross-section of other industries such as the automotive and power generation. The assessment sought to identify critical defect types, current inspection methods, NDE data exchange methods, processes and methods suitable for automation or improvement, and other issues associated with the inspection and certification of composite aerospace structures.

This appendix is intended to provide a broad overview of the survey. Included in the appendix are an executive summary, the design of survey, select survey results for particular questions and categories and a discussion of recommendations and next steps based on the survey results.

A.2 Executive Summary

The results of the survey represent the responses from relevant POCs involved in composite design, testing, fabrication, inspection, NDT equipment sales, NDT Research and Development (R&D), and NDT management. One hundred fifty-three individuals, representing about 1/10th of those invited to participate, took the survey. Nearly half (46%) currently work in the aerospace

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[1]NASA SMAAART Contract No. NNL10AA05B, Task Order NNL15AB47T

industry, with the remainder working in other composite related industries such as the automotive industry. The survey results are summarized here in the Executive Summary, and described in more detail in the sections following.

The primary composite structure type of interest is the graphite epoxy laminate structure, followed by sandwich structure, particularly honeycomb. The type of NDT methods that are most common are Visual and Tap Testing, followed by Through-Transmission Ultrasound (TTUT), Pulse Echo Ultrasound (PEUT), X-ray methods (Digital, Computed Tomography (CT), and Film – in that order), Infrared Thermography (IRT), and Low-Frequency Ultrasound (UT)/Bond Testing.

NDT methods ripe for automation and cost/flow time reductions appear to be those most commonly used for manufacturing inspection and have not generally been fully automated for either data collection or analysis. These are Visual, UT methods (TTUT and PEUT), and IRT. Digital Radiography (DR) and CT are already automated methods. Visual, Tap testing, and Low-Frequency UT/Bond Testing are primarily used for in-service inspection, though automation of these could move them more into manufacturing inspection for selected structures.

Composite manufacturing methods that use a level of automation, such as Automated Fiber Placement (AFP), or Automated Tape Lay-Up (ATL) could benefit from post-fabrication and in-process automated NDT processes, because this could enable more automated manufacturing methods.

Table A.2-1 summarizes the top survey answers to questions about composite defects. The most common composite defects addressed today, according to survey respondents, are delaminations, disbonds, and weak bonds (bond integrity/strength). In addition to being the most common, these three defects also receive the largest amount of research in the industry. The type of defects that are viewed as most challenging to address are microcracking, bond integrity/strength, and moisture ingress. It is important to note when separated as a group, fabricators had porosity, foreign material, and fiber waviness, along with delaminations/disbonds, at the top of their list of most common defects they encounter.

Table A.2-1. Summary of top survey answers to questions about composite defects.

Rank	**Most Challenging Defect**	**Frequency of Defect**	**Better Standards Needed**	**Defects of Concern**	**Effect to Structure**
1	Microcracking	Delaminations	Porosity	Disbonds	Disbonds
2	Bond Integrity/ Strength	Disbonds	Disbonds	Delaminations	Delaminations
3	Moisture Ingress	Bond Integrity/ Strength	Wrinkles / Fiber Waviness	Foreign Material	Bond Integrity/ Strength
4	Heat Damage	Porosity of Laminates	Delaminations	Microcracking	Wrinkles/ Fiber Waviness
5	Wrinkles/ Fiber Waviness	Moisture Ingress	Bond Integrity/ Strength	Bond Integrity/ Strength	Porosity

Most respondents (64%) agreed that they deal with flaws that need better representation in their physical reference standards. Porosity standards are the greatest need, followed by delaminations/disbonds, ply waviness/wrinkles, bond integrity/strength, and microcracks.

The vast majority of respondents said yes to “Do you have fatigue life concerns?” and “Are you concerned about fatigue in the presence of undetected in-service damage?” This result indicates research and development of methods that can measure or correlate fatigue is needed for in-service NDT. Additionally, porosity, foreign material, and fiber waviness, along with delaminations/disbonds, are at the top of composite fabricator's list of most common defects in greatest need of good NDT reference standard.

The number one need for NDT development according to stress/design/test engineers (non-NDT engineers) is "addressing critical defect types that require quantitative defect correlation for residual strength and durability." The NDT community and respondents conducting R&D also selected this as the highest need.

A.3 Survey Design

The Composites Industry SoP Survey questionnaire was developed by the industry team members on the project (Boeing, PW-UTC, GE, and LMCO) through a series of collaborative meetings. The survey was designed to collect background information on the respondent initially and then provide the respondent with a specific set of questions best suited to their specific job function. Background information included industry sector; company/institution type, size and U.S./foreign designation; work group function, composite material; composite structure type, years worked with composites; years worked in NDT; and primary job function.

The primary job function selected by a respondent in the background portion of the survey determined the remaining questions that the respondent would be given. In this way, the questions could be individually tailored to the respondents and more meaningful results could be obtained. While some questions were common to all, others were unique to one or more job functions. The selection options for the 'job function' question were 'Fabricator,' 'In-Service,' 'NDT R&D,' 'Equipment Supplier,' 'Supporting Technology,' and 'General Category,' which included instructors, non-NDT managers, and other NDT-related jobs they could specify. Each selection had specific options one could select, thereby providing additional clarity to the survey-taker and further refinement in respondent data.

Once the survey format and questions were completed and approved by the industry team members, the survey was compiled into a digital format that guided the respondents through the set of questions designed for them based on their answer for 'primary job function.' The survey was made available to willing survey-takers through an online server link sent to them via an email.

Designated industry team members who had some level of professional relationship or history with the particular POCs contacted industry POCs beforehand via phone calls or emails. In order to get a broad perspective, the POCs selected included individuals outside the NDT community, such as composite stress and design engineers. In addition, participants in a drawing for a signed NASA poster at the ASNT (American Society of Nondestructive Testing) 2015 annual meeting were invited to complete the survey as part of the drawing. A third set of survey-takers were gathered from a mass email to all the attendees of the same ASNT conference. To help ensure a good level of participation, as well as representative answers, all survey-takers were given the option of remaining anonymous, by selecting that option at the end of the survey.

A.4 Survey Results

A.4.1 Respondent Information

One hundred fifty-three respondents took the survey, representing about $1/10^{th}$ overall of those who were sent an email directly requesting participation. Table A.4-1 shows that less than half (46%) of the respondents work in the aerospace industry, yet this represented the largest industry segment. Other industries (Automotive/Transportation, Power Generation, Pipeline, Infrastructure, Wind Power Generation Petro/Chemical, Other) were represented by 7−10% each of the total response.

Table A.4-1. Table of respondents by industry sector.

(Note: Since respondents can choose more than one industry sector, the table represents the percent of total responses, not respondents).

Industry Sector	Percent Responses
Aerospace	46%
Automotive/Transportation	10%
Wind Power Generation	9%
Other	8%
Power Generation (exclusive of wind power)	7%
Infrastructure	7%
Petro/Chemical	7%
Pipeline	6%

The response by company or institution was well represented by a full range of respondents, with 'Integrator/ Original Equipment Manufacturer (OEM)' being the largest group (Table A.4-2). Table A.4-3 shows that the work group function for respondents was represented mostly by composites NDT (32%) and Metals NDT (25%). Composite Design (14%), NDT Instrument/Systems Provider (12%), and Composite Manufacturing (11%) represent the remaining work groups (with 7% representing 'Other').

Table A.4-2. Table of respondents by company or institution.

(Note that since respondents can choose more than one institution, the table represents the percent of total responses, not respondents).

Company Type	Percent Responses
Integrator/OEM	23%
Fabricator/Supplier of Comp. Structures	13%
NDT Equipment Developer/Supplier	13%
Facility Specializing in NDE for Multiple Customers	12%
Research Lab	12%
NDT Training Company	9%
Government	8%
University/College	4%
Other	4%
Fabricator / supplier of materials used to make composites	1%

Table A.4-3. Table of respondents by work group function

(Note that since respondents can choose more than one work group, the table represents the percent of total responses, not respondents).

Work Group Function	Percent Responses
NDT of Composites	32%
NDT of Metals	25%
Composites Design	14%
Developer or Provider of NDT Systems	12%
Composites Manufacturing	11%
Other NDT Applications	7%

A.4.1.1 General Results

The primary composite structure type of interest is the graphite epoxy laminate structure, making up 67% of responses; followed by sandwich structure, particularly honeycomb, as shown in Table A.4-4. The type of instrumented manufacturing NDT methods that are most common (when fabrication and in-service NDT are averaged together) are Visual, Tap Testing, TTUT, PEUT, X-ray methods (DR), CT, and Film – in that order, IRT, and Eddy Current methods. The relative use of the methods is shown in Figure A.4-1.

Table A.4-4. Table of respondents by type composite structure, indicating the type with which they primarily work.

Composite Structure Type	Percent Respondents
Solid Laminates	67%
Honeycomb Sandwich	17%
Other Sandwich Structure	8%
Other Structure Type	5%
Foam Core Sandwich	2%

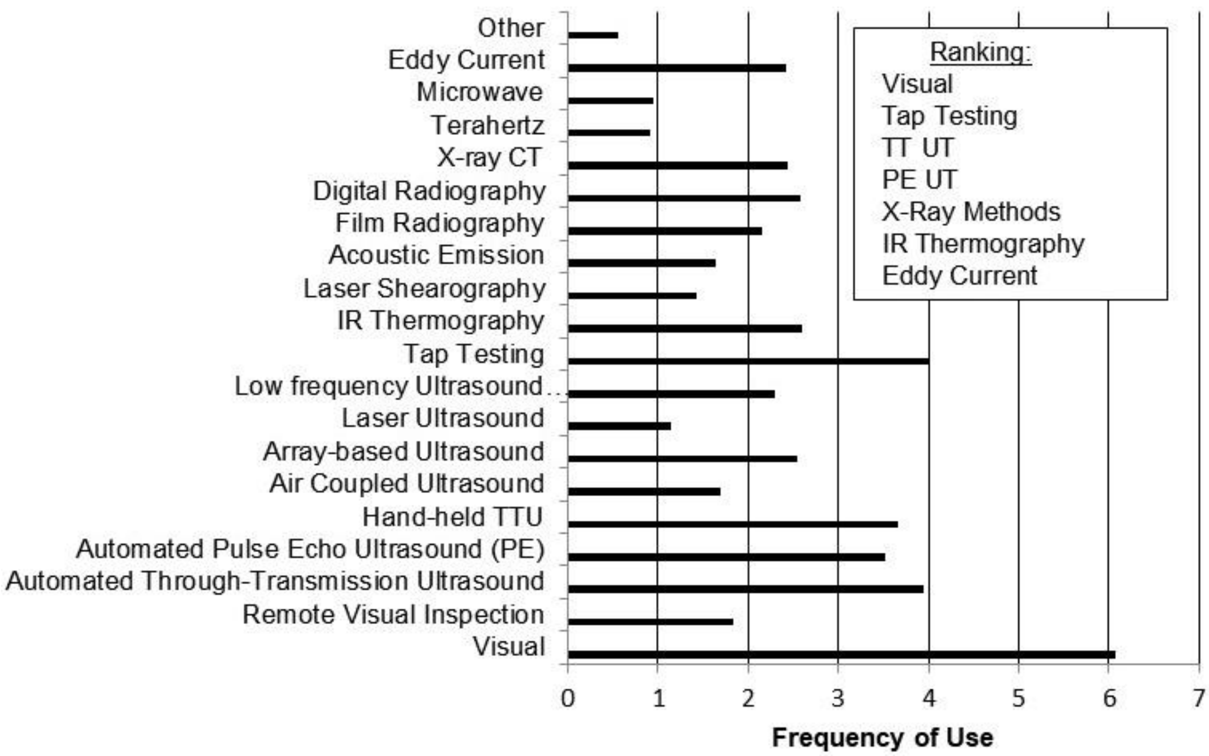


Figure A.4-1. Relative use of NDT methods average response for fabrication and in-service NDT respondents.
Answer to the question: What inspection techniques are currently used? (1 = never, 7 = always)

Since the ACP is interested in the cost and time related to the NDE of composite structure during development, fabrication, and certification, the NDT methods used during manufacturing development or fabrication are most relevant. The fabrication and in-service NDT methods can be separated using specific respondent categories. The results are shown in Figure A.4-2. According to NDT technicians, the most common NDT methods used are Visual, TTUT and PEUT, Tap testing, DR and X-ray CT (XCT), IRT, and finally Low-Frequency UT methods.

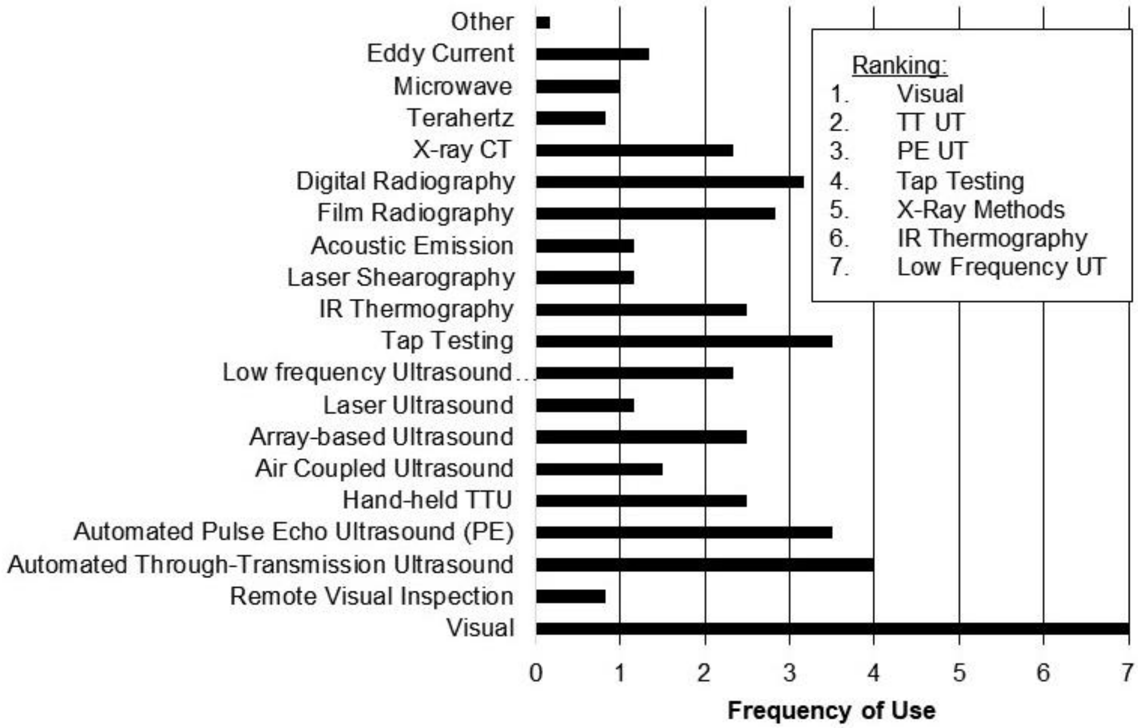


Figure A.4-2. Ranking averaged across NDT Technicians from 1 to 7, the frequency of use of NDT methods used on the structures fabricated or inspected.

A series of survey questions posed to the respondents dealt with the types of flaws they encountered in their jobs. Table A.4-5 is the list of flaw types that were presented to the respondents and these are used in the results presented in Figures A.4-3, A.4-4 and A.4-5. Figure A.4-3 shows the responses from NDT Technicians related to the frequency of occurance for each type of flaw (1 = less frequent, 7 = very frequent). For in-service NDT technicians moisture ingress, heat damage, porosity in repairs and foreign materials repairs are the most frequently occuring flaw types.

Table A.4-5. Indexed listing of flaw types as shown in Figures A.4-3, A.4-4, and A.4-5.

Index	Flaw Type	Index	Flaw Type
1	Delaminations	10	Fiber Waviness
2	Disbonds	11	Density anomalies
3	Foreign Material	12	Porosity in repairs
4	Microcracking	13	Fiber Waviness in repair
5	Bond integrity/strength	14	Bond integrity/strength in repairs
6	Moisture Ingress	15	Foreign material in repairs
7	Heat Damage	16	Heat Damage in repairs
8	Porosity in Laminates	17	Density anomalies in Repairs
9	Porosity over Core	18	Other

Figure A.4-4 shows the results of asking NDT Engineers and Managers working in manufacturing or in-service NDT to rank the difficulty of inspection (1 = not difficult, 7 = very difficult), for each type of flaw in Table A.4-5. Figure A.4-4 shows that NDT Engineers and Managers agreed that fiber waviness in repairs, bond integrity/strength in repairs and heat damage in repairs are the most difficult to inspect.

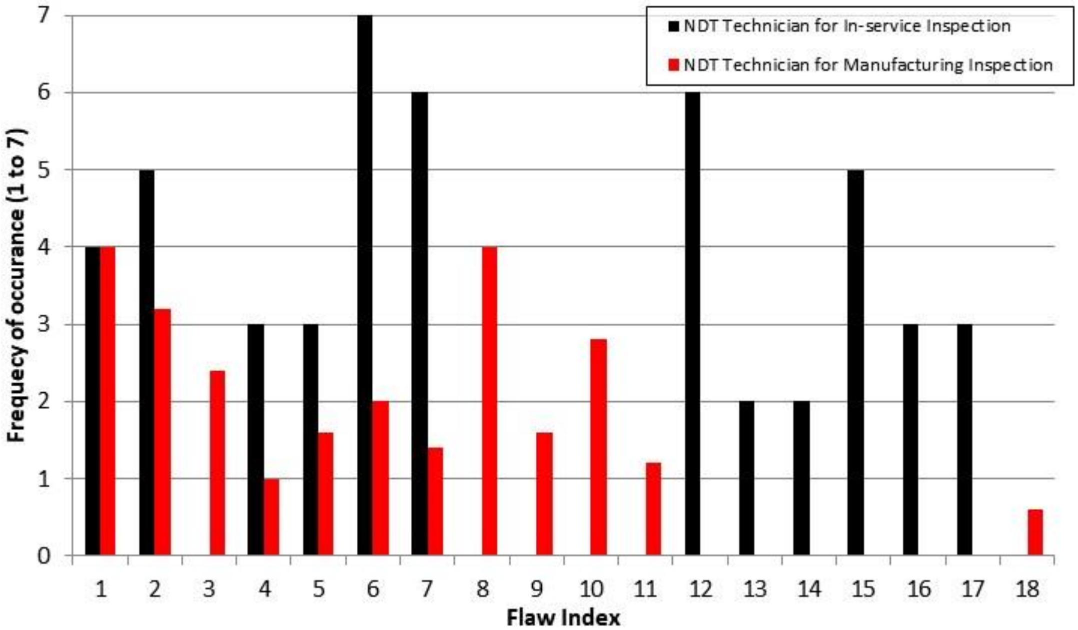


Figure A.4-3. Frequency of occurrence, according to NDT Technicians, for each defect type that is addressed including manufacturing and in-service composite structures. The numbers on horizontal axis refer to the flaws listed in Table A.4-5.

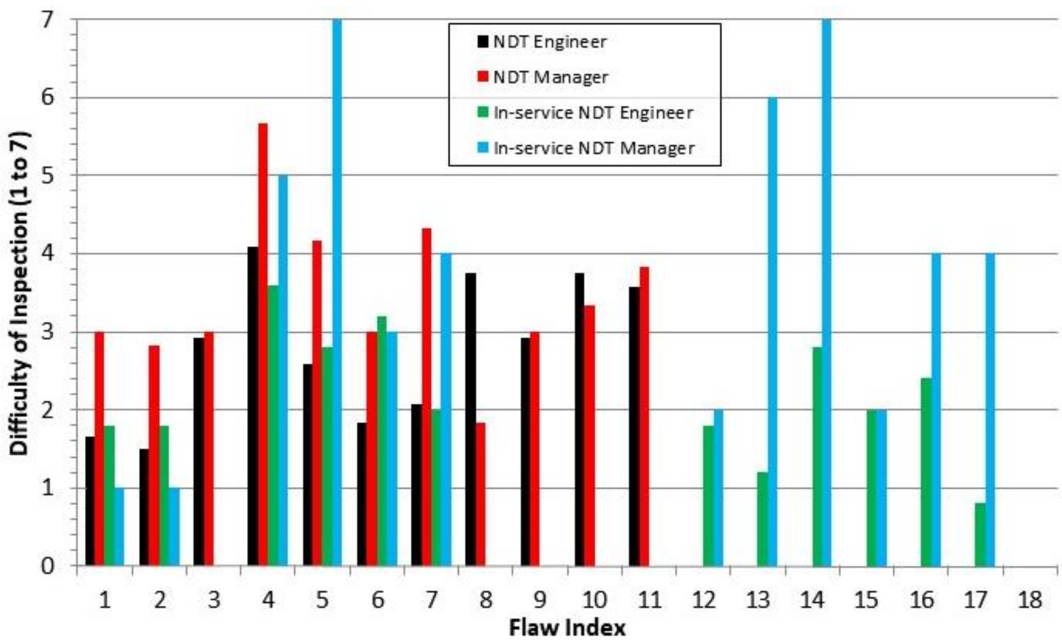


Figure A.4-4. Average difficulty of inspection according to Engineers and Managers who work in manufacturing or in-service NDT. The numbers on horizontal axis refer to the flaws listed in Table A.4-5.

Next, non-NDT engineers and non-NDT R&D personnel were asked for which flaw types are they most concerned about in their design, test, analysis or fabrication roles (1 = not concerned, 7 = very concerned). Since this question was not desiged for in-service personnel, the respondents were only given flaw types 1–11 and "Other" from Table A.4-5. Figure A.4-5 shows the flaws of greatest concern for both non-NDT engineers and non-NDT R&D personnel are delaminations, disbonds and bond integrity / strength.

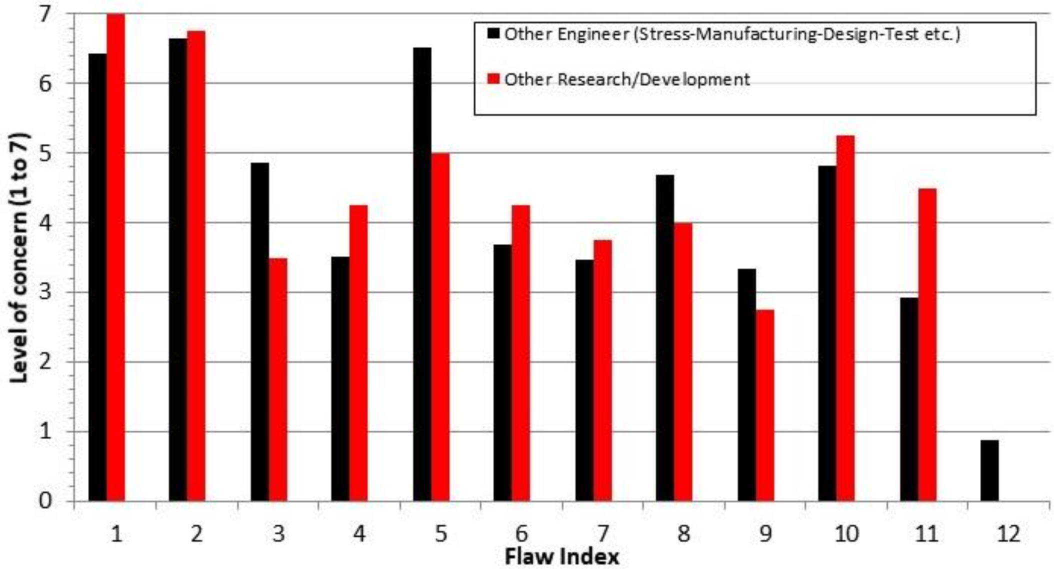


Figure A.4-5. Defects that non-NDT engineers and non-NDT R&D personnel are concerned about in their design, test, analysis or fabrication roles.
The numbers on horizontal axis refer to the flaws listed in Table A.4-5.

The survey attempted to capture areas of NDT that needed further development. To do this responents were provided a list (Table A.4-6) of NDT areas and asked to rate each item in the list from 1 to 7 (1 = not needed, 7 = strongly needed).

Table A.4-6. Indexed listing of areas of NDT that needed further development as shown in Figures A.4-6, A.4-7 and A.4-8.

Index	NDT Area	Index	NDT Area
1	Addressing critical defect types that require quantitative characterization for residual strength and durability	10	Analysis of data acquired from automated inspections
2	Addressing of sources of manufacturing and in-service flaws that are of concern	11	Improved Identification of critical flaw types
3	Improving identification and quantification of risk factors for composite structures	12	Better NDE standards for composite critical flaws
4	Methods used for meaningful data delivery to individuals responsible for dispositioning the part	13	Reduction in Costs in labor and time associated with the inspection processes and methods currently used
5	Methods for archiving the inspection data	14	In-process inspection (during fabrication before part completion)
6	Process used for dispositioning the part when flaws are detected	15	Methods for in-service inspection
7	New parameters for characterization of flaws/damage	16	Probability of detection or improve characterization of inspection performance;
8	Automated inspection techniques	17	Improved resolution of anomalous indications;
9	Automated defect recognition and analysis	18	Other

Figure A.4-6 show the responses from NDT and Manufacturing Engineers. Figure A.4-7 represents the responses according to NDT R&D Managers and Researchers. Finally, Figure A.4-8 represents the responses according to non-NDT engineers and non-NDT R&D personnel. Figures A.4-6, A.4-7, and A.4-8 indicate a wide spread need in improvments for NDT in general.

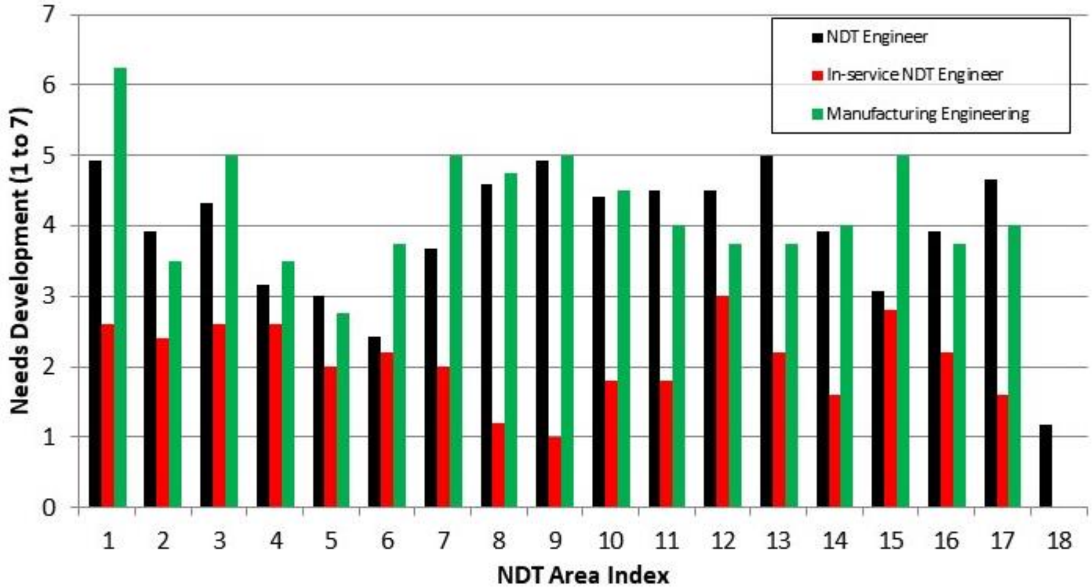


Figure A.4-6. Needed areas of NDT development according to NDT and manufacturing engineers. The numbers on horizontal axis refer to the NDT areas listed in Table A.4-6.

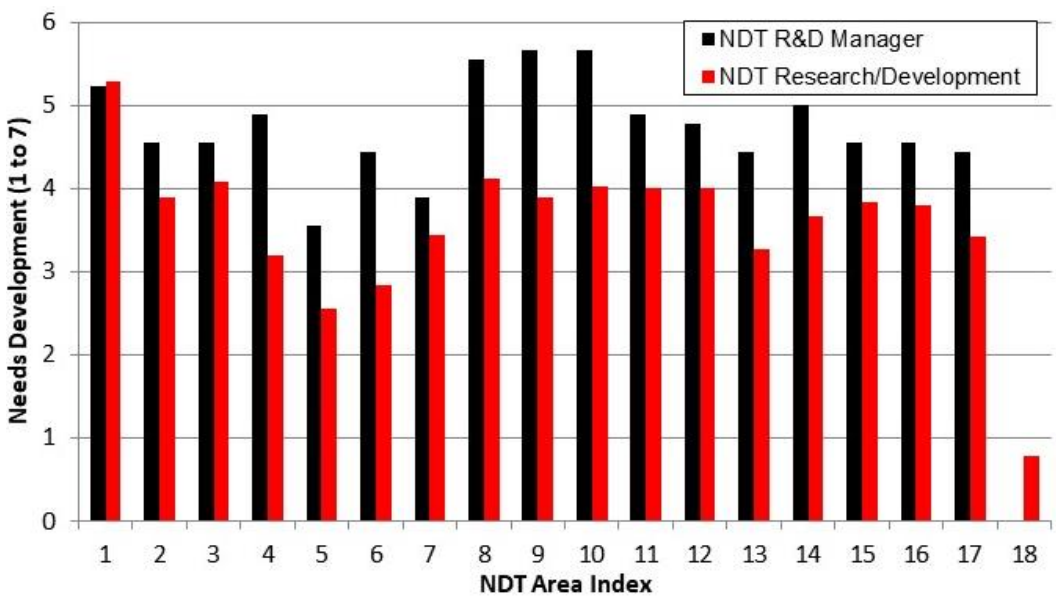


Figure A.4-7. Needed areas of NDT development, according to NDT R&D managers and researchers. The numbers on horizontal axis refer to the NDT areas listed in Table A.4-6.

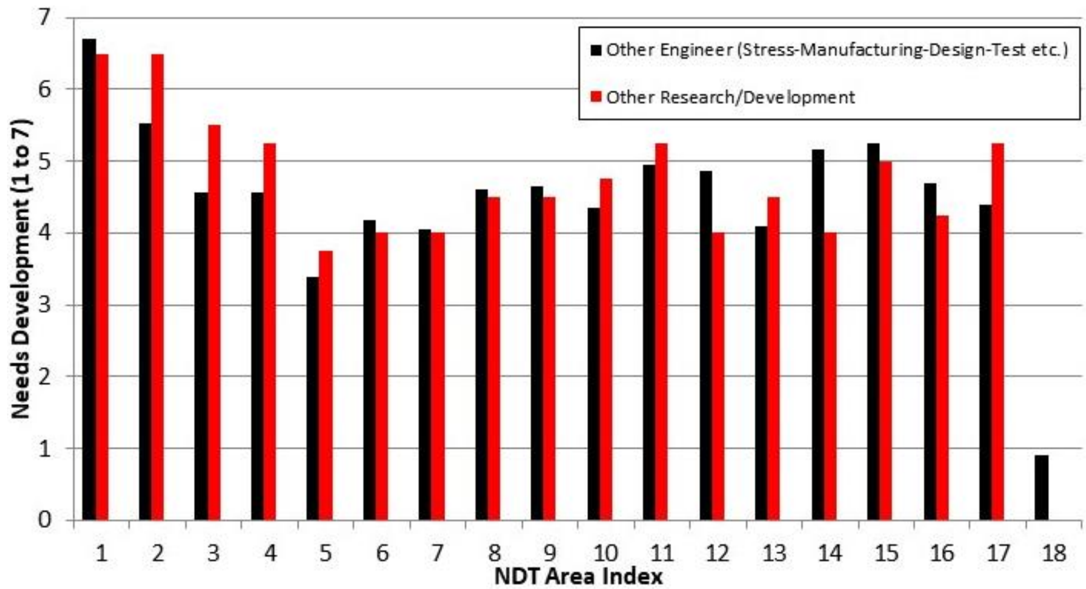


Figure A.4-8. Needed areas of NDT development according to non-NDT engineers and non-NDT R&D personnel.
The numbers on horizontal axis refer to the NDT areas listed in Table A.4-6.

The survey also attempted to capture which methods of NDT further development was already taking place. To do this responents were asked: "In which of the following areas of NDT have you conducted research and/or development, or have used in your research?" Respondents were encouraged to select as many NDT methods as applied. Table A.4-7 shows the NDT methods and percentage of respondent who selected each area. The results indicate that there is a very broad and relatively uniform effort to develop NDT technology and methods.

Table A.4-7. NDT R&D methods, according to those who identify themselves as working in R&D.

NDT Method	Percent Response	NDT Method	Percent Response
Visual	5%	IRT	8%
Remote Visual Insp.	3%	Laser Shearography	4%
Automated TTU	8%	Acoustic Emission	4%
Automated PE-UT	11%	Film Radiography	3%
Hand-held TTU	6%	Digital Radiography	5%
Air Coupled UT	5%	XCT	6%
Array-based UT	8%	Terahertz (THz)	3%
Laser UT	5%	Microwave	2%
Low Frequency UT	5%	Eddy Current	5%
Tap Testing	3%	Other	2%

Over 65% of respondents answered 'Yes' to this question: "Do you deal with flaws that need to be better represented in your standards?" For those that answered 'Yes', they were further asked: "Which flaws need to be better represented by standards?" Table A.4-8 shows the flaw types and the percent of respondents that indicated this type needs better standards. Table A.4-8 demonstrates that good porosity standards are currently the biggest need. Several respondents commented that universal standards are needed that can be used for composite parts.

Table A.4-8. The needs for improved reference standards in the composite industry are represented by the response to the survey question: "Do you deal with flaws that need to be better represented in your standards?"

Flaw Type	Percent Response	Flaw Type	Percent Response
Porosity	25.27%	Bond Quality	10.99%
Delamination	9.89%	Foreign Material	3.30%
Microcracks	7.69%	Thermal Damage	2.20%
Wrinkles	10.99%	Voids	1.10%
Disbonds	10.99%	Fatigue Cracking	1.10%
Fiber Waviness	7.69%	Density	3.30%
Kissing Bonds	3.30%	Density Anomolies	2.20%

A.4.2 Recommendations

Based on the survey results, there are near-term opportunities to impact the composites certification timeline and costs. Porosity, foreign material, and fiber waviness, along with delaminations/disbonds, are at the top of composite fabricators' list of most common defects. Additionally, the NDE methods suitable for automation appear to be those that are most common for manufacturing, including Visual, UT methods, IRT, and Low-Frequency UT/Bond Testing. Composite manufacturing methods that use a level of automation, such as AFP, or ATL could benefit from post-fabrication and in-process automated NDT processes, because this could enable more automated manufacturing methods. Further, efforts aimed at improving standards for composites should be done. Porosity standards are of particular interest and need, as Table A.4-8 shows.

Collaborative opportunities with design and stress analysis activities should be sought wherever possible. The number one need for NDT development according to stress/design/test engineers (non-NDT engineers) is "addressing critical defect types that require quantitative defect correlation for residual strength and durability." It is important to note that this was also selected as the highest need by the NDT community and respondents conducting R&D (Figures A.4-6 through A.4-8), and should be a high priority for the NASA ACP going forward.

Finally, automation of in-service inspection technologies like tap testing and Low-Frequency UT/bond testing may not initially reduce certification timelines, but can reduce composite maintenance costs and enable greater availability of composite platforms. Automation of technologies may also provide timeline benefits if they can be inserted into the manufacturing inspection of certain structures, like honeycomb structure.

A.5 Next Steps

Based on the results of this SoP assessment, NASA procured from the ACP industry partners a set of 64 composite specimens (standards) that contain a range of controlled defects representing those typically found in aerospace composite materials. The standards include 22 with various types of simulated delaminations, 20 with varying amounts of porosity, 9 with AFP tow defects, 7 with fiber wrinkling, 2 with microcracking, and 2 with bond integrity or weak bond defects. A majority, 46, of the standards used an IM7/8552 or IM7/8552-1 material system with the fibers being either uni-directional, braided, woven, or slit-tape. A few of the standards, 10 in total, used BMS 8-276 material system and 8 used T-800SC Triaxial Braid [0/+60/-60] with 3M AMD-825. The geometries produced include 21 flat panels, 10 S-curved panels, 9 wedges, 8 radius corner standards, 8 rotorcraft blade-spar tubes, 4 step, and 4 flange standards.

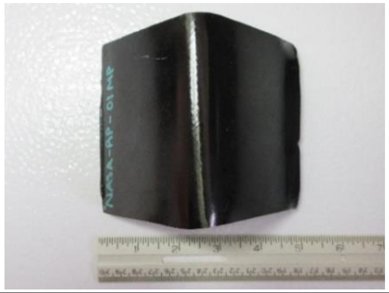
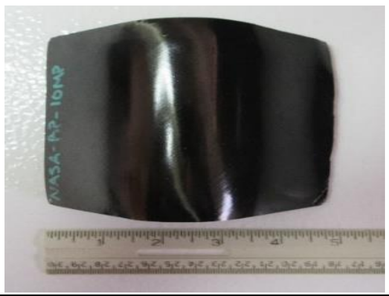
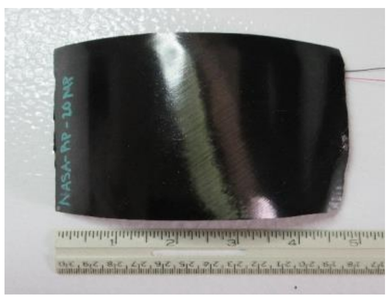
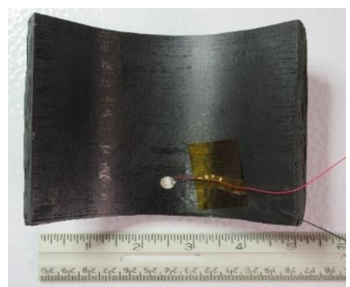
NASA has developed a complete database documenting all of the standards fabricated. Further, NASA has conducted an inter-laboratory round-robin inspection of these standards among the members of the NASA Advanced Composites Consortium (ACC). The ACC is a public-private partnership with five organizations to advance knowledge about composite materials, reduce the certification timeline and improve the performance of future aircraft. The NDE techniques used in the round-robin testing included, but are not limited to ultrasound, laser based ultrasound, thermography, and XCT. The data compiled from this round robin testing are presented in the other sections of this Handbook document.

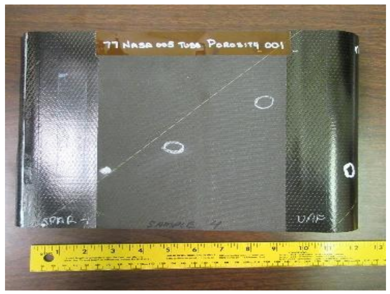
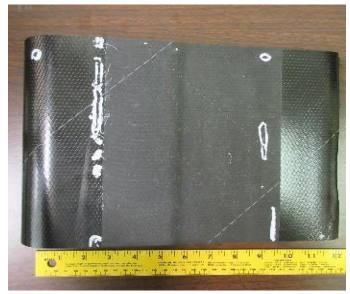
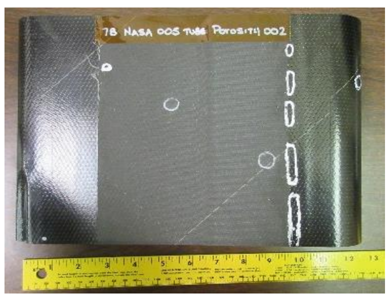
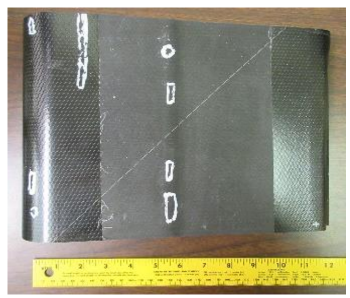
Appendix B Appendix B Overview of Standards: Photos and Descriptions – Listed by Defect Type

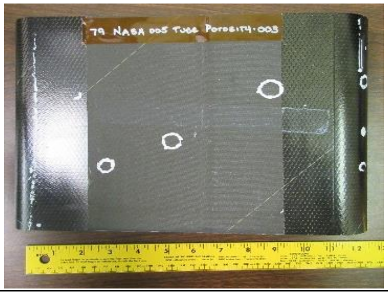
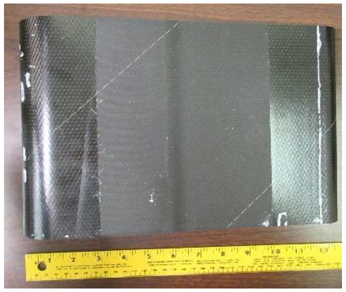
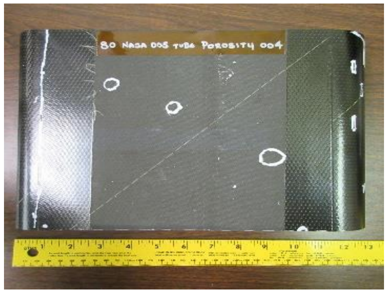
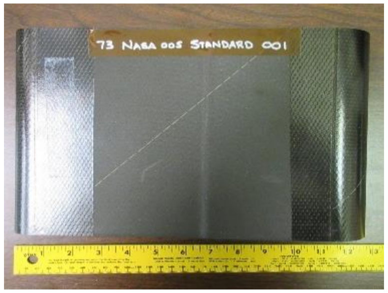
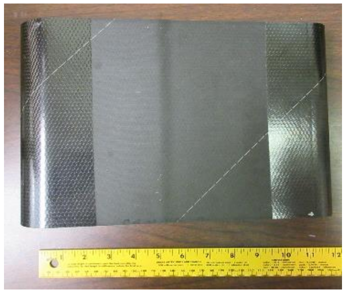
Consortium members fabricated 98 composite laminate standards with representative defect types typical in a manufacturing environment based on the results of the survey discussed in Appendix A. These defects are positioned within both flat panels and geometrically complicated locations and include defects ranging from delaminations and porosity to Automated Fiber Placement (AFP) tow defects and impact damage. Descriptions and photographs are detailed in this appendix, organized by defect type.

B.1 Porosity

B.1.1 Porosity in Radii

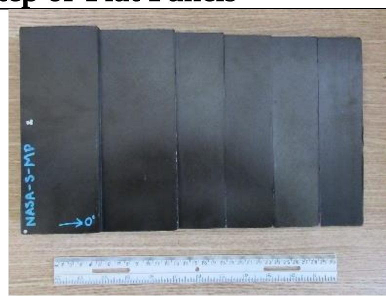
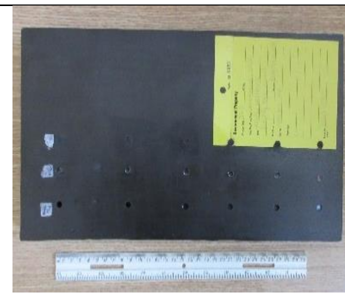
Specimen # 22 NASA-RP-01MP IM7/8552 Radius Panel 0.1-inch Curve Rad with medium porosity 4.5 × 2.5 × 4-inch			
Specimen #26 NASA-RP-10MP IM7/8552 Radius Panel 1.0-inch Curve Rad with medium porosity 4.5 ×2.5 ×4-inch			
Specimen #28 NASA-RP-20MP IM7/8552 Radius Panel 2.0-inch Curve Rad with medium porosity 4.5 ×2.0 ×4-inch			

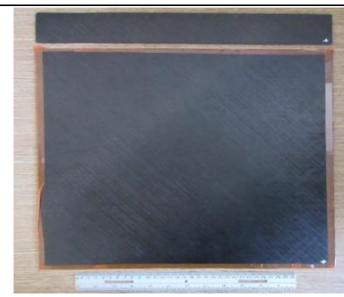
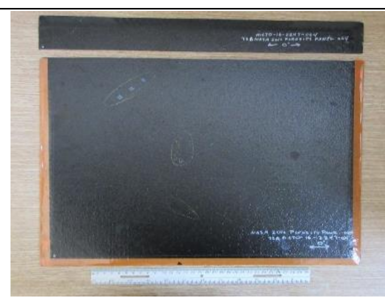
Specimen #30 NASA-RP-40MP IM7/8552 Radius Panel 4.0-inch Curve Rad with medium porosity 4.5 ×1.25 ×6-inch	  
Specimen #77 NASA-005-Porosity- 001 unidirectional IM7/8552 satin weave fabric Rotorcraft blade spar tube 11.5 × 8.5 × 2.8-inch	  
Specimen #78 NASA-005-Porosity- 002 unidirectional IM7/8552 satin weave fabric Rotorcraft blade spar tube 11.5 × 8.5 × 2.8-inch	  

Specimen #79 NASA-005-Porosity-003 unidirectional IM7/8552 satin weave fabric Rotorcraft blade spar tube 11.5 × 8.5 × 2.8-inch	  
Specimen #80 NASA-005-Porosity-004 unidirectional IM7/8552 satin weave fabric Rotorcraft blade spar tube 11.5 × 8.5 × 2.8-inch	  
Specimen #73 Pristine NASA-005-STANDARD-001 unidirectional IM7/8552 satin weave fabric Rotorcraft blade spar tube 11.5 × 8.5 × 2.8-inch	  

Specimen #74 Pristine NASA-005-STANDARD-002 unidirectional IM7/8552 satin weave fabric Rotorcraft blade spar tube 11.5 × 8.5 × 2.8-inch	  

B.1.2 Porosity in Step or Flat Panels

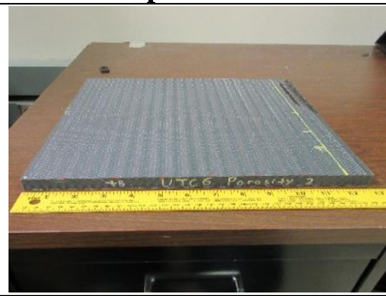
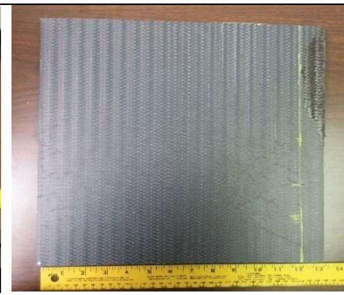
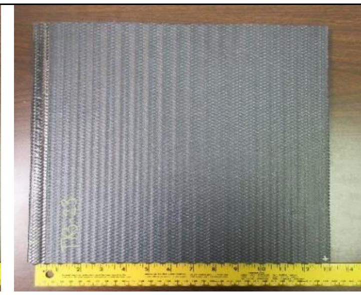
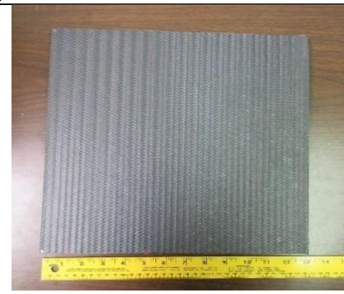
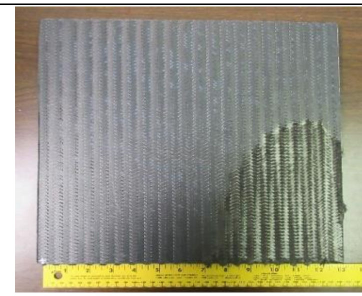
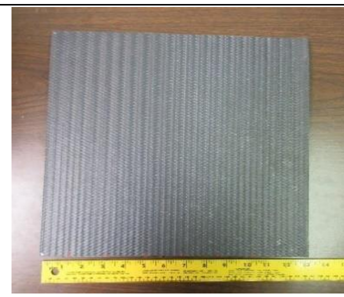
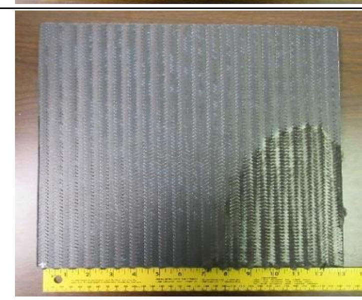
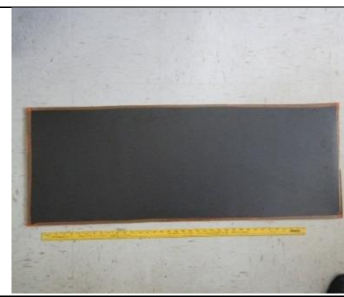
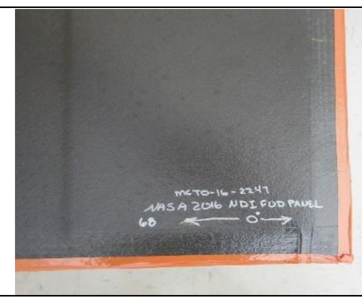
Specimen #2 NASA-S-MP unidirectional IM7/8552 Step heights 0.1-inch to 1.0-inch medium porosity 14 × 8 × 1.5-inch	  
Specimen #3 NASA-S-HP unidirectional IM7/8552 Step heights 0.1-inch to 1.0-inch high porosity 14 × 8 × 1.5-inch	  

Specimen #69 NASA-03-Porosity-Panel-001 Flat panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 15 × 17.5 × 0.15-inch	 
Specimen #70 NASA-03-Porosity-Panel-002 Flat panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 15 × 17.5 × 0.15-inch	 
Specimen #71 A&B NASA-03-Porosity-Panel-003 Flat panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 14 × 16 × 0.15-inch	 
Specimen #72 A&B NASA-03-Porosity-Panel-004 Flat panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 15 × 17.5 × 0.15-inch	 

B.1.3 Porosity in Wedges

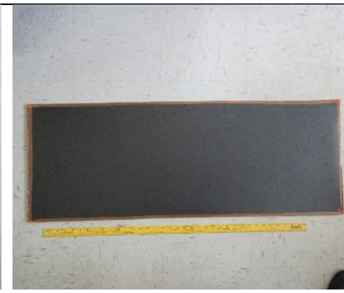
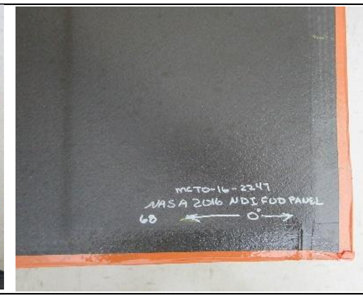
Specimen #10 NASA-W-5MP Wedge Interleaved 5 degrees with medium Porosity IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 12 × 3 × 1.5-inch			
Specimen #12 NASA-W-20MP Wedge Interleaved 20 degrees with medium Porosity IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 12 × 3 × 1-inch			
Specimen #13 NASA-W-IL-20MP Wedge Step 20 degrees with medium Porosity IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 12 × 3 × 1.5-inch			

B.1.4 Porosity in Woven Composites

Specimen #48 UTC 6 Porosity 2 Porosity IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 13 × 13 × 0.65-inch			
Specimen #49 UTC 8 Porosity 1 Porosity IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 13 × 13 × 0.65-inch			
Specimen #50 UTC 11 Baseline 2 Baseline IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML 12 × 11 × 0.5-inch			
Specimen #68 NASA-03-FOD-Panel-001 FOD 19 × 43 × 0.3-inch			

B.2 FOD and Inclusion

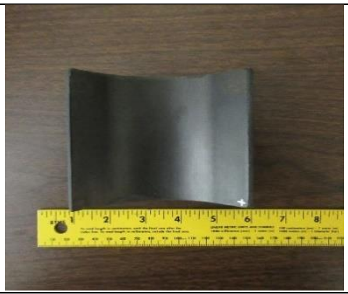
B.2.1 FOD and Inclusion

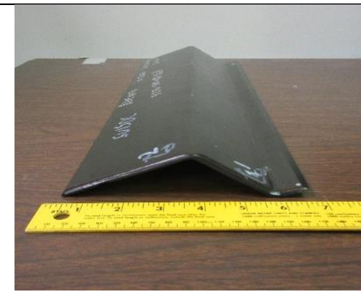
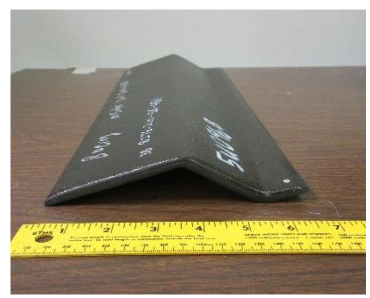
Specimen #68 FOD 19 × 43 × 0.3-inch			

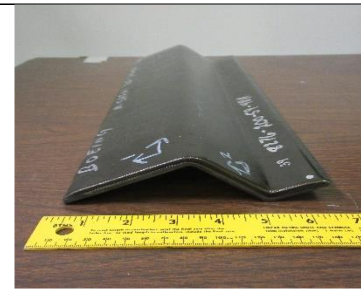
B.3 Delaminations

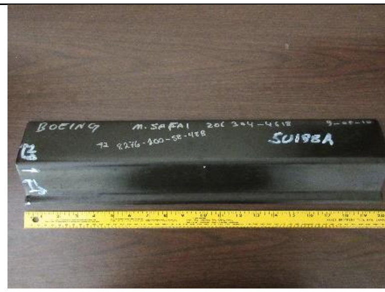
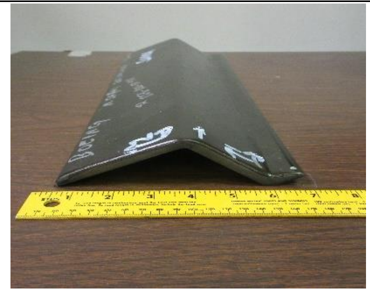
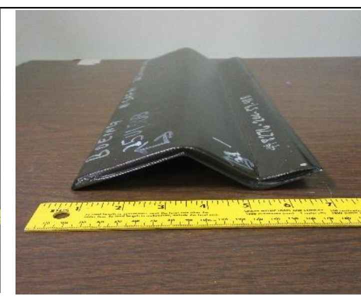
B.3.1 Delaminations at Radii (14 w/ multiple delams at different depths – GE & Boeing)

Specimen #16 NASA-RP-01D Radius Panel 0.1 in Curve Rad with defects- 4.5 × 2.5 × 4-inch			
Specimen #18 NASA-RP-10D Radius Panel 1.0 in Curve Rad with defects- 4.5 × 2.5 × 4-inch			

Specimen #19 NASA-RP-20D Radius Panel 2.0 in Curve Rad with defects- 4.5 × 1.5 × 4-inch			
Specimen #20 NASA-RP-40D Radius Panel 4.0 in Curve Rad with defects- 4.5 × 1.25 × 6-inch			
Specimen #35 8276-200-58-8 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			

Specimen #36 8276-200-58-26 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  
Specimen #37 276-200-58-48 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  
Specimen #38 8276-200-56-48 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  

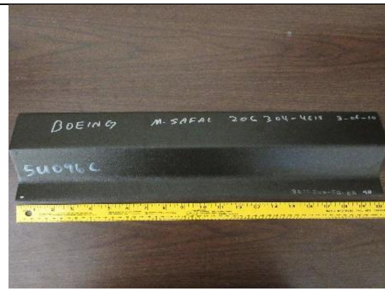
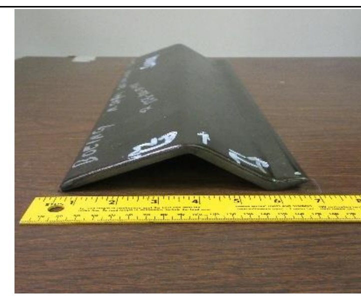
Specimen #39 8276-200-59-48 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #40 8276-200-58-8 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #41 8276-200-58-26 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			

Specimen #42 8276-200-58-48 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  
Specimen #43 8276-200-56-48 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  
Specimen #44 8276-200-59-48 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  

B.3.2 Delaminations In Flat or Step Panels (1 step GE; 10 'S' panels Boeing)

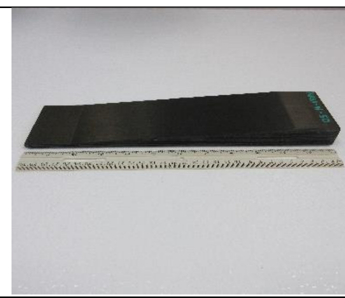
Specimen #1 NASA-S-D Step with FBH defects 14 × 8 × 1.5-inch			
Specimen #35 8276-200-58-8 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #36 8276-200-58-26 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			

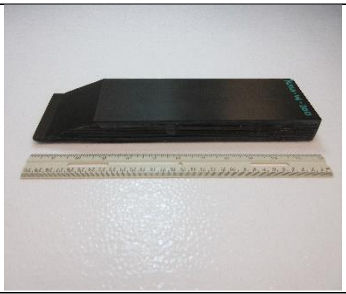
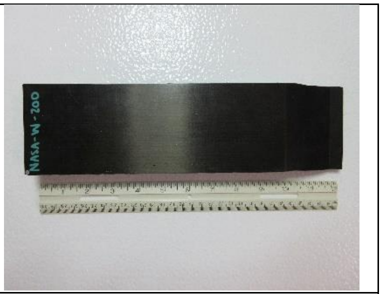
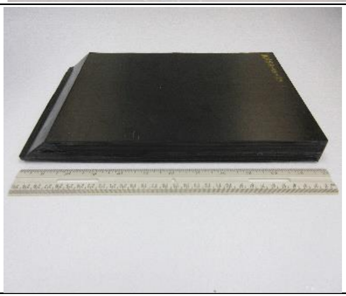
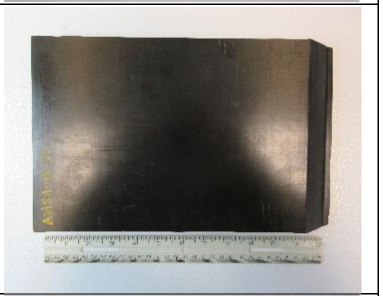
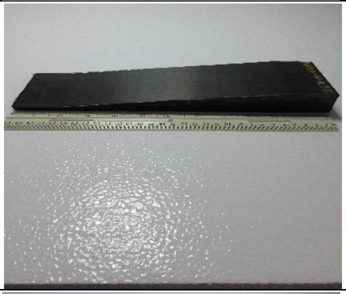
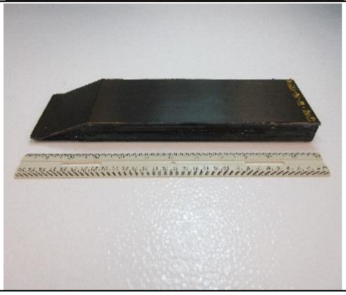
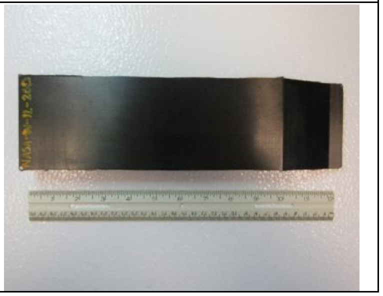
Specimen #37 276-200-58-48 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #38 8276-200-56-48 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #39 8276-200-59-48 A Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			

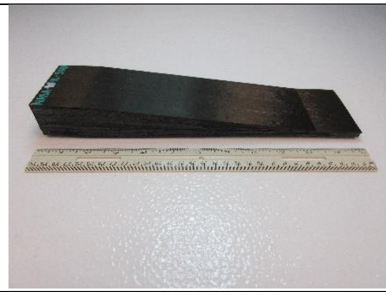
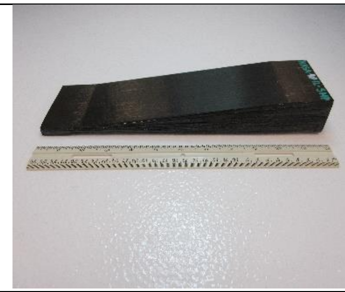
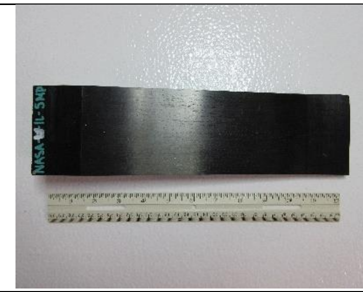
Specimen #40 8276-200-58-8 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #41 8276-200-58-26 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			
Specimen #42 8276-200-58-48 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch			

Specimen #43 8276-200-56-48 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  
Specimen #44 8276-200-59-48 B Multiple Types of delamination simulators (Teflon, Pressure sensitive tape (American Biltrite 6782), air pillows, mold release wax, brass inserts, etc.) 20 × 6 × 2.4-inch	  

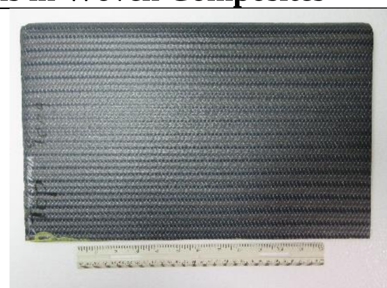
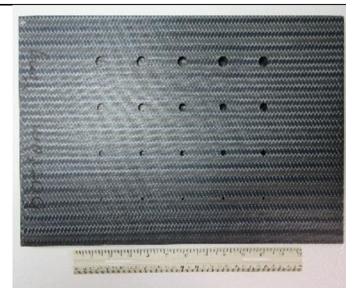
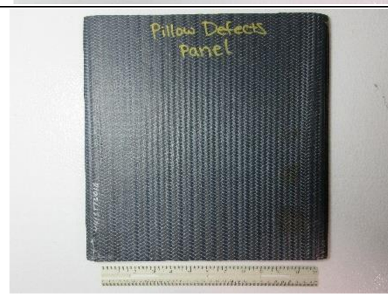
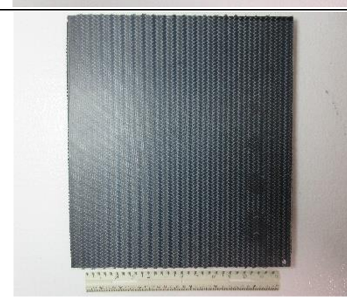
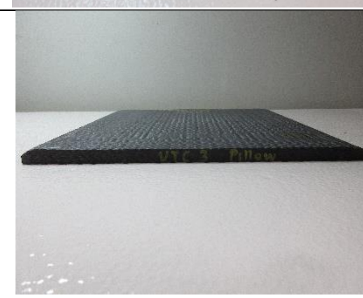
B.3.3 Delamination in Wedge Panels

Specimen #4 NASA-W-5D Wedge Step 5 degrees with defects 12 × 3 × 1.5-inch	  

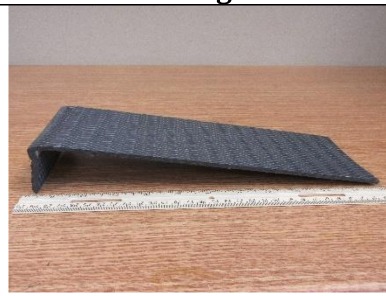
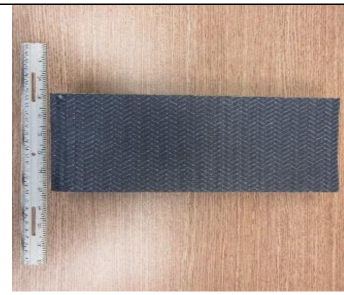
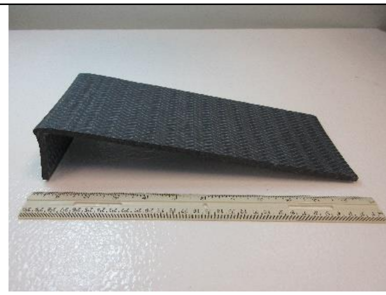
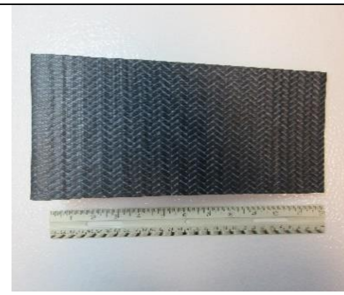
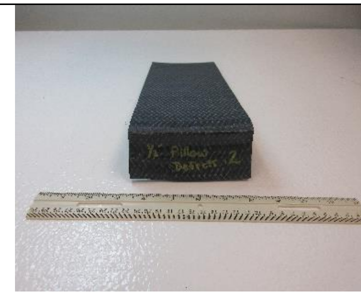
Specimen #5 NASA-W-20D Wedge Step 20 degrees with defects 12 × 3 × 1.1-inch			
Specimen #6 NASA-W-35D Wedge Step 35 degrees with defects 12 × 7 × 1.5-inch			
Specimen #7 NASA-W-IL-5D Wedge Interleaved 5 degrees with defects 12 × 3 × 1.1-inch			
Specimen #8 NASA-W-IL-20D Wedge Interleaved 20 degrees with defects 12 × 3 × 1.1-inch			

Specimen #11 NASA-W-IL-5D Wedge Step 5 degrees with defects 12 × 3 × 1.5-inch			

B.3.4 Delaminations in Woven Composites

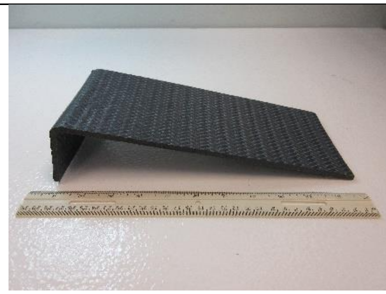
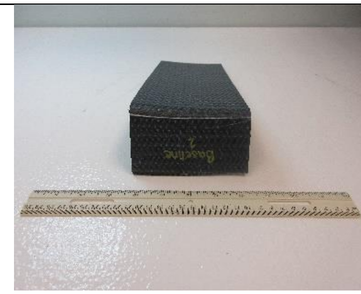
Specimen #45 UTC 1 FBH Delam/disbond (FBH) 16 × 10 × 0.75-inch			
Specimen #47 UTC 3 Pillow Delamination (Air Pillow) 13 × 13 × 0.5-inch			

B.3.5 Delamination in Woven Flange

Specimen #54 UTC 1/2" Pillow Defect Flange 1 Delamination (Air Pillow) 12 × 4.5 × 2.5-inch			
Specimen #55 UTC 1/2" Pillow Defect Flange 2 Delamination (Air Pillow) 12 × 4.5 × 2.5-inch			

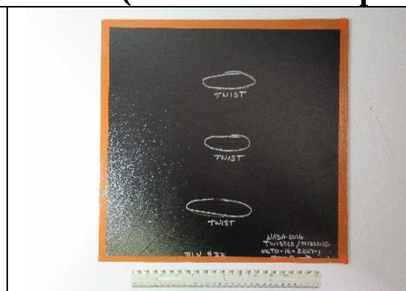
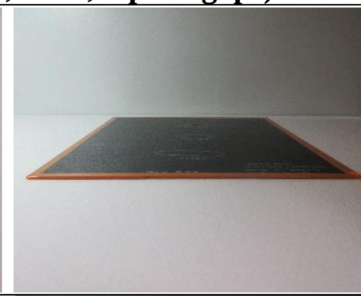
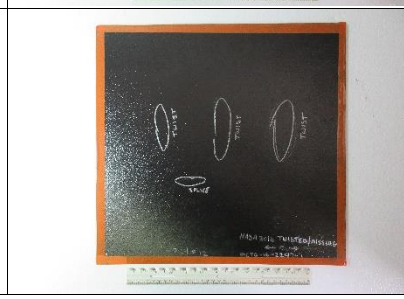
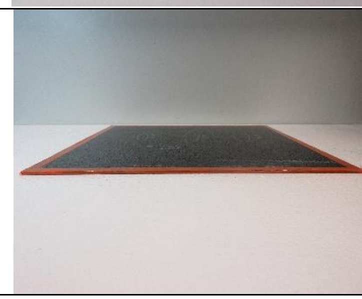
B.3.6 Flange Baseline

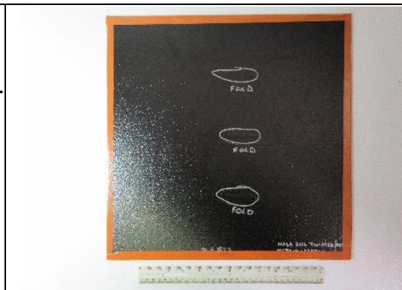
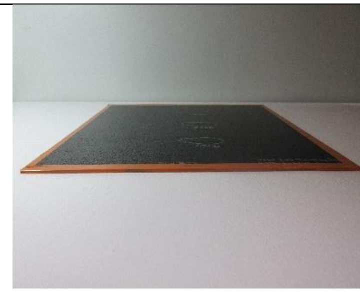
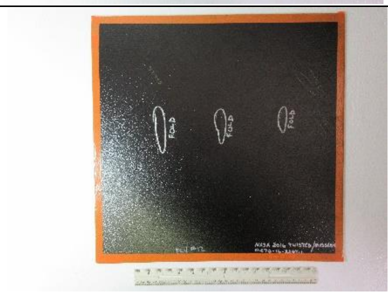
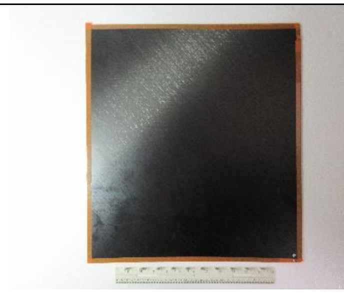
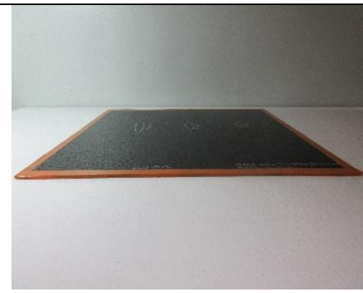
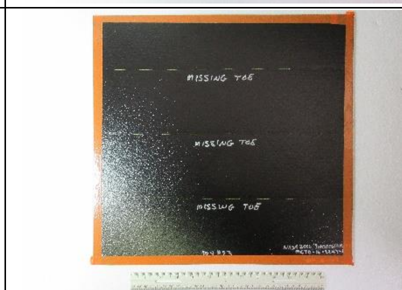
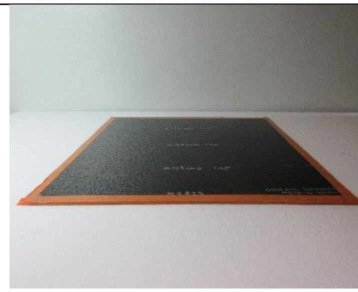
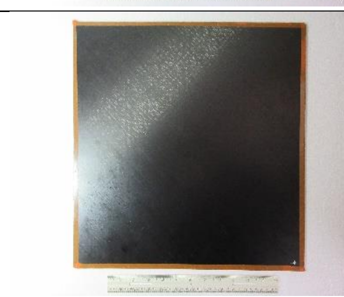
Specimen #52 UTC Flange Baseline 1 Baseline 11 × 4.5 × 2.25-inch			

Specimen #53 UTC Flange Baseline 2 Baseline 13 × 13 × 0.65-inch			

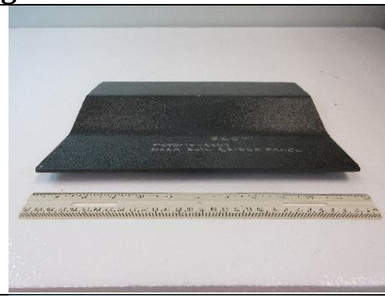
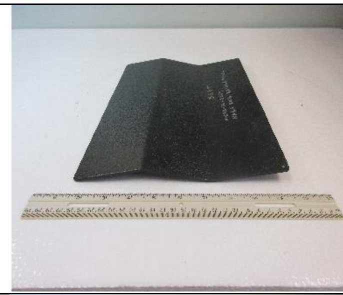
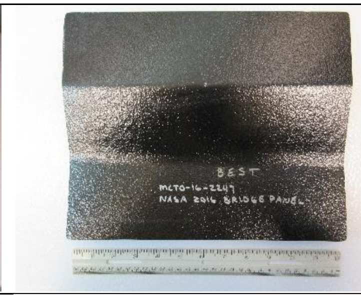
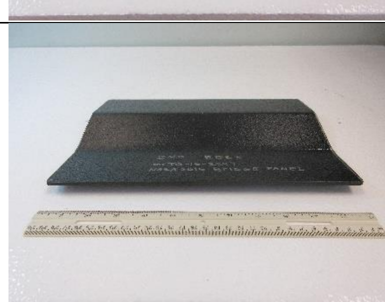
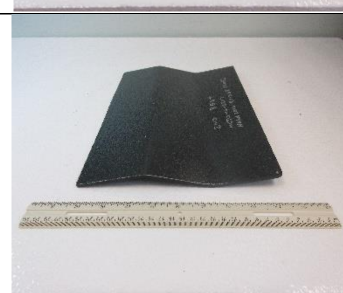
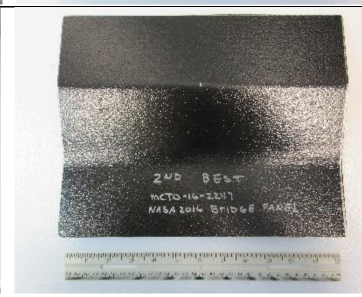
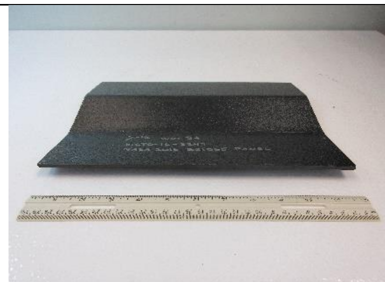
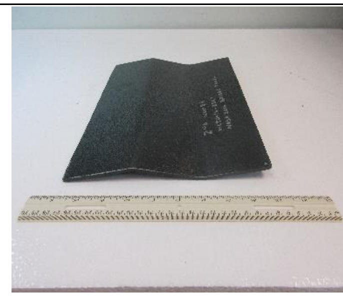
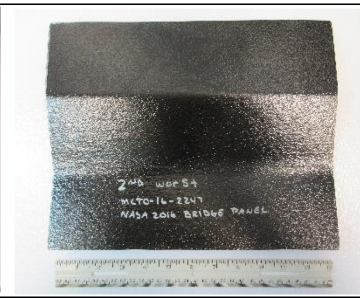
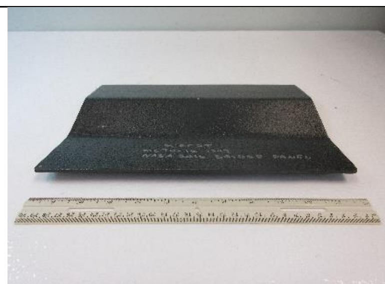
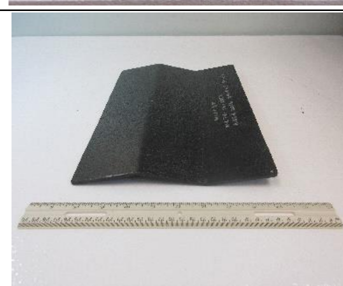
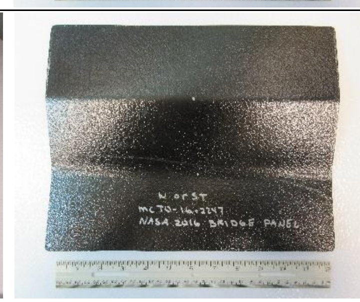
B.4 AFP Fiber Defects (wringles, tow snags)

B.4.1 Tow Defects in AFP (automated fiber placement) composites (twists, folds, laps & gaps)

Specimen #57 NASA-03-Twisted-Tow-001 Twisted Tow - 1 ply 16 × 16 × 0.15-inch			
Specimen #58 NASA-03-Twisted-Tow-002 Twisted Tow – Mid 16 × 16 × 0.15-inch			

Specimen #60 NASA-03-Folded-Tow-001 Folded Tow - 1 ply 16 × 16 × 0.15-inch			
Specimen #61 NASA-03-Folded-Tow-002 Folded Tow – Mid 16 × 16 × 0.15-inch			
Specimen #62 NASA-03-Missing-Tow-001 Missing Tow - 1 ply 16 × 16 × 0.15-inch			
Specimen #63 NASA-03-Missing-Tow-002 Missing Tow – Mid 16 × 16 × 0.15-inch			

B.4.2 Bridging Joggle in AFP

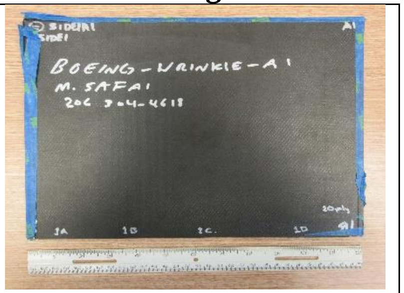
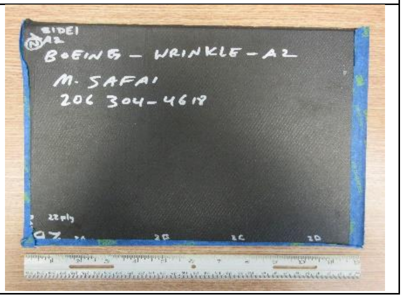
Specimen #64 NASA-03-Bridged-Joggle-001 Bridging – Joggle 12 × 9 × 1.3-inch			
Specimen #65 NASA-03-Bridged-Joggle-002 Bridging – Joggle 12 × 9 × 1.3-inch			
Specimen #66 NASA-03-Bridged-Joggle-003 Bridging – Joggle 12 × 9 × 1.3-inch			
Specimen #67 NASA-03-Bridged-Joggle-004 Bridging – Joggle 12 × 9 × 1.3-inch			

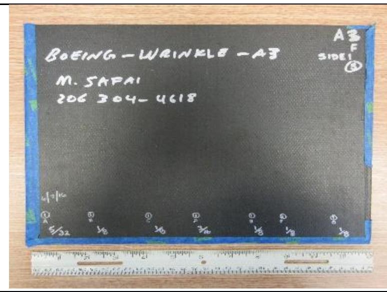
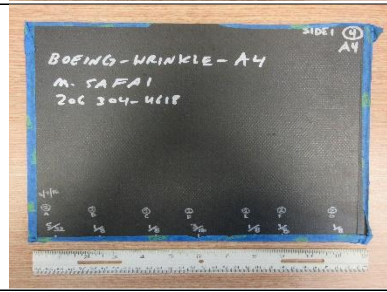
B.4.3 Detection of Tow Orientation in AFP Composite

Specimen #59 NASA-03-Steered-Tow-003 Tow Orientation 46.5 × 46.5 × 0.15-inch		

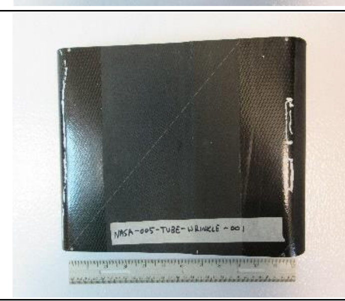
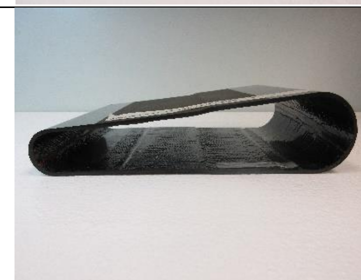
B.5 Fiber Defects (wrinkles, tow snags)

B.5.1 Detection of Fiber Wrinkling in Flat Panels

Specimen #31 Boeing A1 Flat Wrinkles 1.5 × 12 × 0.15-inch	
Specimen #32 Boeing A2 Medium Wrinkles 1.5 × 12 × 0.15-inch	

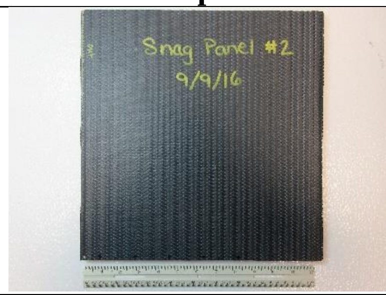
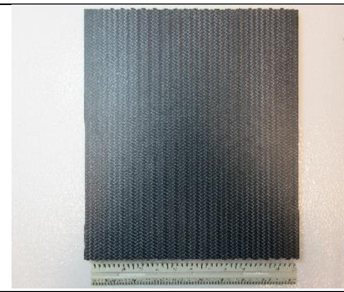
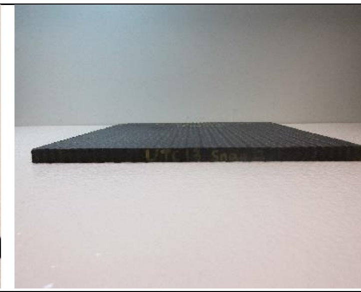
Specimen #33 Boeing A3 Significant Wrinkles 1.5 × 12 × 0.15-inch	
Specimen #34 Boeing A4 Significant Wrinkles 1.5 × 12 × 0.15-inch	

B.5.2 Detection of Wrinkling in Radii

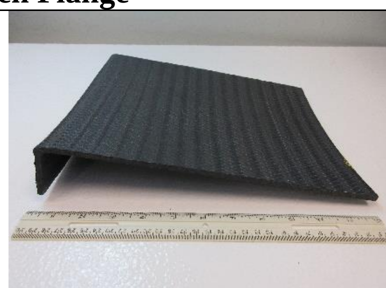
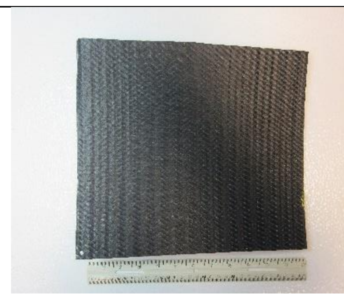
Specimen #74 NASA-005- STANDARD-002 Pristine 11.5 × 8.5 × 2.8-inch			
Specimen #75 NASA-005-Wrinkle- 001 Out of plane wrinkle 11.5 × 8.5 × 2.8-inch			

Specimen #76 NASA-005-Wrinkle-002 Out of plane wrinkle 11.5 × 8.5 × 2.8-inch			

B.5.3 Fabric SNA in Woven Composites

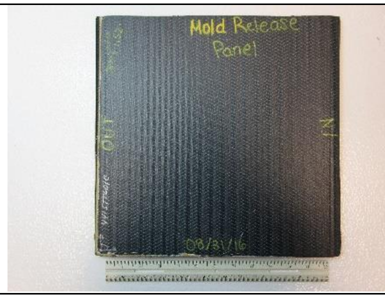
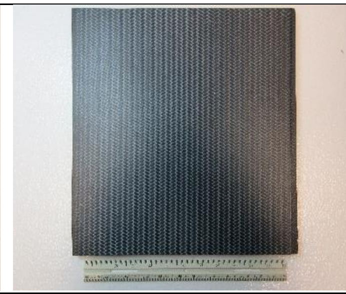
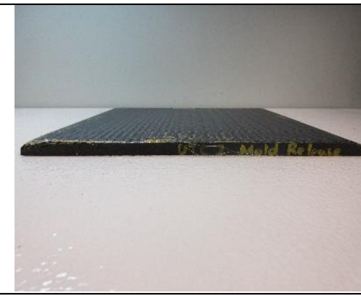
Specimen #51 UTC 13 Snag Fabric Snag 12 × 13 × 0.5-inch			

B.5.4 Snag in Woven Flange

Specimen #56 UTC Snag 1 Fabric Snag 9 × 12 × 2-inch			

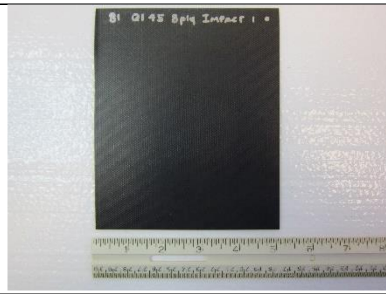
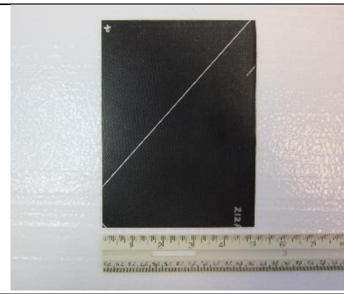
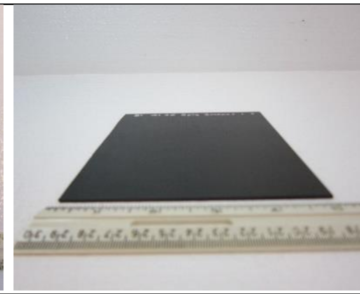
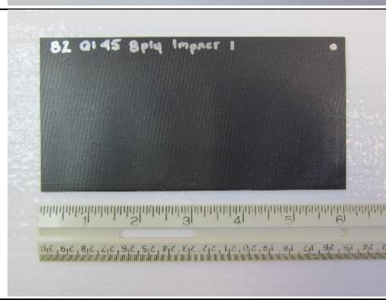
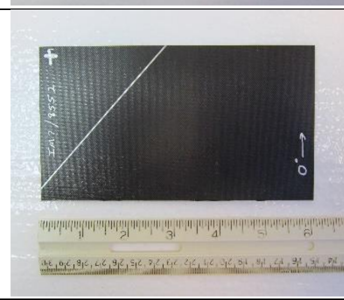
B.6 Bond Strength

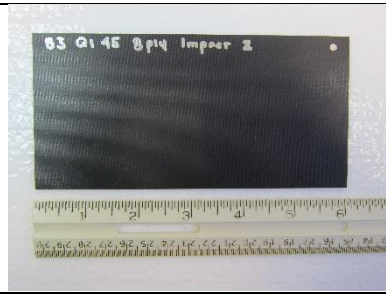
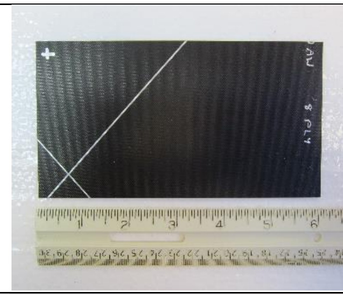
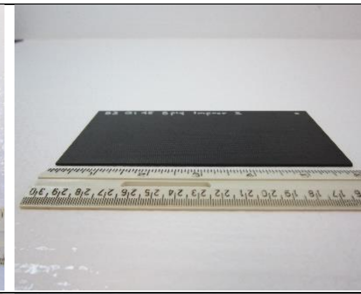
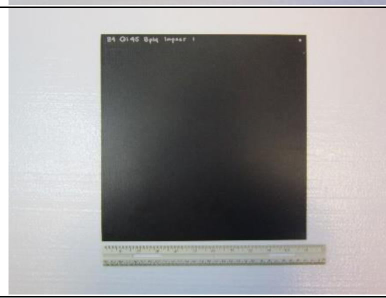
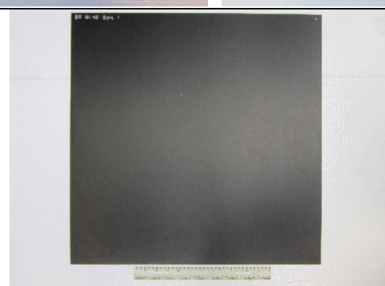
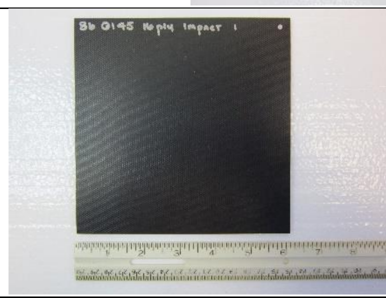
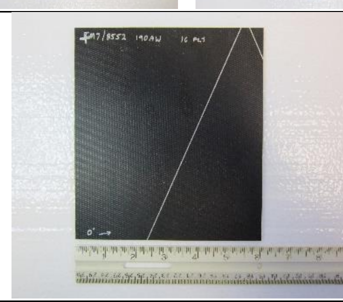
B.6.1 Mold Release

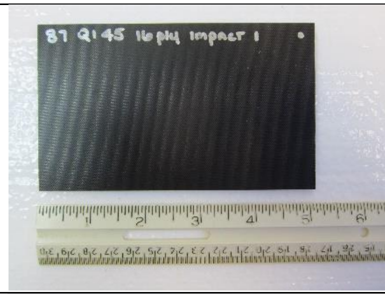
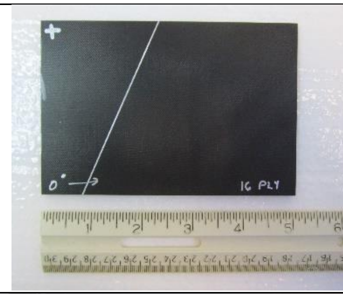
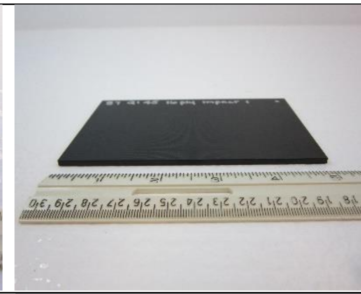
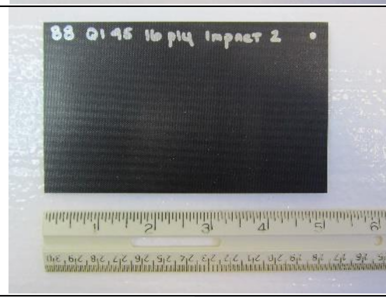
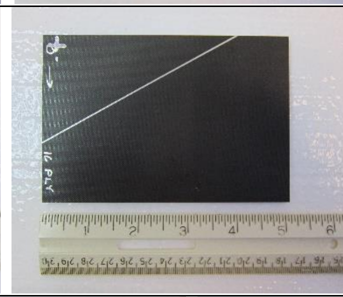
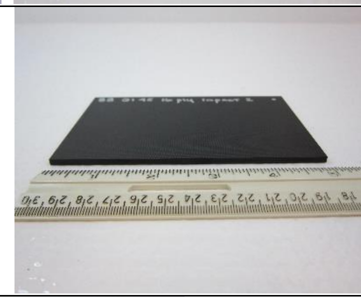
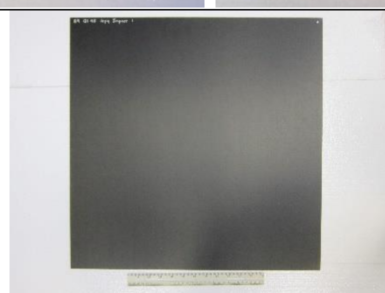
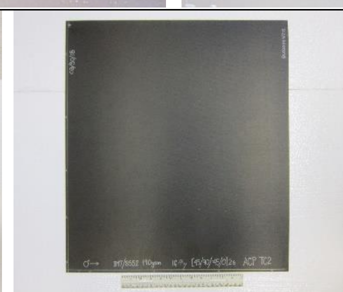
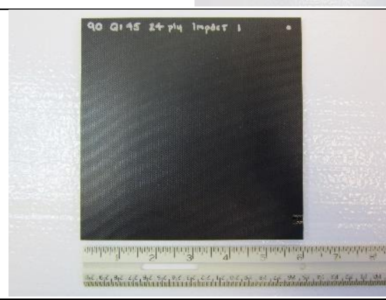
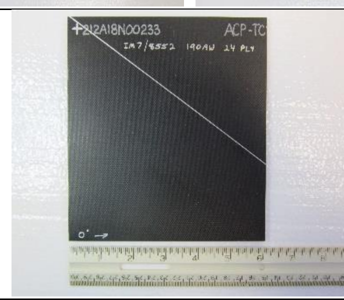
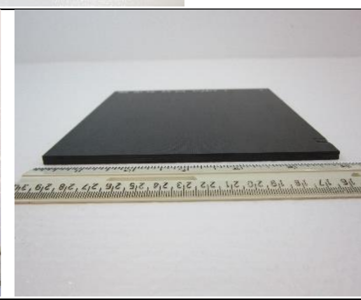
Specimen #46 UTC 2 Mold Release Disbond 13 × 12.5 × 0.5-inch			

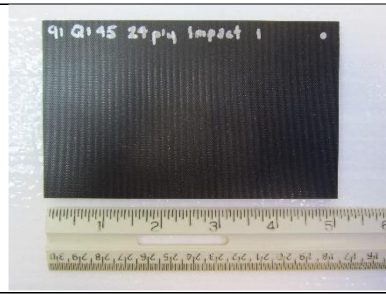
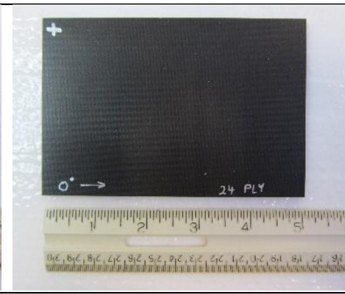
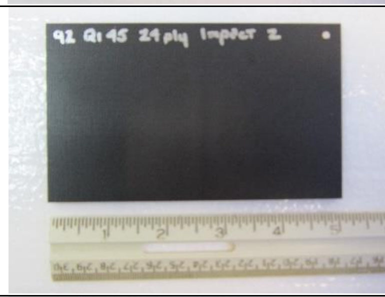
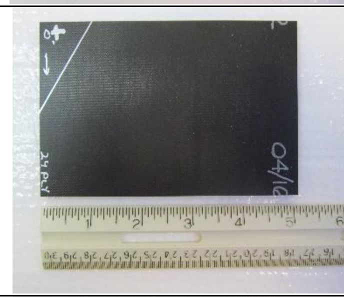
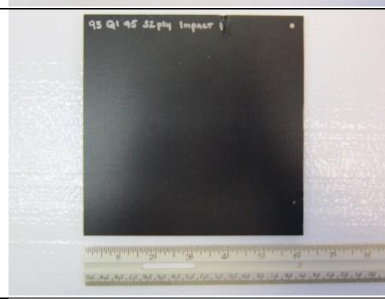
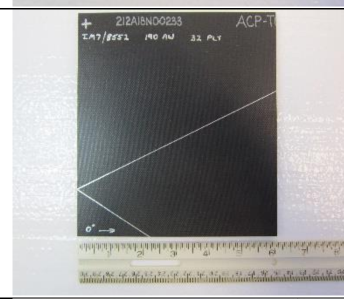
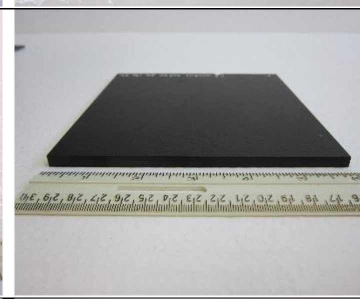
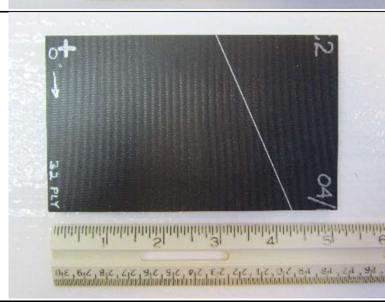
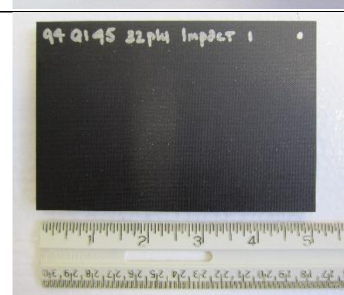
B.7 Impact Damage

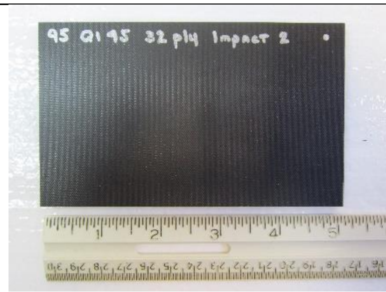
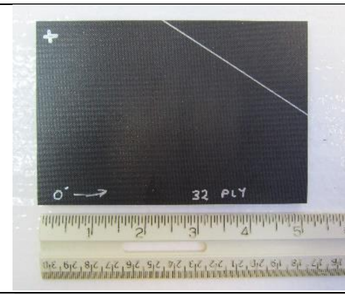
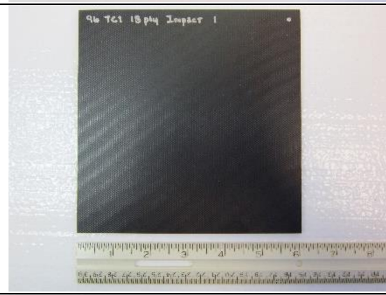
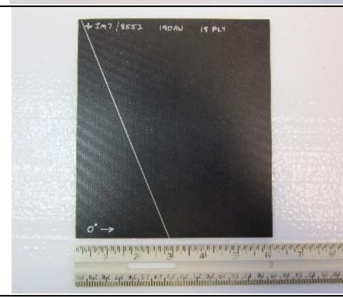
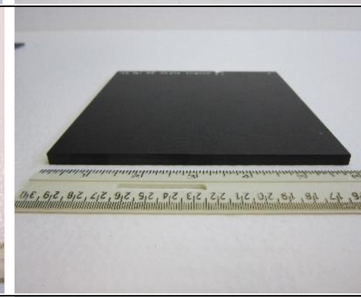
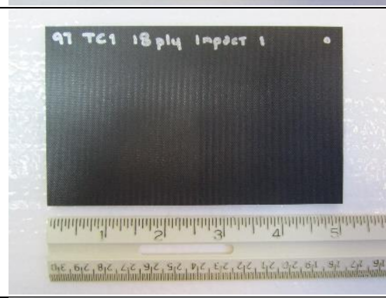
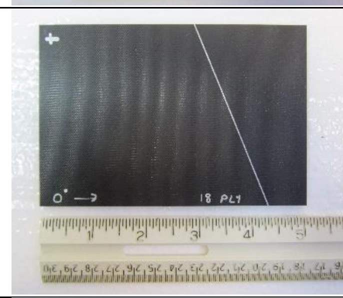
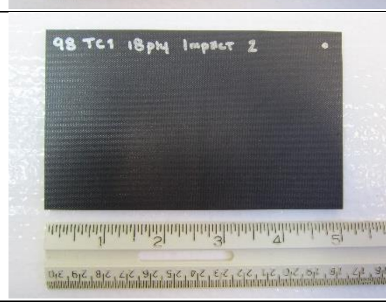
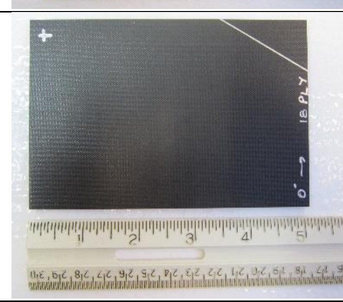
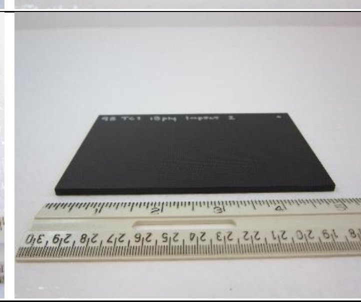
B.7.1 Static Impact

Specimen #81 6 × 6-inch 8-ply IM7/8552 [(45/90/-45/0)]S 1 impact			
Specimen #82 3 × 5-inch 8-ply IM7/8552 [(45/90/-45/0)]S 1 impact			

Specimen #83 3 × 5-inch 8-ply IM7/8552 [(45/90/-45/0)]S 1 impact	  
Specimen #84 11 × 11-inch 8-ply IM7/8552 [(45/90/-45/0)]S Spare. No impact	  
Specimen #85 22 × 22-inch 8-ply IM7/8552 [(45/90/-45/0)]S 4 impacts in center 8 × 8-inch square	 
Specimen #86 6 × 6-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 1 impact	  

Specimen #87 3 × 5-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 1 impact			
Specimen #88 3 × 5-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 1 impact			
Specimen #89 22 × 22-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 4 impacts in center 8 × 8-inch square			
Specimen #90 6 × 6-inch 24-ply IM7/8552 [(45/90/-45/0)3]S 1 impact			

Specimen #91 3 × 5-inch 24-ply IM7/8552 [(45/90/-45/0)3]S 1 impact			
Specimen #92 3 × 5-inch 24-ply IM7/8552 [(45/90/-45/0)3]S 1 impact			
Specimen #93 6 × 6-inch 32-ply IM7/8552 [(45/90/-45/0)4]S 1 impact			
Specimen #94 3 × 5-inch 32-ply IM7/8552 [(45/90/-45/0)4]S 1 impact			

Specimen #95 3 × 5-inch 32-ply IM7/8552 [(45/90/-45/0)4]S 1 impact			
Specimen #96 6 × 6-inch 18-ply IM7/8552 [45/90/-45/0/0/45/90/-45/0]S 1 impact			
Specimen #97 3 × 5-inch 18-ply IM7/8552 [45/90/-45/0/0/45/90/-45/0]S 1 impact			
Specimen #98 3 × 5-inch 18-ply IM7/8552 [45/90/-45/0/0/45/90/-45/0]S 1 impact			

Appendix C Round-Robin Test Matrix

C.1 Round-Robin Testing

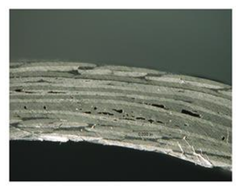
C.1.1 Introduction

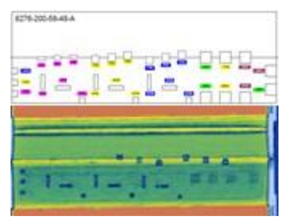
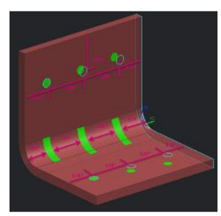
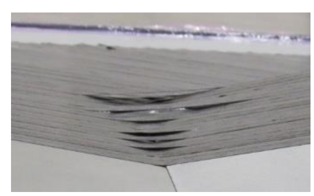
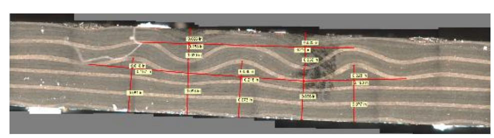
As discussed in detail in Appendix A, each ACP industry partner fabricated a set of composite specimens (standards) that contain a range of controlled defects representing those of higher concern for aerospace composite materials. The “Indefinite Delivery/Indefinite Quantity (IDIQ) contract mechanism was used to procure specimens, resulting in a “best effort” approach to creating a library of specimens with common, realistic defects. Each consortium company chose or was assigned standards to fabricate based on manufacturing capabilities. Defect types included manufacturing defects such as varying amounts of porosity (in a range typically found in autoclave cured aerospace composites) and varying degrees of fiber waviness (both in-plane and out-of-plane), as well as inserts representing delamination type defects. Appendix B includes the round-robin test matrix grouped by defect type. Consortium members fabricated 88 specimens as detailed below.

- Materials:
  - 66 are made of IM7/8552 or IM7/8552-1
  - 10 are made of 8276 tape
  - 12 are T-800SC triaxial braid fabric

- Geometries:
  - 44 Flat panels
  - 10 S curve (__/‾) panels
  - 9 Wedge panels
  - 8 Radius corner panels
  - 8 Rotorcraft blade spar tubes
  - 4 Step panels
  - 5 Flange panels

- Defects:
  - 27 Delamination
  - 21 Porosity
  - 11 AFP tow defects
  - 9 Fiber orientation (in and out of plane)
  - 1 Bond integrity
  - 1 FOD panel
  - 18 Impact damage



C.2 Test Matrix

The standards fabricated under Phase I were tested in a round-robin approach where ACP TC2 Consortium members circulated the specimens to each other based on the defect type and appropriate available NDE test equipment located at each members’ laboratories. Three or more partners tested eleven specimens. Boeing tested 14 specimens with 10 techniques. The University of South Carolina (USC) tested 13 standards with one technique. Northrop Grumman Innovation Systems (NGIS) tested eight standards with four techniques. GE tested 25 specimens with one technique. NASA tested 44 specimens with five techniques. Table C.2-1 details the specific specimens tested by each partner, organized by defect type. The color code key represents the fabrication origin of the specimens without reference to the company name.

Key:

ACC Manufacturing Partner Number					
1	2	3	4	5	6

Partner and Testing Acronyms:

NGIS	Northrop Grumman Innovation Systems
NASA	National Aeronautics and Space Administration
GE	General Electric
Boeing	The Boeing Company
USC	University of South Carolina

PEUT	Pulse-Echo Ultrasound
TTUT	Through transmission Ultrasound
GWUT	Guided Wave Ultrasound
SSIR	Single sided infrared thermography
TTIR	Through transmission infrared thermography
XCT	X-ray Computed Tomography
DR	Digital Radiography
CR	Computed Radiography

Table C.2-1. Specific specimens tested by each partner, organized by defect type.

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
Porosity	Porosity in radii	22	NASA-RP-01MP	Uni-ply 0/90/45)	IM7/8552	0.1" radial inside curve	Radius Panel 0.1 in Curve Rad with medium porosity	4.5 X 2.5 X 4	NASA: SSIR, TTIR
		26	NASA-RP-10MP	Uni-ply 0/90/45)	IM7/8552	1.0" radial inside curve	Radius Panel 1.0 in Curve Rad with medium porosity	4.5 X 2.5 X 4	NASA: SSIR, TTIR
		28	NASA-RP-20MP	Uni-ply 0/90/45)	IM7/8552	2.0" radial inside curve	Radius Panel 2.0 in Curve Rad with medium porosity	4.5 X 2.0 X 4	NASA: SSIR, TTIR
		30	NASA-RP-40MP	Uni-ply 0/90/45)	IM7/8552	4.0" radial inside curve	Radius Panel 4.0 in Curve Rad with medium porosity	4.5 X 1.25 X 6	NASA: PEUT, TTUT USC: GWUT
		77	NASA-005-Porosity-001	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Porosity	11.5 X 8.5 X 2.8	GE: PEUT, TTUT
		78	NASA-005-Porosity-002	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Porosity	11.5 X 8.5 X 2.8	GE: PEUT, TTUT
		79	NASA-005-Porosity-003	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Porosity	11.5 X 8.5 X 2.8	NASA: PEUT GE: PEUT, TTUT
		80	NASA-005-Porosity-004	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Porosity	11.5 X 8.5 X 2.8	GE: PEUT, TTUT
	Porosity baseline	73	NASA-005-STANDARD-001	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Pristine	11.5 X 8.5 X 2.8	GE: PEUT, TTUT

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
Porosity	Porosity in flat (or step) panels	2	NASA-S-MP	Uni-ply 0/90/45)	IM7/8552	Step heights: 0.1" - 1.0"	Step with medium porosity	14 x 8 x 1.5	GE: PEUT, TTUT NASA: XCT NGIS: PEUT, SSIR, TTIR
		3	NASA-S-HP	Uni-ply 0/90/45)	IM7/8552	Step heights: 0.1" - 1.0"	Step with high porosity	14 x 8 x 1.5	GE: PEUT, TTUT NASA: XCT NGIS: PEUT, SSIR, TTIR
		69	NASA-03-Porosity-Panel-001	Fiber Placed Panel	IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML	Flat panel	Porosity	15 X 17.5 X 0.15	NASA: PEUT GE: PEUT, TTUT NGIS: PEUT, TTUT, TTIR, SSIR
		70	NASA-03-Porosity-Panel-002	Fiber Placed Panel	IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML	Flat panel	Porosity	15 X 17.5 X 0.15	NASA: PEUT GE: PEUT, TTUT NGIS: PEUT, TTUT, TTIR, SSIR
		71A&B	NASA-03-Porosity-Panel-003	Fiber Placed Panel	IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML	Flat panel	Porosity	14 X 16 X 0.15	GE: PEUT, TTUT NASA: PEUT, XCT NGIS: PEUT, TTUT, SSIR, TTIR
		72A&B	NASA-03-Porosity-Panel-004	Fiber Placed Panel	IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML	Flat panel	Porosity	15 X 17.5 X 0.15	GE: PEUT, TTUT NASA: PEUT, XCT NGIS: PEUT, TTUT, SSIR, TTIR
	Porosity in wedges	10	NASA-W-5MP	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 5 deg slope	Wedge Interleaved 5 deg with medium porosity	12 X 3 X 1.5	GE: PEUT, TTUT NASA: XCT
		12	NASA-W-20MP	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 20 deg slope	Wedge Interleaved 20 deg with medium porosity	12 X 3 X 1	GE: PEUT, TTUT NASA: XCT
		13	NASA-W-IL-20MP	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 20 deg slope	Wedge Step 20 deg with medium porosity	12 X 3 X 1.5	GE: PEUT, TTUT NASA: XCT
	Porosity in woven composites	48	UTC 6 Porosity 2	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Porosity	13 X 13 X 0.65	GE: PEUT, TTUT NASA: XCT
		49	UTC 8 Porosity 1	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Porosity	13 X 13 X 0.65	GE: PEUT, TTUT
	Porosity in woven baseline	50	UTC 11 Baseline 2	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Baseline	12 X 11 X 0.5	GE: PEUT, TTUT NASA: PEUT

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
FOD & Inclusions	FOD	68	NASA-03-FOD-Panel-001	Fiber Placed Panel	IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML	Flat panel	FOD	19 X 43 X 0.3	GE: PEUT, TTUT NASA: XCT NGIS: PEUT, TTUT
Delaminations	Delaminations at Radii (multiple delams at different depths)	16	NASA-RP-01D	Uni-ply 0/90/45)	IM7/8552	0.1" radial inside curve, delams along curve & flat surfaces	Radius Panel 0.1 in Curve Rad with defects	4.5 X 2.5 X 4	USC: GWUT
		18	NASA-RP-10D	Uni-ply 0/90/45)	IM7/8552	1.0" radial inside curve, delams along curve & flat surfaces	Radius Panel 1.0 in Curve Rad with defects	4.5 X 2.5 X 4	USC: GWUT
		19	NASA-RP-20D	Uni-ply 0/90/45)	IM7/8552	2.0" radial inside curve, delams along curve & flat surfaces	Radius Panel 2.0 in Curve Rad with defects	4.5 X 1.5 X 4	USC: GWUT
		20	NASA-RP-40D	Uni-ply 0/90/45)	IM7/8552	4.0" radial inside curve, delams along curve & flat surfaces	Radius Panel 4.0 in Curve Rad with defects	4.5 X 1.25 X 6	USC: GWUT NASA: PEUT
		35	8276-200-58-8 A	laminate	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	Multiple types of delamination simulators (teflon, graton tape, air pillows, mold release wax, brass inserts, etc)	20 X 6 X 2.4	Boeing: PEUT, SSIR, DR, CR, XCT
		36	8276-200-58-26 A	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: PEUT, SSIR, DR, CR, XCT
		37	8276-200-58-48 A	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: PEUT, SSIR, DR, CR, XCT NASA: PEUT, XCT
		38	8276-200-56-48 A	"	8276 Tape	S curve (__/¯) **56°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: PEUT, SSIR, DR, CR, XCT
		39	8276-200-59-48 A	"	8276 Tape	S curve (__/¯) **59°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: PEUT, SSIR, DR, CR, XCT NASA: XCT
		40	8276-200-58-8 B	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Not Tested
		41	8276-200-58-26 B	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	NASA: XCT
		42	8276-200-58-48 B	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Not Tested
		43	8276-200-56-48 B	"	8276 Tape	S curve (__/¯) **56°** slant with two 0.2° radii	"	20 X 6 X 2.4	NASA: XCT
		44	8276-200-59-48 B	"	8276 Tape	S curve (__/¯) **59°** slant with two 0.2° radii	"	20 X 6 X 2.4	NASA: XCT

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
Delaminations	Delaminations In flat or step panels	1	NASA-S-D	Uni-ply 0/90/45)	IM7/8552	Step heights: 0.1" - 1.0", Delams: Ply 1, Mid Ply, Last Ply	Step with FBH defects	14 x 8 x 1.5	GE: PEUT, TTUT NGIS: PEUT
		35	8276-200-58-8 A	laminate	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	Multiple types of delamination simulators (teflon, graton tape, air pillows, mold release wax, brass inserts, etc)	20 X 6 X 2.4	Boeing: TTUT, SSIR, DR, CR, Backscatter, XCT
		36	8276-200-58-26 A	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: TTUT, SSIR, DR, CR, XCT
		37	8276-200-58-48 A	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: PEUT, SSIR, DR, CR, XCT NASA: PEUT
		38	8276-200-56-48 A	"	8276 Tape	S curve (__/¯) **56°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: TTUT, DR, CR, XCT
		39	8276-200-59-48 A	"	8276 Tape	S curve (__/¯) **59°** slant with two 0.2° radii	"	20 X 6 X 2.4	Boeing: TTUT, DR, CR, XCT NASA: XCT
		40	8276-200-58-8 B	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Not Tested
		41	8276-200-58-26 B	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Not Tested
		42	8276-200-58-48 B	"	8276 Tape	S curve (__/¯) **58°** slant with two 0.2° radii	"	20 X 6 X 2.4	Not Tested
		43	8276-200-56-48 B	"	8276 Tape	S curve (__/¯) **56°** slant with two 0.2° radii	"	20 X 6 X 2.4	NASA: XCT
		44	8276-200-59-48 B	"	8276 Tape	S curve (__/¯) **59°** slant with two 0.2° radii	"	20 X 6 X 2.4	NASA: XCT

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
Delaminations	Delaminations in wedge panels	4	NASA-W-5D	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 5 deg slope, delams start-end of slope	Wedge Step 5 deg with defects	12 X 3 X 1.5	Not Tested
		5	NASA-W-20D	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 20 deg slope, delams start-end of slope	Wedge Step 20 deg with defects	12 X 3 X 1.1	Not Tested
		6	NASA-W-35D	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 35 deg slope, delams start-end of slope	Wedge Step 35 deg with defects	12 X 7 X 1.5	Not Tested
		7	NASA-W-IL-5D	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 5 deg slope, delams start-end of slope	Wedge Interleaved 5 deg with defects	12 X 3 X 1.1	Not Tested
		8	NASA-W-IL-20D	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 20 deg slope, delams start-end of slope	Wedge Interleaved 20 deg with defects	12 X 3 X 1.1	GE: PEUT, TTUT
		11	NASA-W-IL-5D	Uni-ply 0/90/45)	IM7/8552	Height: 0.25"-1.0", 5 deg slope	Wedge Step 5 deg with defects	12 X 3 X 1.5	GE: PEUT, TTUT NASA: XCT
	Delaminations in woven composites	45	NASA-TAB-FBH-FLAT	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Delam/disbond (FBH)	16 X 10 X 0.75	GE: PEUT, TTUT NASA: XCT USC: GWUT
		47	NASA-TAB-P-FLAT	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Delamination (Air Pillow)	13 X 13 X 0.5	GE: PEUT, TTUT NASA: PEUT, XCT USC: GWUT
	Delamination in woven flange	54	NASA-TAB-05P-FLANGE1	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flange	Delamination (Air Pillow)	12 X 4.5 X 2.5	GE: PEUT, TTUT
		55	NASA-TAB-05P-FLANGE2	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flange	Delamination (Air Pillow)	12 X 4.5 X 2.5	NASA: SSIR, TTIR
	Flange baseline	52	NASA-TAB-BASE1-FLANGE	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flange	Baseline	11 X 4.5 X 2.25	GE: PEUT, TTUT
		53	NASA-TAB-BASE2-FLANGE	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flange	Baseline	13 X 13 X 0.65	Not Tested

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
AFP Fiber Defects (wrinkles, tow snags)	Tow defects in AFP (automated fiber placement) composites (twists, folds, laps & gaps)	57	NASA-03-Twisted-Tow-001	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Twisted Tow - 1 ply	16 X 16 X 0.15	NASA: PEUT, SSIR, TTIR
		58	NASA-03-Twisted-Tow-002	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Twisted Tow - Mid	16 X 16 X 0.15	NASA: PEUT, SSIR, TTIR
		60	NASA-03-Folded-Tow-001	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Folded Tow - 1 ply	16 X 16 X 0.15	NASA: PEUT, SSIR, TTIR
		61	NASA-03-Folded-Tow-002	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Folded Tow - Mid	16 X 16 X 0.15	NASA: PEUT, SSIR, TTIR
		62	NASA-03-Missing-Tow-001	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Missing Tow - 1 ply	16 X 16 X 0.15	NASA: PEUT, SSIR, TTIR
		63	NASA-03-Missing-Tow-002	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Missing Tow - Mid	16 X 16 X 0.15	NASA: PEUT, SSIR, TTIR
	Bridging joggle in AFP	64	NASA-03-Bridged-Joggle-001	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Bridging - Joggle	12 X 9 X 1.3	Not Tested
		65	NASA-03-Bridged-Joggle-002	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Bridging - Joggle	12 X 9 X 1.3	Not Tested
		66	NASA-03-Bridged-Joggle-003	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Bridging - Joggle	12 X 9 X 1.3	Not Tested
		67	NASA-03-Bridged-Joggle-004	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Bridging - Joggle	12 X 9 X 1.3	Not Tested
	Detection of tow orientation in AFP composite	59	NASA-03-Steered-Tow-003	Fiber Placed Panel	IM7/8552-1 Slit Tape	Flat panel	Tow Orientation	46.5 X 46.5 X 0.15	Not Tested

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
Fiber Defects (wrinkles, tow snags)	Detection of fiber wrinkling in flat panels	31	Wrinkle A1	Thin laminates	8552-1 slit tape	Flat panel	Flat wrinkles	1.5 X 12 X 0.15	Boeing: SSIR USC: GWUT NASA: XCT, PEUT
		32	Wrinkle A2	Thin laminates	8552-1 slit tape	Flat panel	Medium wrinkles	1.5 X 12 X 0.15	Boeing: SSIR USC: GWUT NASA: XCT, PEUT
		33	Wrinkle A3	Thin laminates	8552-1 slit tape	Flat panel	Significant wrinkles	1.5 X 12 X 0.15	Boeing: SSIR USC: GWUT NASA: XCT, PEUT
		34	Wrinkle A4	Thin laminates	8552-1 slit tape	Flat panel	Significant wrinkles	1.5 X 12 X 0.15	Boeing: SSIR USC: GWUT NASA: XCT, PEUT
	Detection of wrinkling in radii	75	NASA-005-Wrinkle-001	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Out of plane wrinkle	11.5 X 8.5 X 2.8	Not Tested
		76	NASA-005-Wrinkle-002	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Out of plane wrinkle	11.5 X 8.5 X 2.8	NASA: PEUT
	Baseline	74	NASA-005-STANDARD-002	Quasi-isotropic	IM7/8552 satin weave fabric and unidirectional	Rotorcraft blade spar tube	Pristine	11.5 X 8.5 X 2.8	Not Tested
	Fabric snag in woven composites	51	NASA-TAB-SNAG13-FLAT	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Fabric Snag	12 X 13 X 0.5	Not Tested
	Snag in woven flange	56	NASA-TAB-SNAG1-FLAT	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flange	Fabric Snag	9 X 12 X 2	NASA: XCT
Bond strength panels (LBID)	Mold Release 1 UTC	46	NASA-TAB-MOLDREL2-FLAT	Triaxial Braid, 0/+60/-60	T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825	Flat panel	Disbond	13 X 12.5 X 0.5	NASA: PEUT, XCT

Damage Type	Geometry / Location	#	Reference Standard	Structure	Material	Configuration / Radius	Defects and features	Dimensions (inches)	Partner: Tests
Impact Damage	Low energy impacts in flat panels (BVID)	81	QI_45 8ply 6x5 Impact 1	[(45/90/-45/0)]S	IM7/8552	Flat panel	1 impact 0.34"	6"x5"	NASA: SSIR, PEUT Boeing: XCT, CR
		82	QI_45 8ply 3x6 Impact 1	[(45/90/-45/0)]S	IM7/8552	Flat panel	1 impact 0.82"	3"x6"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		83	QI_45 8ply 3x6 Impact 2	[(45/90/-45/0)]S	IM7/8552	Flat panel	1 impact 0.37"	3"x6"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		84	QI_45 8ply 11x11 Impact 1	[(45/90/-45/0)]S	IM7/8552	Flat panel	Spare-no impact	11"x11"	Spare - not tested
		85	QI_45 8ply 22x22 Impact 1	[(45/90/-45/0)]S	IM7/8552	Flat panel	4 impacts 0.22"-0.54"	22"x22"	NASA: SSIR Boeing: CT, CR, Backscatter, Shearography
		86	QI_45 16ply 6x6 Impact 1	[(45/90/-45/0)2]S	IM7/8552	Flat panel	1 impact 0.2"	6"x6"	NASA: SSIR, PEUT Boeing: XCT, CR
		87	QI_45 16ply 3x5 Impact 1	[(45/90/-45/0)2]S	IM7/8552	Flat panel	1 impact 1.28"	3"x5"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		88	QI_45 16ply 3x5 Impact 2	[(45/90/-45/0)2]S	IM7/8552	Flat panel	1 impact 0.88"	3"x5"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		89	QI_45 16ply 22x22 Impact 1	[(45/90/-45/0)2]S	IM7/8552	Flat panel	4 impacts 0.22"-0.75"	22"x22"	NASA: SSIR Boeing: XCT, CR, Shearography
		90	QI_45 24ply 6x6 Impact 1	[(45/90/-45/0)3]S	IM7/8552	Flat panel	1 impact 1"	6"x6"	NASA: SSIR, PEUT Boeing: XCT, CR
		91	QI_45 24ply 3x5 Impact 1	[(45/90/-45/0)3]S	IM7/8552	Flat panel	1 impact 1.11"	3"x5"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		92	QI_45 24ply 3x5 Impact 2	[(45/90/-45/0)3]S	IM7/8552	Flat panel	1 impact 1"	3"x5"	NASA: SSIR,PEUT, XCT Boeing: XCT, CR
		93	QI_45 32ply 6x6 Impact 1	[(45/90/-45/0)4]S	IM7/8552	Flat panel	1 impact 0.23"	6"x6"	NASA: SSIR, PEUT Boeing: XCT, CR
		94	QI_45 32ply 3x5 Impact 1	[(45/90/-45/0)4]S	IM7/8552	Flat panel	1 impact 1.12"	3"x5"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		95	QI_45 32ply 3x5 Impact 2	[(45/90/-45/0)4]S	IM7/8552	Flat panel	1 impact 0.25"	3"x5"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR
		96	TC1 18ply 6x6 Impact 1	[45/90/-45/0/0/45/90/-45/0]S	IM7/8552	Flat panel	1 impact 0.3"	6"x6"	NASA: SSIR, PEUT Boeing: XCT, CR
		97	TC1 18ply 3x5 Impact 1	[45/90/-45/0/0/45/90/-45/0]S	IM7/8552	Flat panel	1 impact 0.92"	3"x5"	NASA: SSIR,PEUT, XCT Boeing: XCT, CR
		98	TC1 18ply 3x5 Impact 2	[45/90/-45/0/0/45/90/-45/0]S	IM7/8552	Flat panel	1 impact 0.96"	3"x5"	NASA: SSIR, PEUT, XCT Boeing: XCT, CR

Appendix D Manufacturing and Design Documents and Validation Reports from IDIQ

As discussed in detail in Appendix A, each ACP industry partner fabricated a set of composite specimens (standards) that contain a range of controlled defects representing those typically found in aerospace composite materials. Each consortium company chose or was assigned standards to fabricate based on manufacturing capabilities. Defect types included such manufacturing defects such as varying amounts of porosity (in a range typically found in autoclave cured aerospace composites) and varying degrees of fiber waviness (both in-plane and out-of-plane), as well as inserts representing delamination type defects. Appendix D details the manufacturing information for each type of standard as fabricated and organized by partner. The specimen numbers as assigned in the round-robin test matrix (Appendix B) are included for each set of standards.

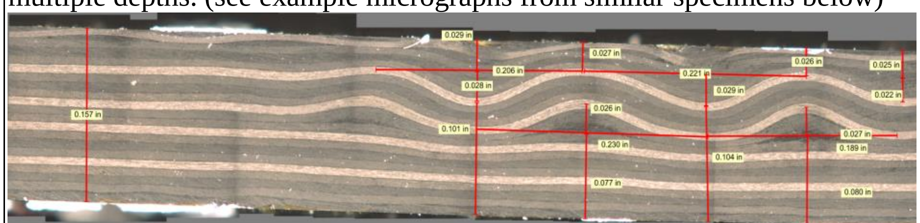
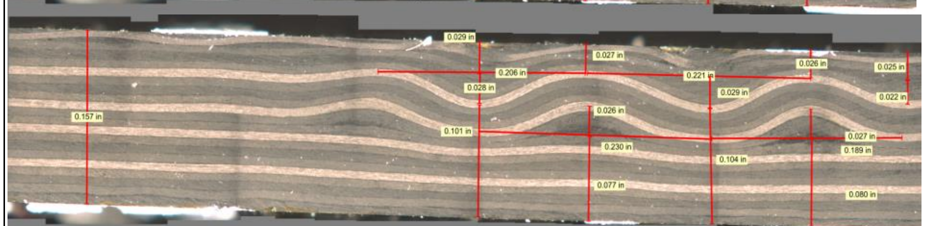
D.1 Manufacturing Information for NDE Standards Provided by Consortium Member #1

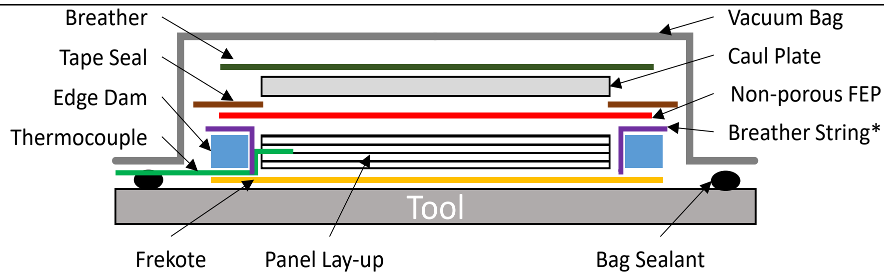
Consortium Member Number	Specimen Number/Name	Description
1	31	Thin laminate IM7/8552-1 slit tape Flat wrinkles
1	32	Thin laminate IM7/8552-1 slit tape Medium wrinkles
1	33	Thin laminate IM7/8552-1 slit tape Significant wrinkles
1	34	Thin laminate IM7/8552-1 slit tape Significant wrinkles
1	35	8276 tape, S curve (__/‾) **58°** slant with two 0.2° radii Multiple types of delamination simulators (Polytetraflouroethylene (PTFE), American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	36	8276 tape, S curve (__/‾) **58°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	37	8276 tape, S curve (__/‾) **58°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	38	8276 tape, S curve (__/‾) **56°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	39	8276 tape, S curve (__/‾) **59°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	40	8276 tape, S curve (__/‾) **58°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)

1	41	8276 tape, S curve (__/‾) **58°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	42	8276 tape, S curve (__/‾) **58°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	43	8276 tape, S curve (__/‾) **56°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)
1	44	8276 tape, S curve (__/‾) **59°** slant with two 0.2° radii Multiple types of delamination simulators (PTFE, American Biltrite 6782, air pillows, mold release wax, brass inserts, etc.)

D.1.1 Wrinkle specimens

D.1.1.1 Specimens 31, 32, 33, 34

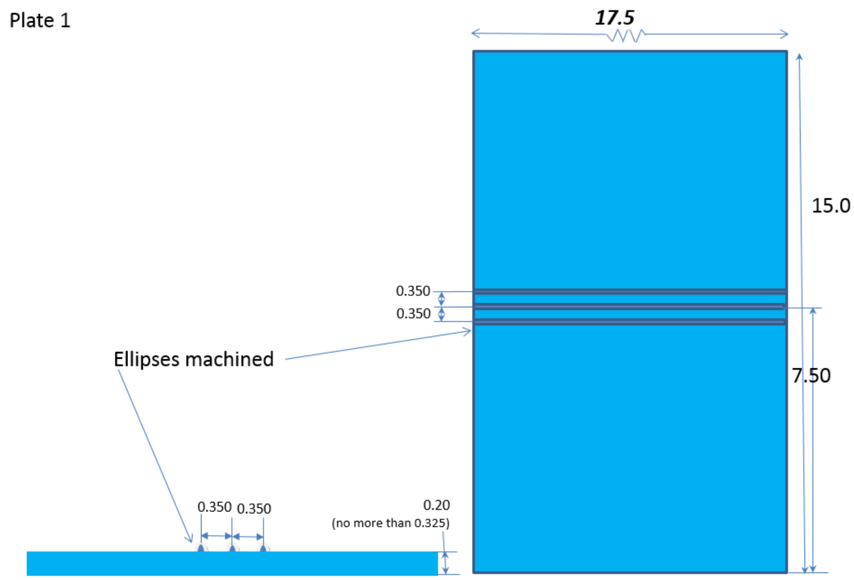
Standard designation, type, and general purpose.	#31, #32, #33, #34 NASA – 02- laminate-wrinkle—001-018 Multiple panels fabricated with wrinkles of varying wavelength and amplitude at multiple depths. (see example micrographs from similar specimens below)  
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** Tape is layered on wrinkle tool surface up to required depth for that individual standard. Plies are pressed into place using hand pressure. **Handling:** Wear clean impervious gloves while handling the material and lab coat.
	Bagging: The bagging scheme is shown in profile below.

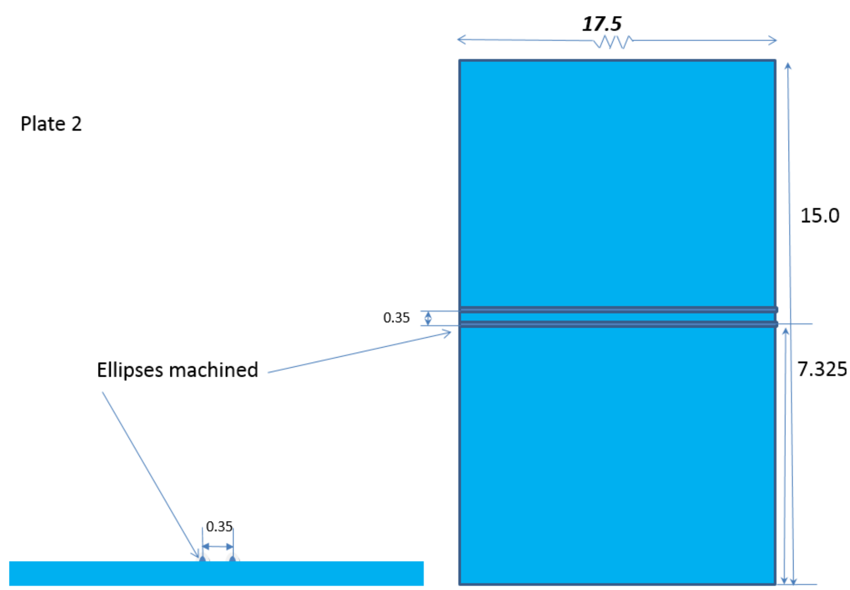
	 *The breather string must be in contact with the edge of the part and extend beyond the seal to touch the breather pad material as shown in the overhead view below. **Backside:** Cured part is removed from the wrinkle tool and the required number of cured plies (dependent on each individual standard) will be bonded to the backside of the part to cover wrinkles and fill troughs with bonding agent.
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film; 10 oz. breather cloth (N10) Silicone Edge Dam; Edge Breather Tape Vacuum Bagging Material
Standard characterization and verification method(s)	Visual. Currently only destructive visual exam can fully characterize the defects. Seeking NDI methods to detect and characterize defect features (i.e. depth, wavelength, amplitude, location)
Comments	Individual panels are cut from a larger plate. One edge of each panel is polished for micrograph inspection to verify wrinkle characteristics.

Wrinkle Standard Plan

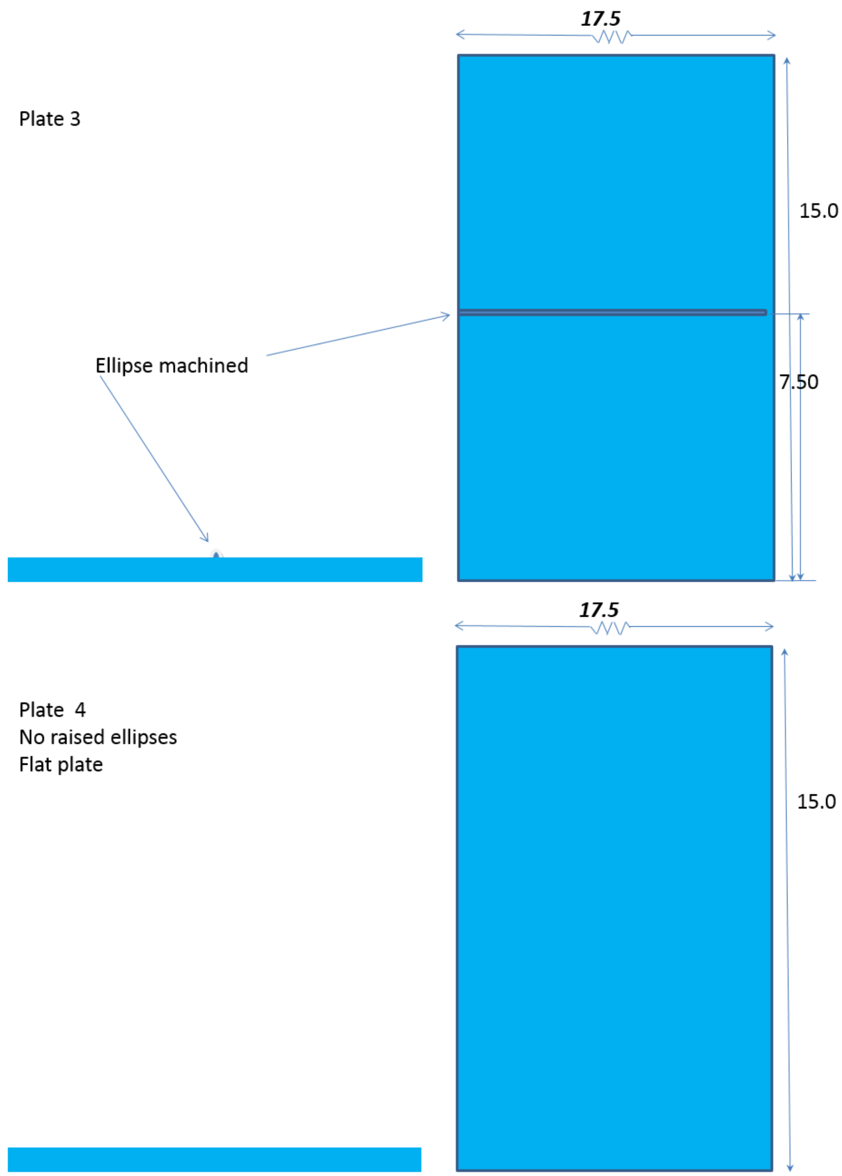
Peak to Peak Amplitude of Wrinkle	Depth to Trough	Panel Thickness
0.01	0.035	0.15
		0.3
	0.05	0.15
		0.3
	0.065	0.15
		0.3
0.02	0.035	0.15
		0.3
	0.05	0.15
		0.3
	0.065	0.15
		0.3
0.03	0.035	0.15
		0.3
	0.05	0.15
		0.3
	0.065	0.15
		0.3

Wrinkle Tool Plates





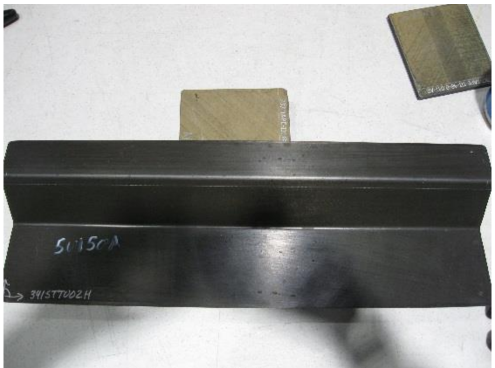
Wrinkle Tool Plates



D.1.2 S-Curve panels with imbedded inserts Partner #1

D.1.2.1 Specimens 35, 36, 37, 38, 39, 40, 41, 42, 43, 44

10 S-Curve Panels



Ply Kitting	Cut 64 zero/ninety degree BMS8-276 carbon fabric plies 7 × 48 inches Cut 6 zero/ninety degree BMS8-331 fiberglass fabric plies 7 × 48 inches Take care to cut the plies exact as possible.

QTY	Reference Standard Part Number	Material	Radius	Angle	Ply Count	Length (inches)	Sides (inches)
	8276-200-58-8 A&B	8276 Tape	0.2	58 deg.	8	24	3 × 3
	8276-200-58-26 A&B	8276 Tape	0.2	58 deg.	26	24	3 × 3
	8276-200-58-48 A&B	8276 Tape	0.2	58 deg.	48	24	3 × 3
	8276-200-56-48 A&B	8276 Tape	0.2	56 deg.	48	24	3 × 3
	8276-200-59-48 A&B	8276 Tape	0.2	59 deg.	48	24	3 × 3

#35 8276-200-58-8 A

#40 8276-200-58-8 B

8276-200-58-8 A&B

NDI Radius Standard from 8-276 material, with .2" Inside Radius, with 58 degrees of radius, 8 plies of BMS8-276 Fabric and 2 plies of BMS8-331 fiberglass
Because of tool length standard is divided into 2 parts.

Insert Numbering

1 B 20

- 20 — Placed on ply sequence from tool surface
- B — Material Type
- 1 — Insert number

Insert Material Type

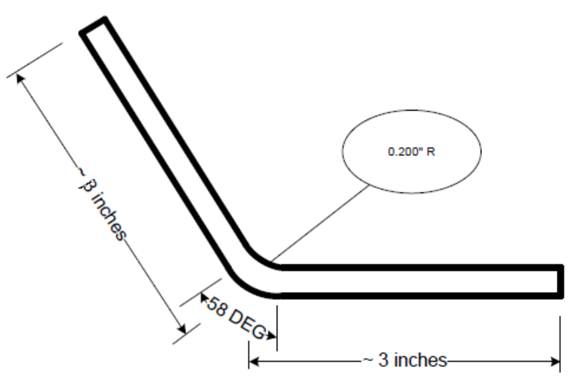
B= Brass Foil 0.001" with frekote
F= Release Ply F (Dry peel ply Air Tech International)
T= Pressure Sensitive Tape (American Biltrite 6782)

8276-200-58-8A

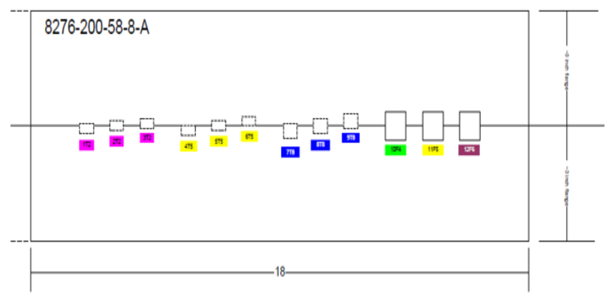
6 TAPE 0.5 X 0.25
3 TAPE 0.5 X 0.38
3 RPF 0.7 X 0.7

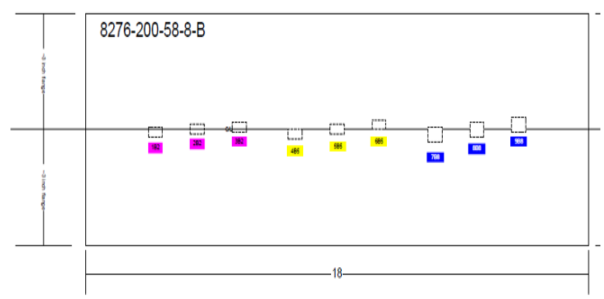
8276-200-58-8B

6 BRASS 0.5 X 0.25
3 BRASS 0.5 X 0.38



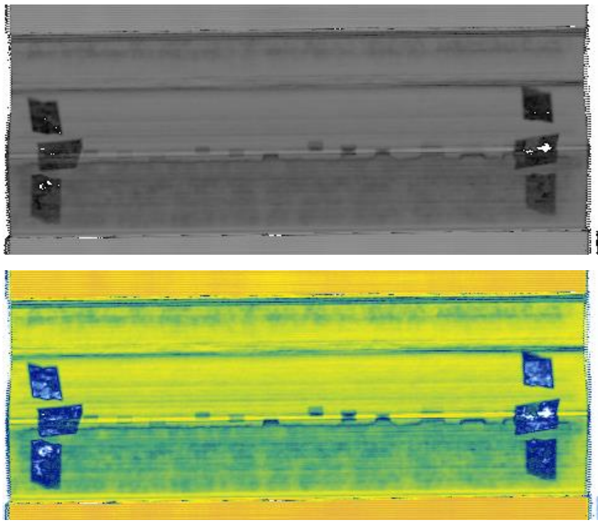
8276-200-58-8	
Constant Gage Standard	
Ply Number	Material
1	F/G
2	Tape
NDI Insert	Brass & PT
3	Tape
4	Tape
NDI Insert	RPF
5	Tape
NDI Insert	ALL
6	Tape
NDI Insert	RPF
7	Tape
8	Tape
NDI Insert	Brass & PT
9	Tape
10	F/G



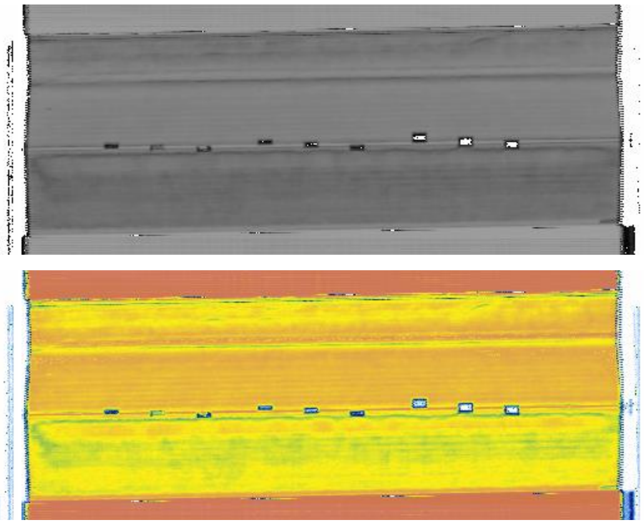


Validation Data

8276-200-58-8A



8276-200-58-8B



#36 8276-200-58-26 A

#41 8276-200-58-26 B

8276-200-58-26 A&B

NDI Radius Standard from 8-276 material, with .2" Inside Radius, with 58 degrees of radius, 26 plies of BMS8-276 Fabric and 2 plies of BMS8-331 fiberglass
Because of tool length standard is divided into 2 parts.

Insert Numbering

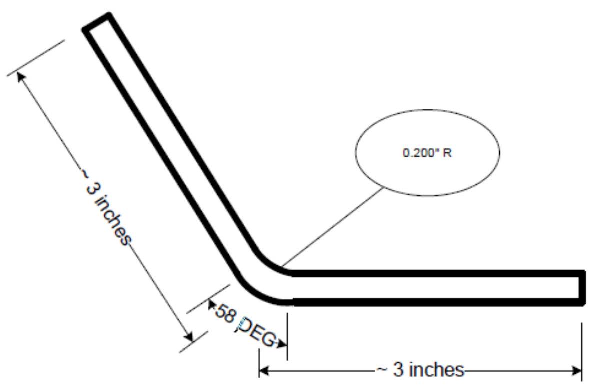
1 B 20
- 20 — Placed on ply sequence from tool surface
- B — Material Type
- 1 — Insert number

Insert Material Type

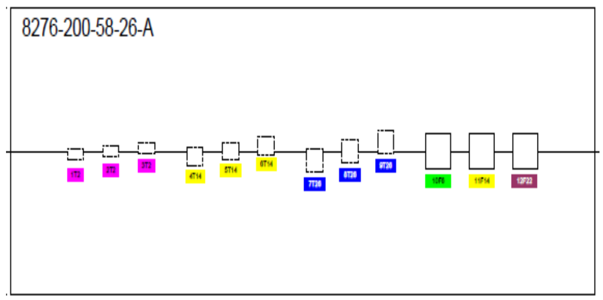
B= Brass Foil 0.001" with frekote
F= Release Ply F (Dry peel ply Air Tech International)
T= Pressure Sensitive Tape (American Biltrite 6782)

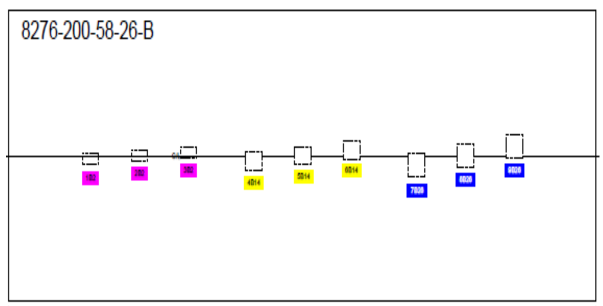
8276-200-58-26A
3 TAPE 0.5 X 0.25
3 TAPE 0.5 X 0.38
3 TAPE 0.5 X 0.5
3 RPF 0.7 X 0.7

8276-200-58-26B
3 BRASS 0.5 X 0.25
3 BRASS 0.5 X 0.38
3 BRASS 0.5 X 0.5



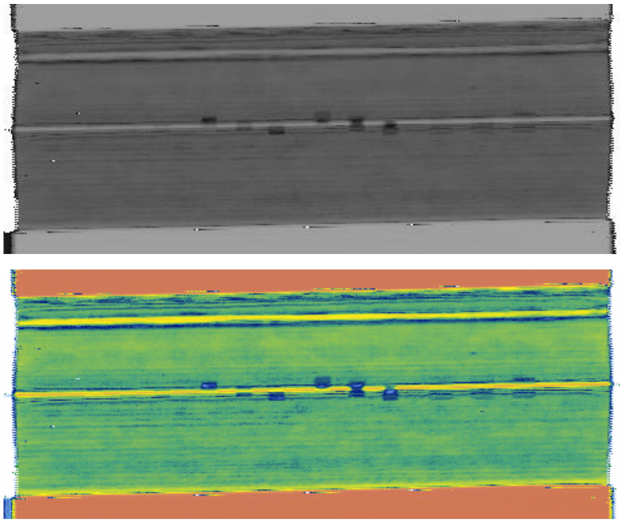
8276-200-58-26	
Constant Gage Standard	
Ply Number	Material
1	F/G
2	Tape
NDI Insert	Brass & PT
3	Tape
4	Tape
5	Tape
6	Tape
NDI Insert	RPF
7	Tape
8	Tape
9	Tape
10	Tape
11	Tape
12	Tape
13	Tape
14	Tape
NDI Insert	ALL
15	Tape
16	Tape
17	Tape
18	Tape
19	Tape
20	Tape
21	Tape
22	Tape
NDI Insert	RPF
23	Tape
24	Tape
25	Tape
26	Tape
NDI Insert	Brass & PT
27	Tape
28	F/G



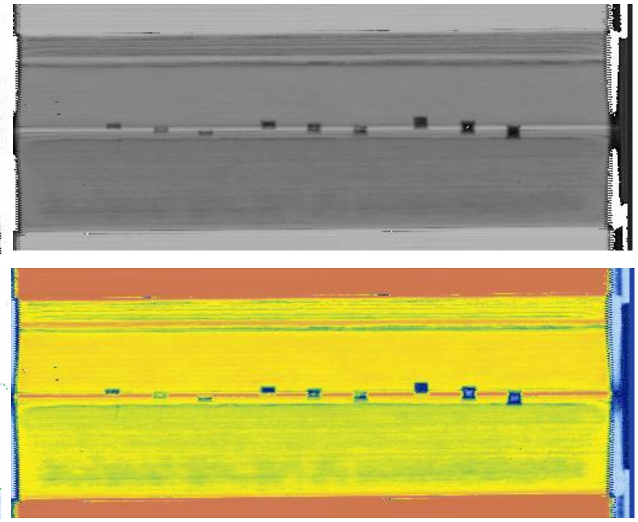


Validation Data

8276-200-58-26A



8276-200-58-26B



#37 8276-200-58-48 A

#42 8276-200-58-48 B

8276-200-58-48 A&B

NDI Radius Standard from 8-276 material, with .2" Inside Radius, with 58 degrees of radius, 48 plies of BMS8-276 Fabric and 2 plies of BMS8-331 fiberglass
Because of tool length standard is divided into 2 parts.

Insert Numbering

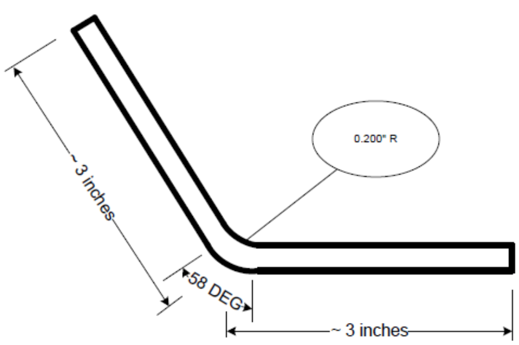
1 B 20
- 20 — Placed on ply sequence from tool surface
- B — Material Type
- 1 — Insert number

Insert Material Type

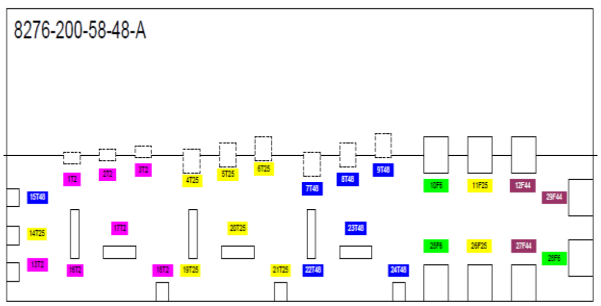
B= Brass Foil 0.001" with frekote
F= Release Ply F (Dry peel ply Air Tech International)
T= Pressure Sensitive Tape (American Biltrite 6782)

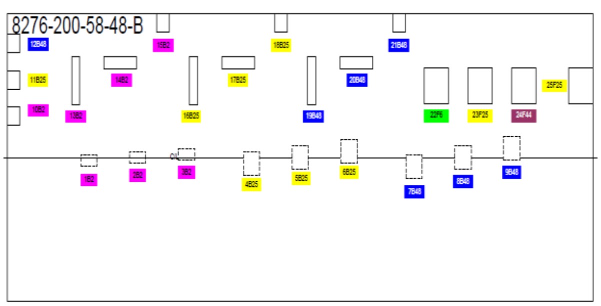
8276-200-58-48A
3 TAPE 0.5 X 0.25
6 TAPE 0.5 X 0.5
6 TAPE 0.38 X 0.38
6 TAPE 0.25 X 1.00
8 RPF 0.7 X 0.7

8276-200-58-48B
3 BRASS 0.5 X 0.25
6 BRASS 0.5 X 0.5
6 BRASS 0.38 X 0.38
6 BRASS 0.25 X 1.00
4 RPF 0.7 X 0.7



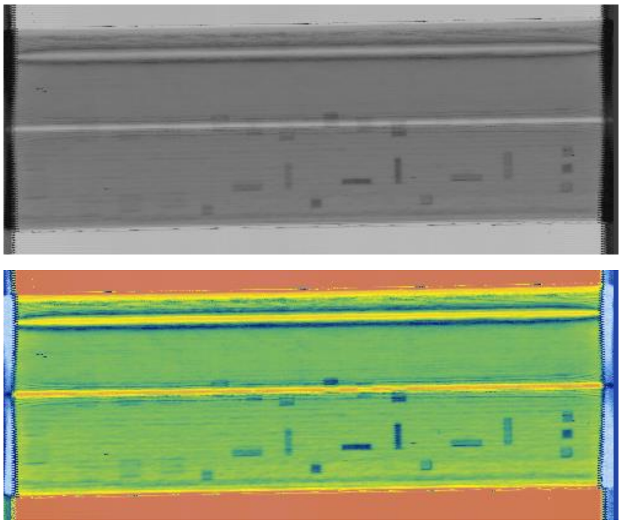
8276-200-58-48	
Constant Gage Standard	
Ply Number	Material
1	F/G
2	Tape
NDI Insert	Brass & PT
3	Tape
4	Tape
5	Tape
6	Tape
NDI Insert	RPF
7	Tape
8	Tape
9	Tape
10	Tape
11	Tape
12	Tape
13	Tape
14	Tape
15	Tape
16	Tape
17	Tape
18	Tape
19	Tape
20	Tape
21	Tape
22	Tape
23	Tape
24	Tape
25	Tape
NDI Insert	ALL
26	Tape
27	Tape
28	Tape
29	Tape
30	Tape
31	Tape
32	Tape
33	Tape
34	Tape
35	Tape
36	Tape
37	Tape
38	Tape
39	Tape
40	Tape
41	Tape
42	Tape
43	Tape
44	Tape
NDI Insert	RPF
45	Tape
46	Tape
47	Tape
48	Tape
NDI Insert	Brass & PT
49	Tape
50	F/G



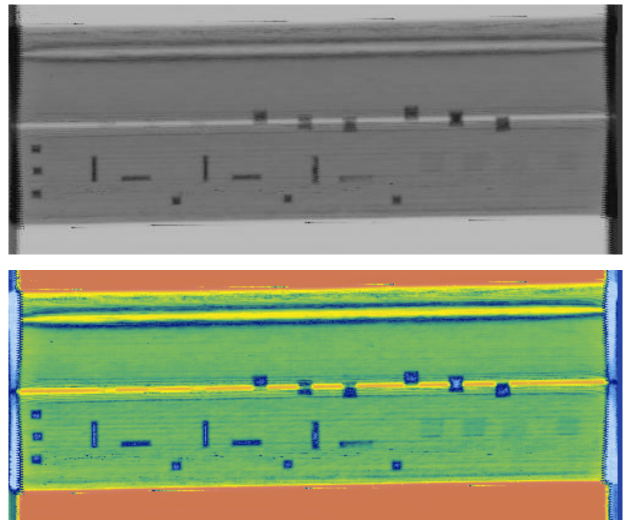


Validation Data

8276-200-58-48A



8276-200-58-48B



#38 8276-200-56-48 A

#43 8276-200-56-48 B

8276-200-56-48 A&B

NDI Radius Standard from 8-276 material, with .2" Inside Radius, with 56 degrees of radius, 48 plies of BMS8-276 Fabric and 2 plies of BMS8-331 fiberglass
Because of tool length standard is divided into 2 parts.

Insert Numbering

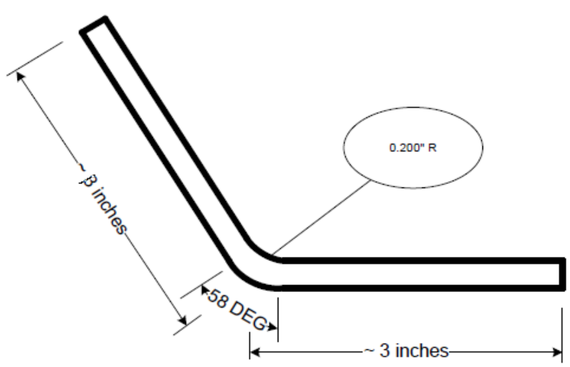
1 B 20
- 20 — Placed on ply sequence from tool surface
- B — Material Type
- 1 — Insert number

Insert Material Type

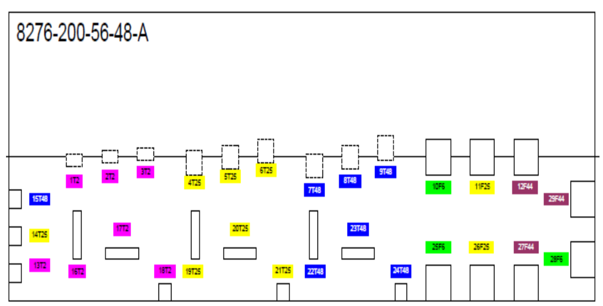
B= Brass Foil 0.001" with frekote
F= Release Ply F (Dry peel ply Air Tech International)
T= Pressure Sensitive Tape (American Biltrite 6782)

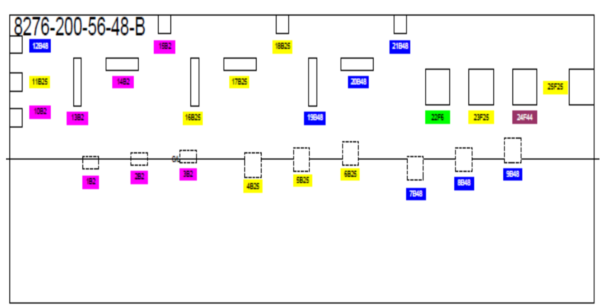
8276-200-56-48A
3 TAPE 0.5 X 0.25
6 TAPE 0.5 X 0.5
6 TAPE 0.38 X 0.38
6 TAPE 0.25 X 1.00
8 RPF 0.7 X 0.7

8276-200-56-48B
3 BRASS 0.5 X 0.25
6 BRASS 0.5 X 0.5
6 BRASS 0.38 X 0.38
6 BRASS 0.25 X 1.00
4 RPF 0.7 X 0.7



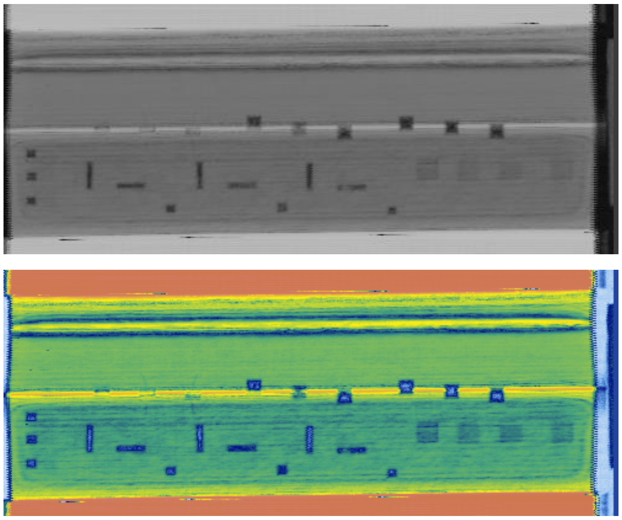
8276-200-56-48			
Constant Gage Standard			
Ply Number	Material	Ply Number	Material
1	F/G		
2	Tape	26	Tape
NDI Insert	Brass & PT	27	Tape
3	Tape	28	Tape
4	Tape	29	Tape
5	Tape	30	Tape
6	Tape	31	Tape
NDI Insert	RPF	32	Tape
7	Tape	33	Tape
8	Tape	34	Tape
9	Tape	35	Tape
10	Tape	36	Tape
11	Tape	37	Tape
12	Tape	38	Tape
13	Tape	39	Tape
14	Tape	40	Tape
15	Tape	41	Tape
16	Tape	42	Tape
17	Tape	43	Tape
18	Tape	44	Tape
19	Tape	NDI Insert	RPF
20	Tape	45	Tape
21	Tape	46	Tape
22	Tape	47	Tape
23	Tape	48	Tape
24	Tape	NDI Insert	Brass & PT
25	Tape	49	Tape
NDI Insert	ALL	50	F/G



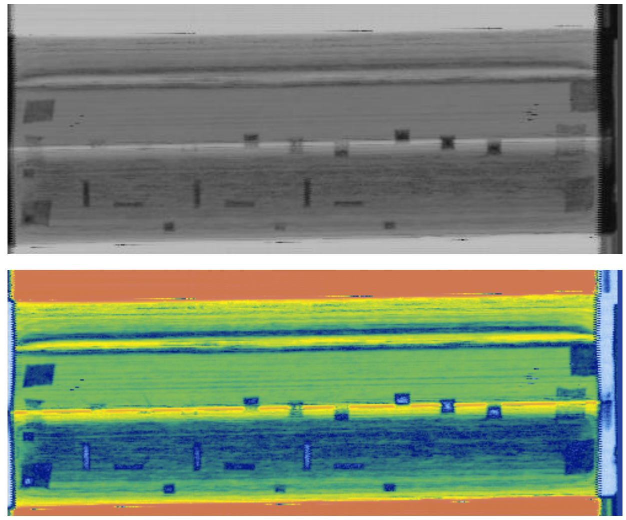


Validation Data

8276-200-56-48A



8276-200-56-48B



#39 8276-200-59-48 A

#44 8276-200-59-48 B

8276-200-58-8 A&B

NDI Radius Standard from 8-276 material, with .2" Inside Radius, with 58 degrees of radius, 8 plies of BMS8-276 Fabric and 2 plies of BMS8-331 fiberglass Because of tool length standard is divided into 2 parts.

Insert Numbering

1 B 20

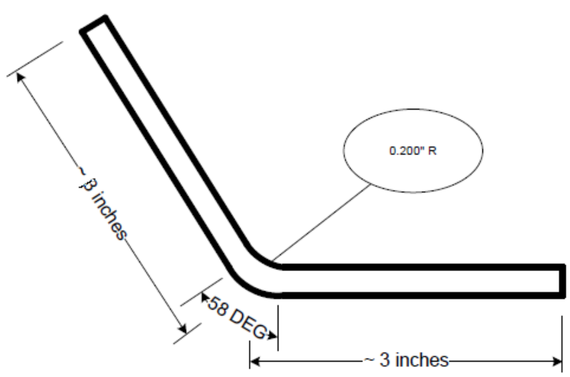
- Placed on ply sequence from tool surface (20)
- Material Type (B)
- Insert number (1)

Insert Material Type

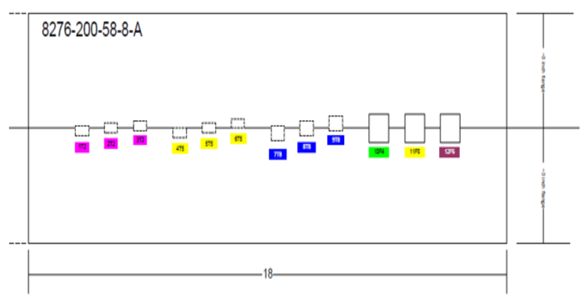
B= Brass Foil 0.001" with frekote
F= Release Ply F (Dry peel ply Air Tech International)
T= Pressure Sensitive Tape (American Biltrite 6782)

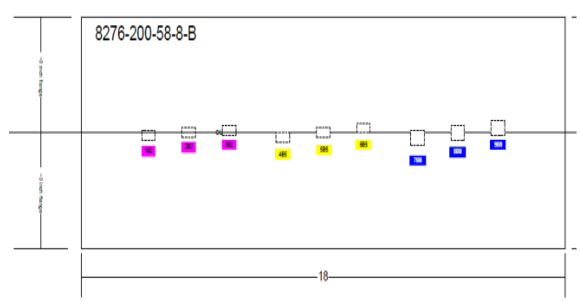
8276-200-58-8A
6 TAPE 0.5 X 0.25
3 TAPE 0.5 X 0.38
3 RPF 0.7 X 0.7

8276-200-58-8B
6 BRASS 0.5 X 0.25
3 BRASS 0.5 X 0.38



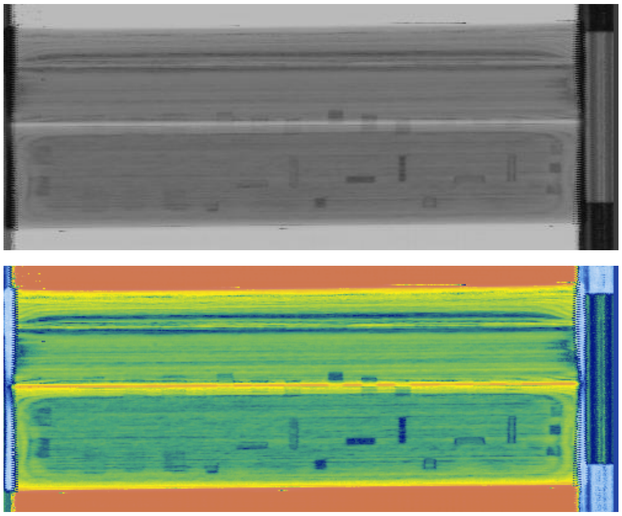
8276-200-58-8	
Constant Gage Standard	
Ply Number	Material
1	F/G
2	Tape
NDI Insert	Brass & PT
3	Tape
4	Tape
NDI Insert	RPF
5	Tape
NDI Insert	ALL
6	Tape
NDI Insert	RPF
7	Tape
8	Tape
NDI Insert	Brass & PT
9	Tape
10	F/G



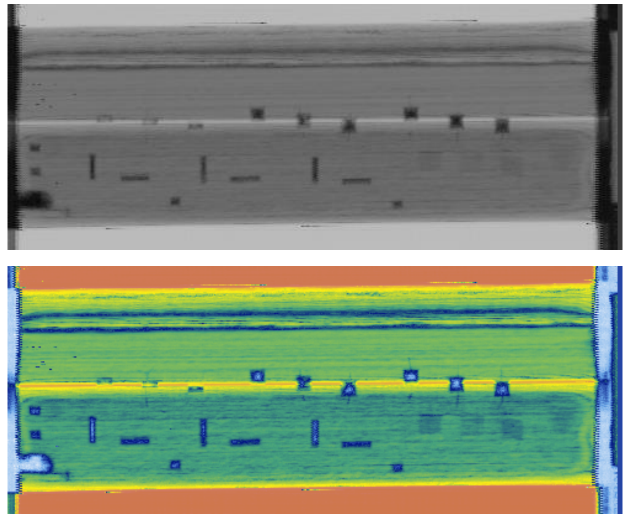


Validation Data

8276-200-59-48A



8276-200-59-48B



D.2 Manufacturing Information for NDE Standards Provided by Consortium Member #2

Consortium Member Number	Specimen Number/ Name	Description
2	1 NASA-S-D	Uni-ply 0/90/45), IM7/8552 Step heights: 0.1 inch to 1.0 inch, Delaminations: Ply 1, Mid Ply, Last Ply Step with FBH defects
2	2 NASA-S-MP	Uni-ply 0/90/45), IM7/8552, Step heights: 0.1 inch to 1.0 inch Step with medium porosity
2	3 NASA-S-HP	Uni-ply 0/90/45) IM7/8552 Step heights: 0.1 inch to 1.0 inch Step with high porosity
2	4 NASA-W-5D	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 5 degrees slope, delaminations start-end of slope Wedge Step 5 degrees with defects
2	5 NASA-W-20D	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 20 degrees slope, delaminations start-end of slope Wedge Step 20 degrees with defects
2	6 NASA-W-35D	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 35 degrees slope, delaminations start-end of slope Wedge Step 35 degrees with defects
2	7 NASA-W-IL-5D	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 5 degrees slope, delaminations start-end of slope Wedge Interleaved 5 degrees with defects
2	8 NASA-W-IL-20D	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 20 degrees slope, delaminations start-end of slope Wedge Interleaved 20 degrees with defects
2	10 NASA-W-5MP	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 5 degrees slope Wedge Interleaved 5 degrees with medium porosity
2	11 NASA-W-IL-5D	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 5 degrees slope Wedge Step 5 degrees with defects

Consortium Member Number	Specimen Number/ Name	Description
2	12 NASA-W-20MP	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 20 degrees slope Wedge Interleaved 20 degrees with medium porosity
2	13 NASA-W-IL-20MP	Uni-ply 0/90/45) IM7/8552 Height: 0.25 inch-1.0 inch, 20 degrees slope Wedge Step 20 degrees with medium porosity
2	16 NASA-RP-01D	Uni-ply 0/90/45) IM7/8552 0.1 inch radial inside curve, delaminations along curve & flat surfaces Radius Panel 0.1 inch Curve Rad with defects
2	18 NASA-RP-10D	Uni-ply 0/90/45) IM7/8552 1.0 inch radial inside curve, delaminations along curve & flat surfaces Radius Panel 1.0 inch Curve Rad with defects
2	19 NASA-RP-20D	Uni-ply 0/90/45) IM7/8552 2.0 inch radial inside curve, delaminations along curve & flat surfaces Radius Panel 2.0 inch Curve Rad with defects
2	20 NASA-RP-40D	Uni-ply 0/90/45) IM7/8552 4.0 inch radial inside curve, delaminations along curve & flat surfaces Radius Panel 4.0 inch Curve Rad with defects
2	22 NASA-RP-01MP	Uni-ply 0/90/45) IM7/8552 0.1 inch radial inside curve Radius Panel 0.1 inch Curve Rad with medium porosity
2	26 NASA-RP-10MP	Uni-ply 0/90/45) IM7/8552 1.0 inch radial inside curve Radius Panel 1.0 inch Curve Rad with medium porosity
2	28 NASA-RP-20MP	Uni-ply 0/90/45) IM7/8552 2.0 inch radial inside curve Radius Panel 2.0 inch Curve Rad with medium porosity
2	30 NASA-RP-40MP	Uni-ply 0/90/45) IM7/8552 4.0 inch radial inside curve Radius Panel 4.0 in Curve Rad with medium porosity

D.2.1 Baseline, Defect and Porosity in Wedges and Flat Panels

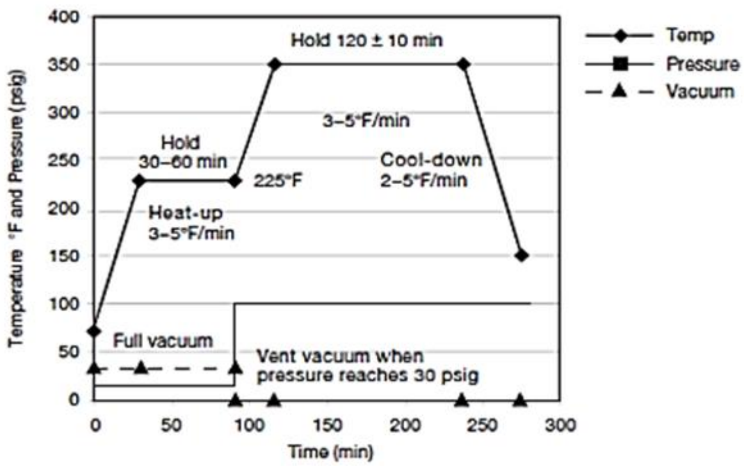
D.2.1.1 Manufacturing - Specimens 1, 2, 3, 4, 5, 6, [7, 8, 10, 11, 12, 13][2], 16, 18, 19, 20, [22, 26, 28, 30][3]

Layup

All panels (baseline, defect and porosity) were laid up using a quasi-isotropic stacking sequence, [0/90/45/-45]*n*s, *n* varied on the panel type. For the wedge panels, the ply drops were stepped or interleaved along the slope. The stepped plies were simply arranged so each successive ply was shorter than the one below it. The interleaved plies were agented symmetrically, so short plies and longer plies were alternated in the stackup sequence. In both cases, a full set of plies, (0,90,±45), was placed as a cover layer over the exposed ply drops of the completed stack.

Cure Cycles

The baseline and defect panels were cured using the recommended cure cycle from the material supplier, Hexcel, and is shown in Figure D.2-1. The medium porosity panels were cured using a modified cure cycle, where the autoclave pressure was halved, as shown in Figure D.2-2. One high porosity panel was also cured using a modified cure cycle, where no autoclave pressure was applied but vacuum was maintained, as shown in Figure D.2-3. The medium porosity cycle, (Figure D.2-2), commonly generated 2% to 4% porosity.



Autoclave

1. Apply full vacuum and 15 psig pressure.
2. Heat at 3–5°F/minute to 225°F.
3. Hold at 225°F for 30–60 minutes.
4. Raise pressure to 85–100 psig;
5. Vent vacuum when pressure reaches 30 psig.
6. Hold at 350°F for 120 ± 10 minutes.
7. Cool at 2–5°F to 150°F and vent pressure.

Note: Alternative cure cycles available upon request.

Figure D.2.-1. Standard cure cycle.

[2] No manufacturing documentation received from OEM.

[3] No manufacturing documentation received from OEM.

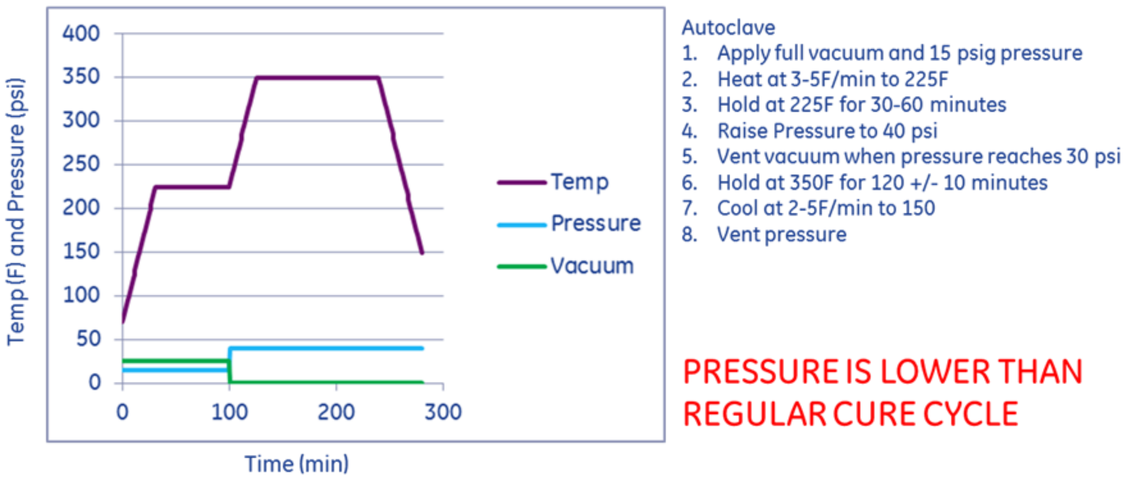


Figure D.2-2. Medium porosity cure cycle.

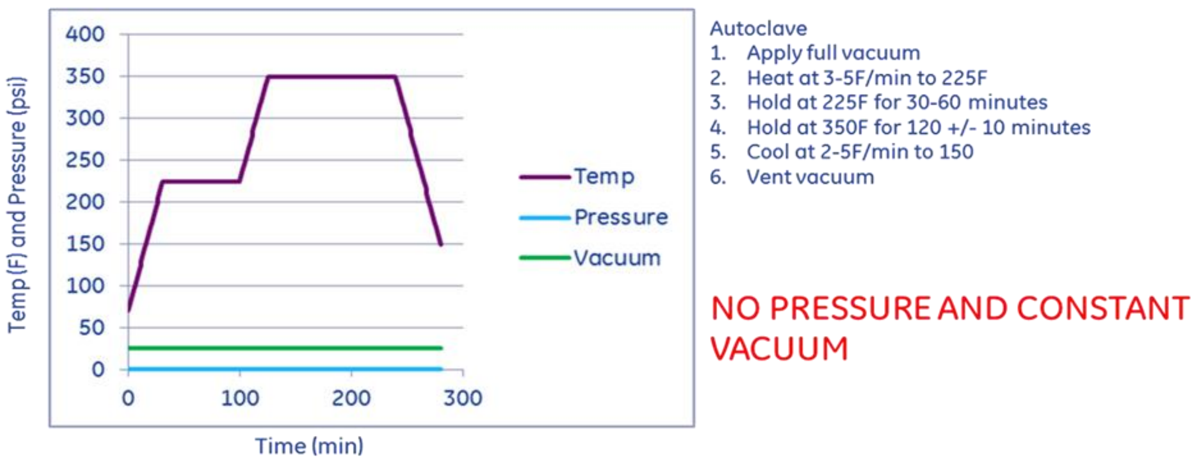


Figure D.2-3. High porosity cure cycle.

D.2.1.2 Specimen Validation

Specimen #1

2 PTFE inserts per row (rad. 0.25in, thickness 0.002in)

3 Flat-Bottom Holes Per Row (rad. 0.25in, 1 ply 1, 2 mid ply)

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-S-D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.1 to 1.0 inch Delaminations: Ply 1, Mid Ply	14 in.	8 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT Phased Array (PA)	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	
Flat Panel	
Step	**X**
Wedge	
Other	

Detection Features in Standard (Flaws Present)

RPF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0 in. Focal Length, 1.0 in. Dia.
Transducer Peak-Peak/root mean squared (RMS) Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	45.03 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	6 Gates
Sampling Frequency	100 million/sec
Data Acquisition (DAQ) Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near surface to Ply 1 inspection

Gate 2: Ply 1 to mid-ply inspection

Gate 3: Mid-ply area inspection

Gate 4: Last ply to back wall inspection

Gate 5: Back wall area inspection

Gate 6: All-ply level inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

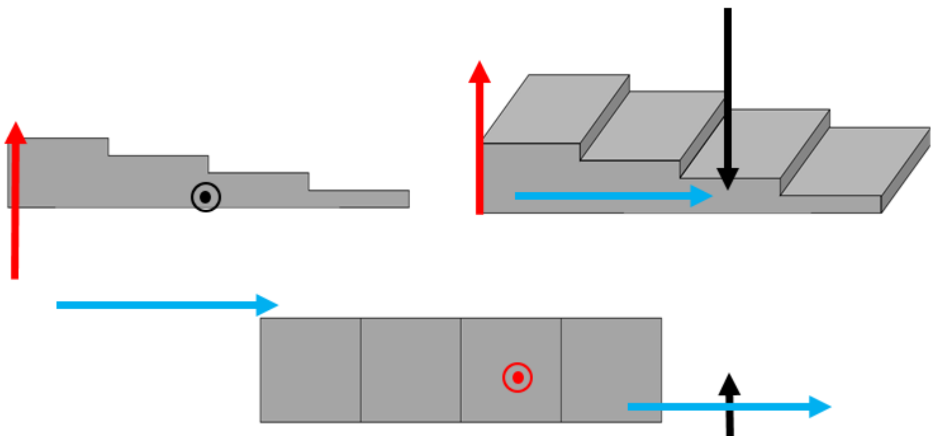


Figure D.2-4. Scanning orientation of NASA-S-D delamination specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 3, and Gate 4 (total gate width is 8.00us of each). Measurement method detected 80% of known defects.

Note:

Region A: Ply 1 PTFE insert

Region B: Mid-ply PTFE insert

Region C: Ply 1 flat-bottom hole

Region D: Mid-ply flat-bottom hole

Region E: Mid-ply flat-bottom hole

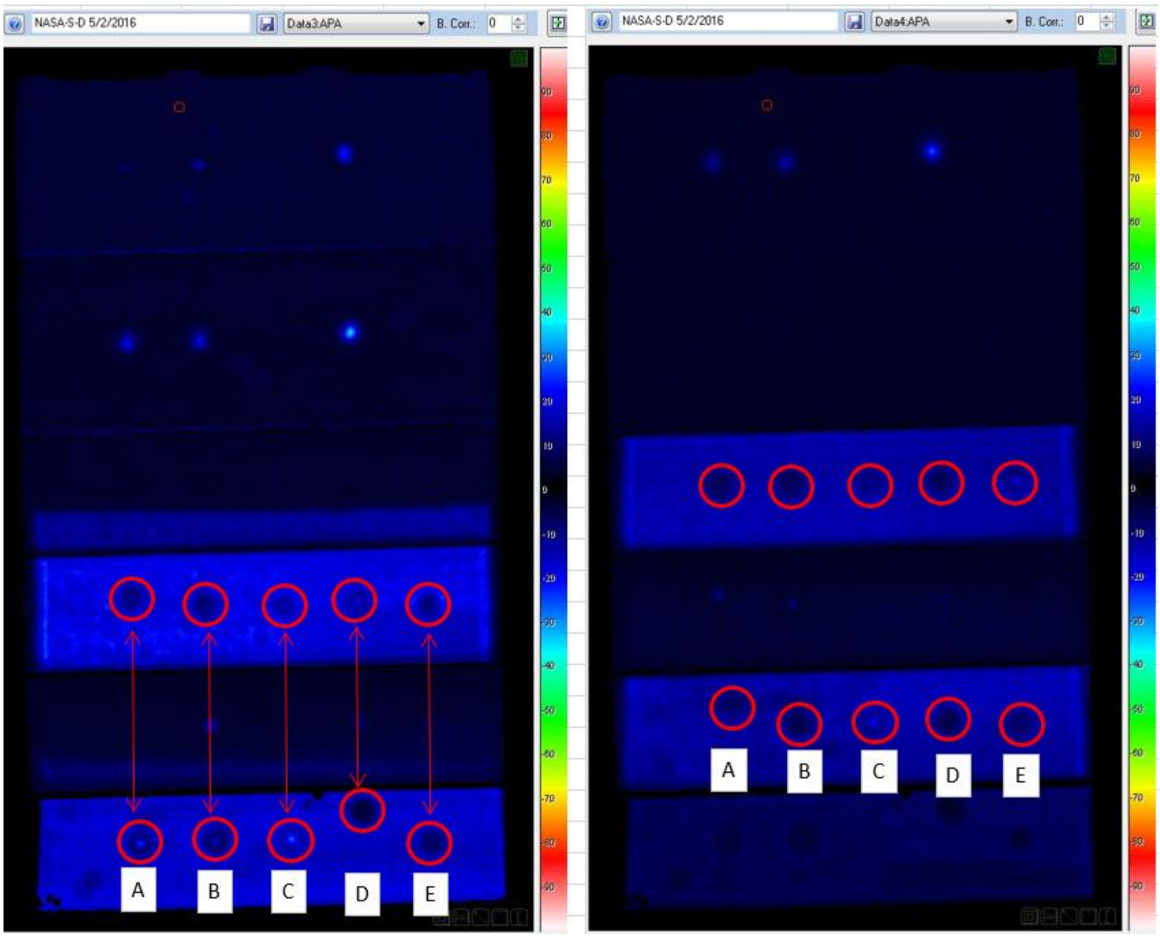


Figure D.2-5. Gate 3 (left) and Gate (4) PEUT scan results from NASA-S-D specimen.

Specimen Photos

Figure D.2-6. Images of NASA-S-D step specimen.

Specimen #2

Medium Porosity Specimen

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-S-MP Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.1 to 1.0 inch Delaminations: Ply 1, Mid Ply	14 in.	8 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	
Flat Panel	
Step	**X**
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	
Microcrack	
Porosity	**X**
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	N/A
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	6 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near Surface to Ply 1 inspection

Gate 2: Ply 1 to mid-inspection

Gate 3: Mid Ply area inspection

Gate 4: Last Ply to back wall inspection

Gate 5: Back wall area inspection

Gate 6: All ply level inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

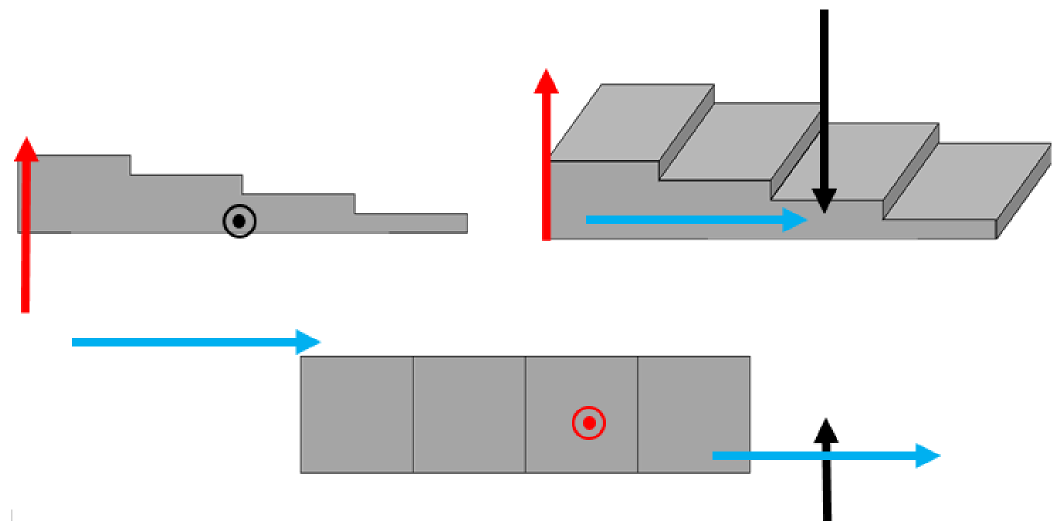


Figure D.2-7. Scanning orientation of NASA-S-MP porosity specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 2 (total gate width is 8.00us). Measurement method detected 80% of known defects.

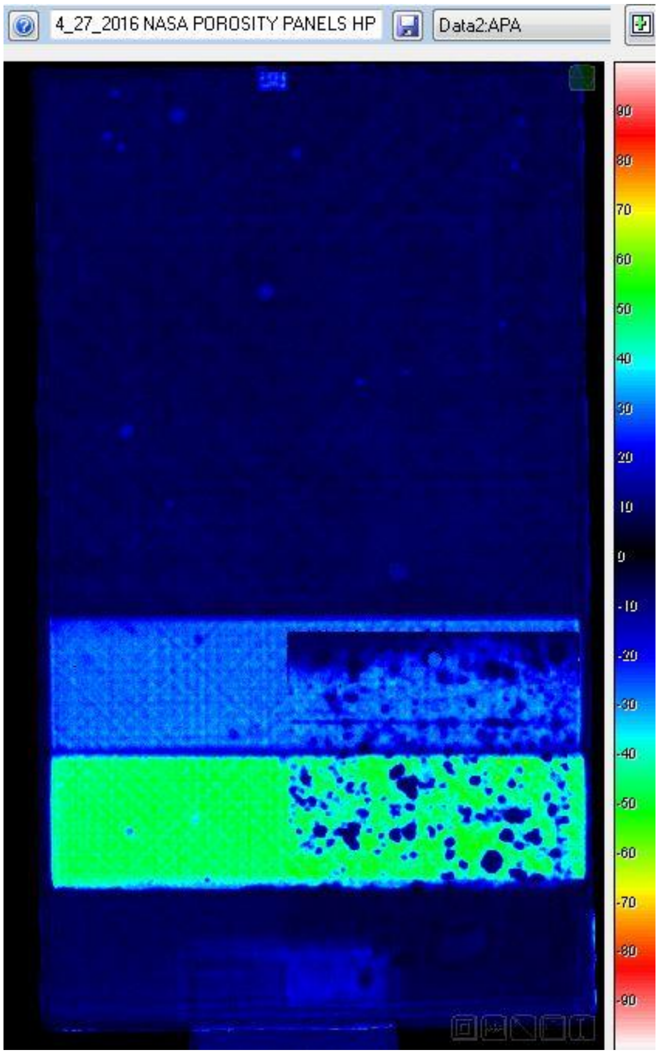


Figure D.2-8. Gate 2 PEUT scan results from NASA-S-MP porosity specimen.

Specimen Photos

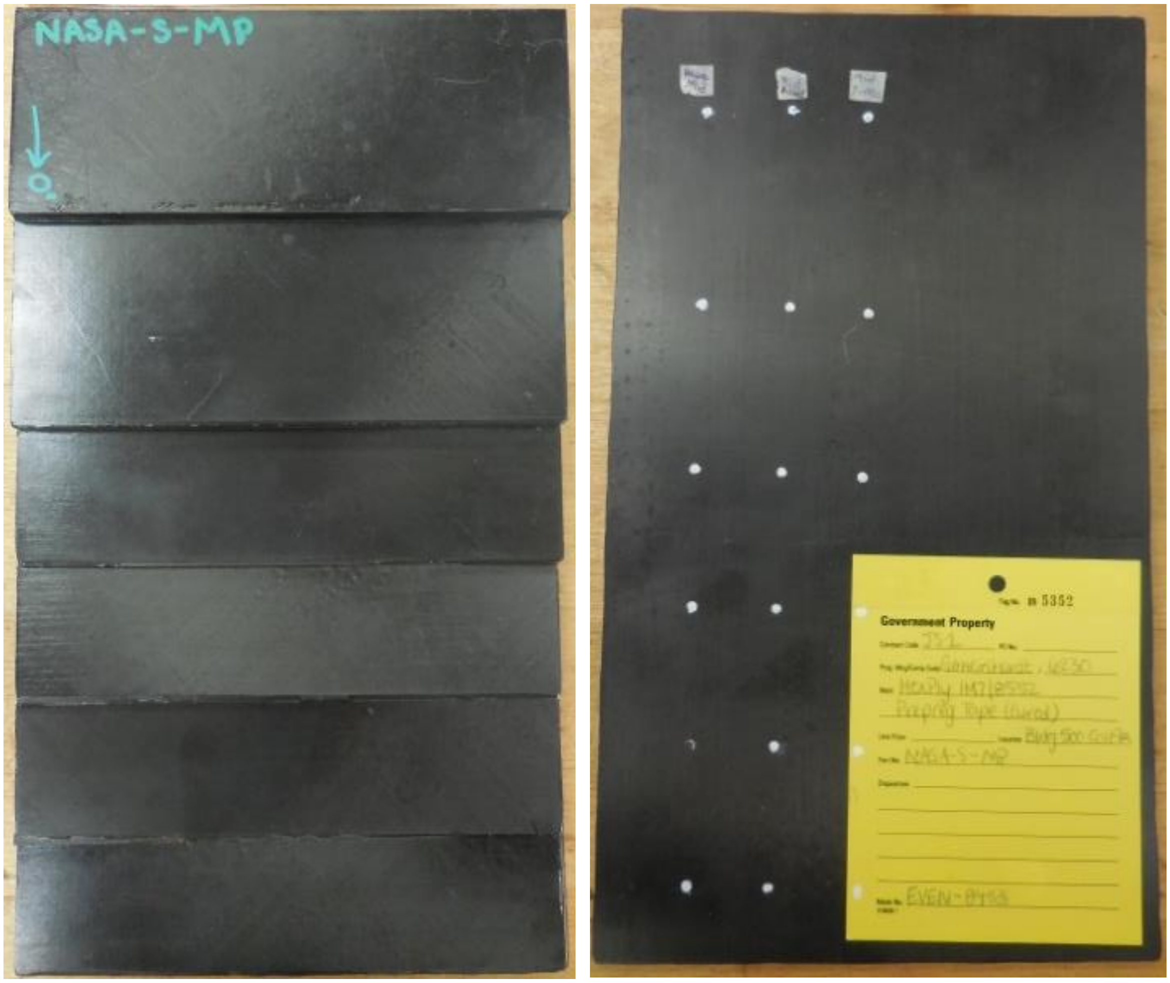


Figure D.2-9. Images of NASA-S-MP porosity specimen.

Specimen #3

High Porosity Specimen

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-S-HP Porosity Specimen	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.1 to 1.0 inch Delaminations: Ply 1, Mid Ply	14 in.	8 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	
Flat Panel	
Step	**X**
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination/Disbond	
Microcrack	
Porosity	**X**
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	N/A
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	6 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near Surface to Ply 1 inspection

Gate 2: Ply 1 to mid inspection

Gate 3: Mid-Ply area inspection

Gate 4: Last Ply to back wall inspection

Gate 5: Back wall area inspection

Gate 6: All ply level inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

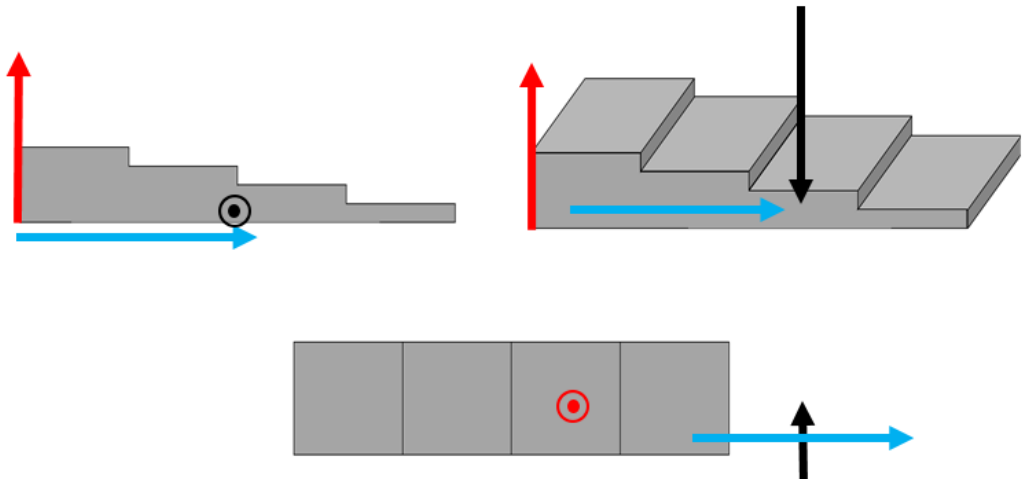


Figure D.2-10. Scanning orientation of NASA-S-HP porosity specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 2 (total gate width is 8.00us). Measurement method detected 80% of known defects.

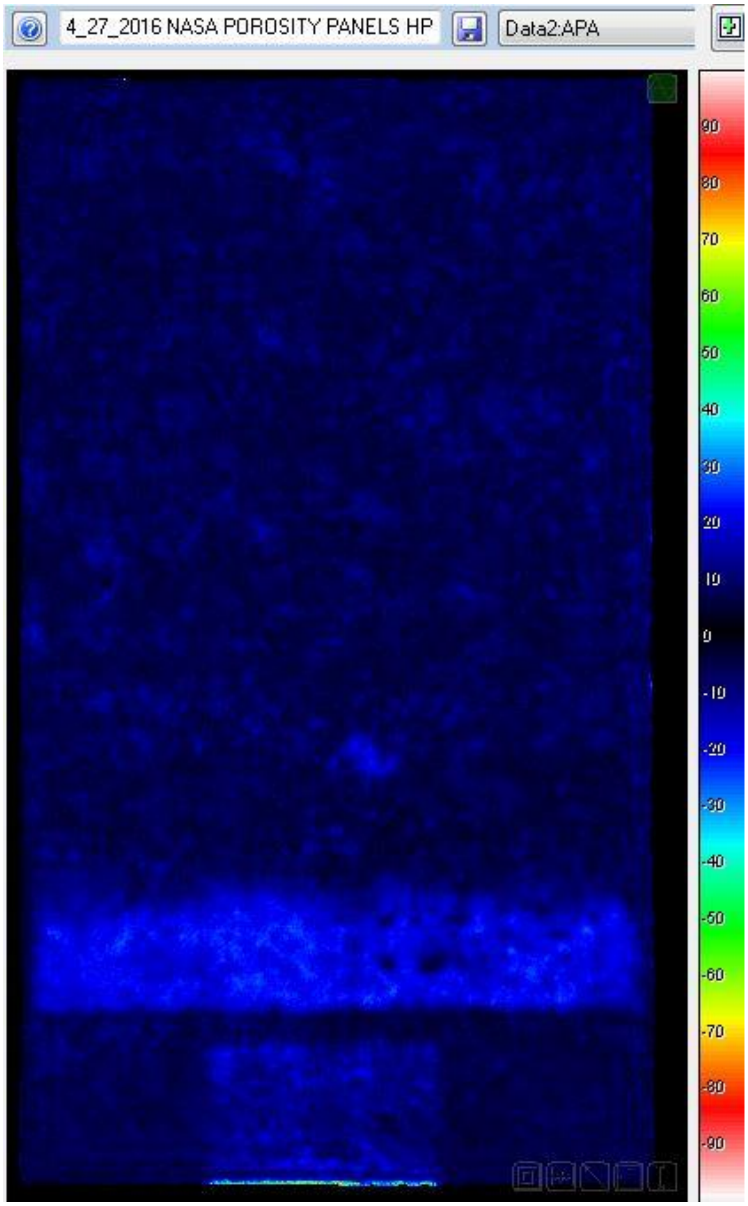


Figure D.2-11. Gate 2 PEUT scan results from NASA-S-HP porosity specimen.

Specimen Photos

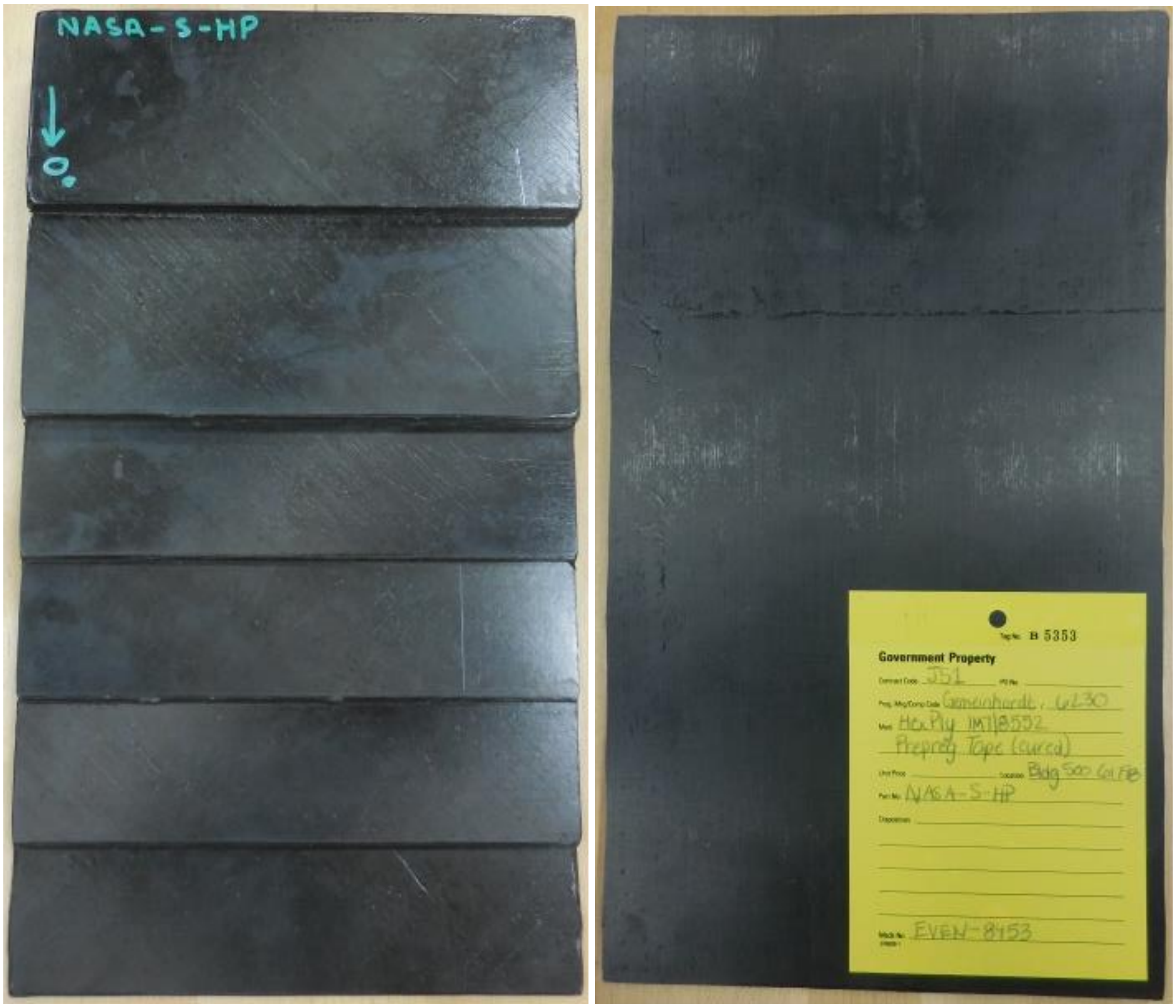


Figure D.2-12. Images of NASA-S-HP porosity specimen.

Specimen #4

3 PTFE Inserts per Row (rad. 0.25in, thickness 0.002in), 12 Total

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-W-5D	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 to 1.0 inch Wedge Angle: 5 deg. Delaminations: Ply 1, Mid Ply, Last Ply	12 in.	3 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	
Flat Panel	
Step	
Wedge	**X**
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	41.00 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	6 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near Surface to Ply 1 inspection

Gate 2: Ply 1 to Mid-inspection

Gate 3: Mid Ply area inspection

Gate 4: Last Ply to back wall inspection

Gate 5: Back wall area inspection

Gate 6: All-ply level inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

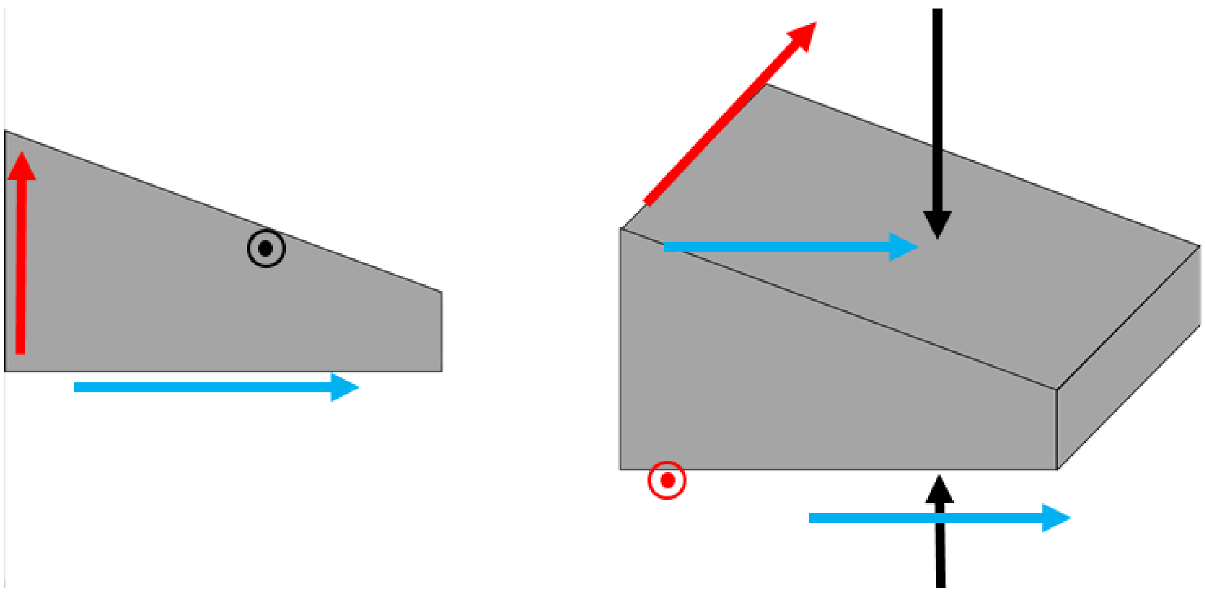


Figure D.2-13. Scan orientation for NASA-W-5D wedge specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 2 (total gate width is 4.00us). Measurement method detected 80% of known defects.

Note: Outlined regions are PTFE inserts.

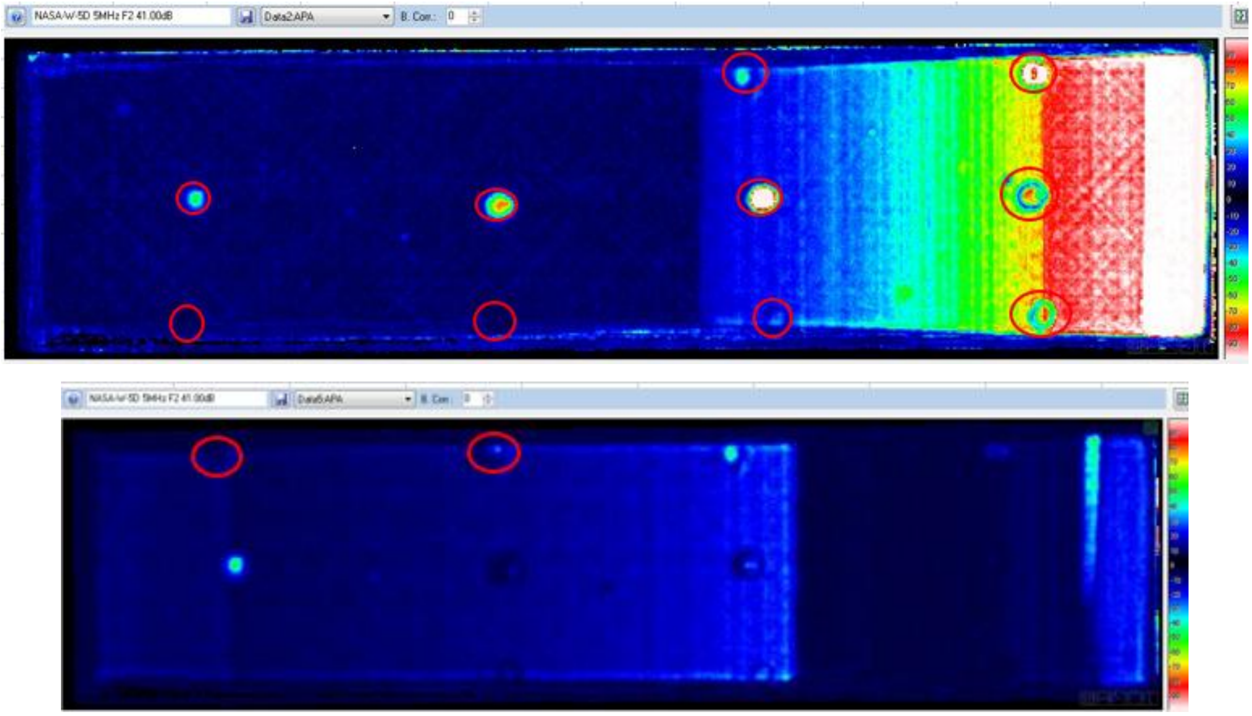


Figure D.2-14. Gate 2 scan results of NASA-W-5D wedge specimen.

Specimen Photos

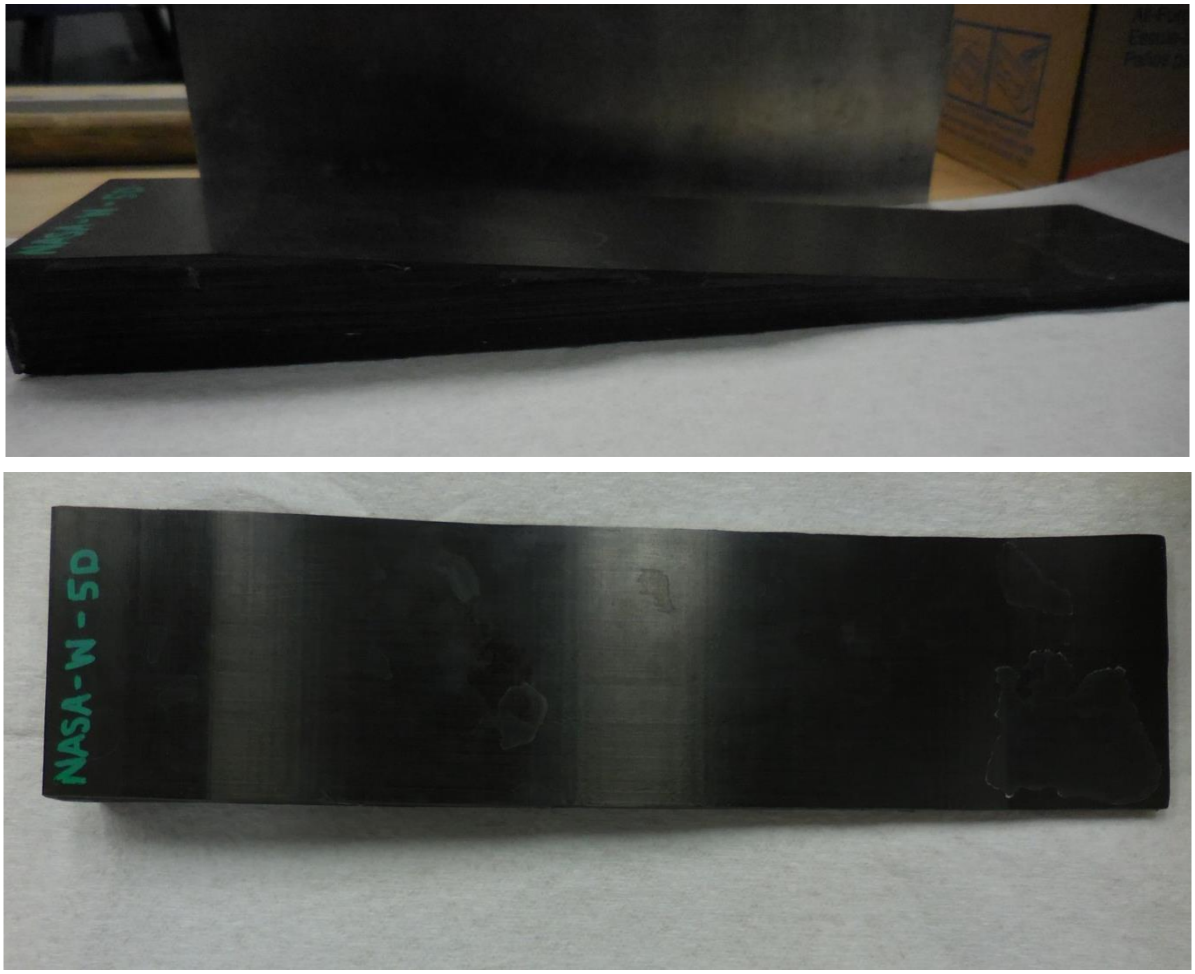


Figure D.2-15. Images of NASA-W-5D wedge specimen.

Specimen #5

3 PTFE Inserts per Row (rad. 0.25in, thickness 0.002in), 12 Total

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-W-20D	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 to 1.0 inch Wedge Angle: 20 deg. Delaminations: Ply 1, Mid Ply, Last Ply	12 in.	3 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	X
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	
Flat Panel	
Step	
Wedge	X
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	X
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	43.01 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	6 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near Surface to Ply 1 inspection

Gate 2: Ply 1 to Mid-inspection

Gate 3: Mid Ply area inspection

Gate 4: Last Ply to back wall inspection

Gate 5: Back wall area inspection

Gate 6: All-ply level inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

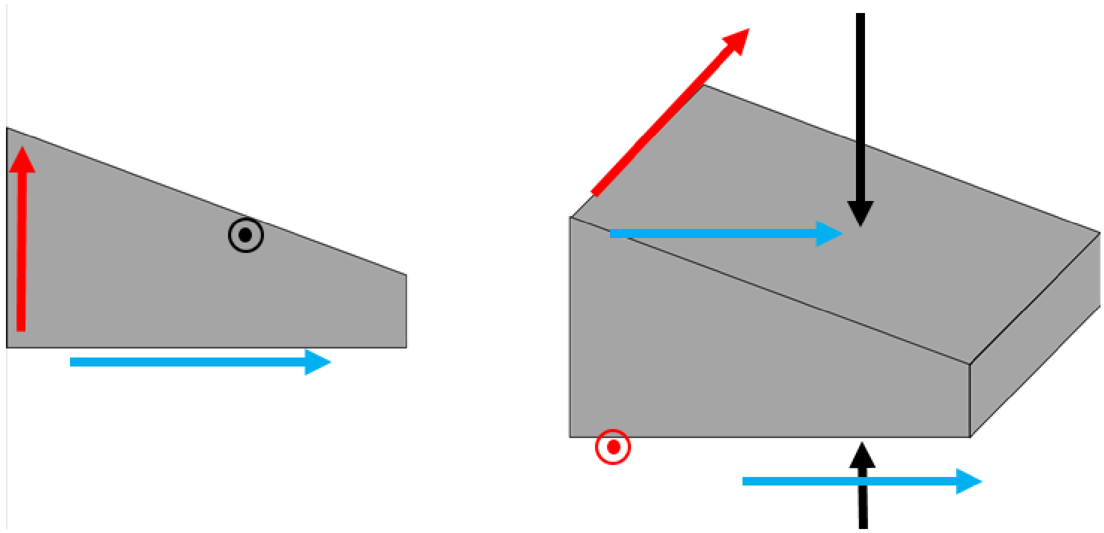


Figure D.2-16. Scan orientation for NASA-W-20D wedge specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 2 (total gate width is 8.00us). Measurement method detected 80% of known defects.

Note: highlighted regions indicate PTFE inserts.

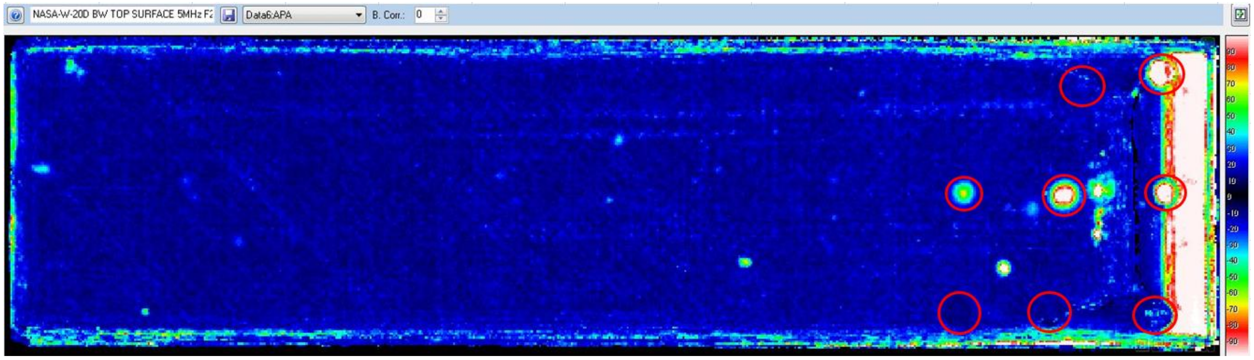


Figure D.2-17. PEUT scan results of NASA-W-20D wedge specimen.

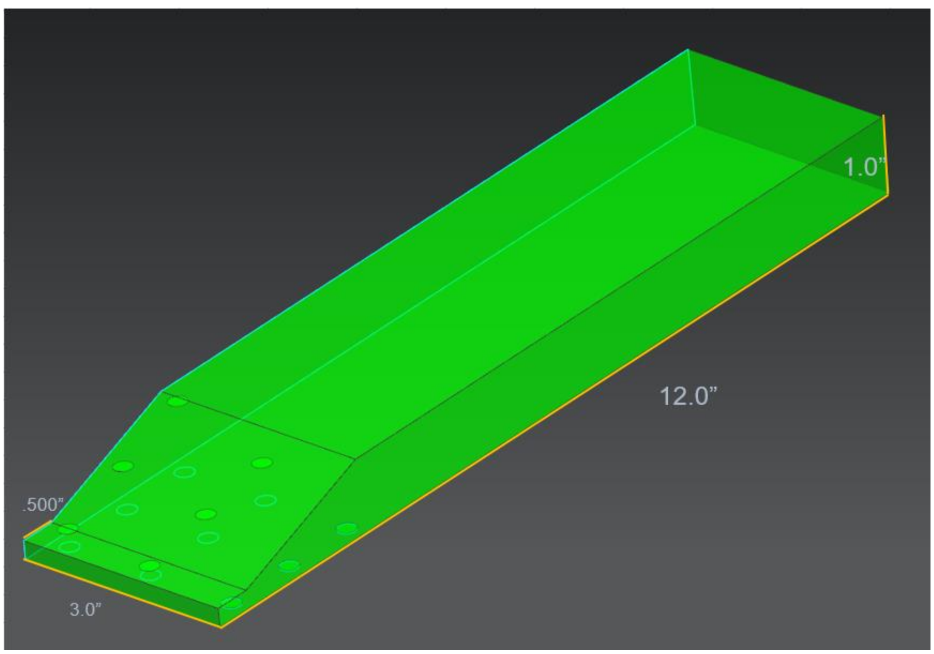


Figure D.2-18. Dimensions of NASA-W-20D wedge specimen.

Specimen Photos

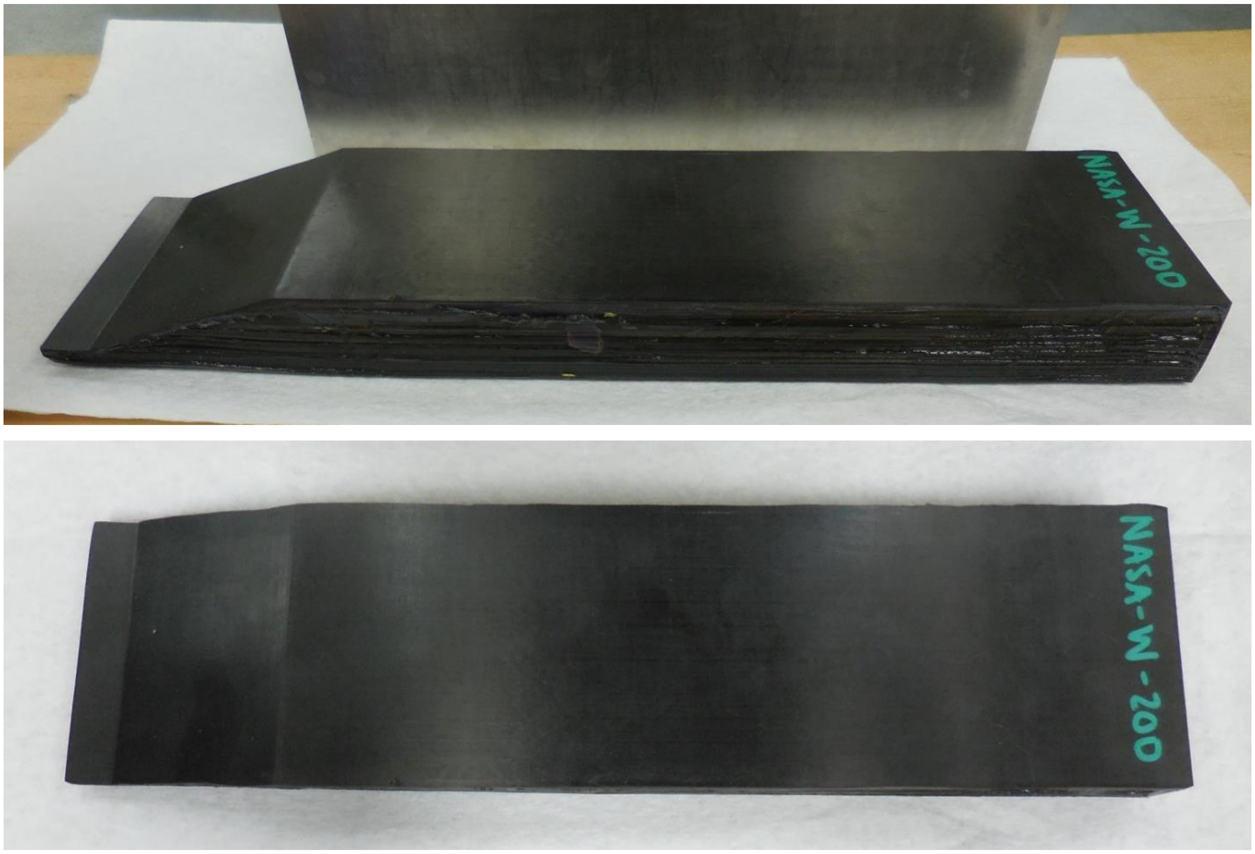


Figure D.2-19. Images of NASA-W-20D wedge specimen.

Specimen #6

3 PTFE Inserts per Row (rad. 0.25in, thickness 0.002in), 12 Total

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-W-35D	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 to 1.0 inch Wedge Angle: 35 deg. Delaminations: Ply 1, Mid Ply, Last Ply	12 in.	7 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	
Flat Panel	
Step	
Wedge	**X**
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	45.03 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	6 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near Surface to Ply 1 inspection

Gate 2: Ply 1 to mid-inspection

Gate 3: Mid Ply area inspection

Gate 4: Last Ply to back wall inspection

Gate 5: Back wall area inspection

Gate 6: All-ply level inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

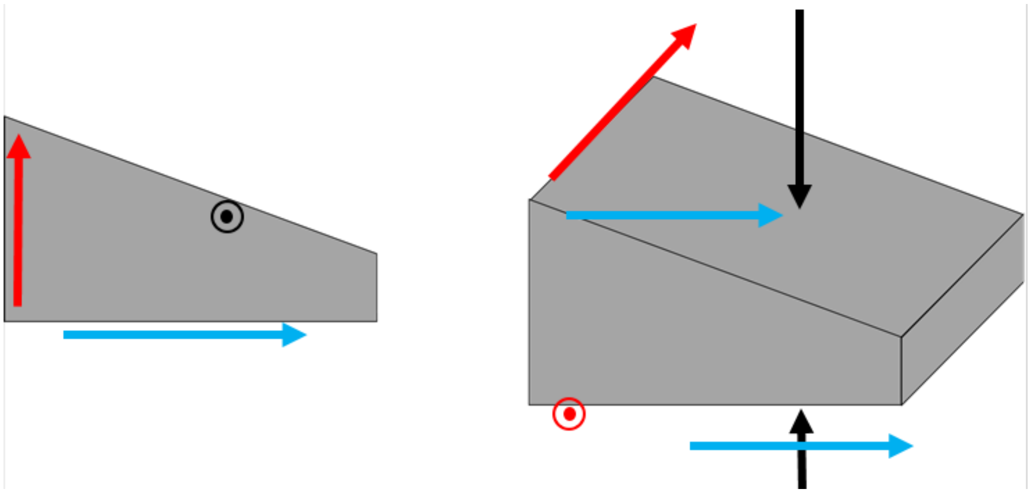


Figure D.2-20. Scan orientation for NASA-W-35D wedge specimen.

Figures and Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 1, Gate 2, Gate 3, and Gate 5 (total gate width is 8.00us of each). Measurement method detected 80% of known defects.

Note: Highlighted regions outline PTFE inserts.

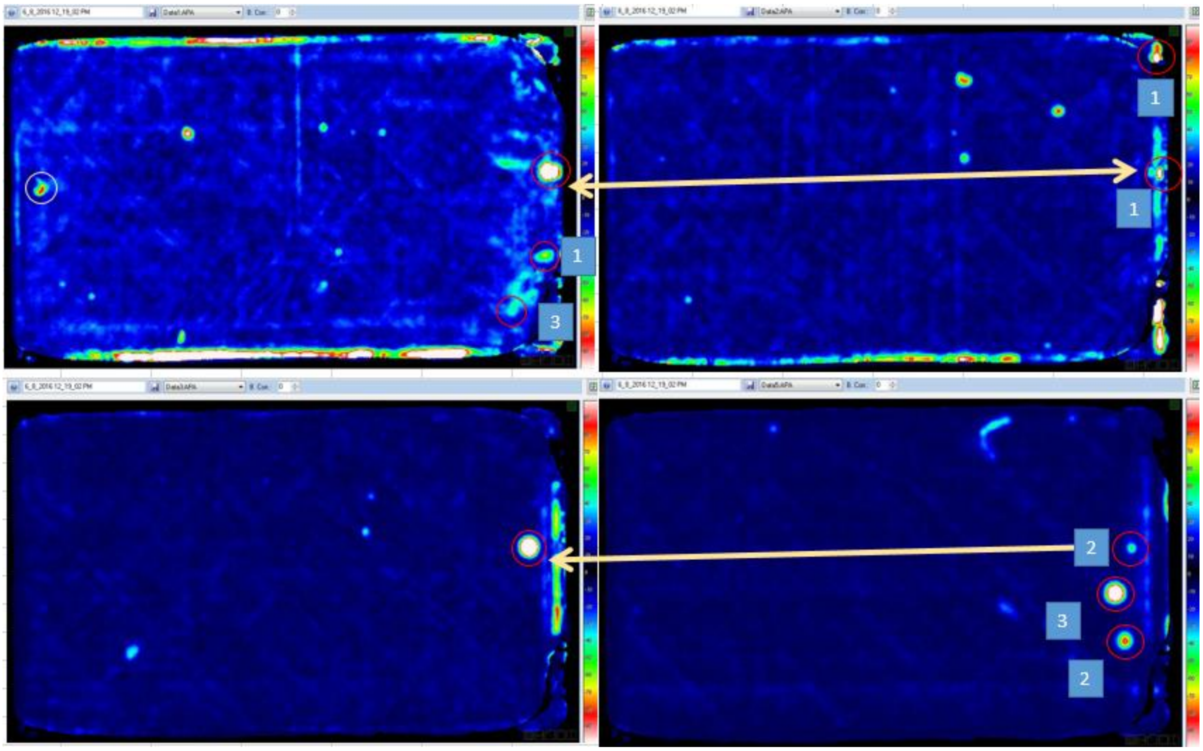


Figure D.2-21. PEUT scan results from (a, upper left) Gate 1, (b, upper right) Gate 2, (c, lower left) Gate 3, (d, lower right) and Gate 4.

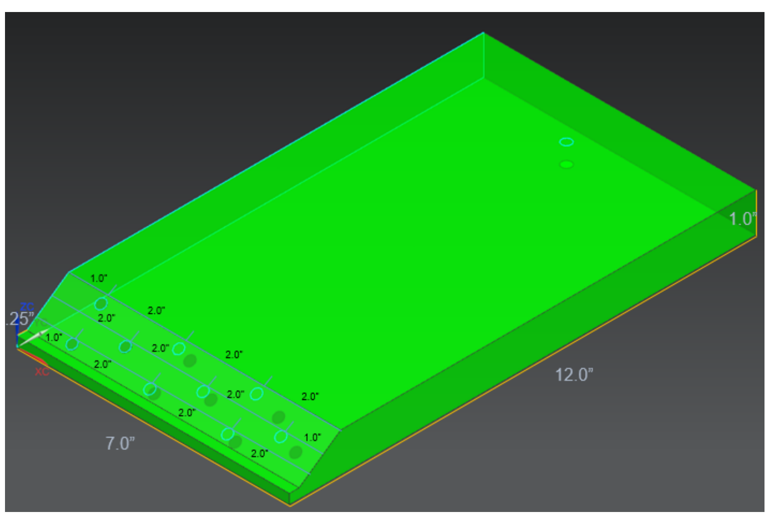


Figure D.2-22. Dimensions of NASA-W-35D wedge specimen.

Specimen Photos

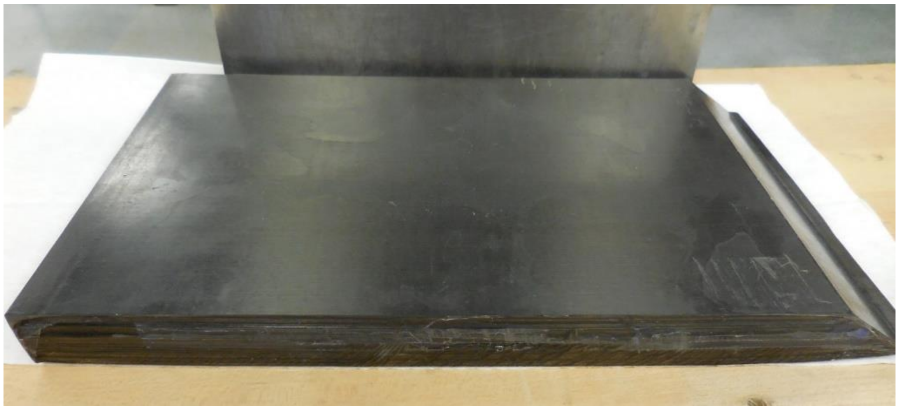


Figure D.2-23. Images of NASA-W-35D wedge specimen.

Specimen #16

2 PTFE Inserts (rad. 0.25in, thickness 0.002in)

Standard Configuration	**Standard Configuration**	**Standard Configuration**	**Standard Configuration**	**Standard Configuration**	**Standard Configuration**	**Standard Configuration**
2	NASA-RP-01D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 0.1 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	**X**
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	25.25 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	7 Gates
Sa,[;omg Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near-surface to ply 1 inspection

Gate 2: Near-surface inspection

Gate 3: Ply 1 area inspection

Gate 4: Mid-ply area inspection

Gate 5: Last-ply area inspection

Gate 6: Ply 1 to back wall inspection

Gate 7: Back wall inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

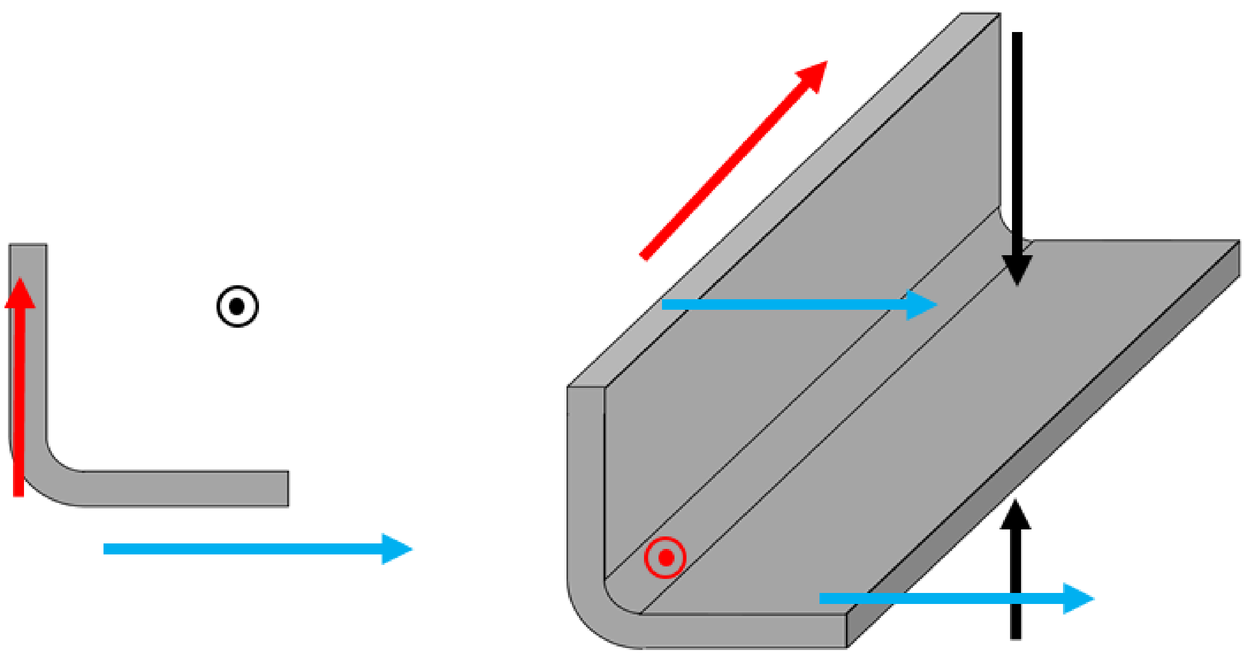


Figure D.2-24. Scanning orientation of NASA-RP-01D delamination specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 6 (total gate width is 4.124us) and Gate 7 (total gate width 1.276us). Measurement method detected 80% of known defects.

Note:

Region A: PTFE inserts

Region B: Nothing

Region C: Air bubbles in water

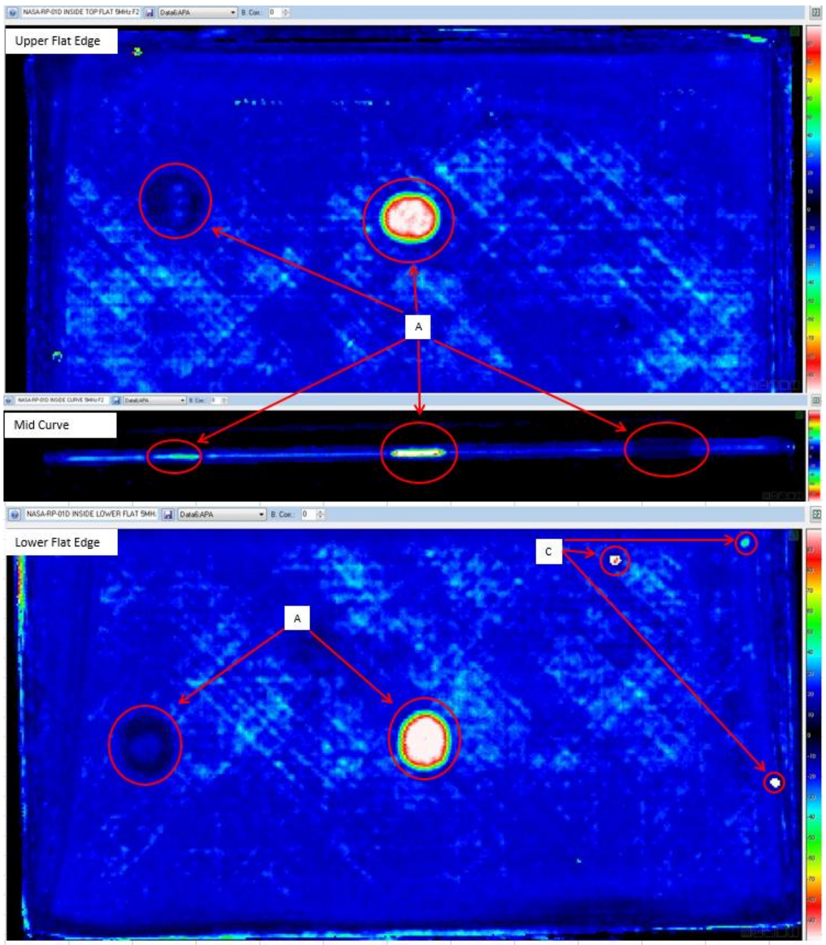


Figure D.2-25. Gate 6 PEUT scan results of NASA-RP-01D specimen.

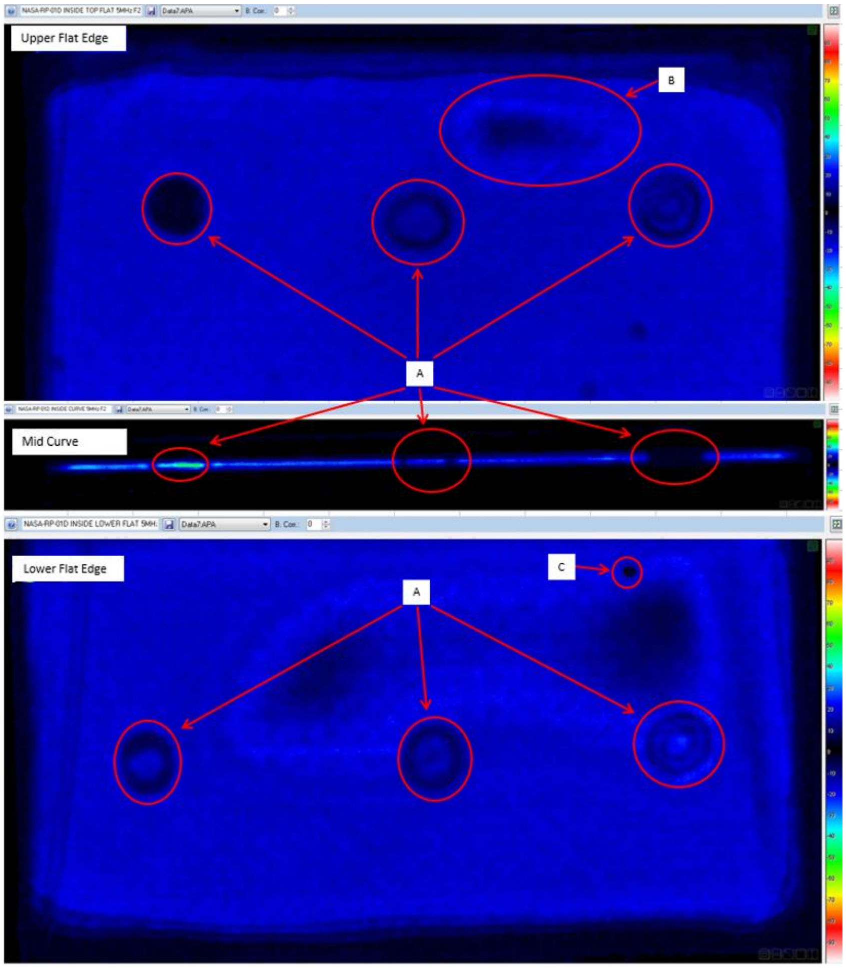


Figure D.2-26. Gate 7 PEUT scan results of NASA-RP-01D specimen.

Specimen Photos

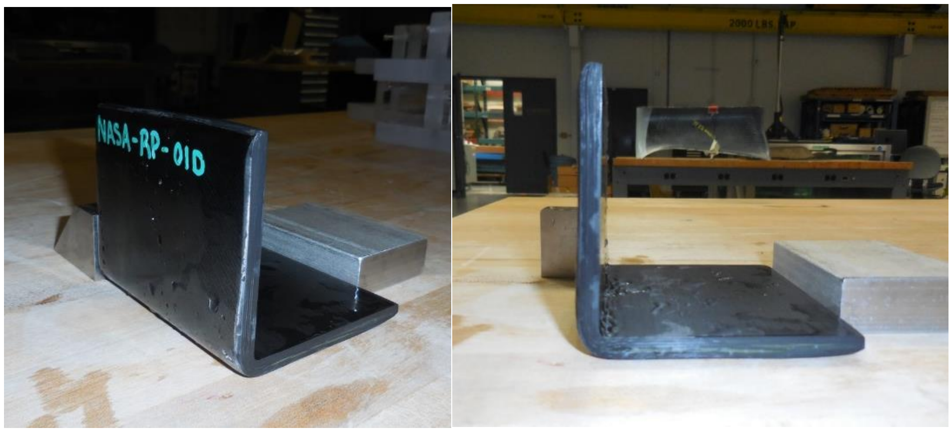


Figure D.2-27. Photos of NASA-RP-01D specimen.

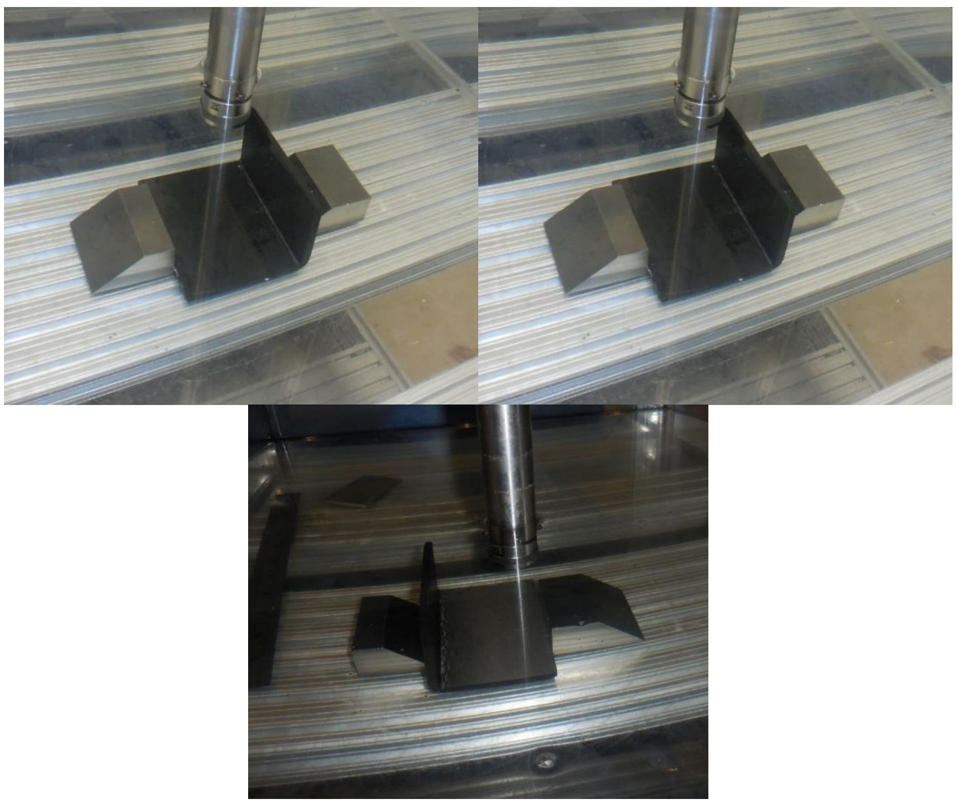


Figure D.2-28. PEUT Scan setup of the lower flat (left), mid curve (right), and upper flat (lower) area.

Specimen #16

Low-Porosity Specimen

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-RP-01D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 0.1 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	
TTUT	**X**
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	**X**
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	
Microcrack	
Porosity	**X**
Other	

Transducer/Equipment Specifications

Transducer Make/Model	KBA GAMMA NDT INST.
Transducer Frequency	2.25 MHz
Transducer Focus, Diameter	6.0in. Focal Length, 0.325in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	Reference: 20.5 dB, Inspection: 27 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	2 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

None

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

Figures and Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 2 (total gate width is 2.000us). Measurement method detected 80% of known defects. Circled regions indicate where the PTFE inserts are located.

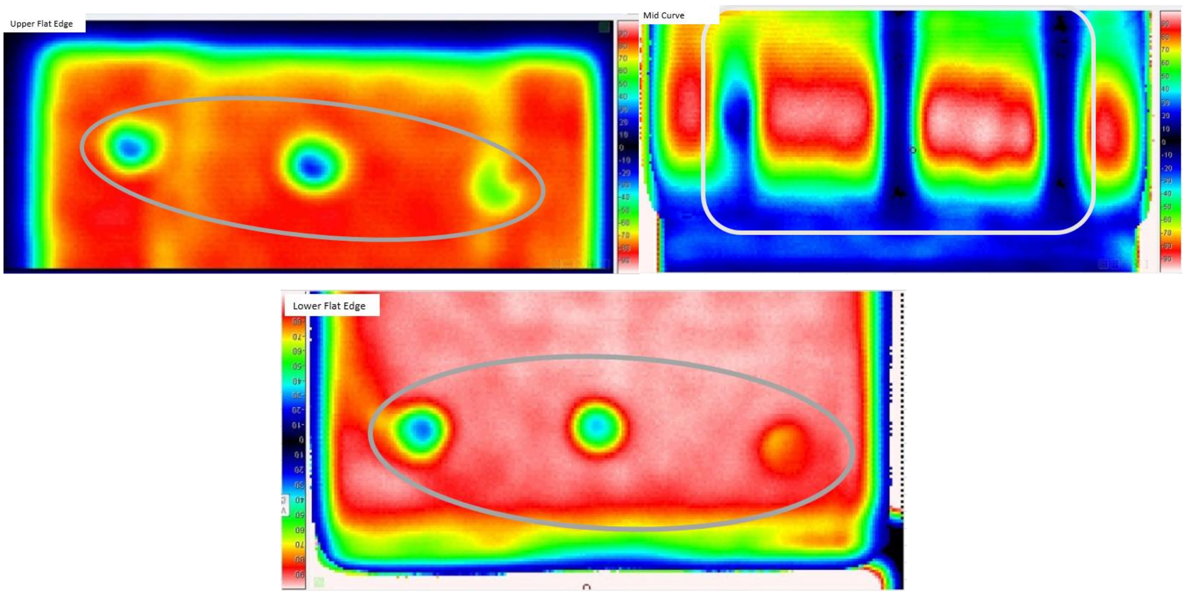


Figure D.2-29. TTUT scan results from the upper flat edge (left), mid curve (right), and lower flat edge (lower) areas.

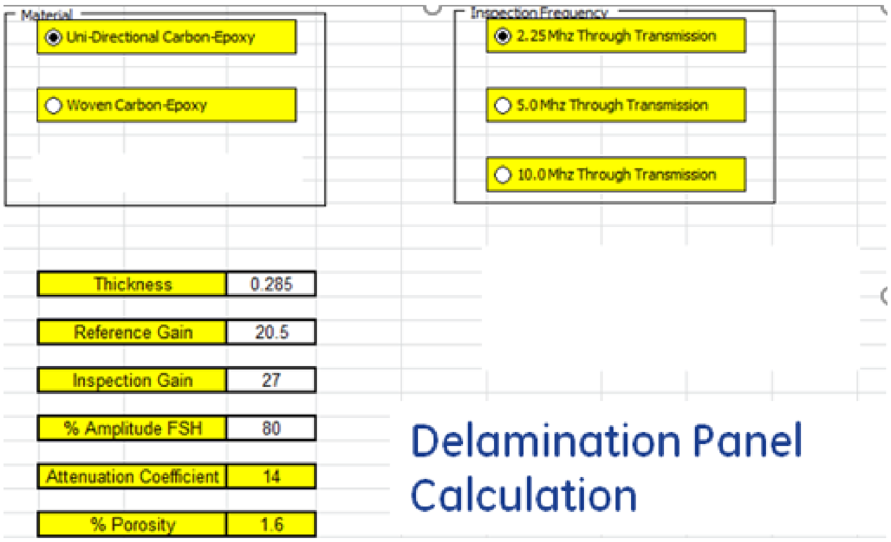


Figure D.2-30. Calculation of the attenuation coefficient and percent porosity for the NASA-RP-01D low-porosity specimen.

Specimen Photos

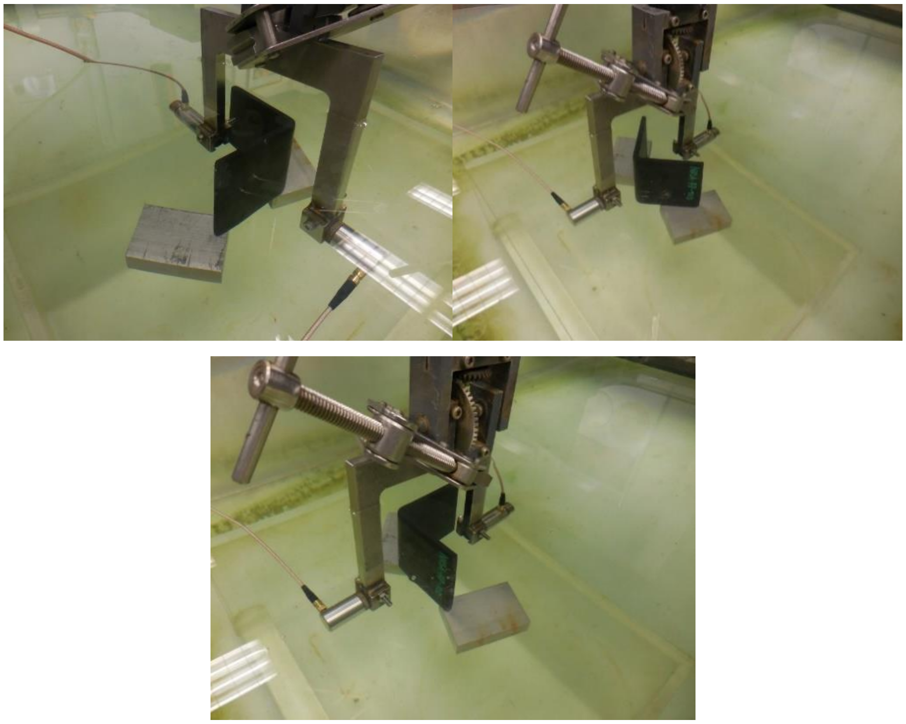


Figure D.2-31. TTUT setup for the lower flat (left), mid curve (right), and upper flat (lower) areas.

Figure D.2-32. Images of NASA-RP-01D specimen as seen in Figure D.2-31.

Specimen #16

Medium-Porosity Specimen

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-RP-01D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 0.1 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	
TTUT	X
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	X
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	
Microcrack	
Porosity	X
Other	

Transducer/Equipment Specifications

Transducer Make/Model	KBA GAMMA NDT INST.
Transducer Frequency	2.25 MHz
Transducer Focus, Diameter	6.0in. Focal Length, 0.325in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	Reference: 20.5 dB, Inspection: 52 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	2 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

None.

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

Figures and Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 2 (total gate width is 2.000us). Measurement method detected 80% of known defects.

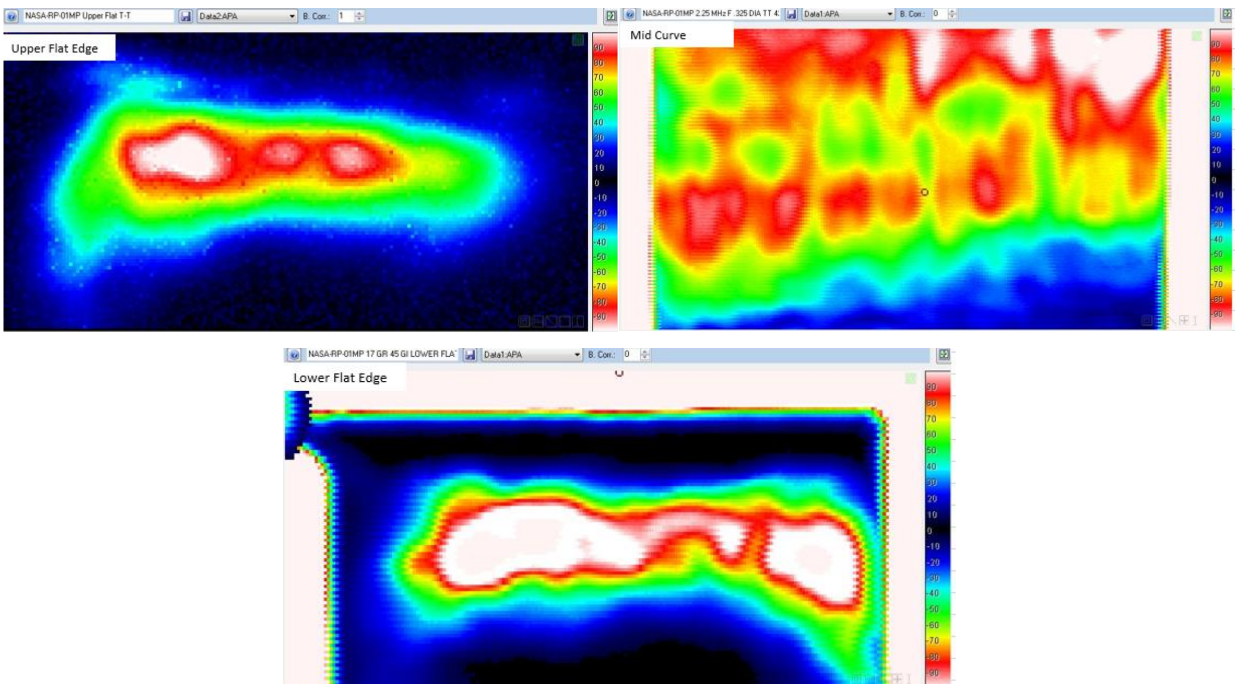


Figure D.2-33. TTUT scan results of the upper flat edge (left), mid curve (right), and lower flat edge (lower) areas.

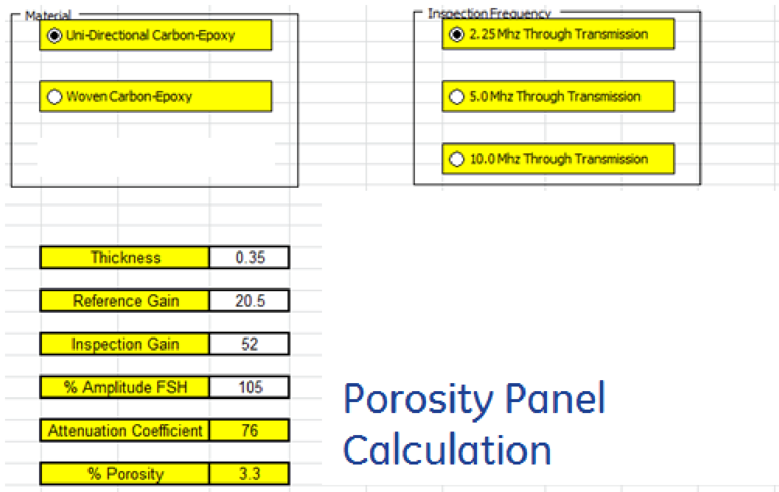


Figure D.2-34. Calculation of the attenuation coefficient and percent porosityfor the NASA-RP-01D medium-porosity specimen.

Specimen Photos

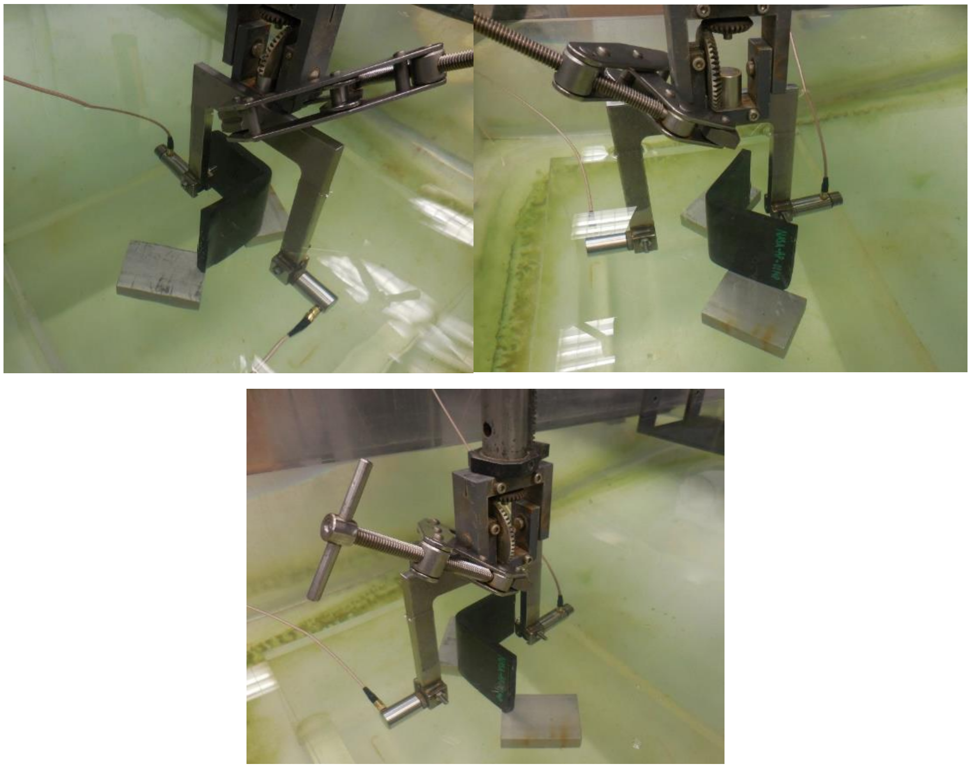


Figure D.2-35. TTUT setup of the lower flat area (left), mid curve (right), and upper flat area (lower).

Specimen #18

2 PTFE Inserts (rad. 0.25in, thickness 0.002in)

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-RP-10D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 1.0 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	**X**
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	25.25 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	7 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near-surface to ply 1 inspection

Gate 2: Near-surface inspection

Gate 3: Ply 1 area inspection

Gate 4: Mid-ply area inspection

Gate 5: Last ply area inspection

Gate 6: Ply 1 to back wall inspection

Gate 7: Back wall inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

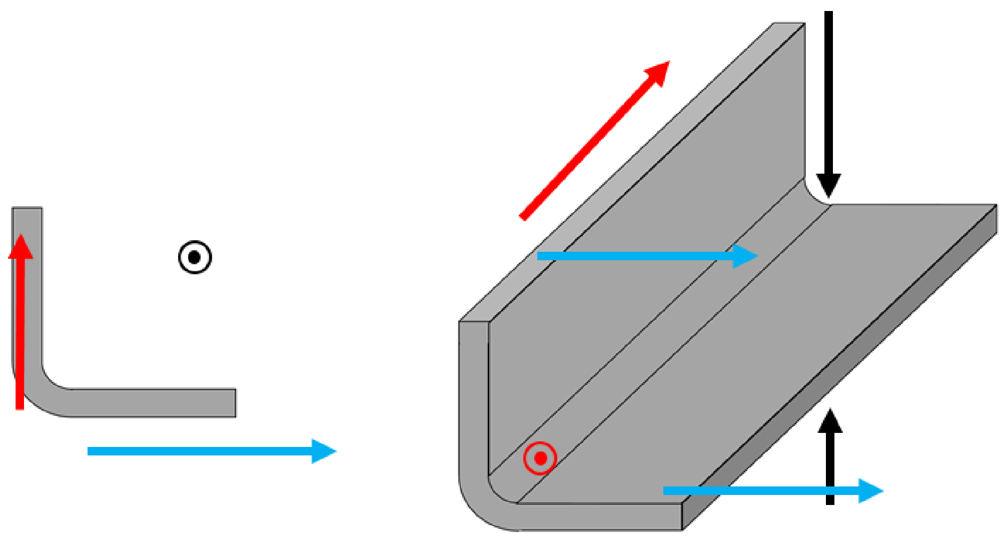


Figure D.2-36. Scanning orientation of NASA-RP-10D delamination specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated Gate 6 (total gate width is 4.124us) and Gate 7 (total gate width 1.276us). Measurement method detected 80% of known defects.

Note:

Region A: PTFE Inserts

Region B: Bubbles

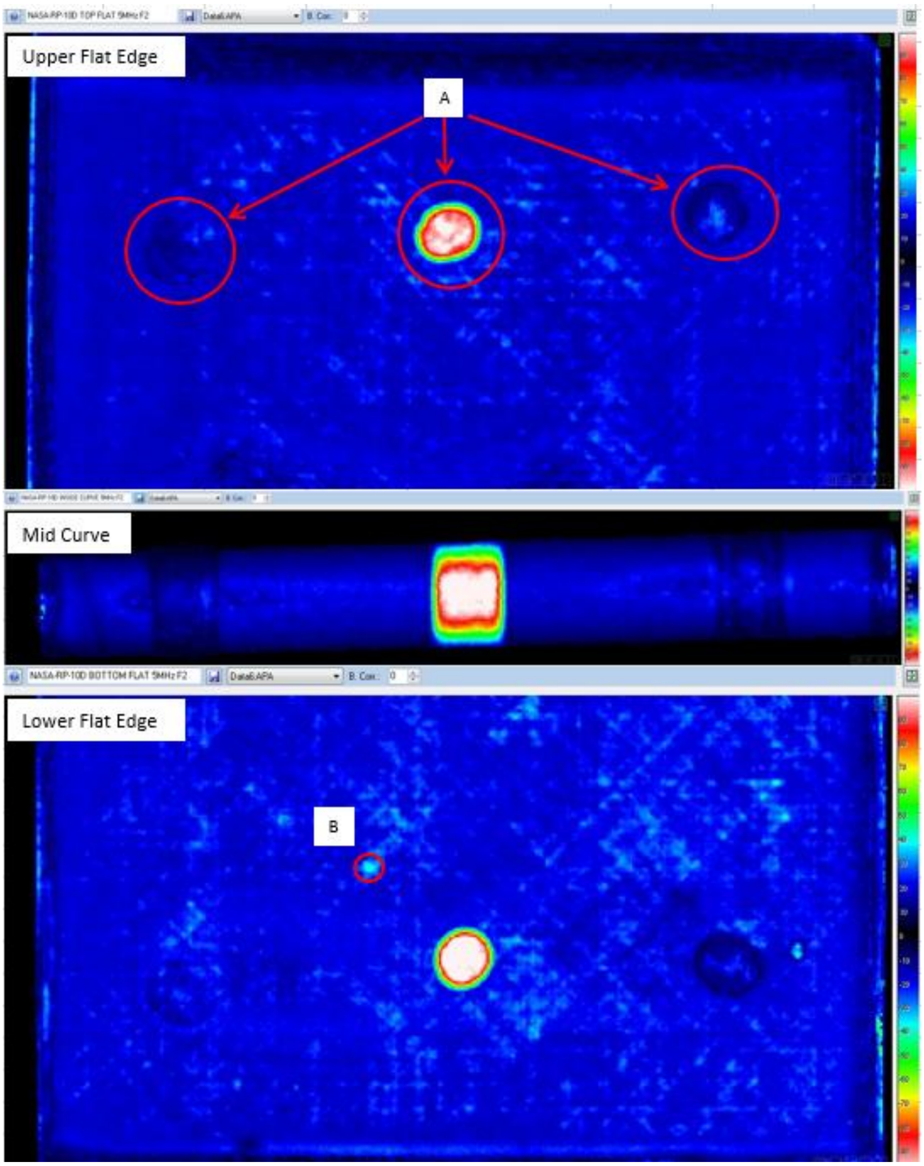


Figure D.2-37. Gate 6 PEUT scan results of NASA-RP-10D specimen.

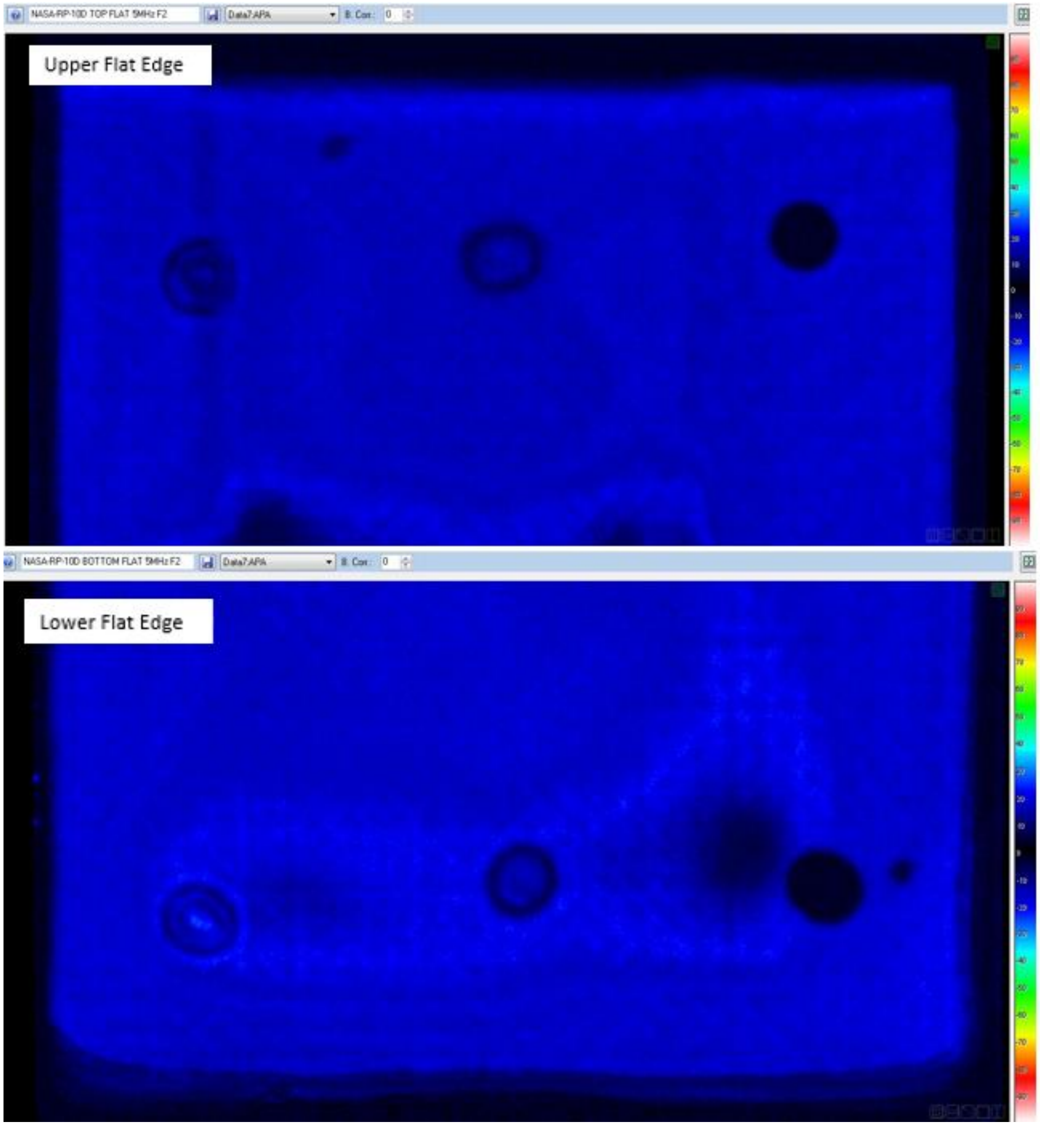


Figure D.2-38. Gate 7 PEUT scan results of NASA-RP-10D specimen.

Specimen Photos

Figure D.2-39. PEUT setup for the lower flat (left), mid curve (right), and upper flat (lower) areas.

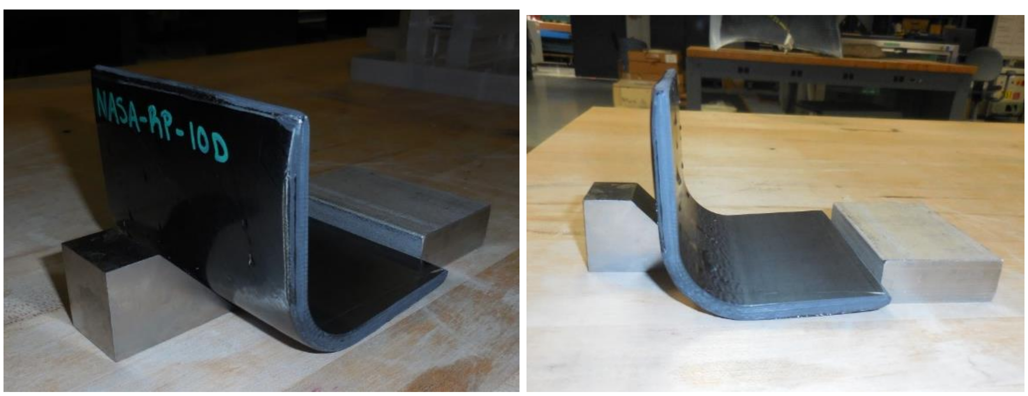


Figure D.2-40. Images of NASA-RP-10D specimen.

Specimen #18

Low-Porosity Specimen

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
1	NASA-RP-10D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 1.0 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	**X**
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	
Microcrack	
Porosity	**X**
Other	

Transducer/Equipment Specifications

Transducer Make/Model	KBA GAMMA NDT INST.
Transducer Frequency	2.25 MHz
Transducer Focus, Diameter	6.0in. Focal Length, 0.325in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	Reference: 20.5 Db, Inspection: 26 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	2 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

None.

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated Gate 1 (total gate width is 2.000us). Measurement method detected 80% of known defects.

Note: Region A: PTFE Inserts

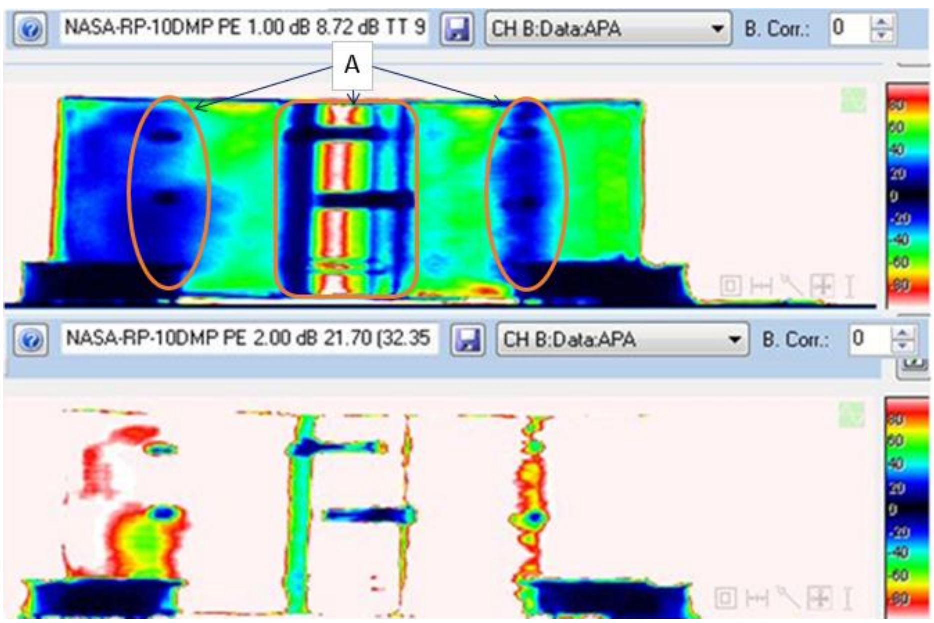


Figure D.2-41. PEUT scan results from NASA-RD-10D low-porosity specimen.

Specimen Photos

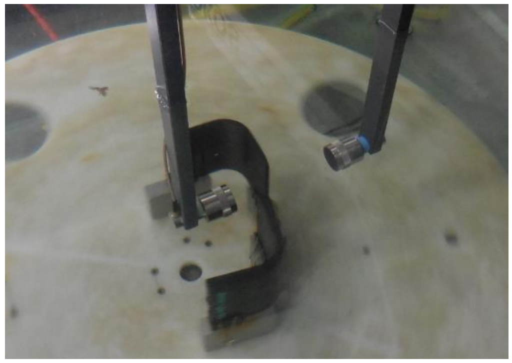


Figure D.2-42. TTUT scan setup for NASA-RD-10D specimen.

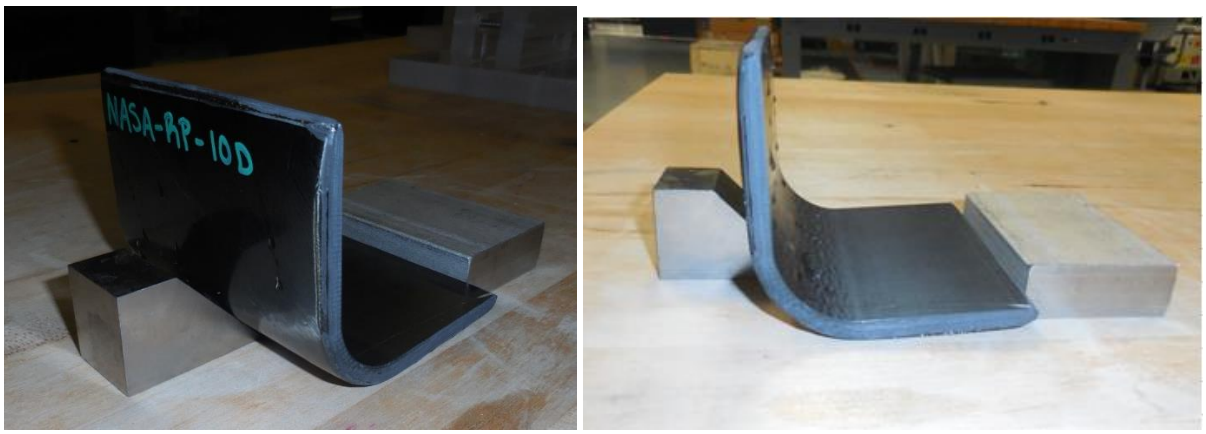


Figure D.2-43. Images of NASA-RP-10D low-porosity specimen.

Specimen #19

2 Stacked PTFE Inserts (rad. 0.25in, thickness 0.002in) Per Target

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-RP-20D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 2.0 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	**X**
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	25.25 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	7 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near-surface to ply 1 inspection

Gate 2: Near-surface inspection

Gate 3: Ply 1 area inspection

Gate 4: Mid-ply area inspection

Gate 5: Last ply area inspection

Gate 6: Ply 1 to back wall inspection

Gate 7: Back wall inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

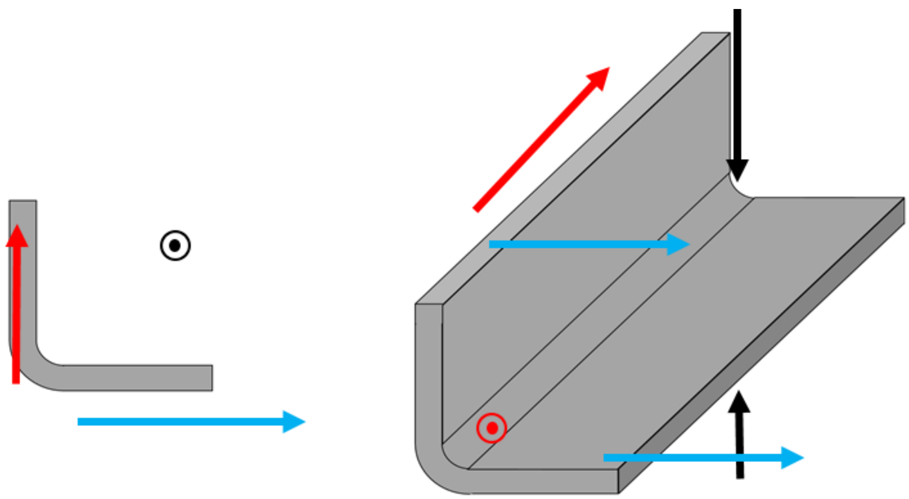


Figure D.2-44. Scanning orientation of NASA-RP-20D specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 6 (total gate width is 4.124us) and Gate 7 (total gate width 1.276us). Measurement method detected 80% of known defects.

Note:

Region A: Air bubble in water

Region B: Saturated noise

Region C: PTFE insert

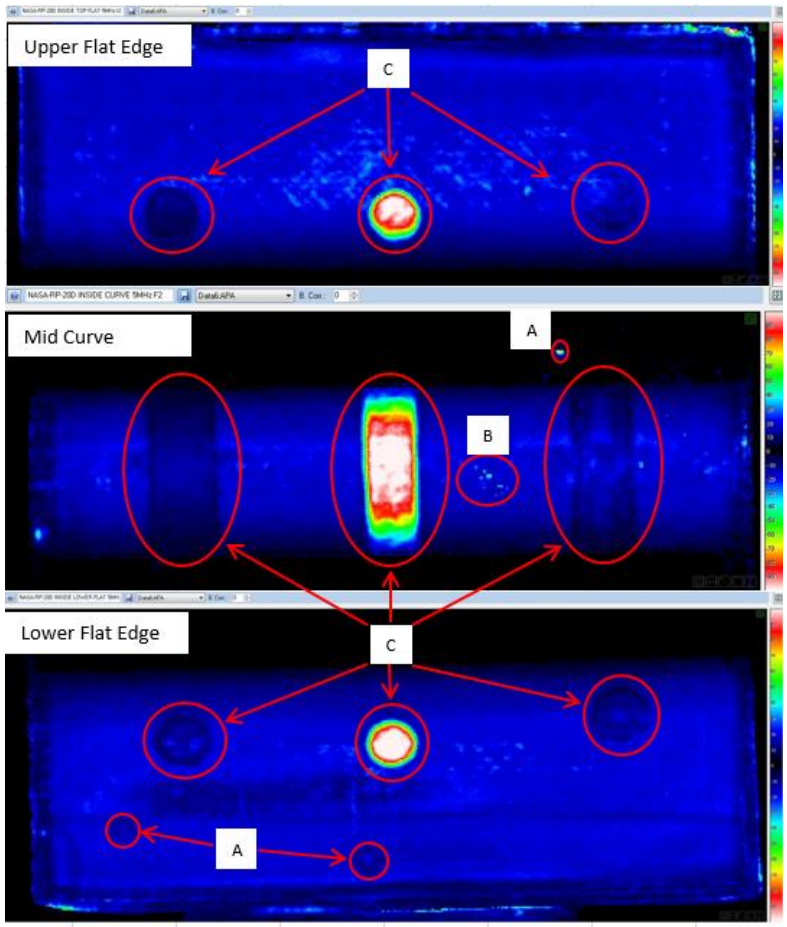


Figure D.2-45. Gate 6 PEUT scan results of NASA-RP-20D specimen.

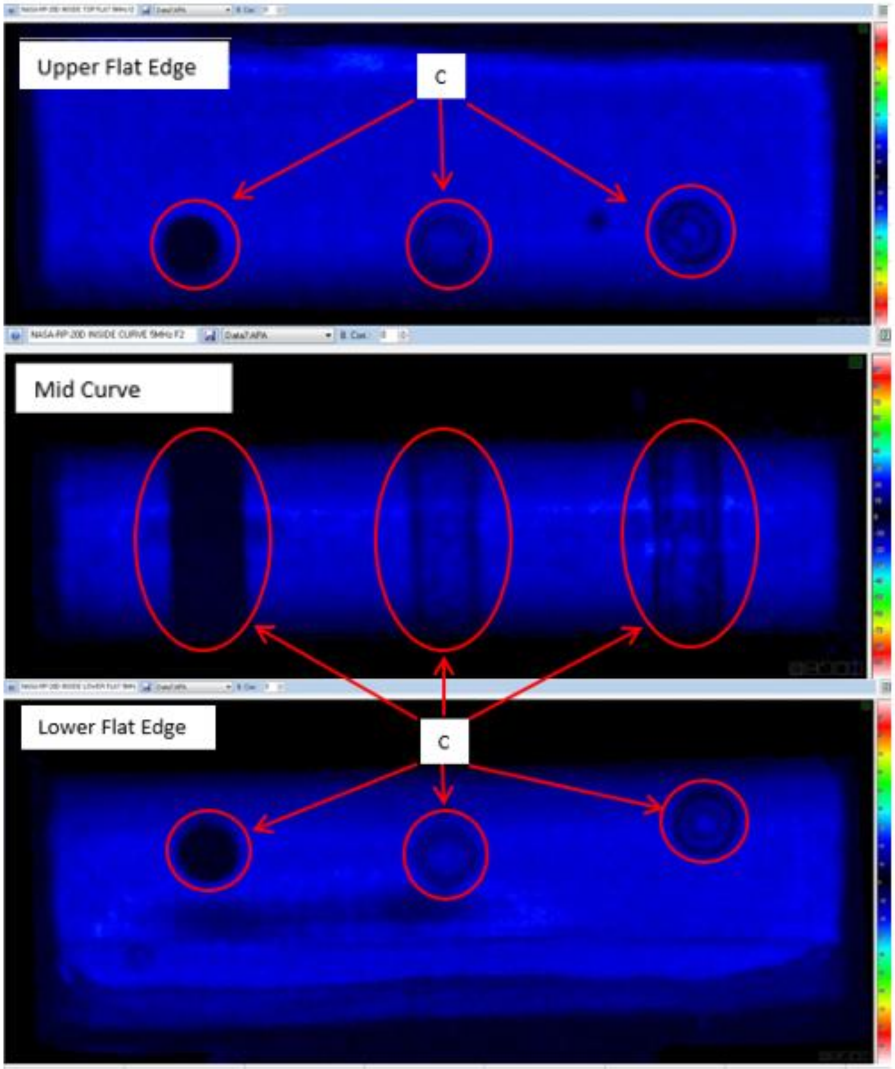


Figure D.2-46. Gate 7 PEUT scan results of NASA-RP-20D specimen.

Specimen Photos:

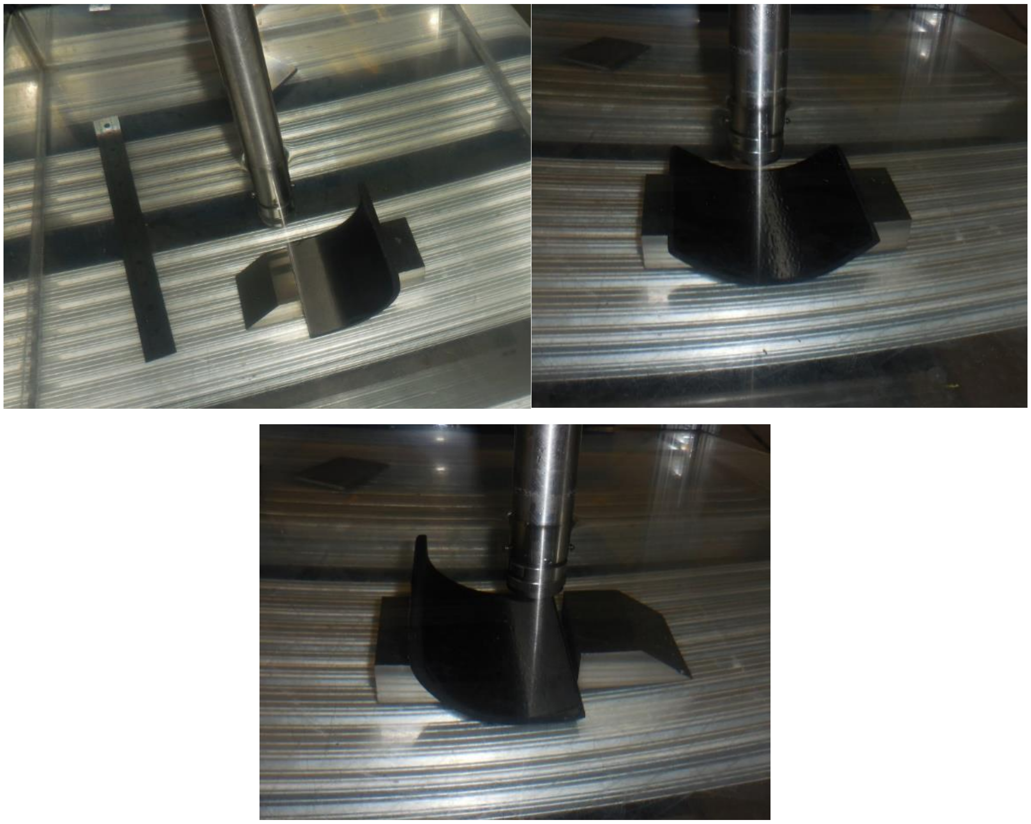


Figure D.2-47. PEUT scan setup for the lower flat (left), mid curve (right), and upper flat (lower) areas.

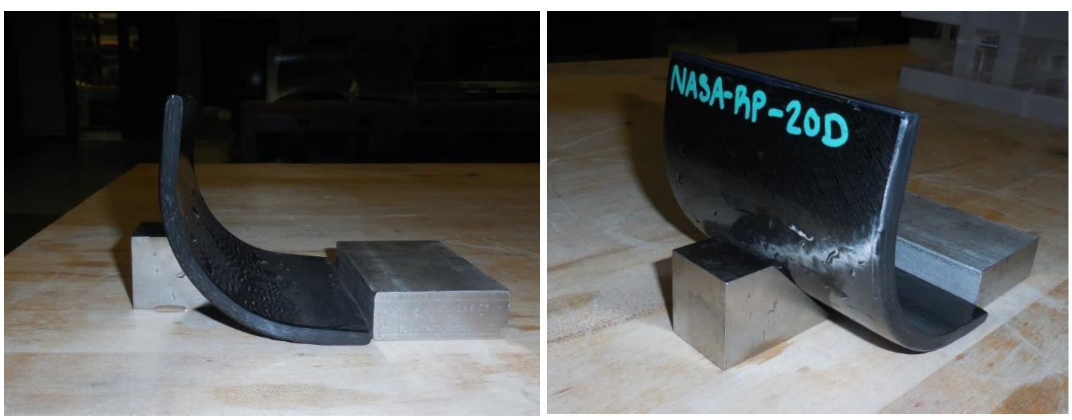


Figure D.2-48. Photos of NASA-RP-20D specimen.

Specimen #19

Low-Porosity Specimen

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
1	NASA-RP-20D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 0.1 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	
TTUT	X
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	X
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	
Microcrack	
Porosity	X
Other	

Transducer/Equipment Specifications

Transducer Make/Model	A304
Transducer Frequency	2.25 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	Reference: -8.03 dB, Inspection: 7.10 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-7.5MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	1 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

None.

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

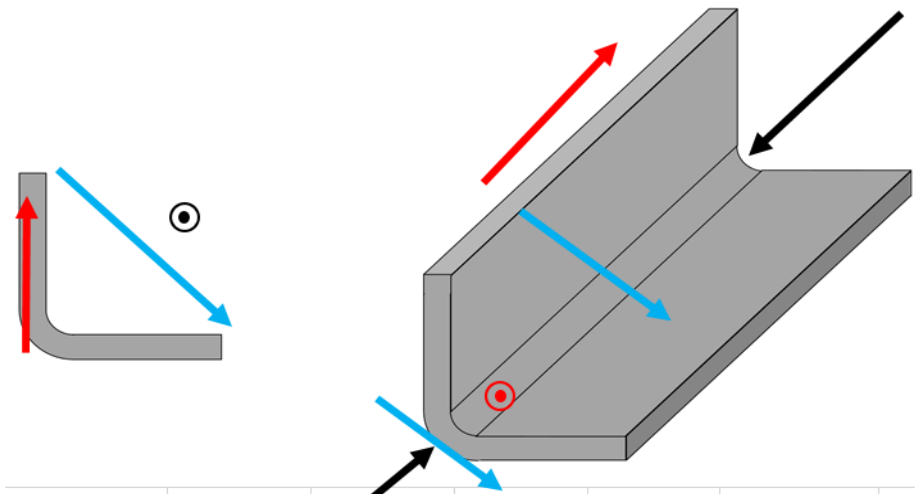


Figure D.2-49. Scanning orientation of NASA-RP-20D low-porosity specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 1 (total gate width is 4.00us). Measurement method detected 80% of known defects.

Note: PTFE inserts are highlighted in Figure D.2-51.

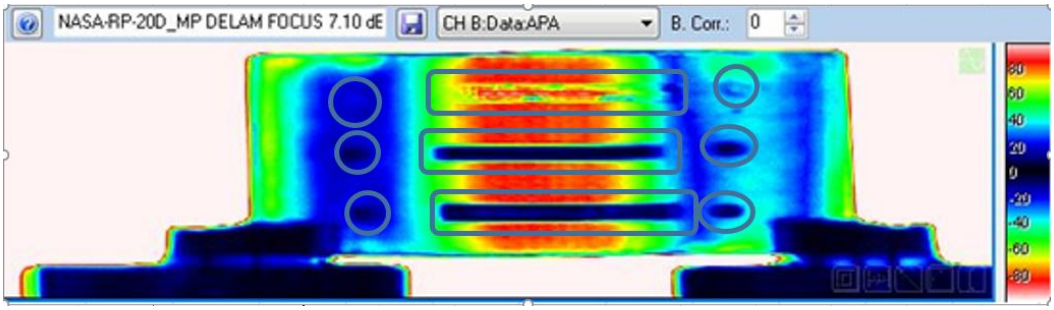


Figure D.2-50. TTUT scan results from NASA-RP-20D low-porosity specimen.

Specimen Photos

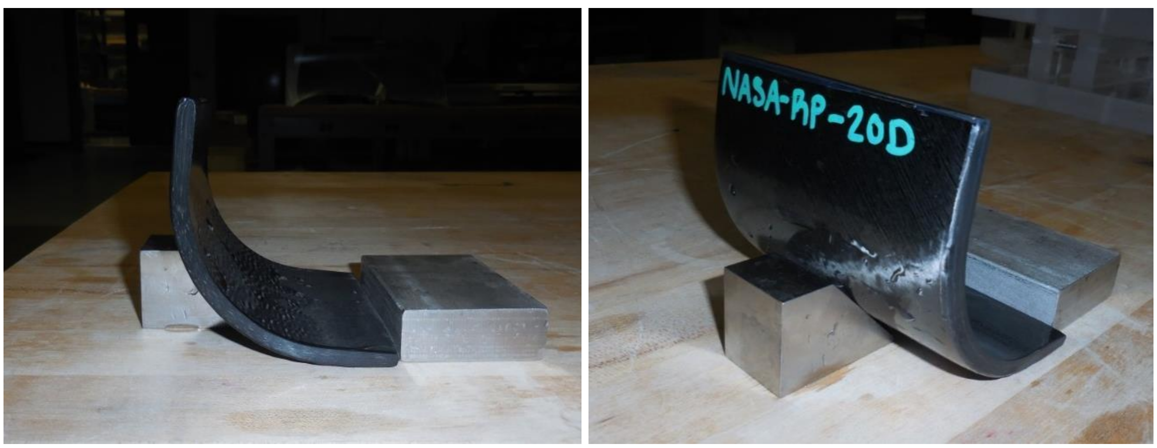


Figure D.2-51. Images of NASA-RP-20D low-porosity specimen.

Specimen #20

2 PTFE Inserts (rad. 0.25in, thickness 0.002in)

Member Designation	Reference Standard	Structure	Material	Specimen Notes	Length	Width
2	NASA-RP-40D Delamination Panel	Uni-Ply (0/90/45)	IM7/8552	Panel Thickness: 0.25 inch Curve Rad: 4.0 inch Delaminations: Ply 1, Mid Ply, Last Ply	6 in.	4 in.

Validation Test Details

Measurement Type

PEUT, Sharp Focus	**X**
TTUT	
TTUT PA	
High Res. CT	
Flash IR	
Laser UT	
Other	

Standard Configuration

Curved Radius	**X**
Flat Panel	
Step	
Wedge	
Other	

Detection Features in Standard (Flaws Present)

APF Tape Defect	
Delamination / Disbond	**X**
Microcrack	
Porosity	
Other	

Transducer/Equipment Specifications

Transducer Make/Model	Olympus V307
Transducer Frequency	5 MHz
Transducer Focus, Diameter	2.0in. Focal Length, 1.0in. Dia.
Transducer Peak-Peak/RMS Voltage	100V
Scanning Spatial Resolution	0.010 in.
Pulser Make/Model	JSR DPR35G
Pulser Gain	25.25 dB
Pulser Damping	1000 Ohms
Pulser Filters	HP-1MHz, LP-22MHz

Testing Specifications

Waveguide/Wedge/Immersion Details	Immersion, Normal Incidence
Data Points Captured	7 Gates
Sampling Frequency	100 million/sec
DAQ Model	0
Averages (if applicable)	---
Final File Format	OKOS

Testing Notes

Gate 1: Near surface to ply 1 inspection

Gate 2: Near surface inspection

Gate 3: Ply 1 area inspection

Gate 4: Mid-ply area inspection

Gate 5: Last ply area inspection

Gate 6: Ply 1 to back wall inspection

Gate 7: Back wall inspection

Scan Orientation

Red Arrow: Indexing Direction

Blue Arrow: Scanning Direction

Black Arrow: Surface normal to measuring instrument.

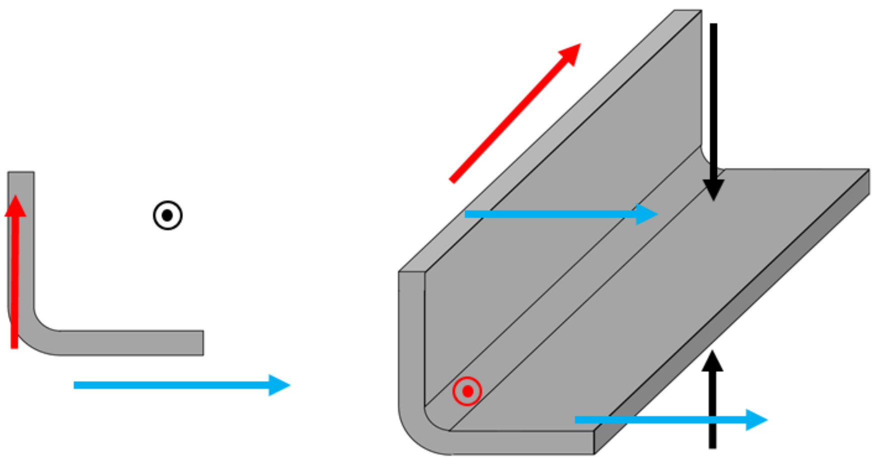


Figure D.2-52. Scanning orientation of NASA-RP-40D specimen.

Figures & Data Highlights

Description: Figure example is post-processed scan along inside curved surface with origin indicated in Step 4 of the cover sheet. Signal to noise was approx. 9.95dB. Image shown is absolute peak amplitude data integrated over Gate 6 (total gate width is 4.124us). Measurement method detected 80% of known defects.

Note: Region A: PTFE insert

Region B: Air bubble in water

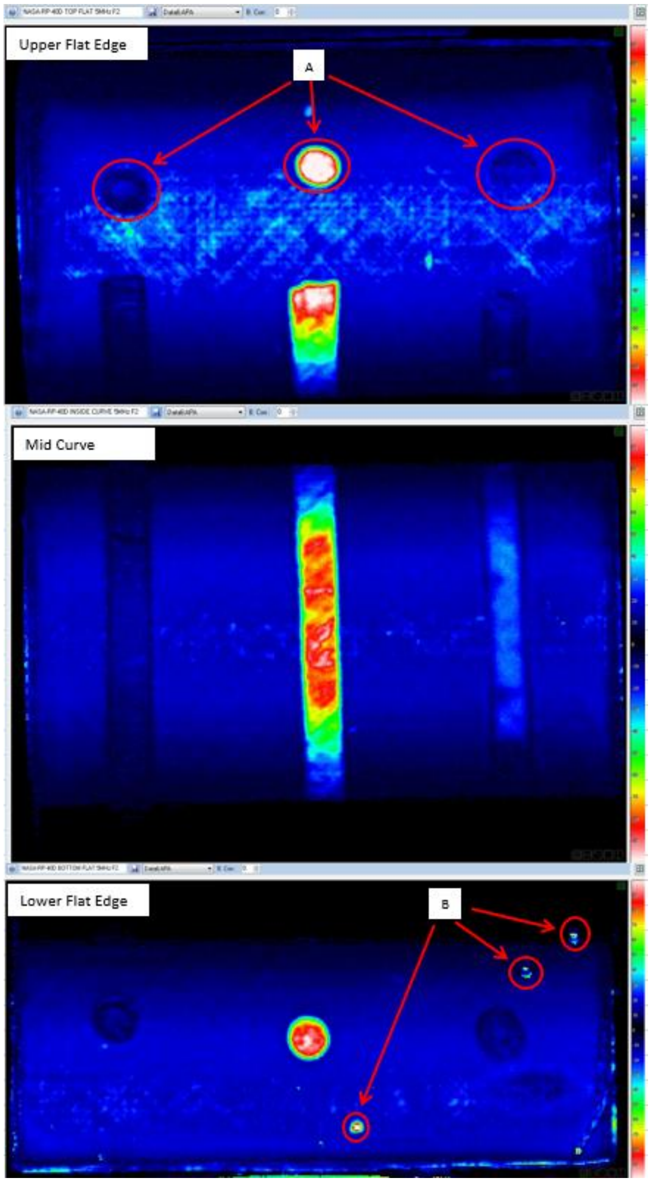


Figure D.2-53. Gate 6 PEUT scan results of NASA-RP-40D specimen.

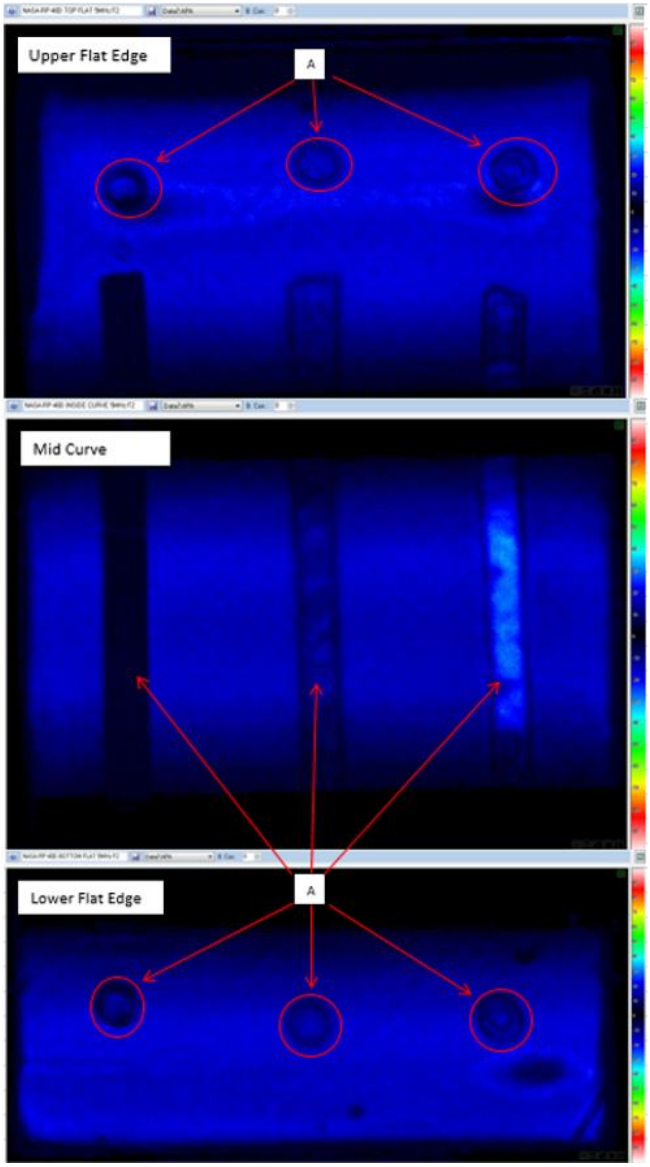


Figure D.2-54. Gate 7 PEUT scan results of NASA-RP-40D specimen.

Specimen Photos:

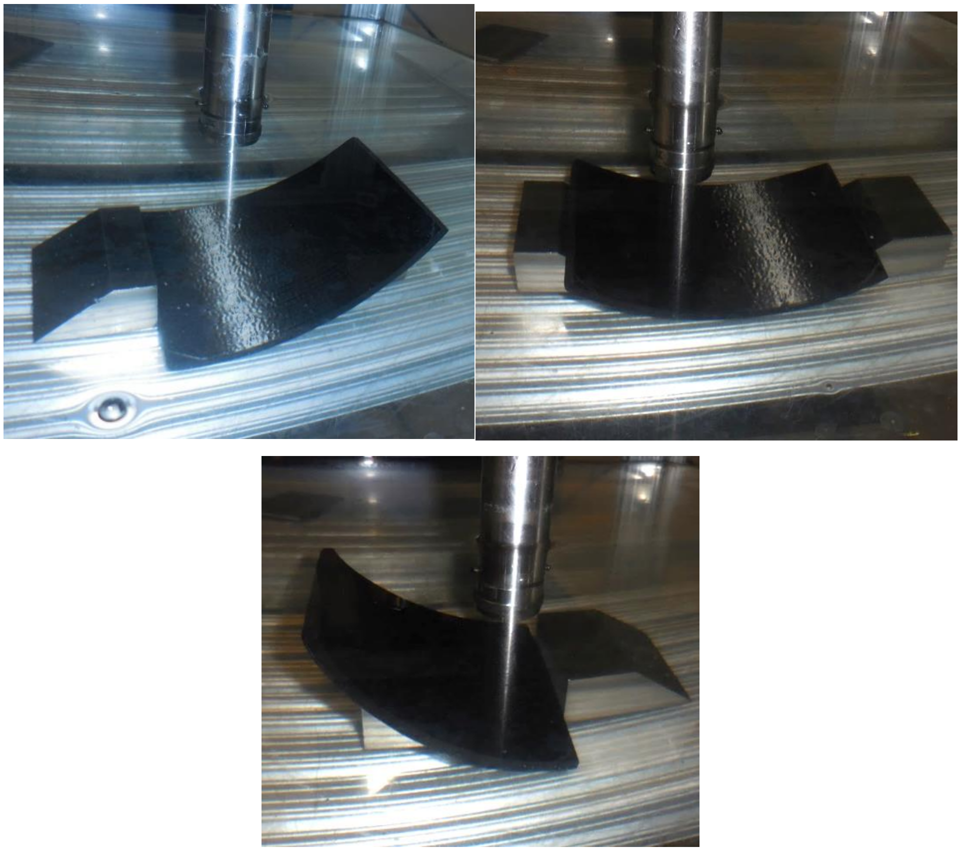


Figure D.2-55. PEUT scan setup for the lower flat (left), mid curve (right), and upper flat (lower) areas.

Figure D.2-56. Images of NASA-RP-40D specimen.

D.3 Manufacturing Information for NDE Standards Provided by Consortium Member #3

Consortium Member Number	Specimen Number/Name	Description
3	57 NASA-03-Twisted-Tow-001	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Twisted Tow - 1 ply
3	58 NASA-03-Twisted-Tow-002	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Twisted Tow - Mid
3	59 NASA-03-Steered-Tow-003	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Tow Orientation
3	60 NASA-03-Folded-Tow-001	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Folded Tow - 1 ply
3	61 NASA-03-Folded-Tow-002	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Folded Tow - Mid
3	62 NASA-03-Missing-Tow-001	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Missing Tow - 1 ply
3	63 NASA-03-Missing-Tow-002	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Missing Tow - Mid
3	64 NASA-03-Bridged-Joggle-001	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Bridging - Joggle
3	65 NASA-03-Bridged-Joggle-002	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Bridging - Joggle
3	66 NASA-03-Bridged-Joggle-003	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Bridging - Joggle
3	67 NASA-03-Bridged-Joggle-004	Fiber Placed Panel IM7/8552-1 Slit Tape Flat panel Bridging - Joggle

Consortium Member Number	Specimen Number/Name	Description
3	68 NASA-03-FOD-Panel-001	Fiber Placed Panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML Flat panel Foreign Object Debris (FOD)
3	69 NASA-03-Porosity-Panel-001	Fiber Placed Panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML Flat panel Porosity
3	70 NASA-03-Porosity-Panel-002	Fiber Placed Panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML Flat panel Porosity
3	71A&B NASA-03-Porosity-Panel-003	Fiber Placed Panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML Flat panel Porosity
3	72A&B NASA-03-Porosity-Panel-004	Fiber Placed Panel IM7/8552-1 Slit Tape w/ IM7/8552 Fabric OML Flat panel Porosity

D.3.1 AFP Defects – twisted tows, missing tows, gaps and laps

D.3.1.1 Specimens 57, 58, 59[4], 60, 61, 62, 63, 64, 65, 66, 67

Introduction

As part of the NASA ACC TC2 IDIQ activity, a set of standards from each of the consortium members were to be developed for use in the following phase in order to detect typical defects. These defects are defined by both the state of practice survey generated also during the IDIQ activity, but also by consortium members' experience. One set of defects that were requested were AFP panels, and the defects that are both specific to AFP (e.g., twisted tows, missing tows, etc.) and generic to composite manufacturing (e.g., porosity).The equipment and processes used to manufacture the panels and to scan the panels is described below.

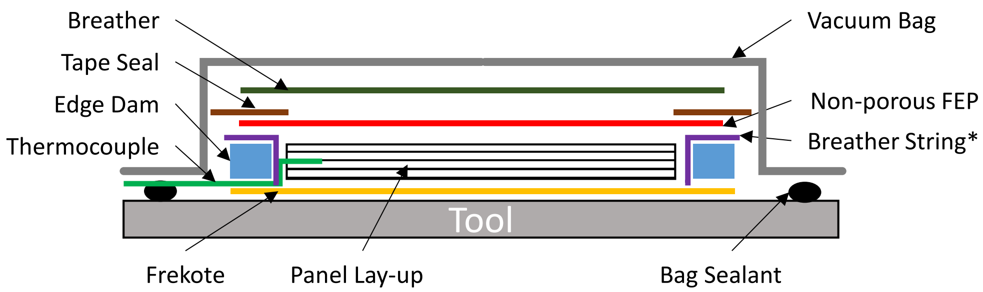
Manufacturing

All of the following panels were built using Hexcel's IM7/8552-1 graphite/epoxy autoclave material system. The panels were placed using an Ingersoll Mongoose gantry style AFP machine located at the Lockheed Martin Aeronautics facility in Palmdale, CA. All panels were placed with the following machine parameters unless otherwise noted: Heater: 110 °F, Compaction: 165 lbs, Feedrate: 300 in/min, Roller: 4-inch-wide Roller Durometer 40 Shore A. The cure cycle varied between the panels, but all panels are cured in an autoclave. All panels are bagged in a consistent manner as shown below.

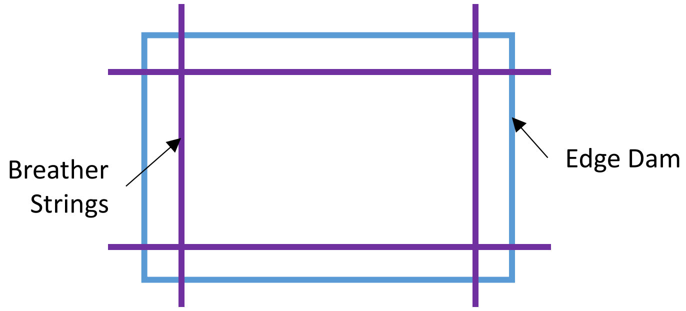
[4] No manufacturing documentation received from OEM.

Bagging:

The bagging scheme used for all panels is shown in the following profile.



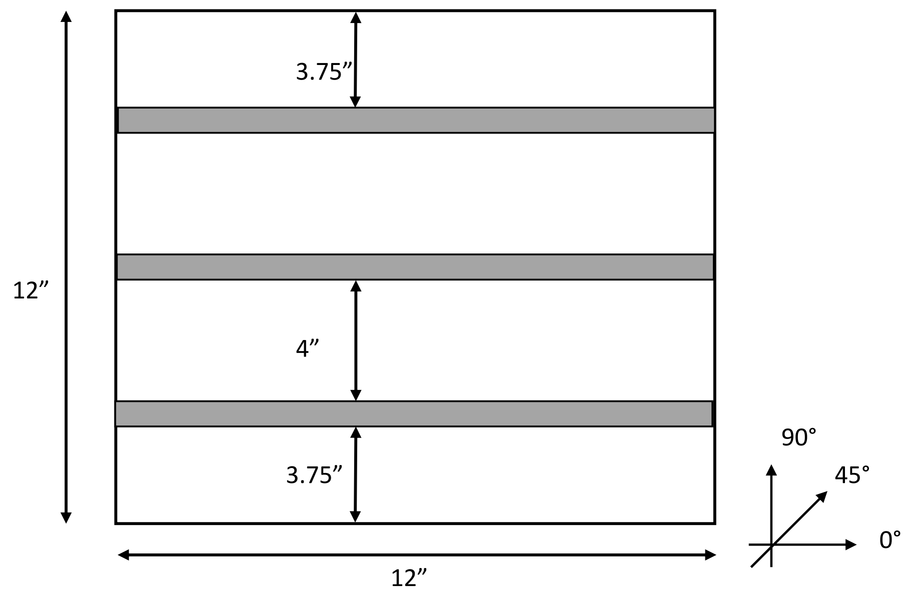
*The breather string must be in contact with the edge of the part and extend beyond the seal to touch the breather pad material as shown in the overhead view below.



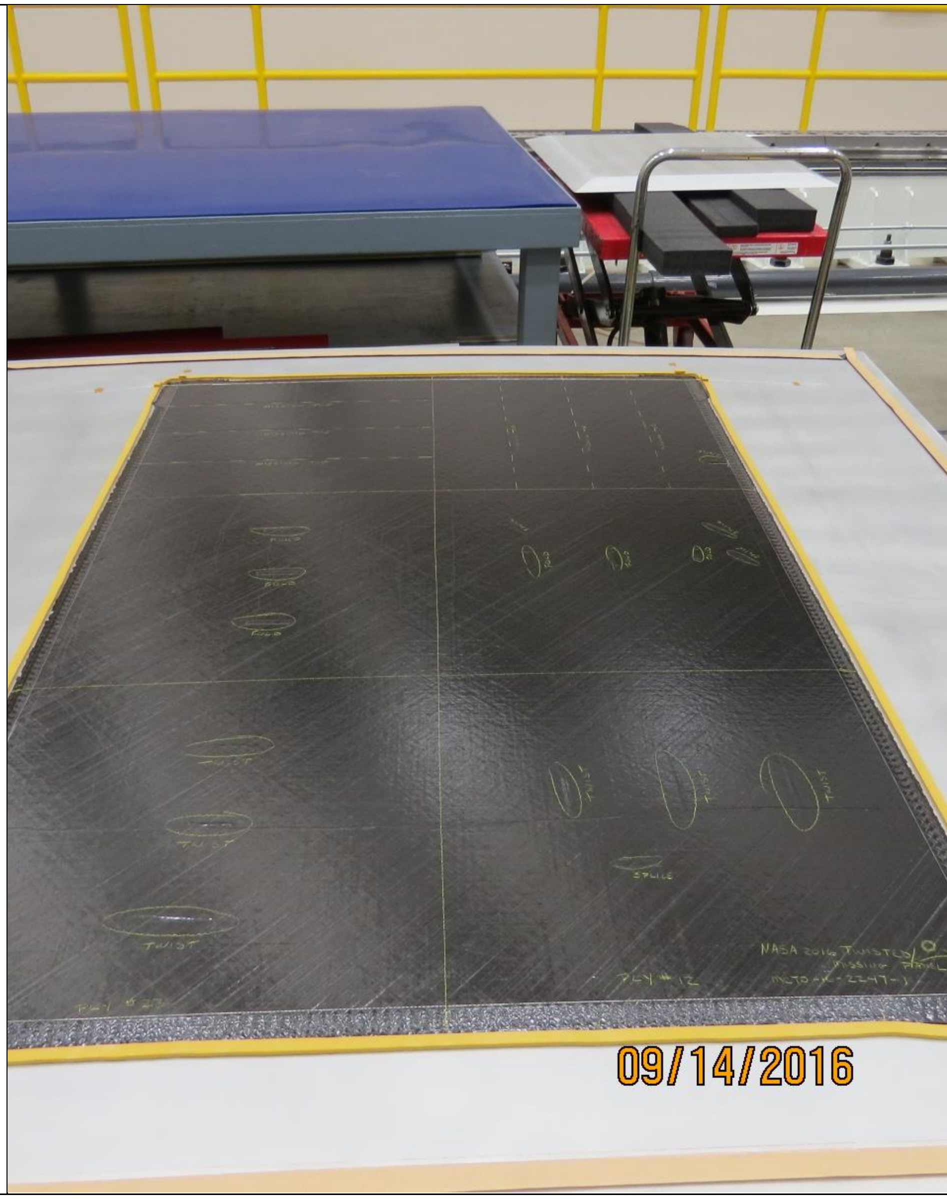
The variable details for each specific panel are described in the individual manufacturing descriptions below.

Inspection

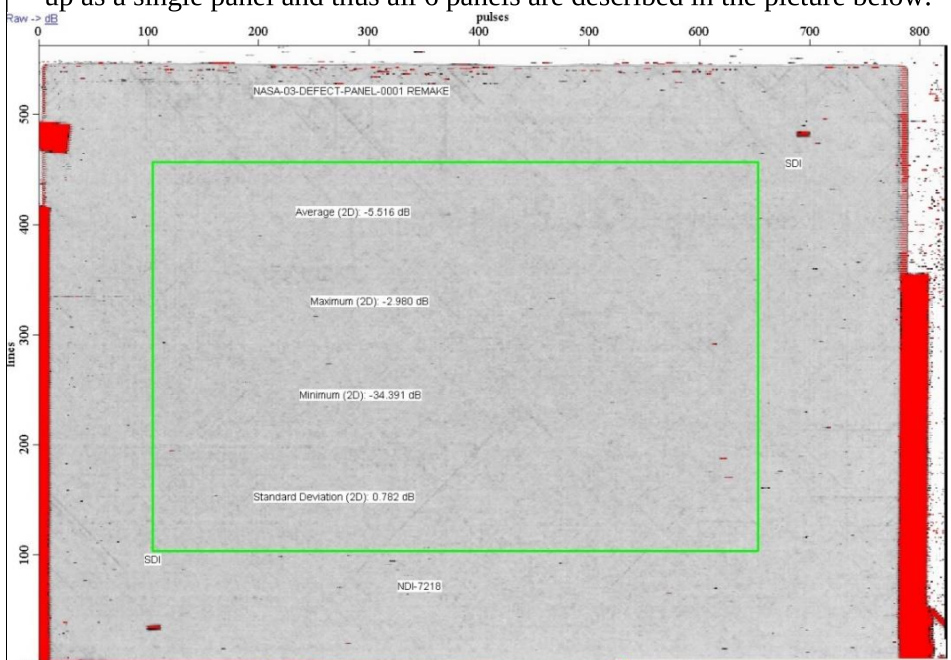
All panels were scanned using an Explorer 5 Mhz TTUT system with water couplant. All initial scanning took place at the Lockheed Martin Aeronautics facility in Palmdale, CA and performed by level three inspectors. These scans are provided in image form in this document.

Standard designation, type, and general purpose. Described/illustrated on slide(s)/ figure(s):	**#57 NASA-03-Twisted-Tow-001** A twisted tow is placed at the 23rd ply in a 24-ply panel. This is a common AFP defect. The location of the defect is to simulate in-situ detection of the flaw. A representation of the panel is shown below where the grey bars represent the tow of interest. Please note the drawing is not to scale. All twisted, Missing, and Folded tow panels were built on a single panel and then machined into the six individual panels. A second defect panel containing all six defects was made after the first one was run with very low pressure in the autoclave in an effort to minimize compacting the defects. That original panel had a large delamination that completely hid any sign of the embedded defects. The second panel was run with 15 psi and was found to have acceptable porosity in general, but more difficult to discern defects. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle,	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** The tows identified are placed as usual, removed, twisted by hand, and then placed back in the appropriate location. Ply is pressed into place using hand pressure and then the following ply fiber placed using the machine on top. Defect locations will be marked on the tool for tracking. **Handling:** Wear clean impervious gloves while handling the material and lab coat.

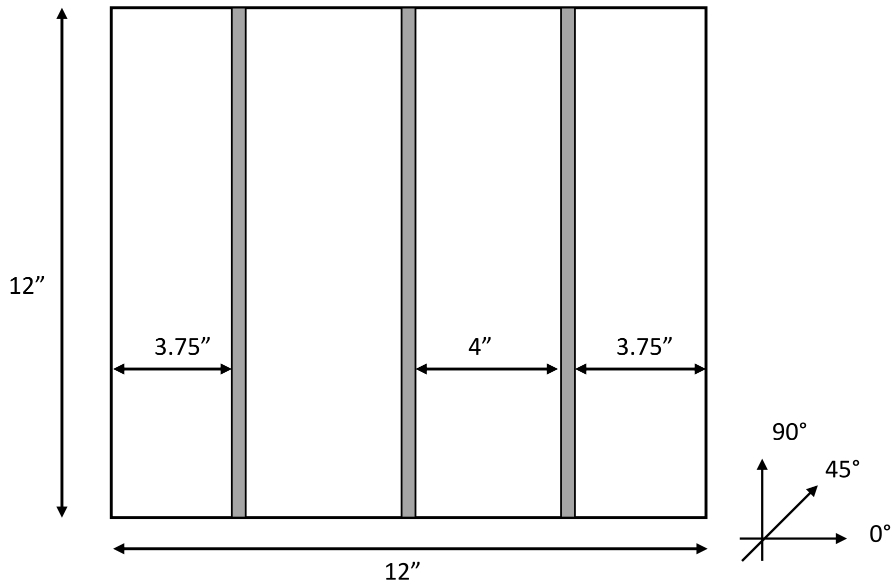
machining) required	**Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Apply full vacuum and 15 psig pressure Heat at 3-5°F/min to 225°F Hold at 225°F for 30-60 minutes Raise pressure to 15 psig (reduced pressure from pristine to reduce compaction on the placed defects) Vent Vacuum when pressure reaches 30 psig Heat at 3-5°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 2-5°F **Machining:** Panels NASA-03-Twisted-Tow-01, NASA-03-Twisted-Tow-02, NASA-03-Missing-Tow-01, and NASA-03-Missing-Tow-02 are fabricated in a single panel and machined to net shape as shown above. Rough machining will be done using a table saw with a grinding wheel or band saw with a diamond blade.
Standard characterization and verification method(s)	Visual Inspection Prior to cure is shown below. Note the circled defects (twists and folds) and the dashed lines (missing tows). Additional images of the defects in question will be included in the relevant sections. Twisted tows are shown in this section.


TWIST
SPLICE
09/14/2016

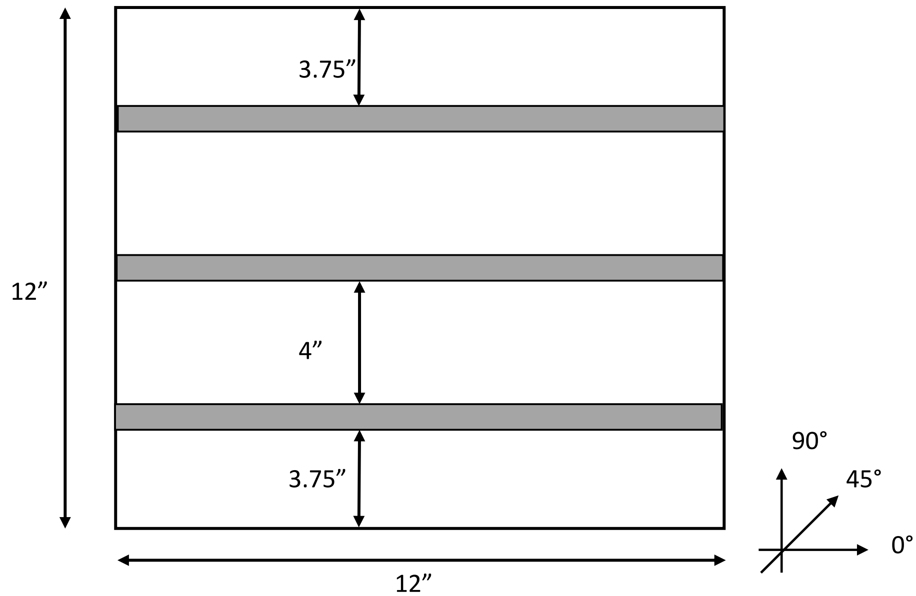
C-Scan performed as per description above. Note that the defect panel was layed up as a single panel and thus all 6 panels are described in the picture below.

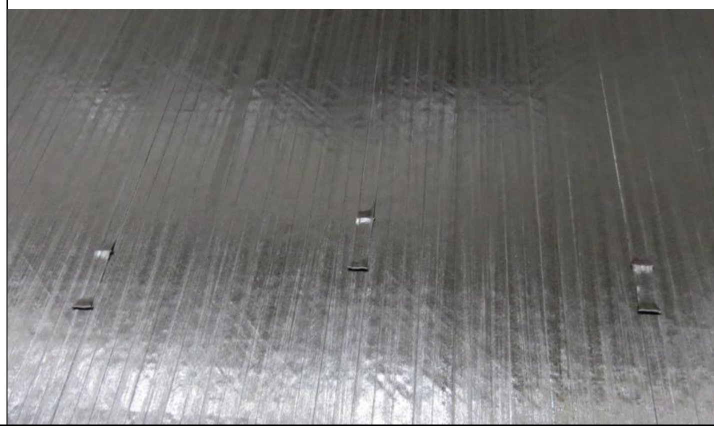


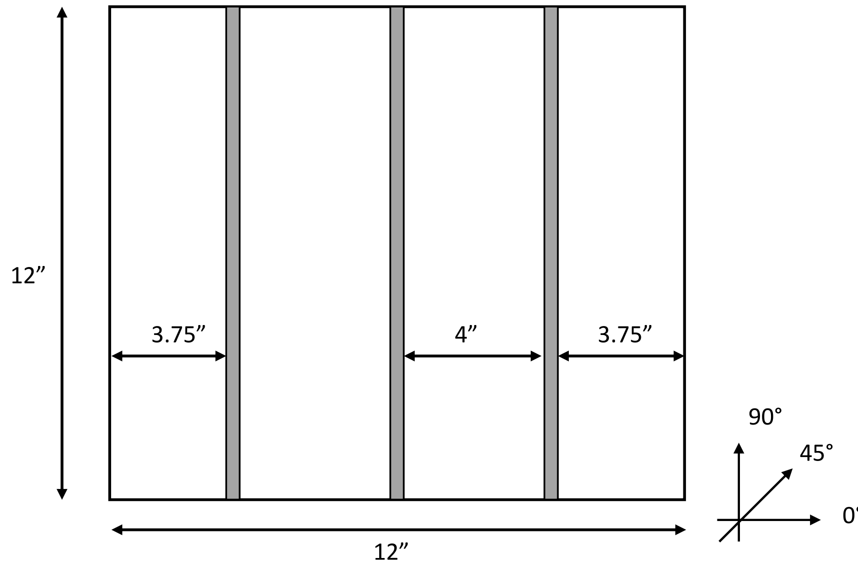
Average (2D): -5.516db
Max (2D): -2.980db
Min (2D): -34.391db
Standard Deviation (2D) 0.782db

Standard designation, type, and general purpose. Described/illustrated on lide(s)/figure(s):	**#58 NASA-03-Twisted-Tow-002** A twisted tow is placed in the middle at the 12th ply in a 24-ply panel. This is a common AFP defect. The location of the defect is to simulate post-cure detection of the flaw. A representation of the panel is shown below where the gray bars represent the tow of interest. Please note the drawing is not to scale. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz. breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete three coats of the release agent. **Defect Placement:** The tows identified are placed as usual, removed, twisted by hand, and then placed back in the appropriate location. Ply is pressed into place using hand pressure and then the following ply fiber placed using the machine on top. Defect locations will be marked on the tool for tracking. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs Feedrate: 300 in/min Roller: 4” wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Apply full vacuum and 15 psig pressure Heat at 3-5°F/min to 225°F

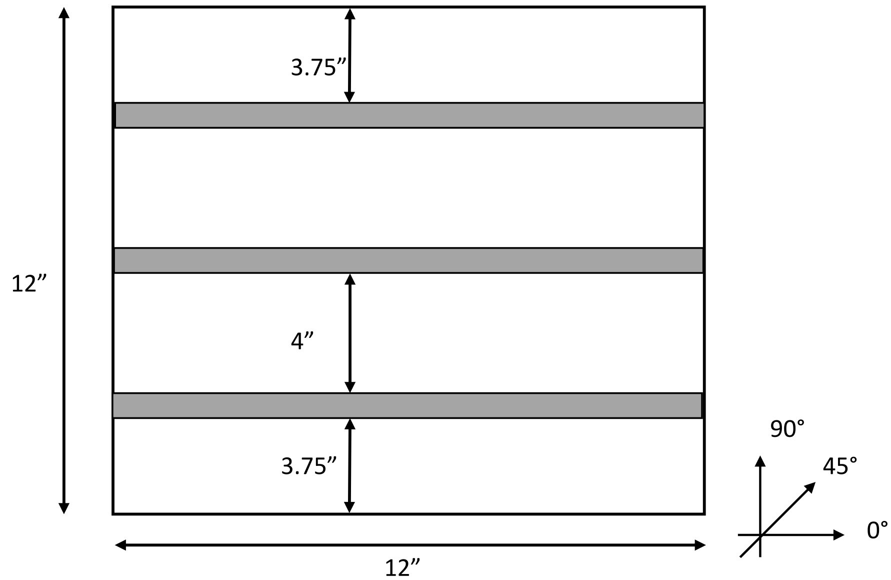
	Hold at 225°F for 30-60 minutes Raise pressure to 15 psig (reduced pressure from pristine to reduce compaction on the placed defects) Vent Vacuum when pressure reaches 30 psig Heat at 3-5°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 2-5°F **Machining:** Panels NASA-03-Twisted-Tow-01, NASA-03-Twisted-Tow-02, NASA-03-Missing-Tow-01, and NASA-03-Missing-Tow-02 are fabricated in a single panel and machined to net shape as shown above. Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade. Panel is milled to final configuration.
Standard characterization and verification method(s)	Description and image provided under NASA-03-Twisted-Tow-001.

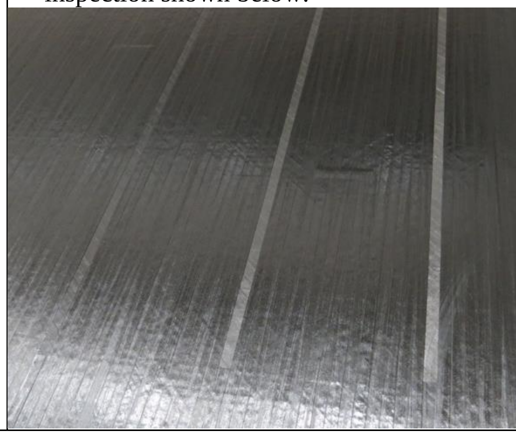
Standard designation, type, and general purpose. Described/illustrated on slide(s)/figure(s):	**#60 NASA-03-Folded-Tow-001** A folded tow will be placed at the 23rd ply in a 24-ply panel. This is a common AFP defect. The location of the defect is to simulate in-situ detection of the flaw. A representation of the panel is shown below where the gray bars represent the tow of interest. Please note the drawing is not to scale. All Twisted, Missing, and Folded tow panels are built on a single panel and then machined into the 6 individual panels. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated ¼” slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminium **Bagging Materials:** A400 Release Film 10 oz. breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** The tows identified is placed as usual, removed, folded by hand, and then placed back in the appropriate location. Ply is pressed into place using hand pressure and then the following ply fiber placed using the machine on top. Defect locations will be marked on the tool for tracking. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Apply full vacuum and 15 psig pressure Heat at 3-5°F/min to 225°F Hold at 225°F for 30-60 minutes Raise pressure to 15 psig (reduced pressure from pristine to reduce compaction on the placed defects) Vent Vacuum when pressure reaches 30 psig

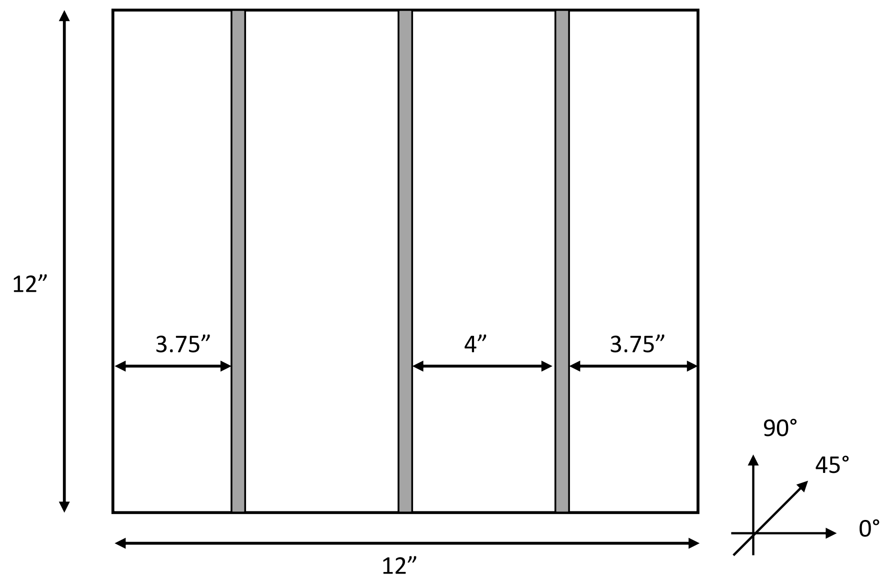
	Heat at 3-5°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 2-5°F **Machining:** Panels NASA-03-Twisted-Tow-01, NASA-03-Twisted-Tow-02, NASA-03-Missing-Tow-01, NASA-03-Missing-Tow-02, NASA-03-Folded-Tow-01, and NASA-03-Folded-Tow-02 are fabricated in a single panel and machined to net shape as shown above. Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade.
Standard characterization and verification method(s)	Description and image provided under NASA-03-Twisted-Tow-001. Folded tows are shown below. 

Standard designation, type, and general purpose. Described/illustrated on slide(s)/figure(s):	**#61 NASA-03-Folded-Tow-002** A folded tow will be placed in the middle at the 12th ply in a 24-ply panel. This is a common AFP defect. The location of the defect is to simulate post-cure detection of the flaw. A representation of the panel is shown below where the gray bars represent the tow of interest. Please note the drawing is not to scale. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz. breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** The tows identified is placed as usual, removed, folded by hand, and then placed back in the appropriate location. Ply is pressed into place using hand pressure and then the following ply fiber placed using the machine on top. Defect locations will be marked on the tool for tracking. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs Feedrate: 300 in/min Roller: 4” wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Apply full vacuum and 15 psig pressure Heat at 3-5°F/min to 225°F Hold at 225°F for 30-60 minutes Raise pressure to 15 psig (reduced pressure from pristine to reduce compaction on the placed defects)

	Vent Vacuum when pressure reaches 30 psig Heat at 3-5°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 2-5°F **Machining:** Panels NASA-03-Twisted-Tow-01, NASA-03-Twisted-Tow-02, NASA-03-Missing-Tow-01, and NASA-03-Missing-Tow-02 are fabricated in a single panel and machined to net shape as shown above. Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade. Panel is milled to final configuration.
Standard characterization and verification method(s)	Description and image provided under NASA-03-Twisted-Tow-001.

Standard designation, type, and general purpose. Described/illustrated on slide(s)/figure(s):	**#62 NASA-03-Missing-Tow-001** A missing tow defect is placed at the 23rd ply in a 24-ply panel. This is a common AFP defect. The location of the defect is to simulate in-situ detection of the flaw. A representation of the panel is shown below where the gray bars represent the tow of interest. Please note the drawing is not to scale. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** The tows identified are placed as usual and then removed by hand. The following ply will then be fiber placed using the machine on top. Defect locations will be marked on the tool for tracking. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs Feedrate: 300 in/min Roller: 4” wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Apply full vacuum and 15 psig pressure Heat at 3-5°F/min to 225°F Hold at 225°F for 30-60 minutes Raise pressure to 15 psig (reduced pressure from pristine to reduce compaction on the placed defects)

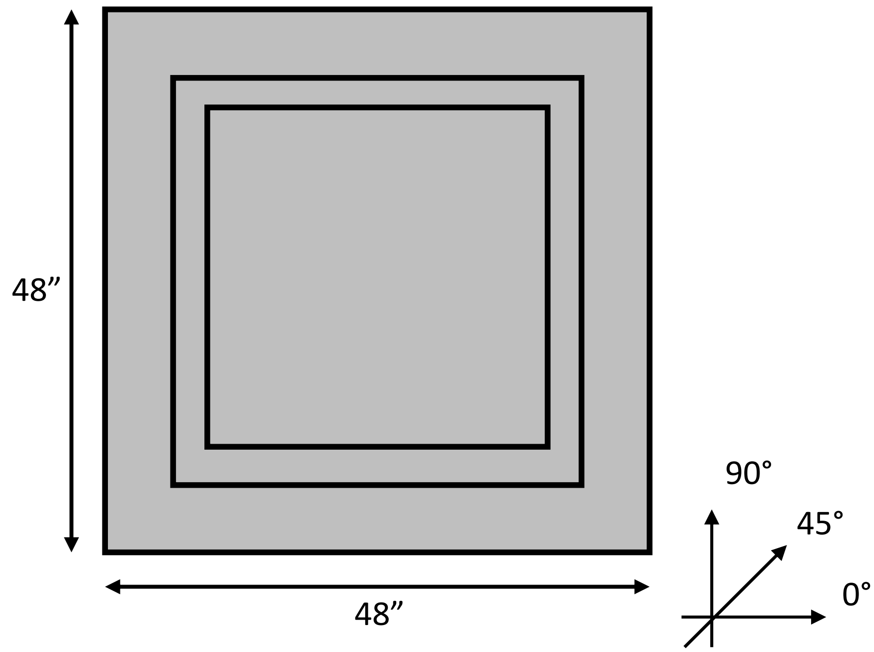
	Vent Vacuum when pressure reaches 30 psig Heat at 3-5°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 2-5°F **Machining:** Panels NASA-03-Twisted-Tow-01, NASA-03-Twisted-Tow-02, NASA-03-Missing-Tow-01, NASA-03-Missing-Tow-02, NASA-03-Folded-Tow-01, and NASA-03-Folded-Tow-02 are fabricated in a single panel and machined to net shape as shown above. Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade.
Standard characterization and verification method(s)	Description and image provided under NASA-03-Twisted-Tow-001. Missing tow visual inspection shown below: 

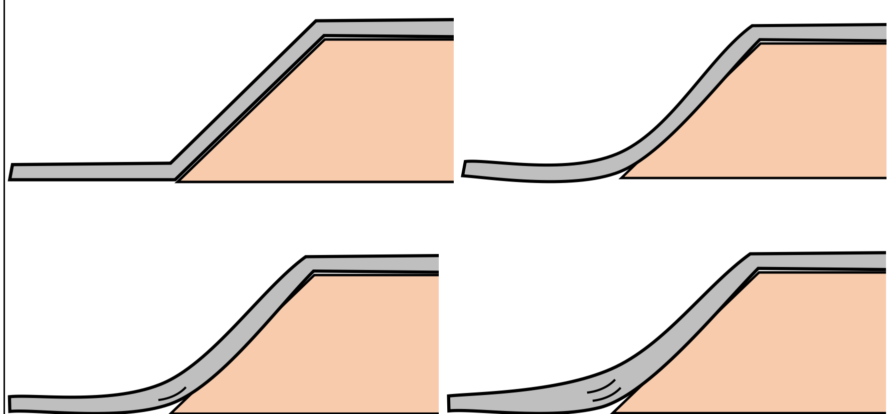
Standard designation, type, and general purpose. Described/illustrated on slide(s)/figure(s):	**#63 NASA-03-Missing-Tow-002** A missing tow defect is placed in the middle at the 12th ply in a 24-ply panel. This is a common AFP defect. The location of the defect is to simulate post-cure detection of the flaw. A representation of the panel is shown below where the gray bars represent the tow of interest. Please note the drawing is not to scale. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** The tows identified is placed as usual and then removed by hand. The following ply will then be fiber placed using the machine on top. Defect locations will be marked on the tool for tracking. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs Feedrate: 300 in/min Roller: 4” wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Apply full vacuum and 15 psig pressure Heat at 3-5°F/min to 225°F Hold at 225°F for 30-60 minutes Raise pressure to 15 psig (reduced pressure from pristine to reduce compaction on the placed defects)

	Vent Vacuum when pressure reaches 30 psig Heat at 3-5°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 2-5°F **Machining:** Panels NASA-03-Twisted-Tow-01, NASA-03-Twisted-Tow-02, NASA-03-Missing-Tow-01, NASA-03-Missing-Tow-02, NASA-03-Folded-Tow-01, and NASA-03-Folded-Tow-02 are fabricated in a single panel and machined to net shape as shown above. Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade. Panel is milled to final configuration.
Standard characterization and verification method(s)	Description and image provided under NASA-03-Twisted-Tow-001.

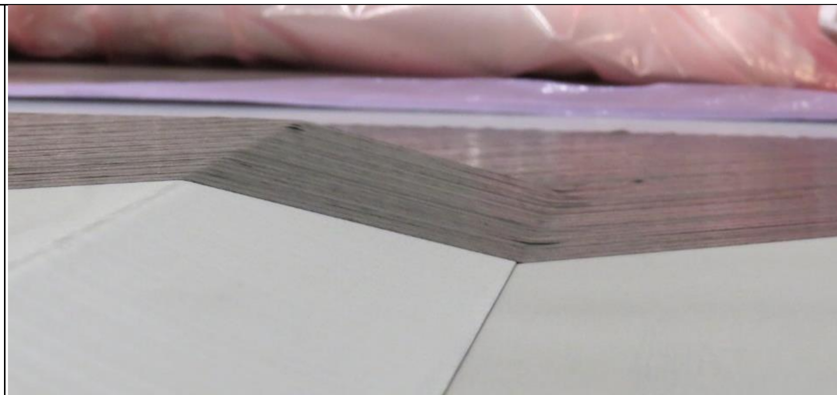
<table>
<tr>
<td>Standard designation, type, and general purpose.

Described/illustrated on slide(s)/figure(s):</td>
<td>#64, #65, #66, #67 NASA-03-Bridged-Joggle-001, -002, -003 and -004

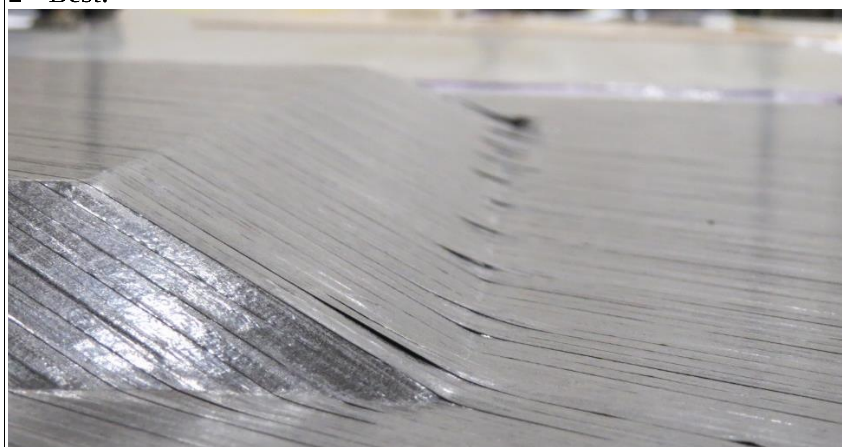
A single panel will be fiber placed with an integral joggle typical of a door. The four edges of the joggle will have varying machine settings applied including tow tension and overfeed which will generate varying levels of bridging in the radii. Please note the drawing is not to scale. The first drawing is the overhead view while the following four drawings are cross sectional representations of the varying level of bridging along each of the edges. Those four cross sections are what will represent standard panels NASA-03-Bridged-Joggle-001, -002, -003, and -004.


</td>
</tr>
<tr>
<td>List of materials, processes, tools and equipment used for the fabrication of the standard.</td>
<td>Material: IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape
Ply Schedule: [45/0/-45/90]3s
Tool Type: Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum
Bagging Materials:
A400 Release Film
10 oz. breather cloth (N10)
Silicone Edge Dam</td>
</tr>
</table>

	Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** A fiberglass insert is bonded onto the surface of the metal tool. This fiberglass tool will represent the door and create the joggle to be built. After the fiberglass insert is bonded, the tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** The defects are developed using a combination of tow tension settings and pinch overfeed. The exact values are not known at this time, but will be provided upon completion of the panels. These values will affect varying plies as the impact the edge under consideration. The effects of the autoclave pressure on the radii will also need to be examined and experimented with. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs Feedrate: TBD Roller: 4” wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Cure Cycle used follows Hexcel’s recommended autoclave cycle: Apply full vacuum and 15 psig pressure Heat at 4°F/min to 225°F Hold at 225°F for 60 minutes Raise pressure to 15 psig (minimize pressure to reduce compaction on the radii) Vent Vacuum when pressure reaches 30 psig Heat at 4°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 4°F **Machining:** Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade.
Standard characterization and verification method(s)	Visual inspection is done at two times. The first images taken while laying up the first ply (a 45°) shown below. Best:

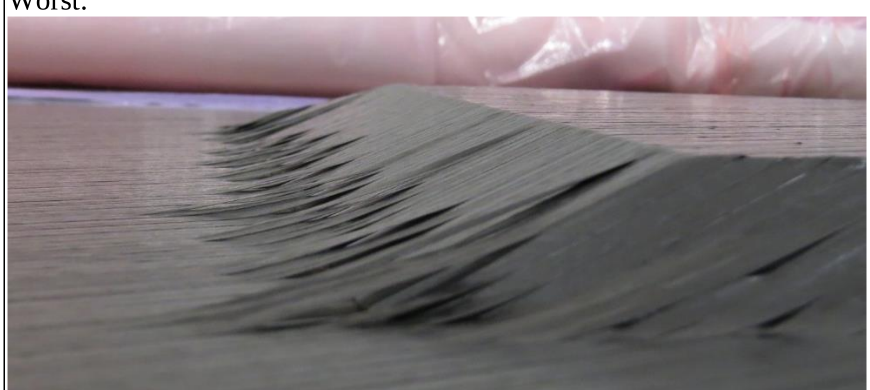


2nd Best:

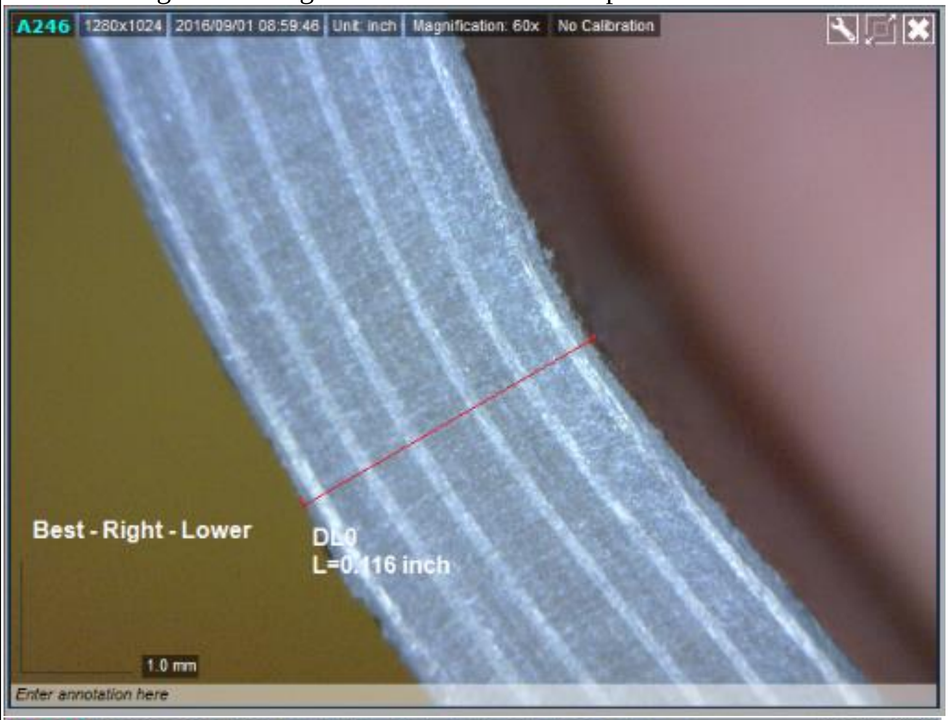


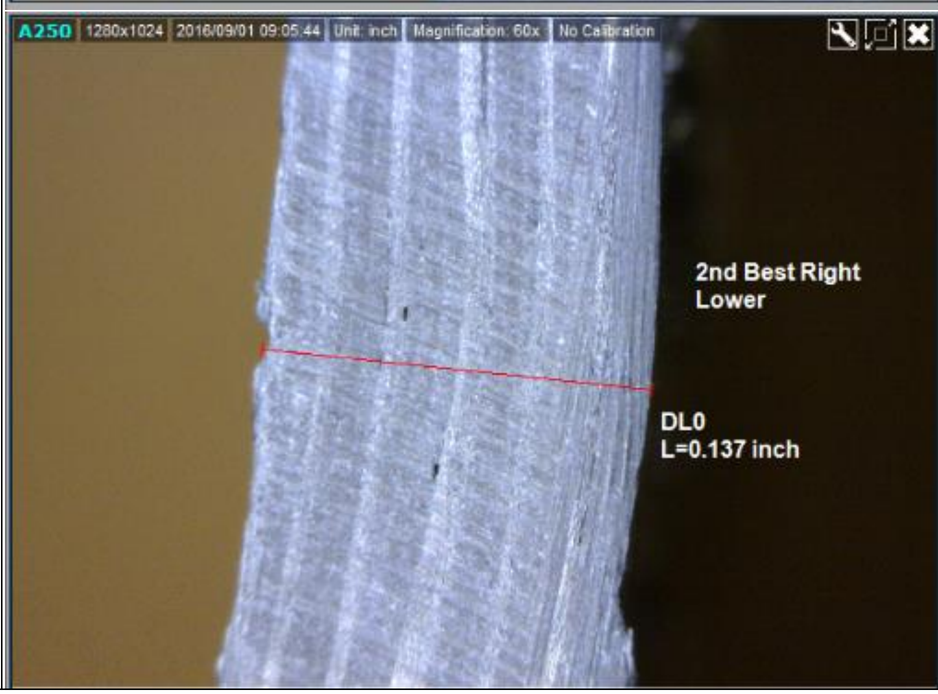
2nd Worst:

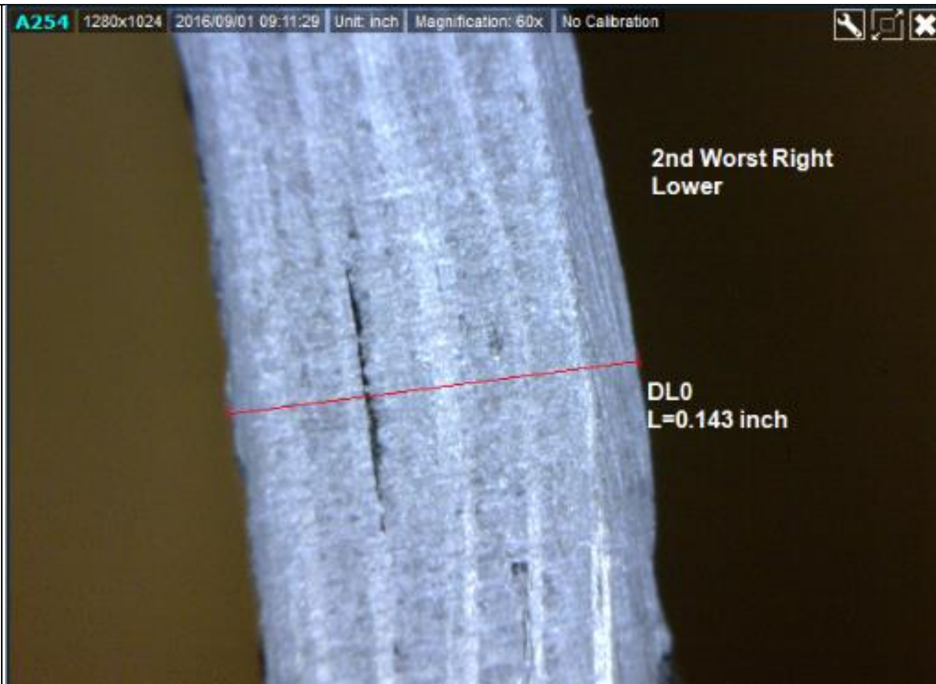
Worst:



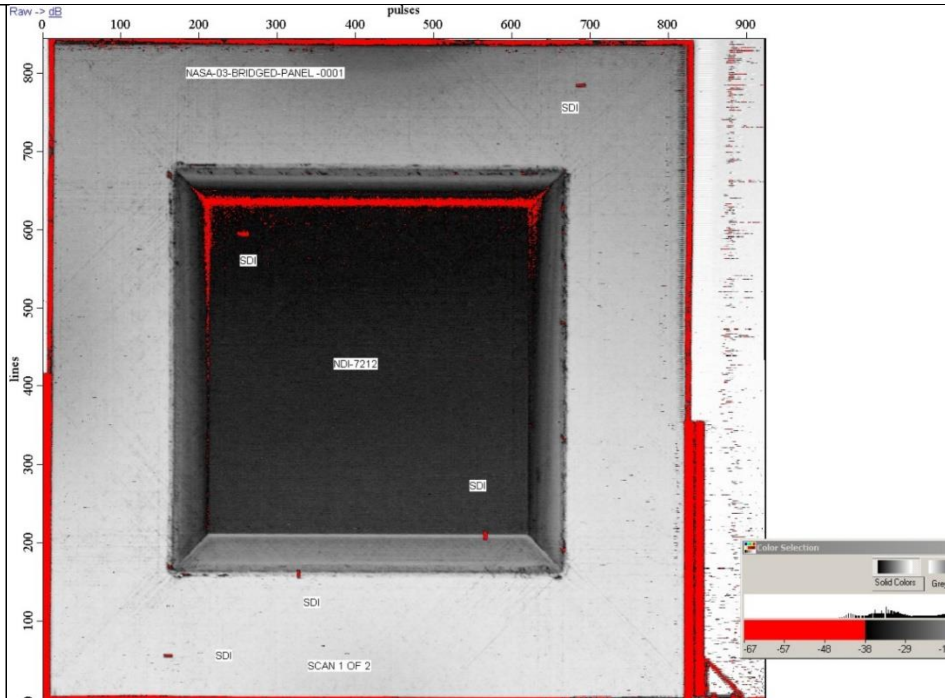
The following visual images are from uncalibrated photos taken after cure:



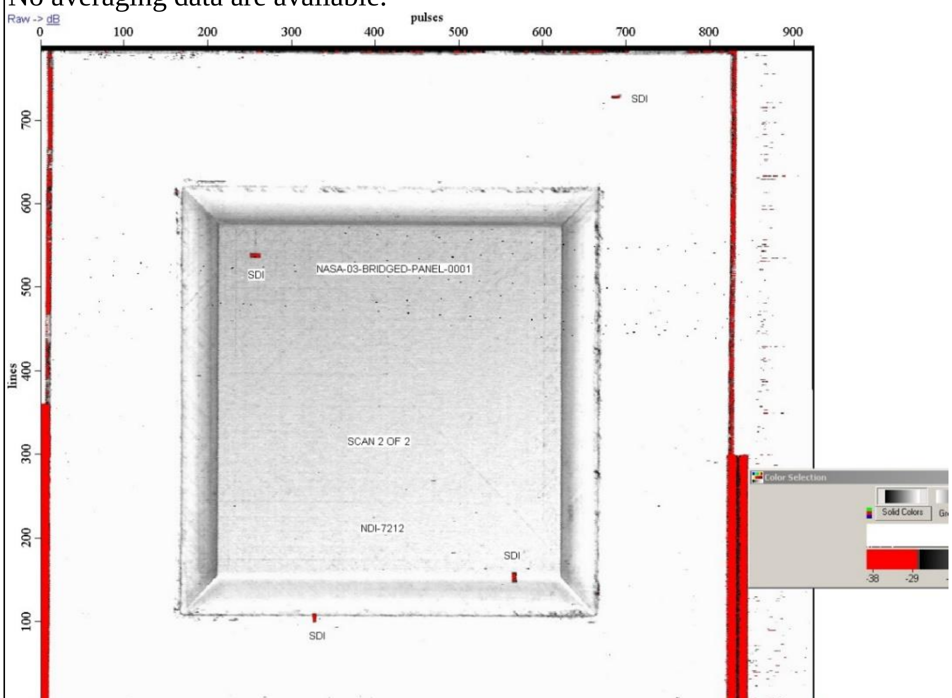




C-Scan performed as per description above. The radii were not inspected for porosity as the radius is below 1”. Two images are taken, one for the flat monolithic laminate on the periphery and one for the laminate in the core-stiffened region.

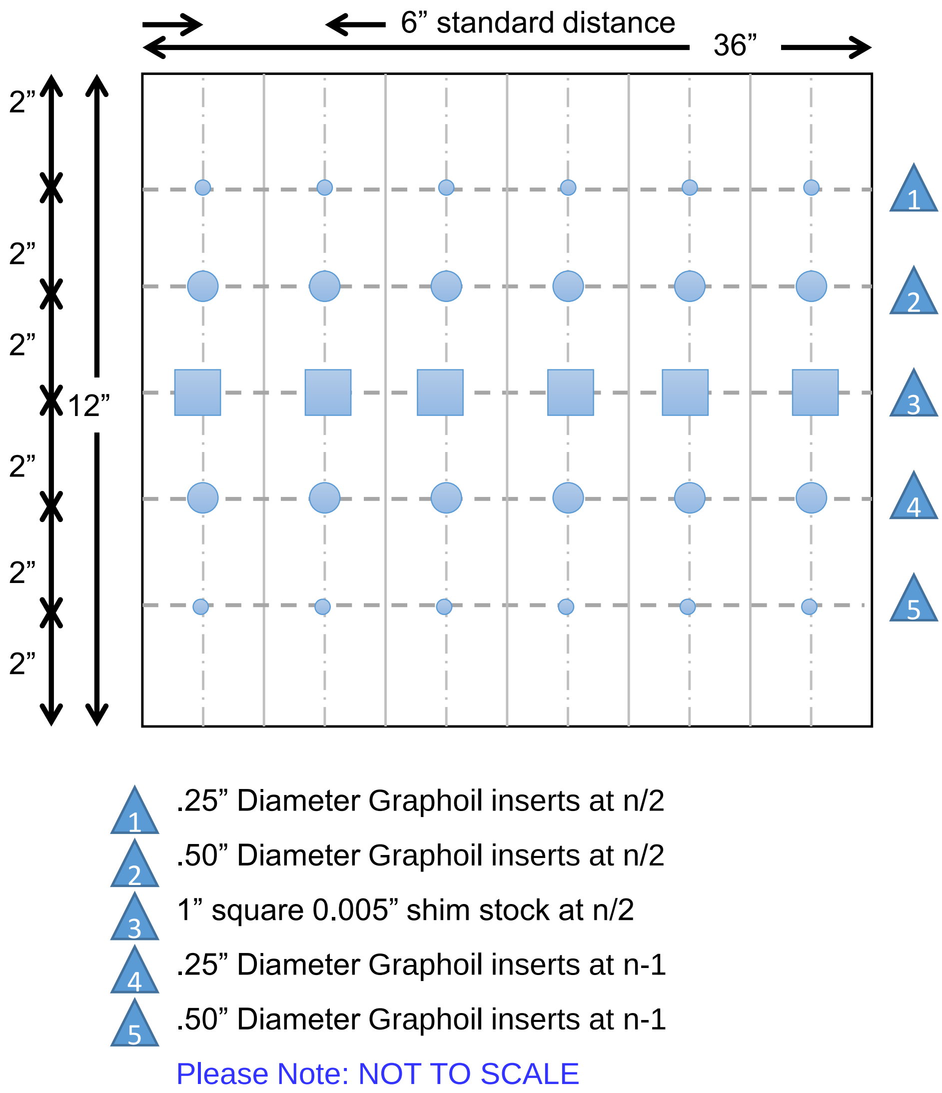


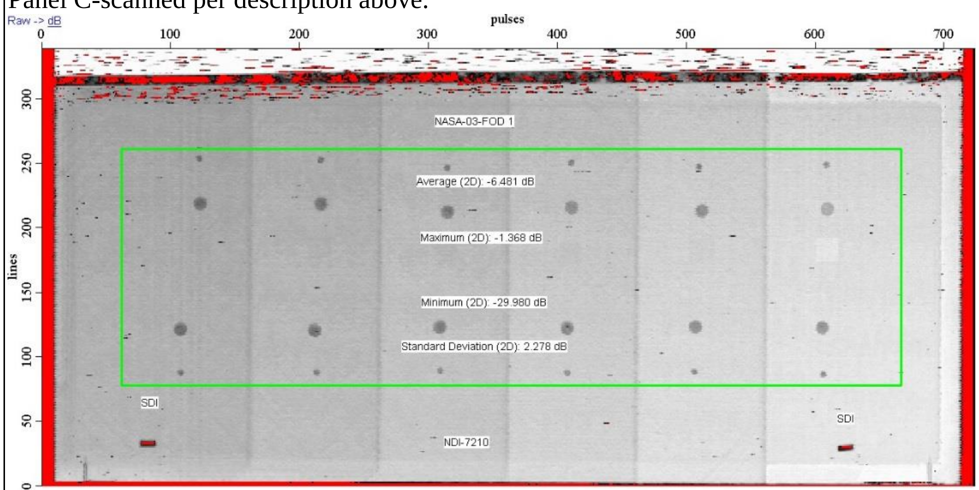
No averaging data are available.

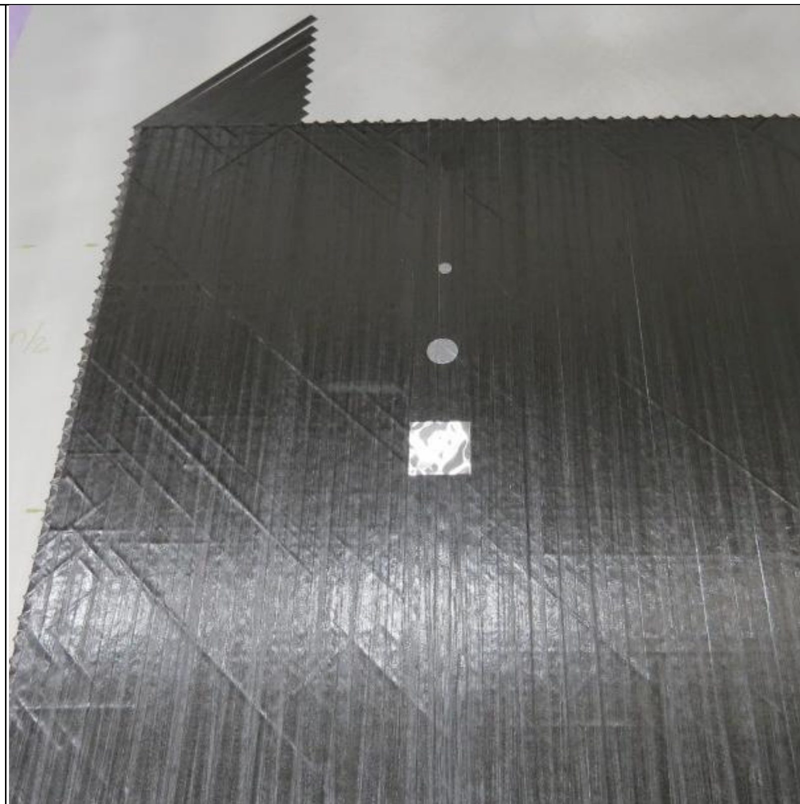


D.3.2 FOD Panel

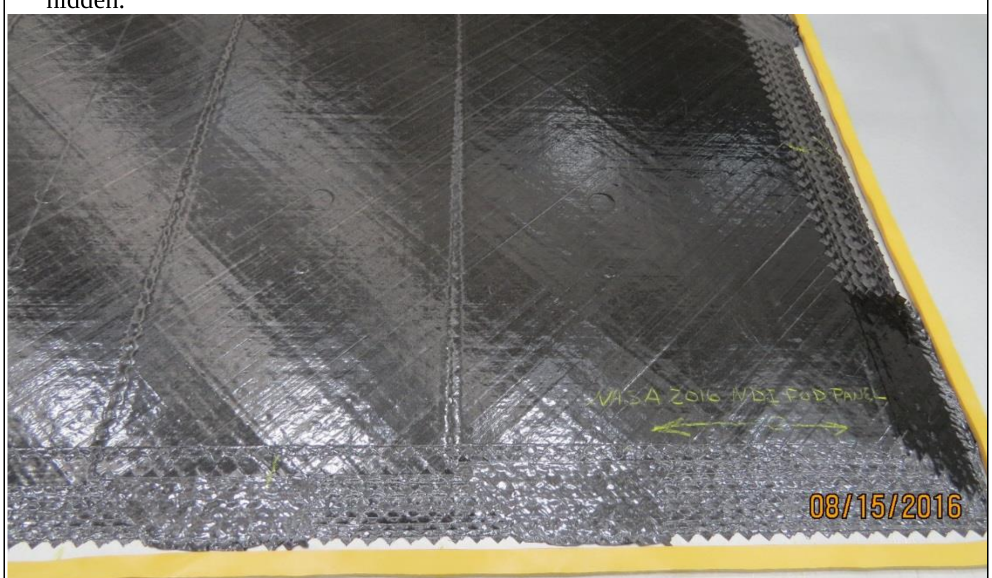
D.3.2.1 Specimens #68

Standard designation, type, and general purpose. Described/illustrated on slide(s)/figure(s):	**#68 NASA-03-FOD-Panel-001** The FOD panel will include varying sizes of Graphoil inserts placed at the Mid-ply for varying thicknesses. Please note the drawing is not to scale. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** Varying from 8 to 48 plies. Full schedule to be included after fabrication. **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz. breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material Graphoil Inserts

Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** Graphoil inserts is placed at the mid ply of the stackup. Ply will vary from 8 plies to 48 plies in 8 ply increments. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs/TBD Feedrate: 300 in/min Roller: 4" wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Cure Cycle used follows Hexcel's recommended autoclave cycle: Apply full vacuum and 15 psig pressure Heat at 4°F/min to 225°F Hold at 225°F for 60 minutes Raise pressure to 100 psig Vent Vacuum when pressure reaches 30 psig Heat at 4°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 4°F **Machining:** Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade.
Standard characterization and verification method(s)	Panel C-scanned per description above.  Note that the shim stock (center square) is barely visible on the thinnest section of the FOD panel. The graphene inserts though show up vividly all thicknesses and depths. The image below shows the placement of the first 3 inserts at the mid-depth of the 8-ply section.

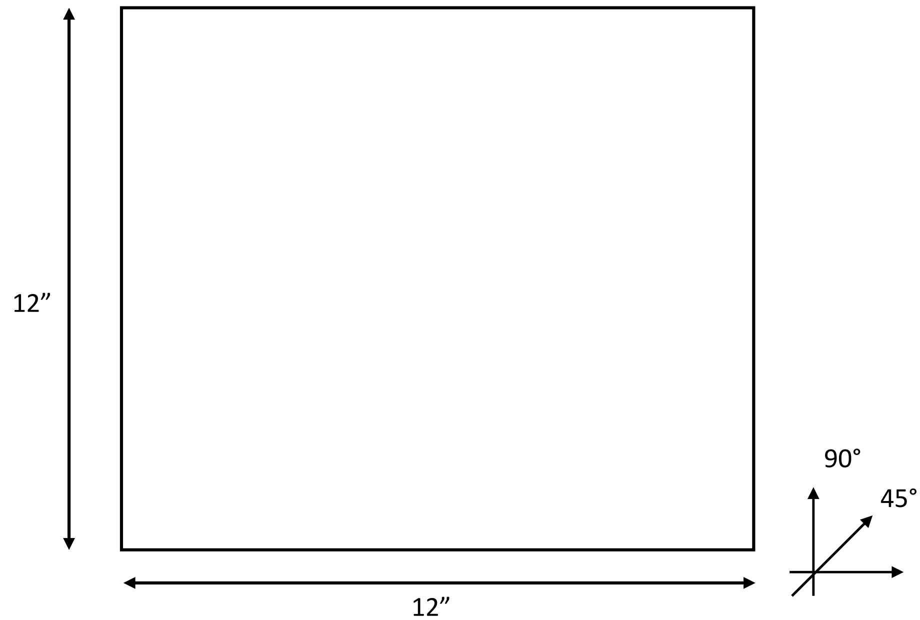


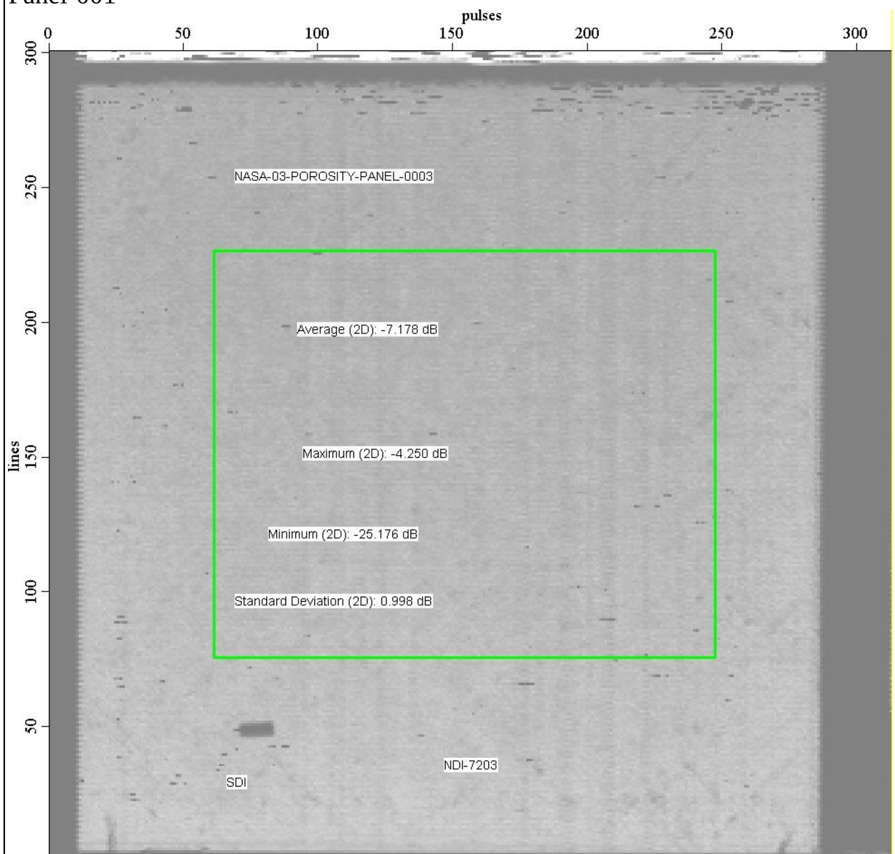
The image below shows the completed panel pre-cure. The circular inserts at n-1 depth are barely visible in the image below while the inserts at n/2 are almost completely hidden.

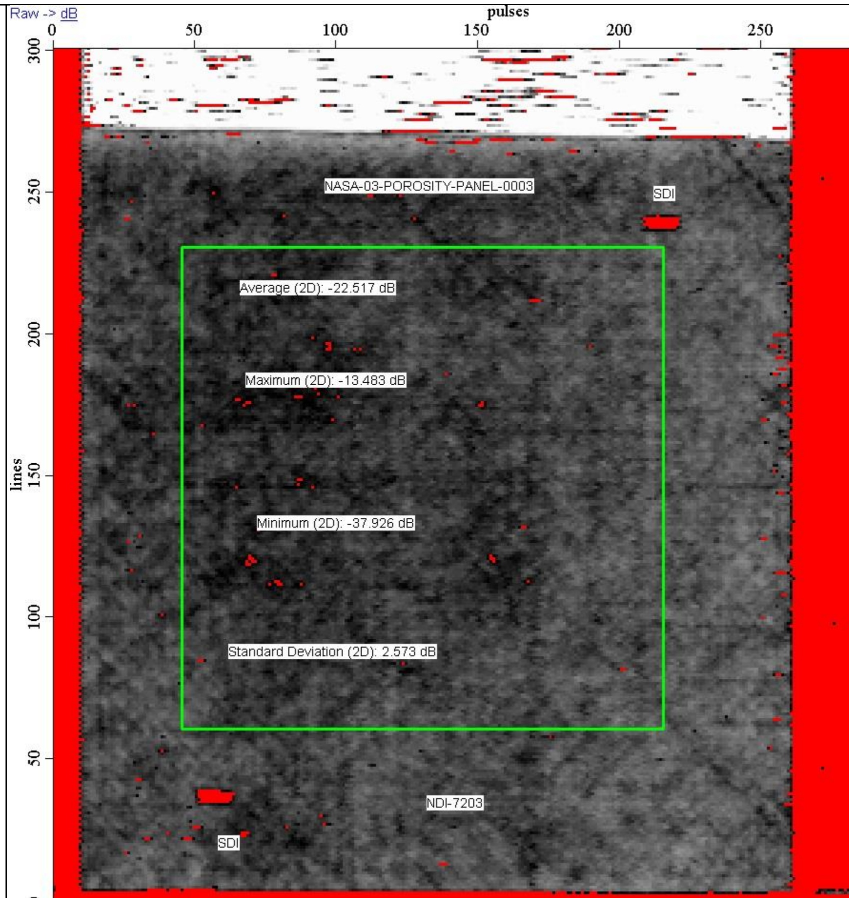


D.3.3 Porosity Panels

D.3.3.1 Specimens #69, 70, 71A&B, 72A&B

Standard designation, type, and general purpose. Described/illustrated on slide(s)/figure(s):	**#69, #70, #71A&B, #72A&B NASA-03-Porosity-Panel-001, -002, -003, and -004** The four separate porosity panels will represent a pristine (-001), an acceptable (-002), a moderate (-003) and a severe (-004) levels of porosity. Please note the drawing is not to scale. 
List of materials, processes, tools and equipment used for the fabrication of the standard.	**Material:** IM7/8552-1 Carbon Fiber/Epoxy full impregnated 0.25-inch slit tape **Ply Schedule:** [45/0/-45/90]3s **Tool Type:** Utilize a rolling cart capable of withstanding the autoclave. The tool surface will be either steel or aluminum **Bagging Materials:** A400 Release Film 10 oz. breather cloth (N10) Silicone Edge Dam Edge Breather Tape Vacuum Bagging Material
Fabrication processes and procedures (e.g., material type, tool prep, material handling requirements, defect placement, ply debulk intervals, bagging, cure cycle, machining) required	**Tool Prep:** The tool is cleaned with acetone followed by a thorough wipe down with a release agent such as Frekote 710 LV. Complete 3 coats of the release agent. **Defect Placement:** Porosity in the panel is generated by varying the amount of pressure in the autoclave. The delta db between 100psi and 15psi is still considered acceptable, while no pressure and no vacuum after the 225F hold was severe. The “moderate” was generated using 5- psi autoclave pressure. **Handling:** Wear clean impervious gloves while handling the material and lab coat. **Machine Settings:** Heater: 110F Compaction: 165lbs/TBD Feedrate: 300 in/min Roller: 4” wide Roller Durometer 40 Shore A **Debulk:** First ply debulk to ensure the laminate is firm to the tool surface. No further debulking is required as AFP provides compaction. **Cure Cycle:** Cure Cycle used follows Hexcel’s recommended autoclave cycle: Apply full vacuum and 15 psig pressure (except for -004, no autoclave pressure) Heat at 4°F/min to 225°F Hold at 225°F for 60 minutes

	Raise pressure to: 100 psig for -001 15 psig for -002 5 psig for -003 0 psig for -004 Vent Vacuum when pressure reaches 30 psig (vent vacuum from -004 when temperature hits 350°F) Heat at 4°F/min to 350°F Hold at 350°F for 120 +/-10 minutes Cool at 4°F **Machining:** Rough machining is done using a table saw with a grinding wheel or band saw with a diamond blade. Panel is milled to final configuration.
Standard characterization and verification method(s)	C-Scan performed as per description above. Panel-001  Average (2D): -7.178db Max (2D): -4.25db Min (2D): -25.176db Standard Deviation (2D) 0.998db Porosity-003



Average (2D): -22.517db
Max (2D): -13.483db
Min (2D): -37.926db
Standard Deviation (2D) 2.573db

Sections are removed from the bottom edges of all four panels. These cutouts can be used to generate photo-mics to get a 2D representation of the porosity in the panel as well as help determine the location and shapes of the porosity (inter-laminar vs. intra-laminar).

D.4 Manufacturing Information for NDE Standards Provided by Consortium Member #4

Consortium Member Number	Specimen Number/Name	Description
4	81	6 × 6-inch 8-ply IM7/8552 [(45/90/-45/0)]S 1 impact
4	82	3 × 5-inch 8-ply IM7/8552 [(45/90/-45/0)]S 1 impact
4	83	3 × 5-inch 8-ply IM7/8552 [(45/90/-45/0)]S 1 impact
4	84	11 × 11-inch 8-ply IM7/8552 [(45/90/-45/0)]S Spare. No impact
4	85	22 × 22-inch 8-ply IM7/8552 [(45/90/-45/0)]S 4 impacts in center 8 × 8-inch square
4	86	6 × 6-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 1 impact
4	87	3 × 5-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 1 impact
4	88	3 × 5-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 1 impact
4	89	22 × 22-inch 16-ply IM7/8552 [(45/90/-45/0)2]S 4 impacts in center 8 × 8-inch square
4	90	6 × 6-inch 24-ply IM7/8552 [(45/90/-45/0)3]S 1 impact
4	91	3 × 5-inch 24-ply IM7/8552 [(45/90/-45/0)3]S 1 impact
4	92	3 × 5-inch 24-ply IM7/8552 [(45/90/-45/0)3]S 1 impact
4	93	6 × 6-inch 32-ply IM7/8552 [(45/90/-45/0)4]S 1 impact
4	94	3 × 5-inch 32-ply IM7/8552 [(45/90/-45/0)4]S 1 impact
4	95	3 × 5-inch 32-ply IM7/8552 [(45/90/-45/0)4]S 1 impact

4	96	6 × 6-inch 18-ply IM7/8552 [45/90/-45/0/0/45/90/-45/0]S 1 impact
4	97	3 × 5-inch 18-ply IM7/8552 [45/90/-45/0/0/45/90/-45/0]S 1 impact
4	98	3 × 5-inch 18-ply IM7/8552 [45/90/-45/0/0/45/90/-45/0]S 1 impact

D.4.1 Impact Specimens #81-98

Introduction

Seventeen specimens were manufactured with a range of thicknesses, layups, and sizes of interest and later impacted to create manufacturing-type impact damage standards, as shown below in Table D.4-1. All panels were layed up using a quasi-isotropic stacking sequence, with the exception of a particular layup sequence of interest to ACP Tech Challenge 1 containing 18 plies. Two large specimens, measuring 22 × 22 inches with thicknesses of 8 and 16 plies were manufactured with the particular intent to provide impact standards for Shearography measurements. Five 6 × 6-inch panels and 10 3 × 3-inch panels were made for XCT, thermography, and ultrasonic standards. The panels were cured using as shown in Figure D.4.1. Impacts were performed to represent tool drops and other manufacturing-type impact damage scenarios, with an impactor mass of 3.817 lbs and an impactor tip of 1.0 inches in diameter. Ultrasonic validation was performed after impact, and if no damage was found the location was impacted again at a higher energy (subsequent impacts denoted by 'b,' 'c,' 'd' events as appropriate). Unless otherwise noted, impacts were targeted to the center of the specimen.

Table D.4-1. Configurations of impact specimen standards.

Configuration	Q-I	Layup	# Plies	Thickness (in)	(panel size (in))*# panels Specimen #		
TC1	No	[45/90/-45/0/0/45/90/-45/0]S	18	0.3		(6x6)*1 #96	(3x5)*2 #97 & #98
QI-45 24ply	Yes	[(45/90/-45/0)3]S	24	0.173		(6x6)*1 #90	(3x5)*2 #91 & #92
QI-45 32ply	Yes	[(45/90/-45/0)4]S	32	0.231		(6x6)*1 #93	(3x5)*2 #94 & #95
QI-45 16ply	Yes	[(45/90/-45/0)2]S	16	0.116	(22x22)*1 #89	(6x6)*1 #86	(3x5)*2 #87 & #88
QI-45 8ply	Yes	[(45/90/-45/0)]S	8	0.058	(22x22)*1 #85	(6x6)*1 #81	(3x5)*2 #82 & #83

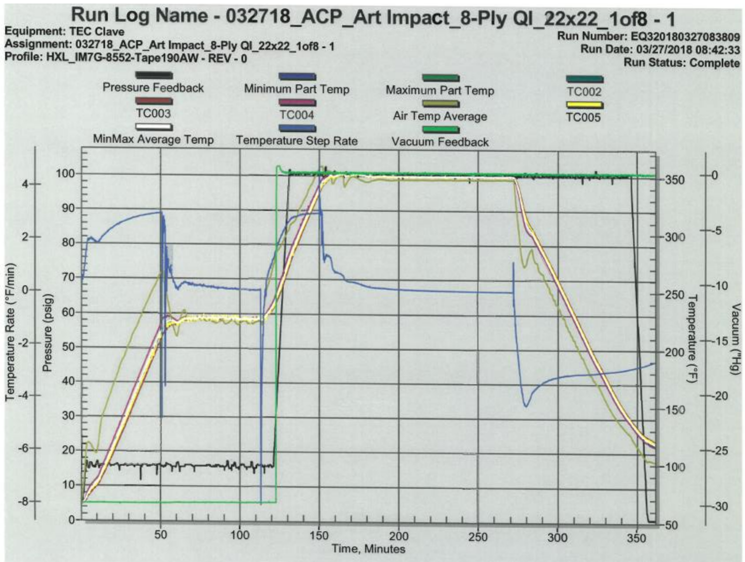
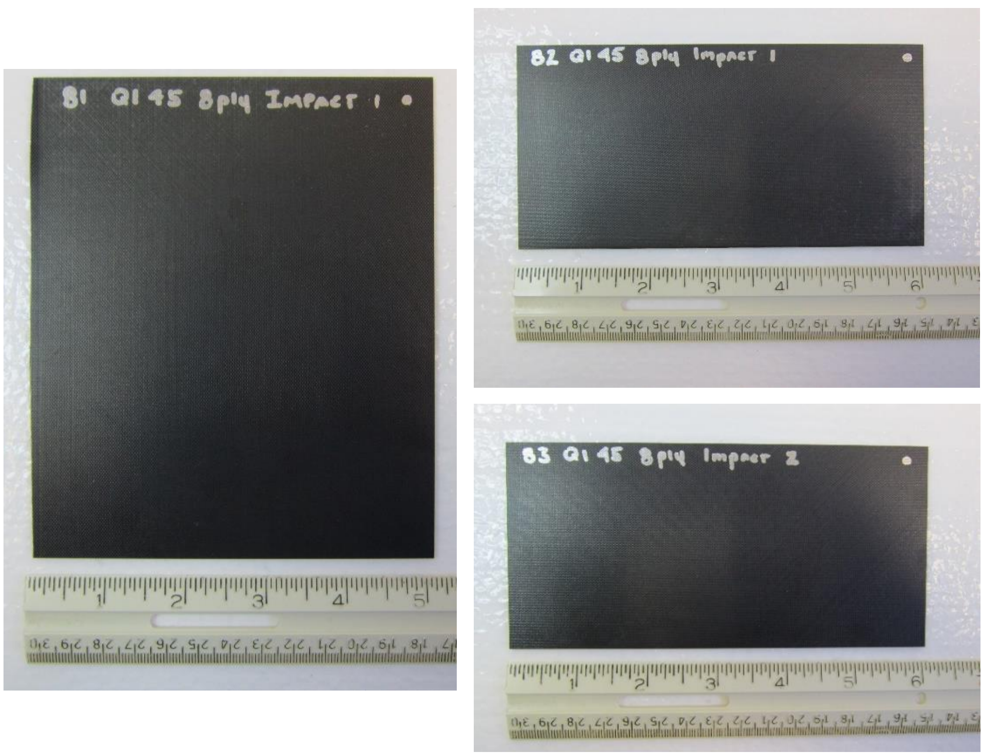


Figure D.4-1. TEC cure graphs.

D.4.1.1 Specimen #81-83: 8-ply Impact Specimens



Impact energies to create damage

Specimen/ Impact #	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
82	3x5	1.8	0.82
83	3x5	1.5	0.37
81	5x6	1.5	0.34

D.4.1.2 Specimen #84: Spare 8-ply Impact Specimen

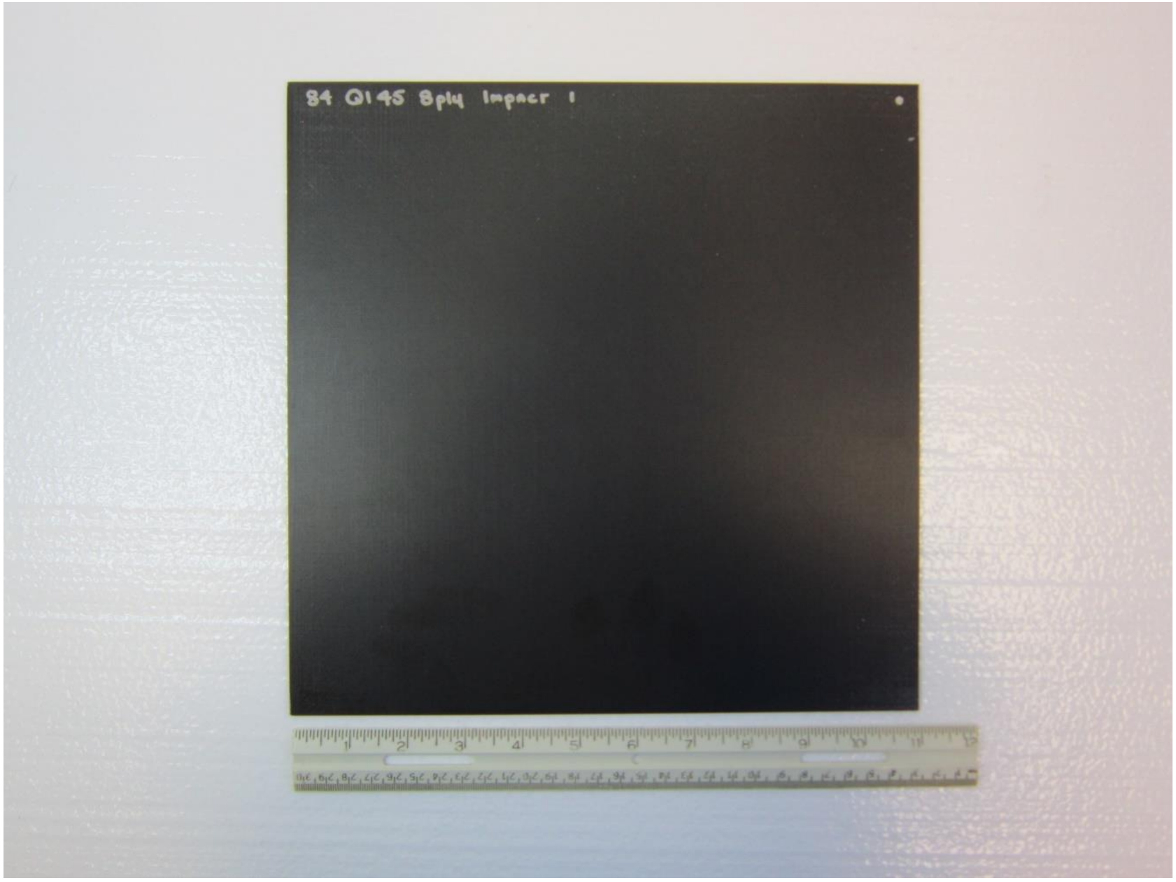
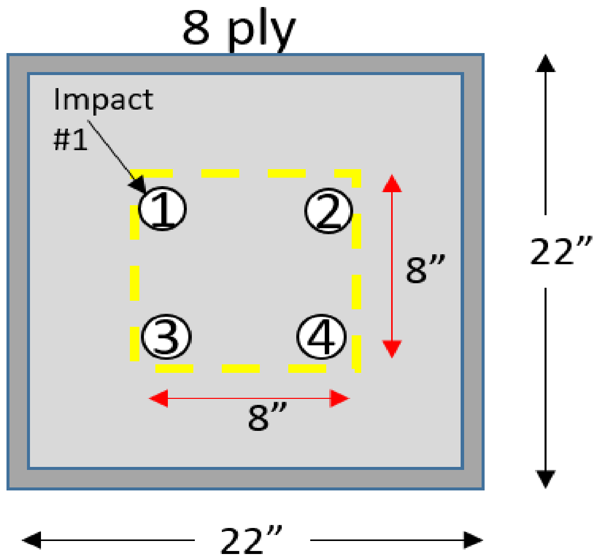


Figure D.4-2. An 11 × 11-inch spare impact panel created but not impacted.

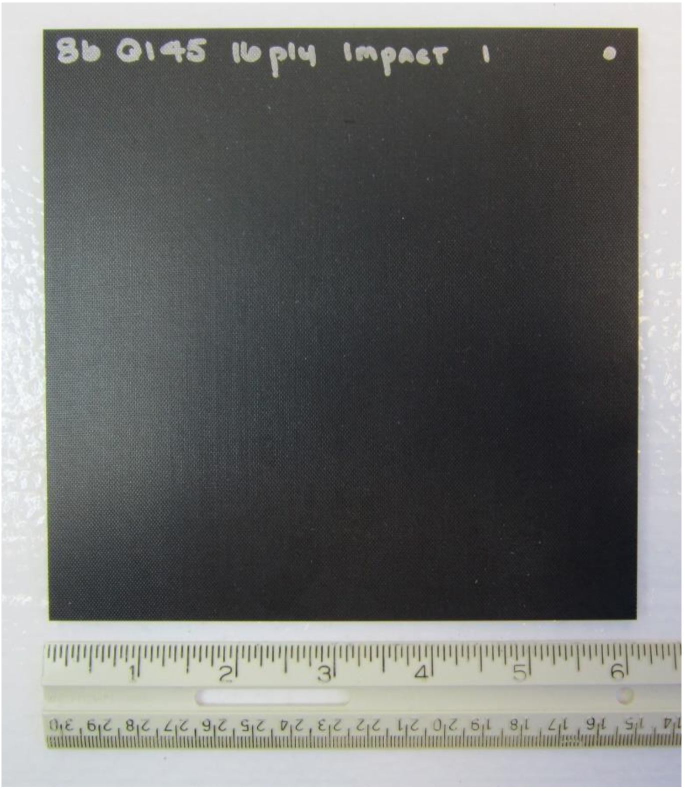
D.4.1.3 Specimen #85

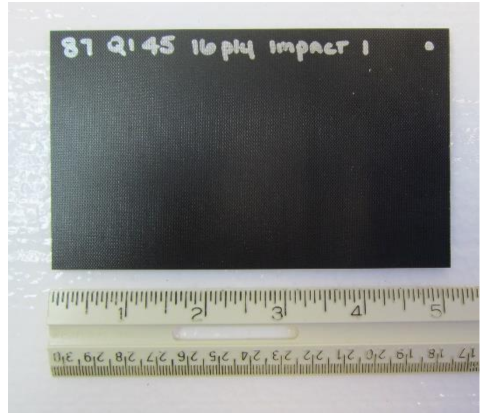


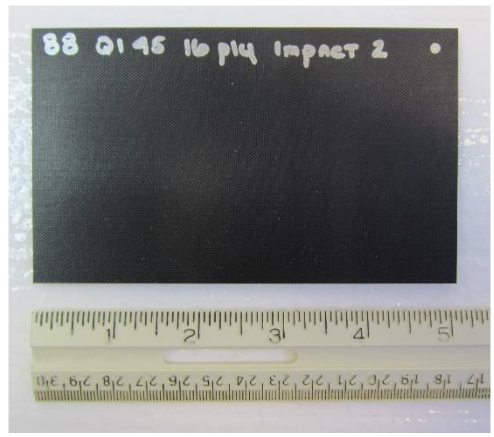
Impact energies to create damage

Specimen/ Impact #	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
85-1a	22x22	4	0
85-2	22x22	5	0.22
85-3	22x22	6	0.33
85-4	22x22	7	0.38
85-1b	22x22	8	0.54

D.4.1.4 Specimen #86-88: 16-ply Impact Specimens





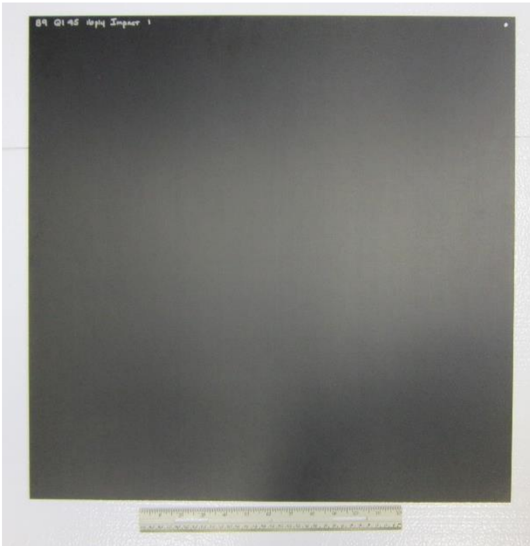


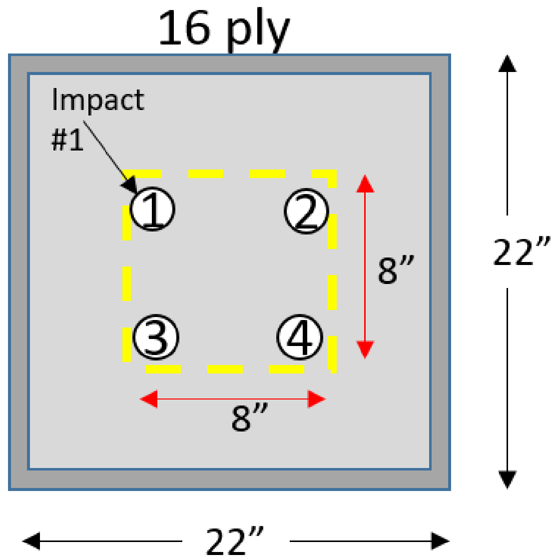
Impact energies to create damage

Specimen/ Impact Info*	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
86a	6x6	2.5	0
86b	6x6	3.2	0
86c	6x6	3.75	0.2
87	3x5	4	1.28
88	3x5	3.5	0.88

* a,b,c,d letters indicate repeat tests at the same location (i.e., no damage occurred on previous impact. 1,2,3 numbers indicate impacts at location 1, location2, etc. on the same sample.

D.4.1.5 Specimen #89

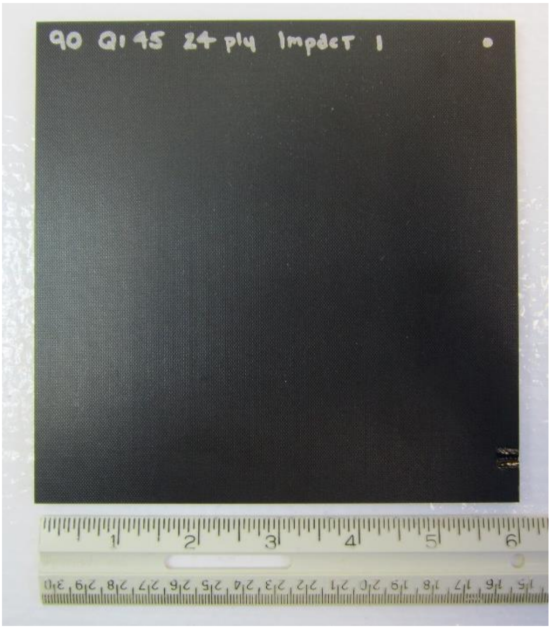


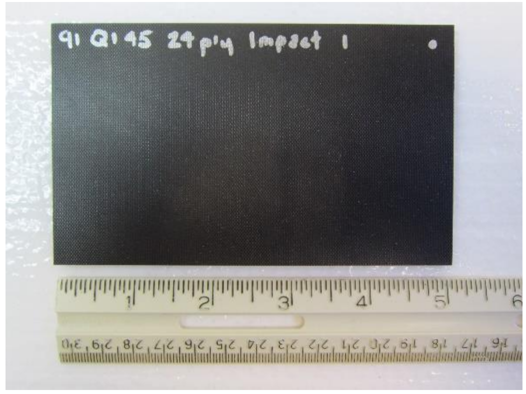


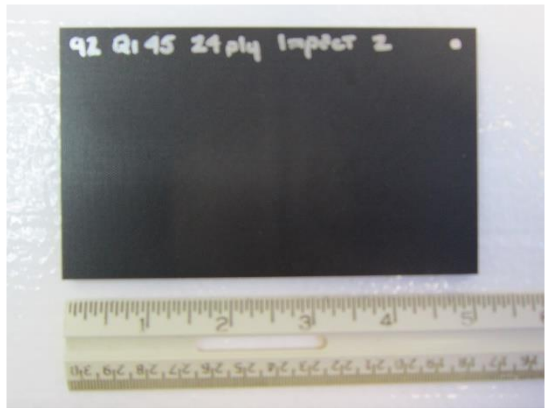
Impact energies to create damage

Specimen/ Impact #	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
89-1a	22x22	8	0
89-2a	22x22	10	0
89-1b	22x22	12	0
89-2b	22x22	14	0
89-2c	22x22	16	0
89-1c	22x22	18	0.22
89-2d	22x22	20	0.46
89-3a	22x22	22	0.6
89-4a	22x22	23	0.75

D.4.1.6 Specimen #90-#92: 24-ply Impact Specimens



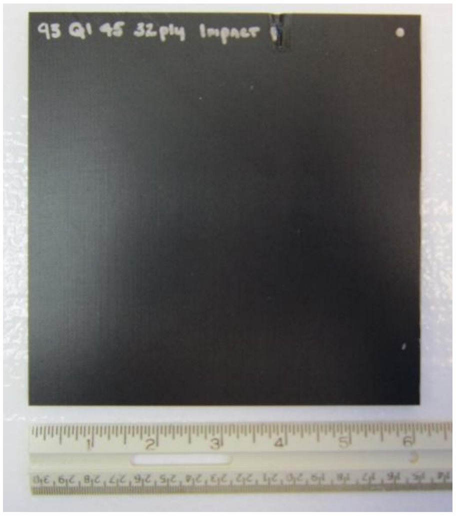


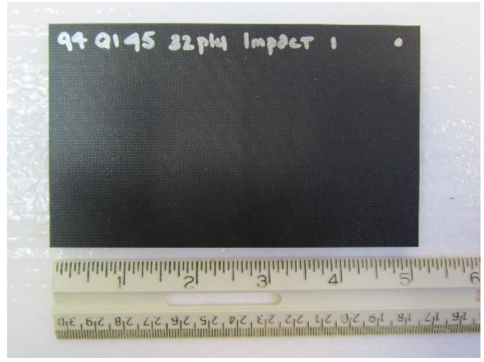


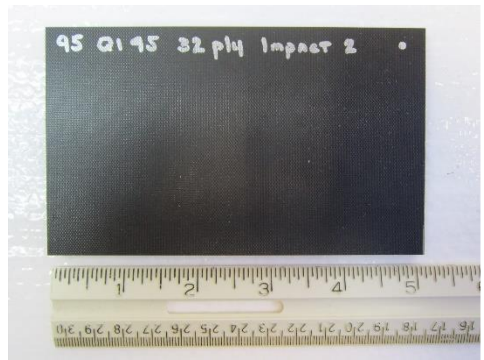
Impact energies to create damage

Specimen/ Impact #	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
90a	6x6	6	0
90b	6x6	7	0
90c	6x6	8	1
92	3x5	6	1
91	3x5	5	1.11

D.4.1.7 Specimen #93-#95: 32-ply Impact Specimens



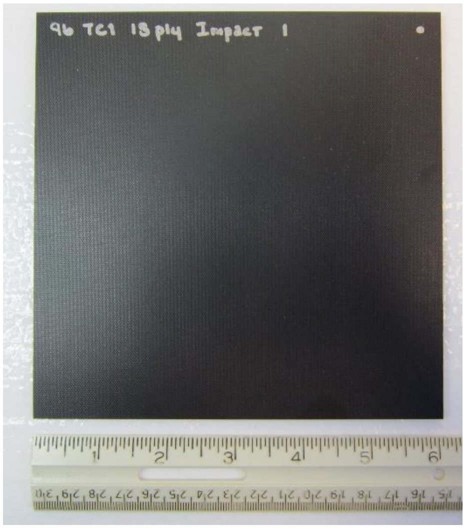


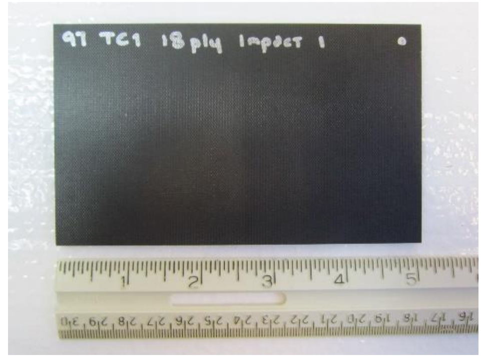


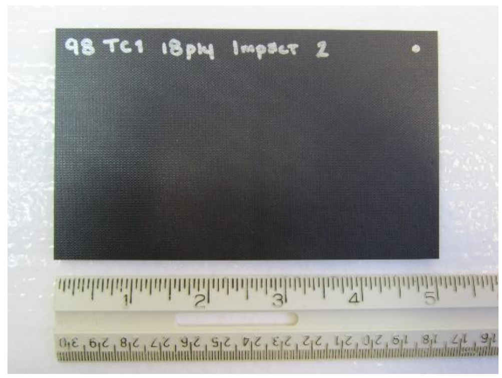
Impact energies to create damage

Specimen/ Impact #	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
95	3x5	5	0.25
94	3x5	5.5	1.12
93	6x6	8	0.23

D.4.1.8 Specimen #96-#98: 18-ply Non-Isotropic Impact Specimens







Impact energies to create damage

Specimen/ Impact #	Specimen Size, in	Nominal Impact Energy, ft-lbs	Damage Diameter, in
98	3x5	3.5	0.96
97	3x5	3	0.92
96a	6x6	3	0
96b	6x6	3.5	0
96c	6x6	4	0
96d	6x6	4.25	0.3

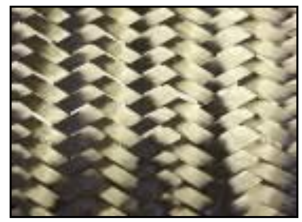
D.5 Manufacturing Information for NDE Standards Provided by Consortium Member #5

Consortium Member Number	Specimen Number/Name	Description
5	45 UTC 1 FBH	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Delamination/disbond (FBH)
5	46 UTC 2 Mold Release	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Disbond
5	47 UTC 3 Pillow	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Delamination (Air Pillow)
5	48 UTC 6 Porosity 2	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Porosity
5	49 UTC 8 Porosity 1	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Porosity
5	50 UTC 11 Baseline 2	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Baseline
5	51 UTC 13 Snag	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flat panel Fabric Snag
5	52 UTC Flange Baseline 1	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flange Baseline
5	53 UTC Flange Baseline 2	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flange Baseline
5	54 UTC 1/2-inch Pillow Defect Flange 1	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flange Delamination (Air Pillow)
5	55 UTC 1/2-inch Pillow Defect Flange 2	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flange Delamination (Air Pillow)
5	56 UTC Snag 1	Triaxial Braid, 0/+60/-60 T-800SC Triaxial Braid 0/+60/-60 with 3M AMD-825 Flange Fabric Snag

D.5.1 Panel Deliverables

Panel Orientation	# of Panels	Panel Name	Defect Type	Date Delivered
Flat Panel, 13 × 13-inch	1	Baseline	No Defects	9/21/16
	1	Pillow Defects	Delaminations	9/8/2016
	1	FBH	Calibration	9/8/2016
	1	Mold Release	Weak Bond	9/8/2016
	1	Snag Defects	Tow Displacement	9/21/2016
	2	Porosity	Porosity	9/21/2016
Flange	2	Baseline	No Defects	10/10/2016
	2	Pillow Defects	Delaminations	10/10/2016
	1	Snag Defects	Tow Displacement	10/10/2016

D.5.2 Reinforcement/Resin System

Reinforcement	T800 Carbon Fiber • Triaxial Braid 0°,+/- 60° • Areal Weight ~800 g/m^2 • Cured ply thickness ~.027 in. 
Resin	AMD 825 Toughened Epoxy 3M Developmental Resin

D.5.3 Vacuum Bag Lay-up (Figure D.5-1)

1. Kapton® and solid Armalon® used to prevent resin from contaminating plate.
2. Flow media used to enhance resin flow from flow channel to braid.
   a. Two layers under outlet end of braid.
   b. Four layers to enhance flow over the braid.
3. Porous Armalon® used as a release ply.
4. For all panels, plies are laid in the same direction, nesting the 0° tow.

*Flanges are made with the same vacuum bag lay up on a 90° tool. See Figure D.5-2.

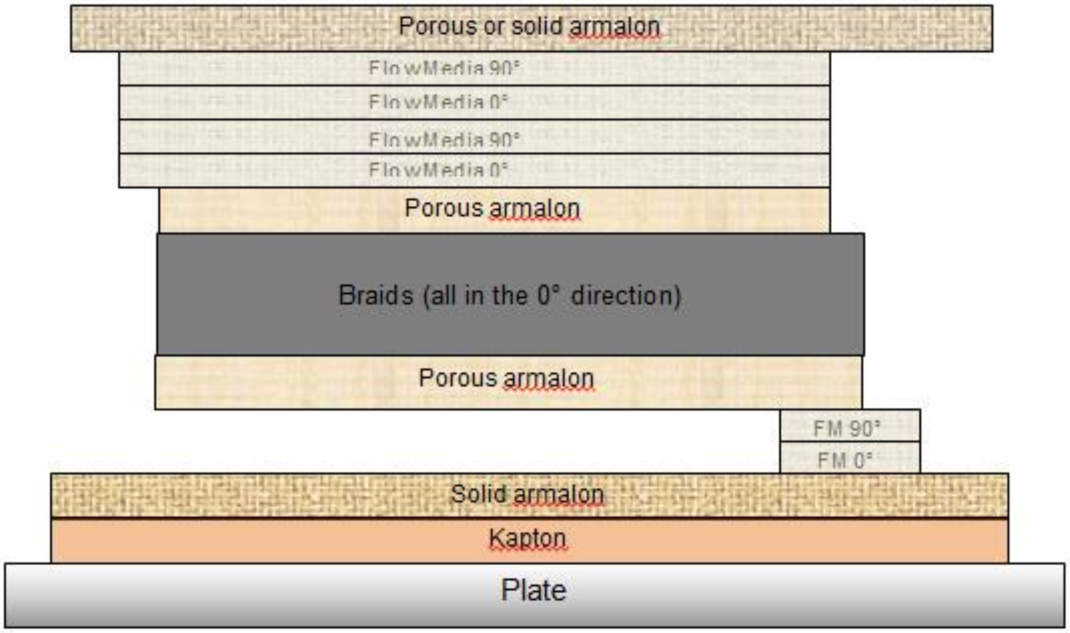


Figure D.5-1. Vacuum bag lay-up for a flat panel and flange.

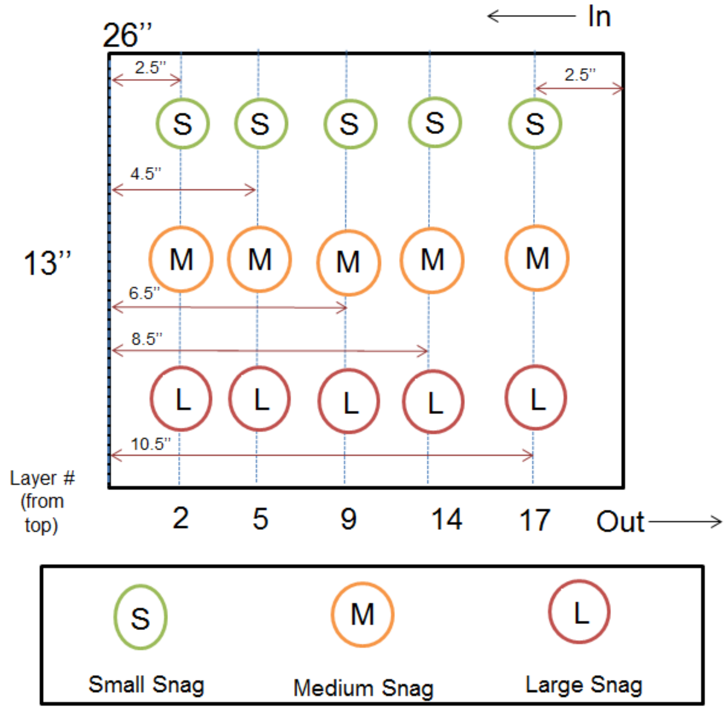


Figure D.5-2. Snag panel lay-up.

D.5.4 Fabrication Method – VaRTM

- Panels fabricated by vacuum assisted resin transfer molding (VaRTM)
    - Composite is molded in a rigid, heated vacuum bag
    - Cured under low pressure in an autoclave (see V. Cure Cycle)
    - Equipment: Baron autoclave

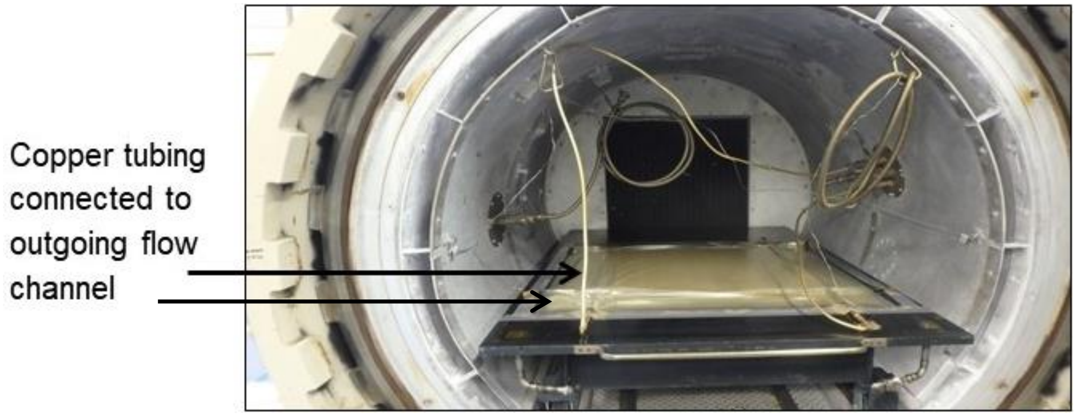


Figure D.5-3. Baron autoclave.

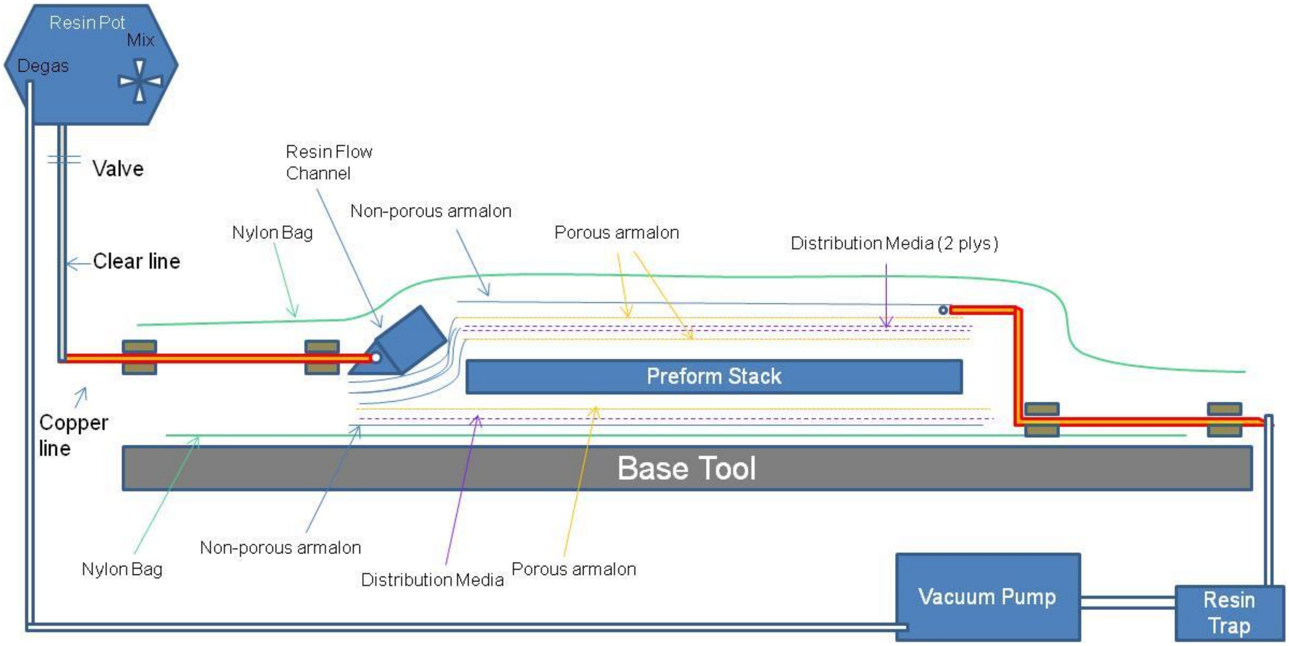
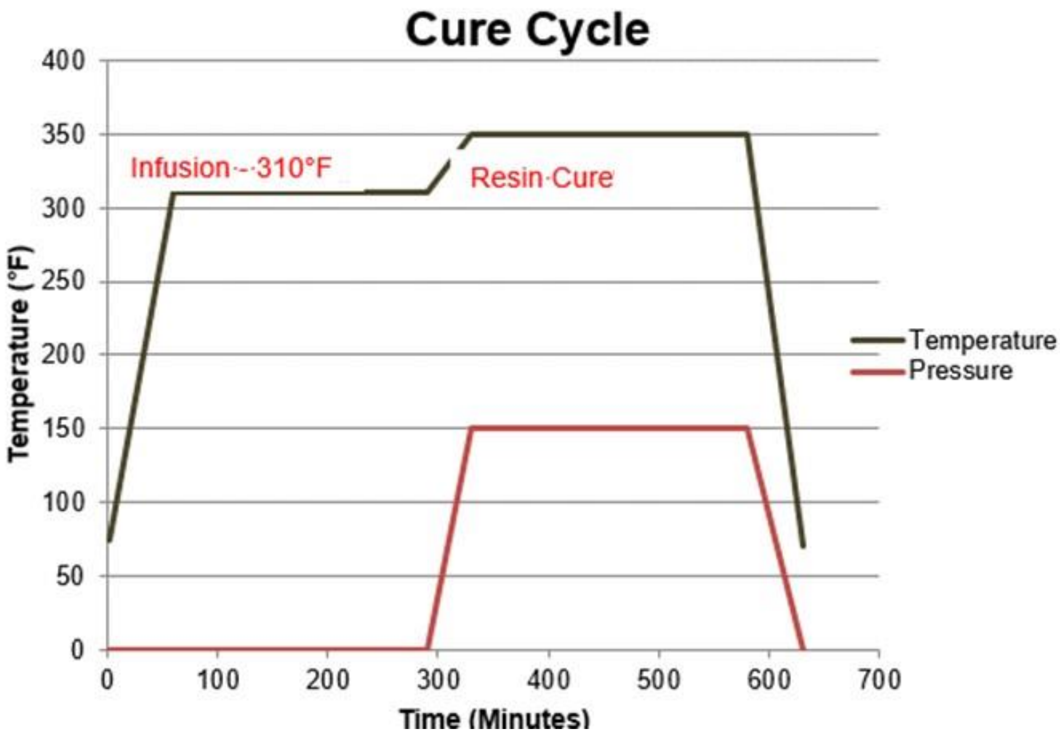


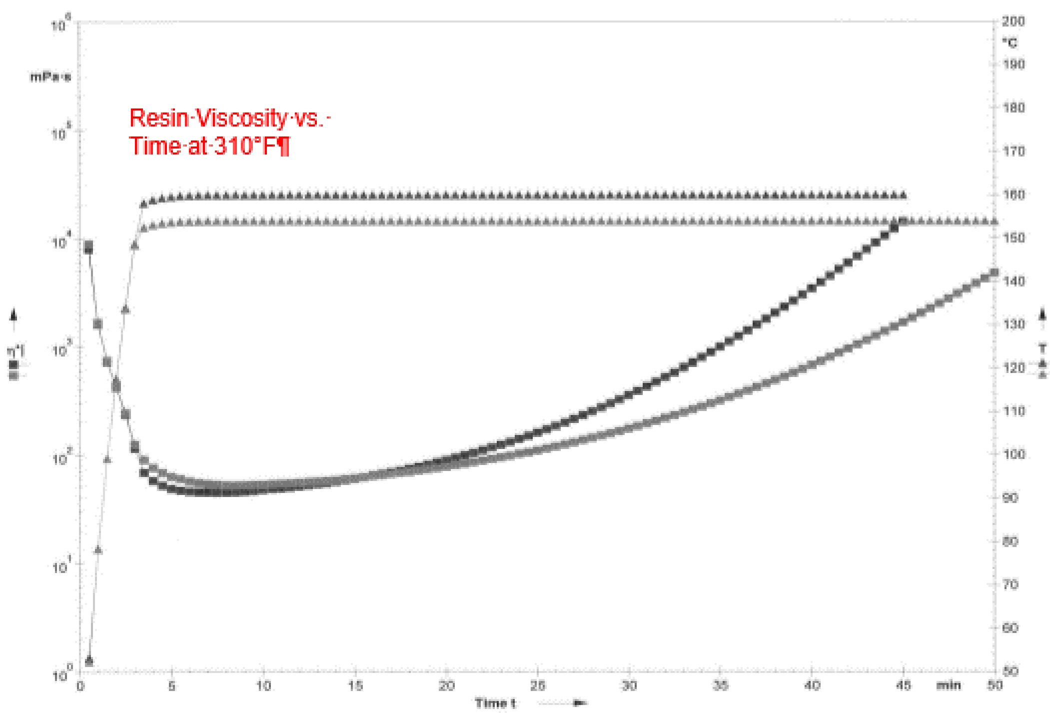
Figure D.5-4. VaRTM process.

- Vacuum pump degasses resin and pulls vacuum through the resin trap, the preform stack, and to the resin pot
  - Valve at the resin pot is opened, resin flows through preform and eventually into resin trap.

D.5.5 Cure Cycle



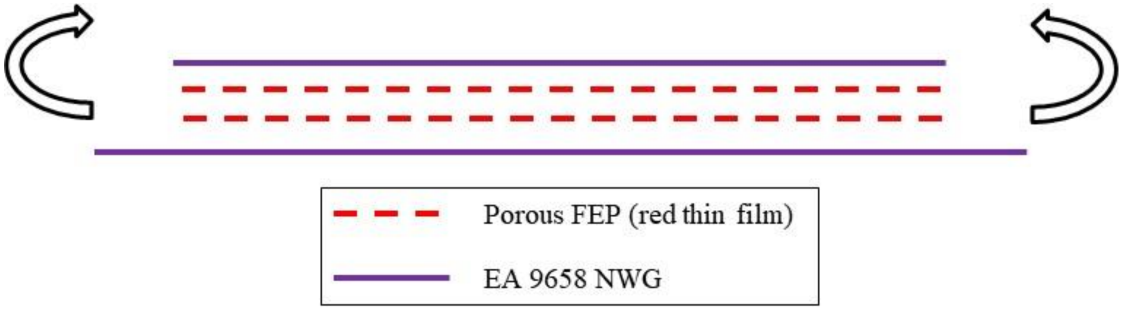
D.5.6 Resin Viscosity Profile - 310 °F



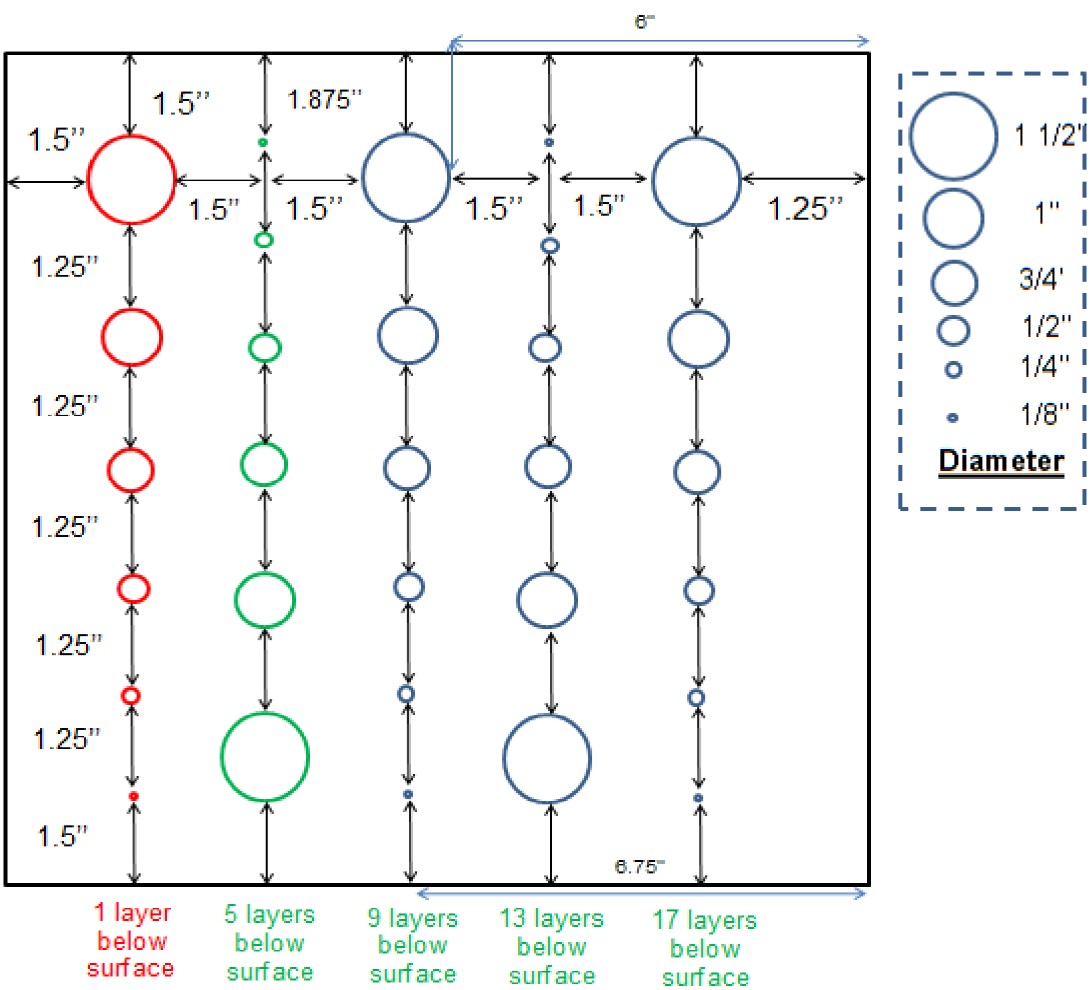
D.5.7 Defect Manufacturing

i. Baseline – panel/flange manufactured by normal procedures, no defects intentionally added

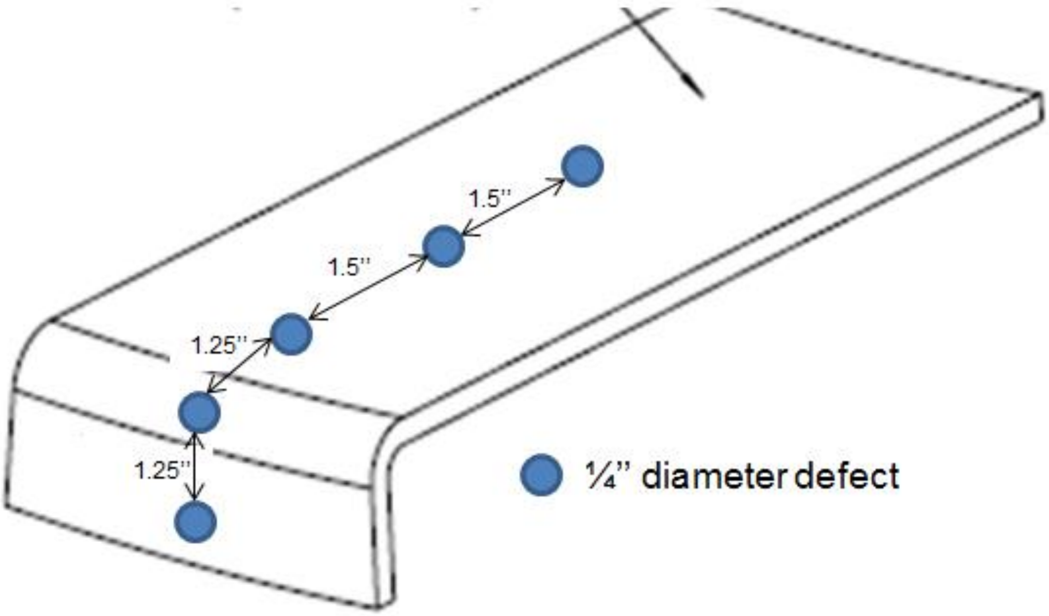
ii. Pillow Defects

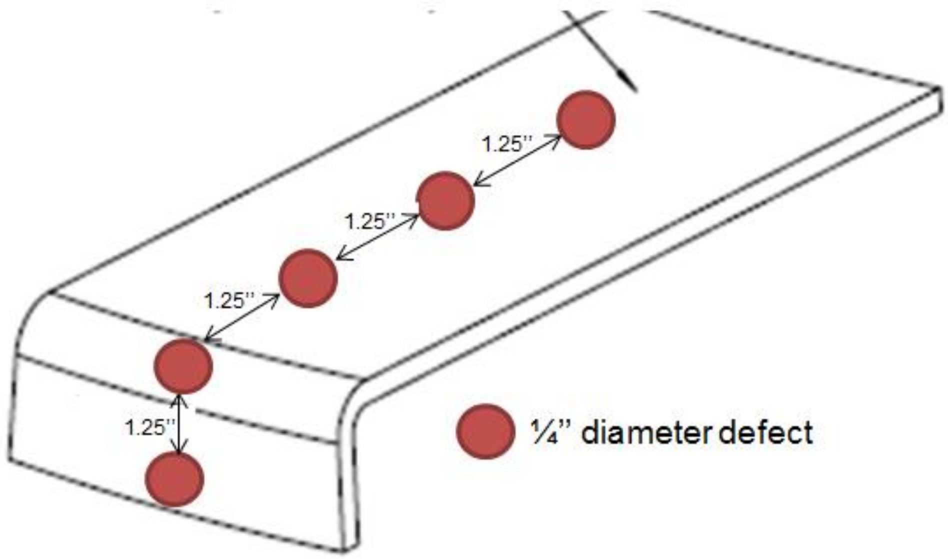


1. Use stamps to cut 1.5-, 1-, 0.75-, 0.5-, 0.25-, and 0.125-inch circles from the adhesive. The top layer should be the target size of the defect. The bottom layer should be one size larger.
2. Use a knife or stamps to cut 2 layers of Fluorinated Ethylene Propylene (FEP) film (same size as target defect and top layer of adhesive).
3. Create the stack and fold the larger bottom layer of adhesive around the stack, creating a pillow.



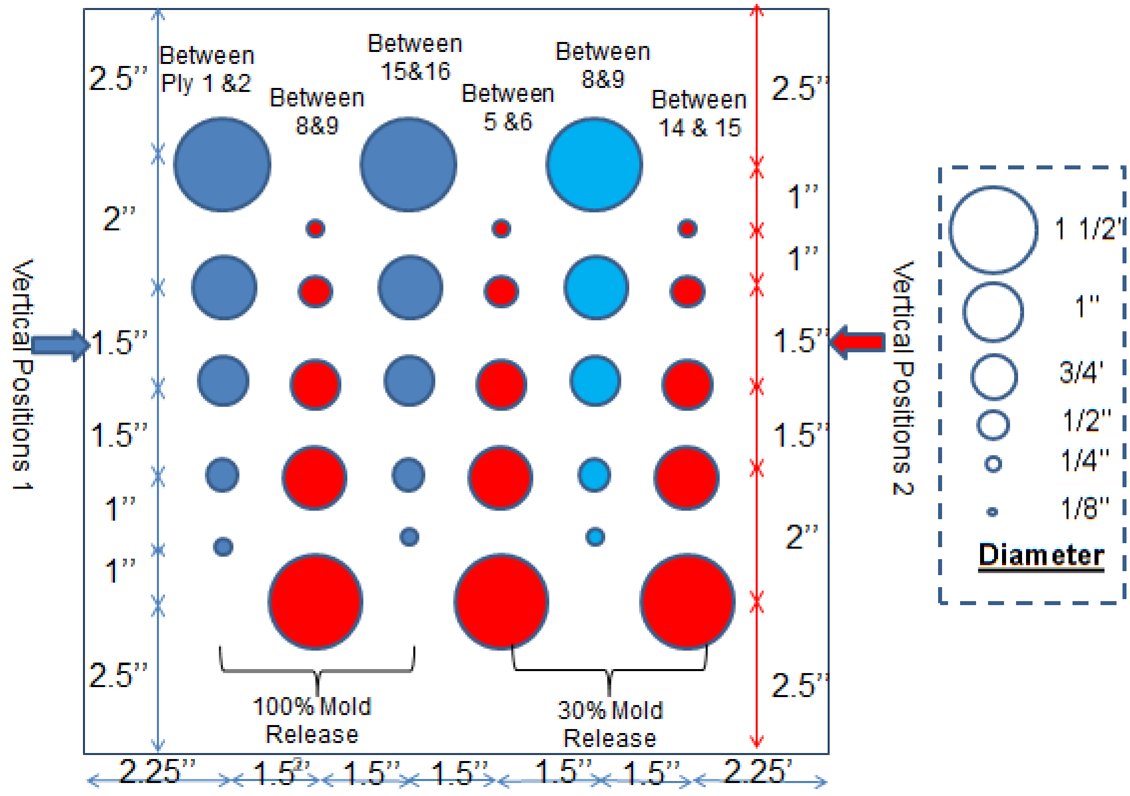
Pillow Defects for the flange are made the same way however only 0.25- and 0.5-inch sizes were used. The defects are put in the center of the panel – between plies 6 and 7.





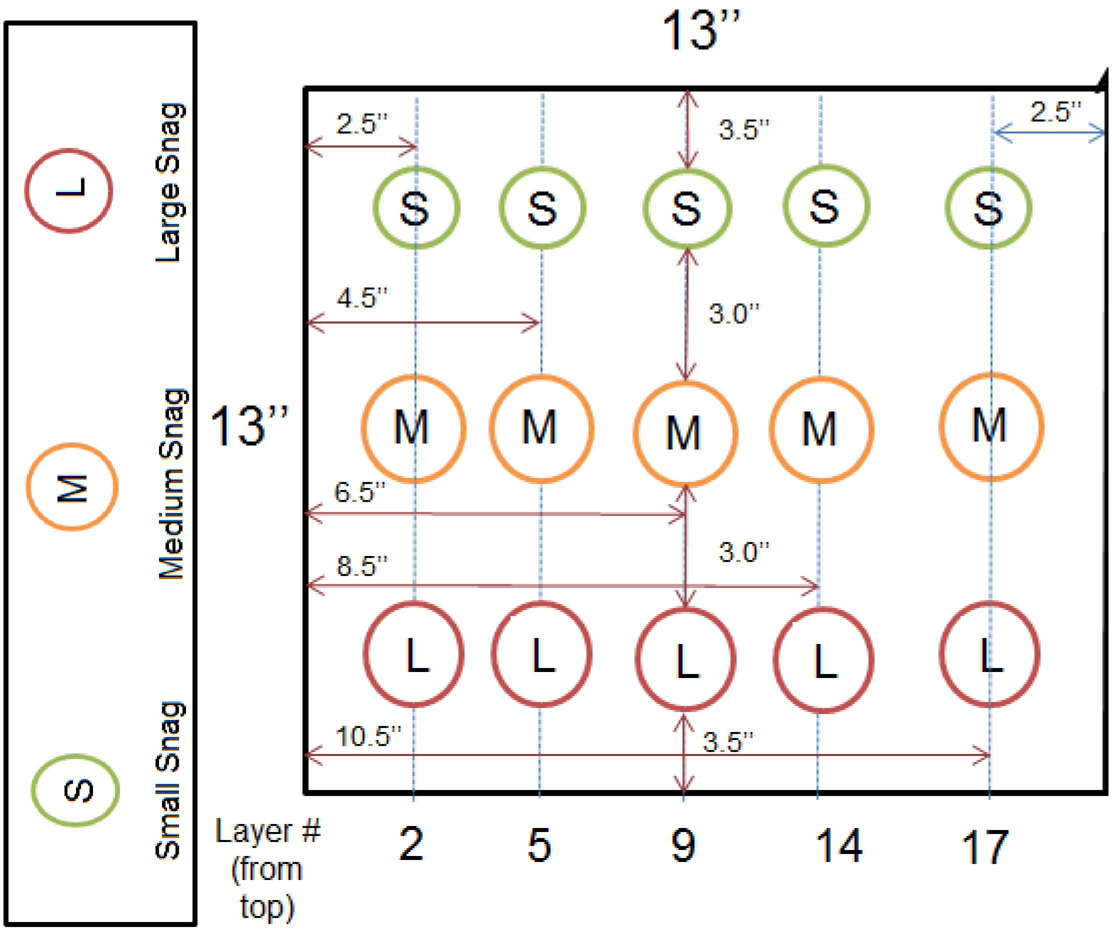
iii. Mold Release Defects

Mold release is meant to create a "kissing bond" between the fabric plies – representing weak bond integrity but no gap. Mold release is only used as an intentional defect in the flat panel.



iv. Snag Defects

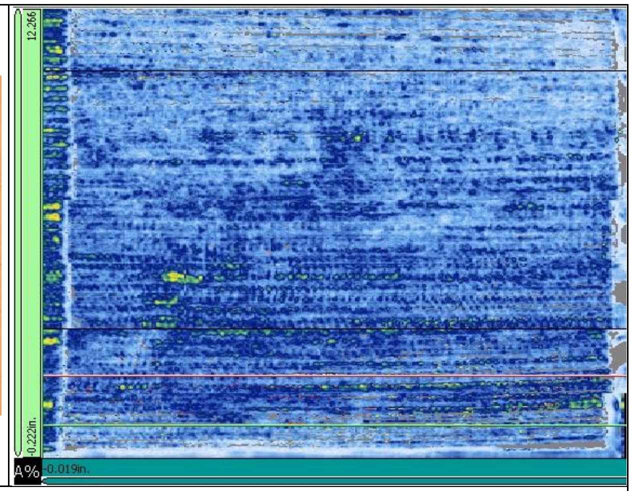
In the flat panel, snags were made by pulling up one tow from the plane. A large snag indicated that the tow was pulled about an inch off the surface. A medium snag indicated a 0.5-inch and the small snag was about a 0.25-inch off the plane.



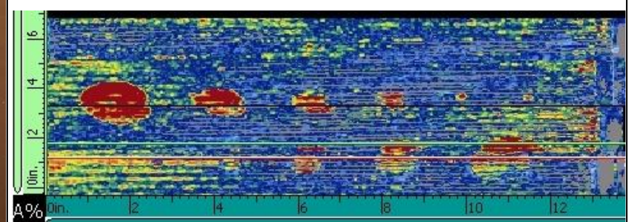
v. Porosity Defects

The porosity panels are made without standard procedures. The root cause of the porosity is the vacuum bag leaking while pressurizing post-infusion.

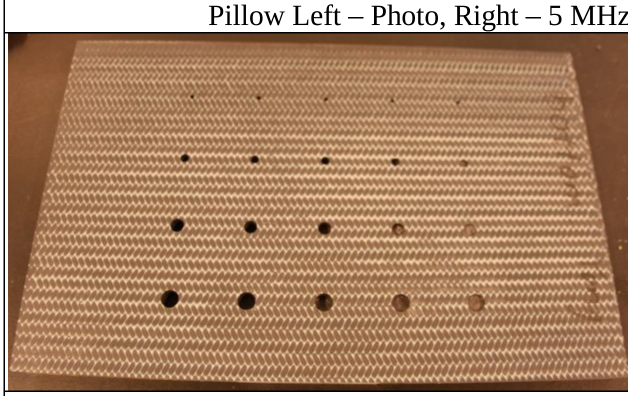
D.5.8 Validation Data

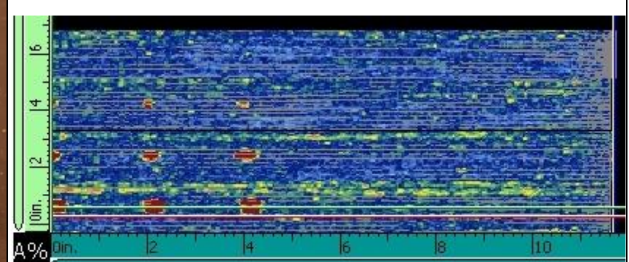


Baseline #2 Left – Photo, Right – 5 MHz Phased Array UT Roll Form Probe

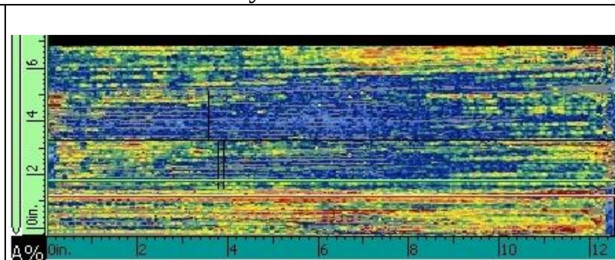


Pillow Left – Photo, Right – 5 MHz Phased Array UT Roll Form Probe

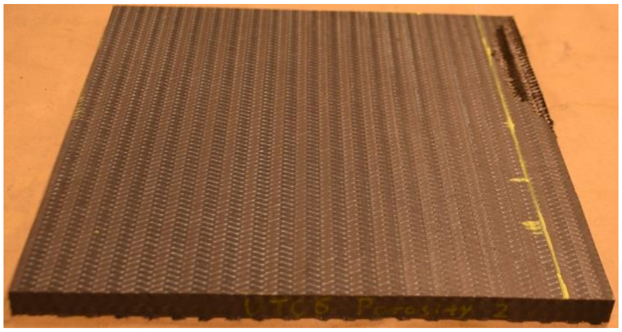


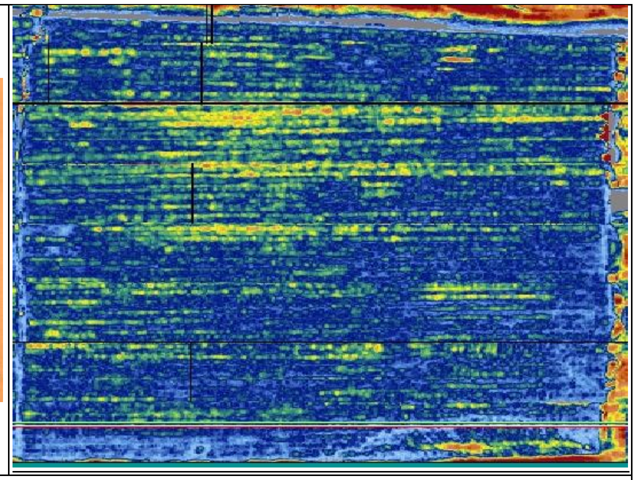


FBH Left – Photo, Bottom Surface, Right – 5 MHz Phased Array UT Roll Form Probe

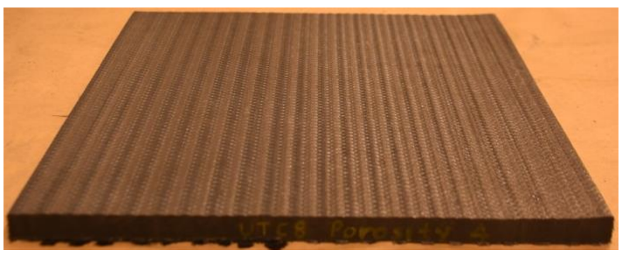


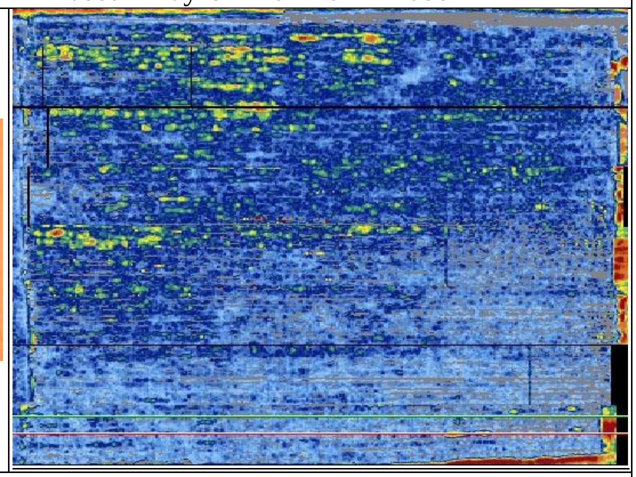
Mold Release Left – Photo, Right – 5 MHz Phased Array UT Roll Form Probe



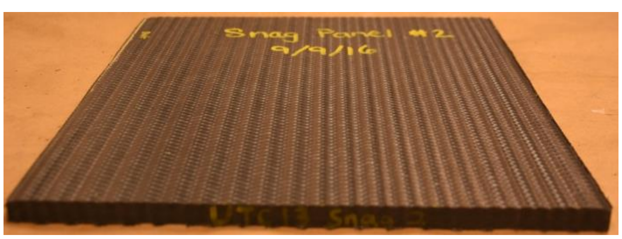


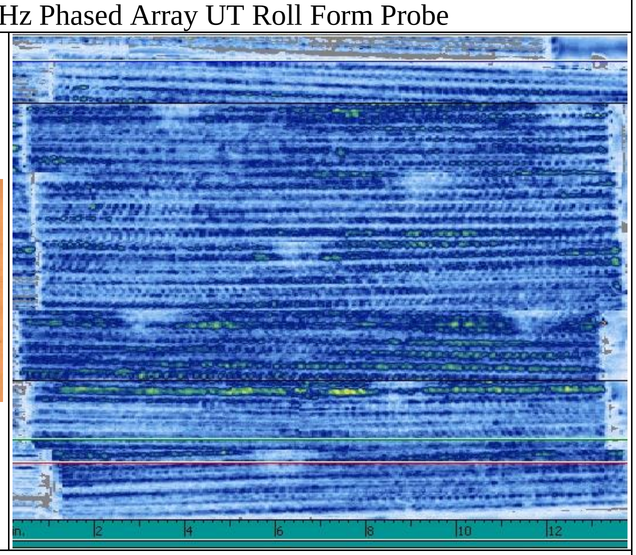
Porosity 2 Left – Photo, Right – 5 MHz Phased Array UT Roll Form Probe





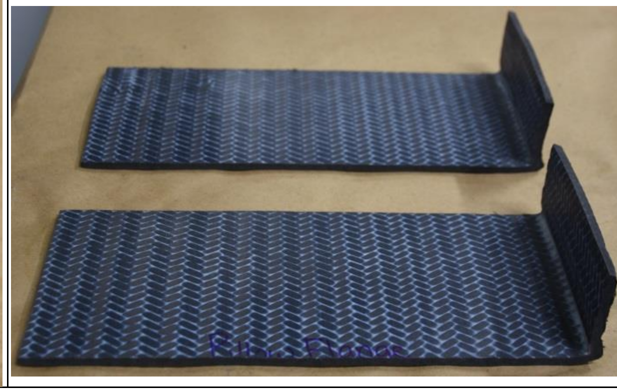
Porosity 4 Left – Photo, Right – 5 MHz Phased Array UT Roll Form Probe





Snag 2 Left – Photo, Right – 5 MHz Phased Array UT Roll Form Probe

Flange Panel Pictures

<table>
<tr><th>Panel Image</th><th>Roller Probe UT Scan</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Pillow Defect #1, #2</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Baseline</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Snag #1</td></tr>
</table>

D.6 Manufacturing Information for NDE Standards Provided by Consortium Member #6

Consortium Member Number	**Specimen Number/Name**	**Description**
6	73 NASA-005-STANDARD-001	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Pristine
6	74 NASA-005-STANDARD-002	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Pristine
6	75 NASA-005-Wrinkle-001	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Out of plane wrinkle
6	76 NASA-005-Wrinkle-002	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Out of plane wrinkle
6	77 NASA-005-Porosity-001	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Porosity
6	78 NASA-005-Porosity-002	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Porosity
6	79 NASA-005-Porosity-003	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Porosity
6	80 NASA-005-Porosity-004	Quasi-isotropic IM7/8552 satin weave fabric and unidirectional Rotorcraft blade spar tube Porosity

Non-Destructive Test (NDT) reference standards provided by Consortium member #6 are generic elliptical airfoil shaped tubes that are representative of main and tail-rotor blade spar structures. The closed shape geometry presents significant challenges for manufacturing and inspection due to changing thickness, variable radii, internal ply drop-offs, and bulk factors that can lead to porosity, bridging, delamination, wrinkles, and marcelling. The closed shape, which in practical application can be over 20 feet in length, also presents a challenge for common NDT processes due to limited internal surface access and the conic radii. Inspection in radii presents particular difficulty because ultrasonic signals may not be reflected back normal to the transducer with conventional ultrasonic inspection techniques. In addition, specific details such as distinguishing disbonds/delaminations from porosity and determining precise ply depth location is sometimes elusive, particularly if defects are stacked throughout a thickness.

Wrinkles and marcels are even more pervasive, in that most current techniques cannot accurately characterize the internal dimensions of a wrinkle or marcel, except by destructive means. This generally results in zero acceptances for wrinkle defects or surface distortions in most structural applications. Development of new automated Nondestructive Inspection (NDI) methods that can speed inspection and distinguish precise through-thickness features for porosity and wrinkles; would help the analyst better determine the acceptability of a part; speed analysis of production quality; and potentially save parts that are presently scrapped due to assuming the worst-case defect size, while also preventing the escape of a critical defect.

The objective of this task was to create tubular shaped NDT reference standards that can be used to develop improved NDT techniques for better definition of wrinkles, marcels, porosity, and disbonds in tubular structures that represent rotorcraft blade spars, and by extension, potentially other tubular composite structure such as drive shafts.

NDT reference standards are defined based on the most prevalent and difficult to assess defects seen in production applications for closed shape tubular designs such as rotor blade spars. The material selected was Hexcel IM7/8552, using a construction of both 8 Harness Satin weave Fabric at 370 gsm areal weight (SGP370-8H, Batch 19026, Roll 014) and unidirectional 12 K tow material at 320 gsm areal weight (IM7/8552, Batch 17078, roll 006). The layup is shown in Tables D.6-1 and D.6-2, and Figure D.6-1. The same layup was used for all standards, both good and those with defects.

Table D.6-1. Layup sequence for tubular shaped standards.

Layer	Type	Location	Orientation	Thickness (in)
1	Woven 8HS	Full Wrap	+/-45	0.015
2	Woven 8HS	Full Wrap	+/-45	0.015
3	Uni	Full Wrap	+45	0.012
4	Uni	Full Wrap	-45	0.012
5	Uni	Flat Dropoff	0	0.012
6	Uni	Flat Dropoff	0	0.012
7	Uni	Full Wrap	+45	0.012
8	Uni	Full Wrap	-45	0.012
9	Uni	Flat Dropoff	0	0.012
10	Uni	Flat Dropoff	0	0.012
11	Uni	Full Wrap	+45	0.012
12	Uni	Full Wrap	-45	0.012
13	Uni	Flat Dropoff	0	0.012
14	Uni	Flat Dropoff	0	0.012
15	Uni	Full Wrap	+45	0.012
16	Uni	Full Wrap	-45	0.012
17	Woven 8HS	Full Wrap	+/-45	0.015
18	Woven 8HS	Full Wrap	+/-45	0.015

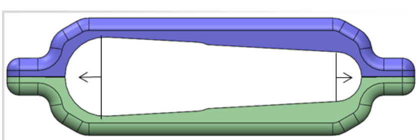


Table D.6-2. Ply drop-off definition unidirectional plies (flats).

	Leading Conic	Trailing Conic	Length
Layer	Inches	Inches	Ratio
5	0.677	0.383	0.403
6	0.980	0.554	0.583
9	0.840	0.475	0.500
10	1.120	0.633	0.667
13	0.187	0.106	0.111
14	0.513	0.290	0.306

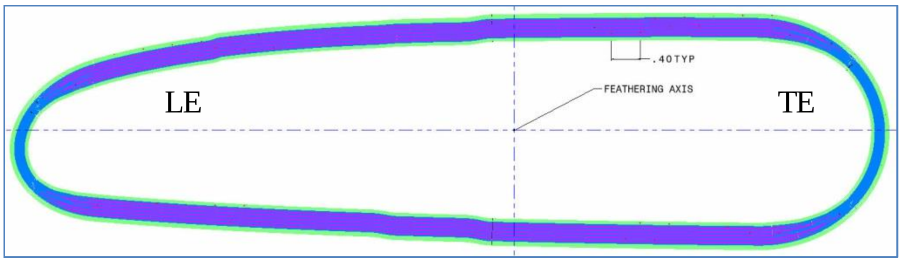


Figure D.6-1. Graphic representation of typical layup.

Table D.6-3. Full wrap plies were two pieces with butt trim locations from the conic apex.

	Layer	UAF	LAF	SPAN	Butt TRIM location		Trim Location	
					LE	TE	LE	TE
last ply down	1	14"	20"	24"	0.75"	1.25"		
	2	20"	14"	24"	0.75"	1.25"		
	3	14"	20"	24"	0.5"	1.0"		
	4	20"	14"	24"	0.5"	1.0"		
	5	10.5"	10.5"	24"			0.677"	0.383"
	6	11.3"	11.3"	24"			0.98"	0.554"
	7	14"	20"	24"	0.75"	1.25"		
	8	20"	14"	24"	0.75"	1.25"		
	9	10.9"	10.9"	24"			0.84"	0.475"
	10	9.9"	9.9"	24"			1.12"	0.63"
	11	14"	20"	24"	0.5"	1.0"		
	12	20"	14"	24"	0.5"	1.0"		
	13	9.7"	9.7"	24"			0.187"	0.106"
	14	10.2"	10.2"	24"			0.513"	0.29"
	15	14"	20"	24"	0.75"	1.25"		
	16	20"	14"	24"	0.75"	1.25"		
	17	14"	20"	24"	0.5"	1.0"		
First ply down	18	20"	14"	24"	0.5"	1.0"		
	MANDREL							

The generic specimen geometry was identified as a tubular section of airfoil shape as shown in Figures D.6-2 through D.6-4.

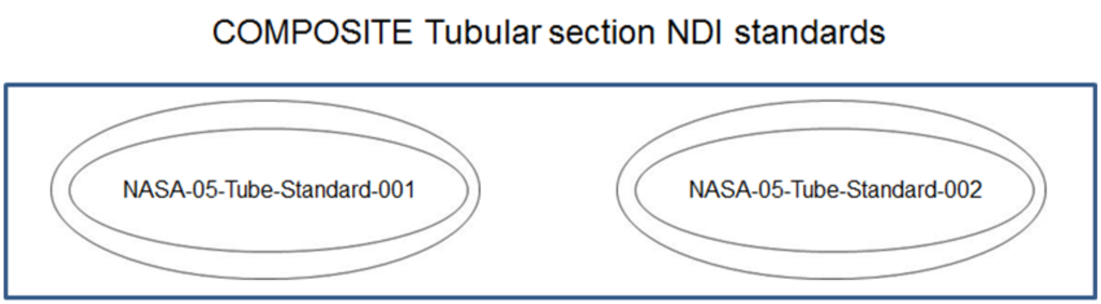


Figure D.6-2. Defect-free standards.

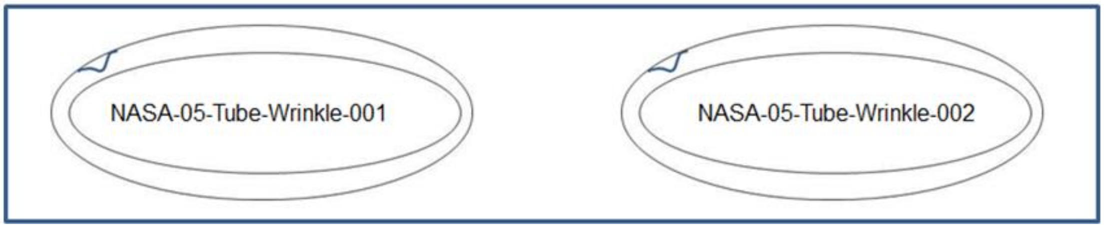


Figure D.6-3. Wrinkle standards.

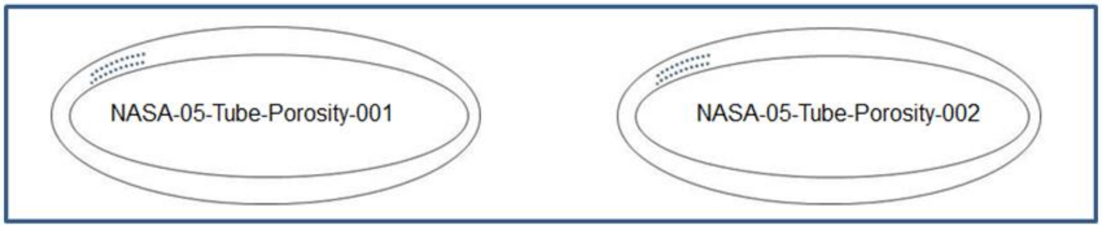


Figure D.6-4. Porosity standards.

The Manufacturing Process used is basically the same for all standards with specific process variables and conditions adjusted to achieve the desired defects. The general process flow is shown in Figure D.6-5. To expedite the making of standards, specimens are cured at 270 °F to shorten the cure process. This allowed us to ascertain more quickly if the process conditions selected would yield the defects desired. As defects will form in the region between minimum viscosity (180 °F to 220 °F) and 250 °F when the material gels, but it is not fully cross-linked, it was possible to obtain desired defects using a lower temperature shorter cure cycle. IM7/8552 successfully cures at 250 °F, though obviously has a lower Glass Transition temperature (Tg) and 10% to 20% lower mechanical properties when cured at that temperature. Mechanical properties and Tg were not pertinent to this study, and the specimens can be post-cured in an oven at 350 °F for complete crosslinking if required for future investigation of structural implications of the defects created.

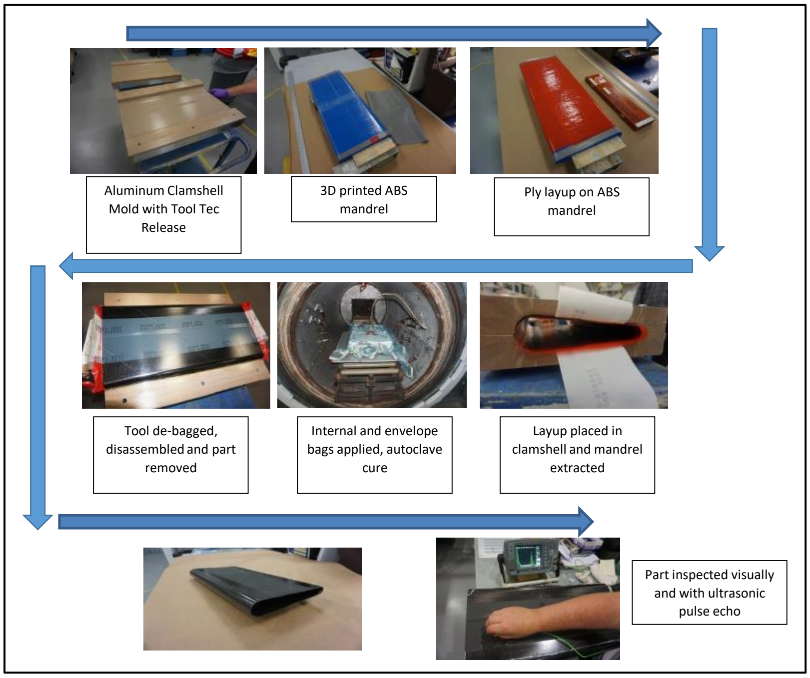


Figure D.6-5. Basic manufacturing flow for NDT Standards.

Two baseline standards, NASA-05-STANDARD-001 and -002 representing a defect free configuration is provided to help calibrate any NDT method selected for evaluation. The good samples were produced using best practices for selecting the starting layup mandrel size, maximizing debulking of the preform (15 minute vacuum at room temperature per debulk cycle), best practice pleating of the vacuum bag and a high-pressure (100 psi) cure. Details of the process variables to produce good standards is shown in Figure D.6-6.

	Layer	Type	Location	Orientation	Thickness (in)	UAF	LAF	SPAN	Butt TRIM location		Trim Location	
									LE	TE	LE	TE
last ply down	1	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.75"	1.25"		
↑	2	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.75"	1.25"		
	3	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	4	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	5	Uni	Flat Dropoff	0	0.012	10.5"	10.5"	24"			0.677"	0.383"
	6	Uni	Flat Dropoff	0	0.012	11.3"	11.3"	24"			0.98"	0.554"
	7	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	8	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	9	Uni	Flat Dropoff	0	0.012	10.9"	10.9"	24"			0.84"	0.475"
	10	Uni	Flat Dropoff	0	0.012	9.9"	9.9"	24"			1.12"	0.63"
	11	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	12	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	13	Uni	Flat Dropoff	0	0.012	9.7"	9.7"	24"			0.187"	0.106"
	14	Uni	Flat Dropoff	0	0.012	10.2"	10.2"	24"			0.513"	0.29"
	15	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	16	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	17	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.5"	1.0"		
First ply down	18	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.5"	1.0"		

MANDREL

		inches
1	Measure circumference of prepped mandrel before first ply	24.725
2	Measure circumference of layup after final ply	25.612
3	Measure chordwise dimension of mandrel before first ply	11.18
4	Measure chordwise dimension of layup	11.44
5	Clamshell Mold chordwise dimension.	11.71

Part #2 "Good Part"
Add 1/16 rubber to OML of Mandrel as a spacer - 2 pieces or more to conform to mandrel - tape together
Re-prep mandrel - get perf FEP tight as possible
Debulk first ply
Debult second ply
Debulk every two plies thereafter
Add 1/8 rubber mandrel for IML of part to prevent wrinkles
Protect collar of laminate (FEP tape overwrap of N10 or equiv. collar)
Three bag pleats in large radius conic
One bag pleat in small radius conic

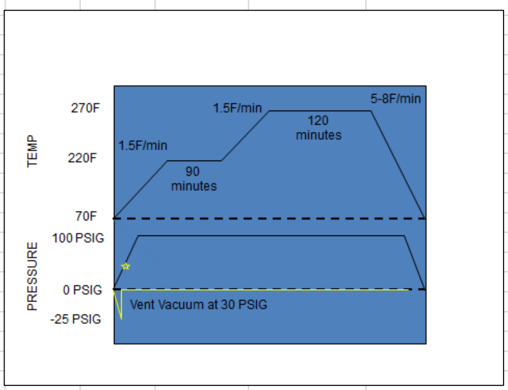


Figure D.6-6. Process variables for NASA-005-Tube-STANDARD-001 and -002.

Two standards are produced that represent internal wrinkles, NASA-005-Tube-Wrinkles-001 and -002, evidenced by ply distortion on the surface and loss of back wall upon ultrasonic inspection. However, the magnitude of the wrinkle is not readily evident unless destructively sectioned and a visual examination performed. Wrinkles were produced by over sizing the layup mandrel, minimizing debulking of the preform (15 minute vacuum at room temperature per debulk cycle), using best practice for pleating the internal vacuum bag, and using a high-pressure cure cycle

(100 psi). Process Variable details to produce wrinkles are shown in Figure D.6-7. There was one unintended consequence: some of the inner mold line (IML) wrinkles entrapped the red FEP release film, so there are some wrinkles with FOD present.

	Layer	Type	Location	Orientation	Thickness (in)	UAF	LAF	SPAN	Butt TRIM location		Trim Location	
									LE	TE	LE	TE
last ply down	1	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.75"	1.25"		
	2	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.75"	1.25"		
	3	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	4	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	5	Uni	Flat Dropoff	0	0.012	10.5"	10.5"	24"			0.677"	0.383"
	6	Uni	Flat Dropoff	0	0.012	11.3"	11.3"	24"			0.98"	0.554"
	7	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	8	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	9	Uni	Flat Dropoff	0	0.012	10.9"	10.9"	24"			0.84"	0.475"
	10	Uni	Flat Dropoff	0	0.012	9.9"	9.9"	24"			1.12"	0.63"
	11	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	12	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	13	Uni	Flat Dropoff	0	0.012	9.7"	9.7"	24"			0.187"	0.106"
	14	Uni	Flat Dropoff	0	0.012	10.2"	10.2"	24"			0.513"	0.29"
	15	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	16	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	17	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.5"	1.0"		
First ply down	18	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.5"	1.0"		

MANDREL

		inches
1	Measure circumference of prepped mandrel before first ply	25.345
2	Measure circumference of layup after final ply	26.375
3	Measure chordwise dimension of layup	11.180"
3	Measure chordwise dimension of layup	11.75
4	Clamshell Mold chordwise dimension.	11.71

Part #3 "Wrinkled Partt"
Add 1/8" rubber to OML of Mandrel as a spacer - 2 pieces or more to conform to mandrel - tape together
Re-prep mandrel - get perf FEP tight as possible
Debulk first ply
Debult second ply
Debulk last ply
Add 1/8 rubber mandrel for IML of part to prevent wrinkles
Protect collar of laminate (FEP tape overwrap of N10 or equiv. collar)
Three bag pleats in large radius conic
One bag pleat in small radius conic

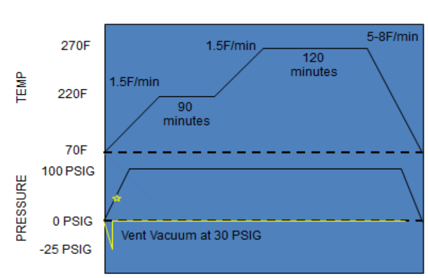


Figure D.6-7. Process variables for NASA-005-Tube-Wrinkle-001 and -002.

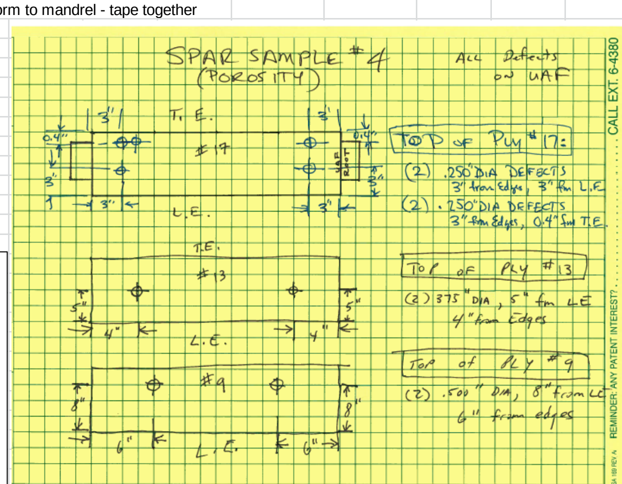
The third set of two standards, NASA-005-TUBE-Porosity-001 and -002, represent porosity and disbond defects. Seeded defects using 0.250-inch diameter, 0.375-inch diameter and 0.500-inch diameter PTFE tape buttons were planted in the laminate. In addition, natural porosity and disbonds were produced by moisture conditioning a single ply mid laminate, minimizing debulking of the preform (15 minute vacuum room temperature per debulk cycle), minimizing pleats in the internal bag, and using a low-pressure (45 psi) cure cycle. Details are shown in Figure D.6-8. The initial attempt to produce porosity defects resulted in a collapse of the internal rubber caul sheet during cure and gross depressions of the small radius conic. The remaining sections of the airfoil were usable so they are provided as standards for the flat areas and large conic. However, we decided to make a second set of porosity standards to obtain porosity representative of the small radius conic. NASA-005-Tube-porosity-003 and -004 were manufactured in identical fashion to NASA-005-Tube-porosity-001 and -002, except the moisture conditioning of ply 7 was limited to the center 8 inches of the ply by segmenting it into three 8-inch segments. This is based on feedback from the NDT inspector on porosity specimens -001 and -002 on the difficulty in trying to distinguish good and bad within a single layer of the laminate when the entire ply may be porous. The segmented approach also disrupted possible air paths for the moisture to escape by having the center section isolated from the ends through severing of the fibers. The use of seeded defects in porosity -003 and -004 was identical to that of porosity -001 and -002. The internal rubber caul remained in place for the second attempt and a usable small radius conic is obtained. The small radius conic of -003 and -004 exhibited significant porosity. Process details for porosity -003 and -004 are shown in Figure D.6-9.

	Layer	Type	Location	Orientation	Thickness (in)	UAF	LAF	SPAN	Butt TRIM location		Trim Location	
									LE	TE	LE	TE
last ply down	1	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.75"	1.25"		
	2	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.75"	1.25"		
	3	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	4	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	5	Uni	Flat Dropoff	0	0.012	10.5"	10.5"	24"			0.677"	0.383"
	6	Uni	Flat Dropoff	0	0.012	11.3"	11.3"	24"			0.98"	0.554"
	7	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	8	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	9	Uni	Flat Dropoff	0	0.012	10.9"	10.9"	24"			0.84"	0.475"
	10	Uni	Flat Dropoff	0	0.012	9.9"	9.9"	24"			1.12"	0.63"
	11	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	12	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	13	Uni	Flat Dropoff	0	0.012	9.7"	9.7"	24"			0.187"	0.106"
	14	Uni	Flat Dropoff	0	0.012	10.2"	10.2"	24"			0.513"	0.29"
	15	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	16	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	17	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.5"	1.0"		
First ply down	18	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.5"	1.0"		

MANDREL

		inches
1	Measure circumference of prepped mandrel before first ply	24.72
2	Measure circumference of layup after final ply	25.77
3	Measure chordwise dimension of mandrel before first ply	11.202
4	Measure chordwise dimension of layup	11.5
5	Clamshell Mold chordwise dimension.	11.71

Part #4 "Porosity"
Add .040 " rubber to OML of Mandrel as a spacer - 2 pieces or more to conform to mandrel - tape together
Re-prep mandrel - get perf FEP tight as possible
Debulk first ply
Debult second ply
Insert four 0.250 diameter teflon tape defects on top of ply 17 per diagram
Insert two 0.375 diameter teflon tape defects on top of ply 13 per diagram
Insert two 0.500 diameter teflon tape defects on top of ply 9 per diagram
Condition ply 7 for 3 hours in a 120°F 98% RH chamber prior to layup
Add 1/8 rubber mandrel for IML of part to prevent wrinkles
Protect collar of laminate (FEP tape overwrap of N10 or equiv. collar)
One bag pleat in large radius conic
One bag pleat in small radius conic



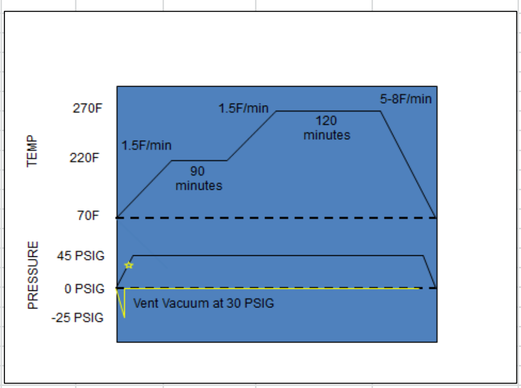


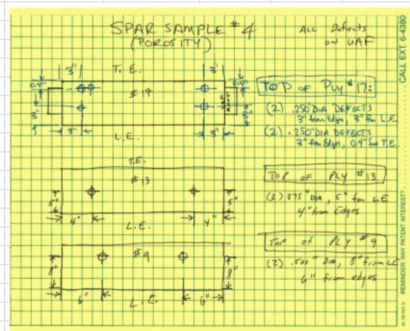
Figure D.6-8. Process variables for NASA-005-Tube-Porosity-001 and -002.

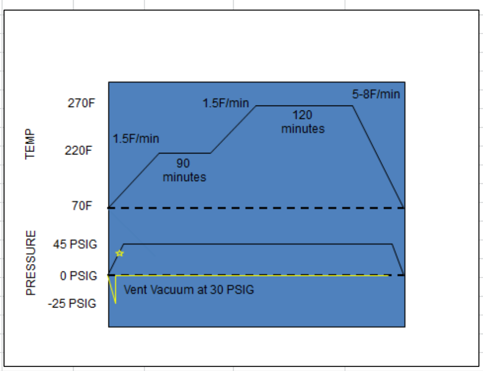
	Layer	Type	Location	Orientation	Thickness (in)	UAF	LAF	SPAN	Butt TRIM location		Trim Location	
									LE	TE	LE	TE
last ply dov	1	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.75"	1.25"		
	2	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.75"	1.25"		
	3	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	4	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	5	Uni	Flat Dropoff	0	0.012	10.5"	10.5"	24"			0.677"	0.383"
	6	Uni	Flat Dropoff	0	0.012	11.3"	11.3"	24"			0.98"	0.554"
	7	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	8	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	9	Uni	Flat Dropoff	0	0.012	10.9"	10.9"	24"			0.84"	0.475"
	10	Uni	Flat Dropoff	0	0.012	9.9"	9.9"	24"			1.12"	0.63"
	11	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.5"	1.0"		
	12	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.5"	1.0"		
	13	Uni	Flat Dropoff	0	0.012	9.7"	9.7"	24"			0.187"	0.106"
	14	Uni	Flat Dropoff	0	0.012	10.2"	10.2"	24"			0.513"	0.29"
	15	Uni	Full Wrap	+45	0.012	14"	20"	24"	0.75"	1.25"		
	16	Uni	Full Wrap	-45	0.012	20"	14"	24"	0.75"	1.25"		
	17	Woven 8HS	Full Wrap	+/-45	0.015	14"	20"	24"	0.5"	1.0"		
First ply dc	18	Woven 8HS	Full Wrap	+/-45	0.015	20"	14"	24"	0.5"	1.0"		

MANDREL

		inches
1	Measure circumference of prepped mandrel before first ply	24.73
2	Measure circumference of layup after final ply	25.79
3	Measure chordwise dimension of mandrel before first ply	11.194
4	Measure chordwise dimension of layup	11.51
5	Clamshell Mold chordwise dimension.	11.71

Part #4 "Porosity"
Add .040 " rubber to OML of Mandrel as a spacer - 2 pieces or more to conform to mandrel - tape together
Re-prep mandrel - get perf FEP tight as possible
Debulk first ply
Debult second ply
Insert four 0.250 diameter teflon tape defects on top of ply 17 per diagram
Insert two 0.375 diameter teflon tape defects on top of ply 13 per diagram
Insert two 0.500 diameter teflon tape defects on top of ply 9 per diagram
Condition center 8 " segment of ply 7 for 3 hours in a 120°F 98% RH chamber prior to layup (photo)
Add 1/8 rubber mandrel for IML of part to prevent wrinkles
Protect collar of laminate (FEP tape overwrap of N10 or equiv. collar)
One bag pleat in large radius conic
One bag pleat in small radius conic





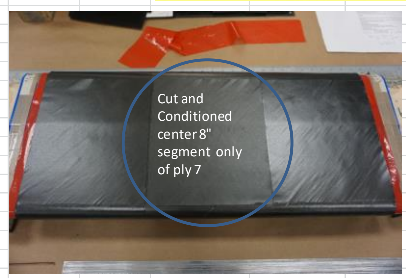


Figure D.6-9. Process variables for NASA-005-Tube-Porosity-003 and -004.

In general, the fabrication proceeded well, but we did have a few challenges to address. The original plan was to make a basic ellipse but an Office of Naval Research (ONR) project "The Reduction of Thick-Walled Composite Manufacturing Variability Through Process Modeling and Optimization," Contract Number N00014-14-C-0026, by the United Technologies Research Center has been underway to develop process simulation models for predicting/eliminating defects for a generic airfoil shape. Rather than create a unique geometry for the SMAAART IDIQ effort, we decided to replicate the geometry of that program to create potential future synergy between the NASA ACC work and the ONR Project. It would be beneficial to eventually connect process modeling for defect prediction, with defect detection and NDT standards, and ultimately with structural analysis of those defects. The metal clamshell mold defining the OML geometry of the tubular shape is based on the dimensions from the ONR Project. We also changed our plan to use a foam mandrel to layup the elliptical tubular airfoil shape. The lead-time for obtaining foam to match the custom geometry of the clamshell tool was too long. Therefore, an acrylonitrile butadiene styrene (ABS) mandrel was 3D printed in lieu of foam, to accomplish a more precise geometry much faster than was possible with the foam. Our first attempt to cure an airfoil resulted in a blown bag during the critical 220 °F to 250 °F-cycle segment and it caused significant internal diameter surface wrinkles and air shot defects. Corrective actions from that attempt resulted in an improved bagging technique to protect the ends of the clamshell where it intersected with the internal bag and we introduced rubber caul plates on the inner diameter (ID) of the part to minimize ID wrinkles. The second run produced a good spar to serve as the baseline standard. Our third run produced a wrinkled spar. The OML internal wrinkles achieved the desired result but some of the IML entrapped the FEP release film creating an additional defect of FOD. While not our original intent, the FOD defect creates another defect category worthy of NDT development for distinguishing it from other defect types. Our fourth run produced a spar with porosity and seeded defects, but it also experienced an unintended issue, where a rubber caul collapsed in the smaller radius conic of the part, leading to significant wrinkle/depressions in that conic. These wrinkles were not interfering with the flats and large radius section so we decided to continue with them as porosity/disbond specimens due to schedule limitations. A fifth tubular set of specimens was fabricated replicating the fourth (porosity) run, but without experiencing a caul collapse. Those specimens will also be provided as standards (NASA-005-Tube-Porosity-003 and -004) since both conics are intact and represent varying degrees of porosity. One area for future improvement for all specimens is the IML definition. Due to time constraints, a 4-piece rubber caul is used for IML definition, which created mark off lines. Improved IML definition may be possible with continuous custom internal rubber bags for future studies.

Standards were inspected visually to identify internal and external defects, ultrasonically using a Masterscan 340 Flaw Detector, performing a Pulse Echo Inspection with a 5-MHZ. 0.250-inch-diameter Delay Tip Transducer on the flats, and a 5-MHZ., 0.250-inch-diameter Flat Tip Transducer for the Leading and Trailing edge conics at 5 MHZ. frequency on the instrument. Gain is adjusted to 80% back wall to establish a criterion, and anything greater than 10% is marked. Areas were marked on the standards where back wall signal attenuation occurred, intermediate reflection is detected, or complete loss of back wall signal was detected. Back wall loss due to call plate impressions on the IML are not marked, these occur at the transition of the flats to conic sections and are readily visible and are not intended to be part of the standard. Representative ultrasonic indications are shown in Figures D.6-10 through D.6-13. Mylar maps are provided with each standard showing the location of the defects, to allow for obliteration of each standard's defect markings and to allow for the ability to perform "blind" inspections if desired. In addition, the edges of the standards were lightly polished to allow for microscopic examination of laminate quality and defect characterization. This is particularly helpful in distinguishing wrinkle characteristics, which can be quite complex, as well as, varying degrees of porosity observed.

Figure D.6-10. Standard showing good front and back wall signal definition.

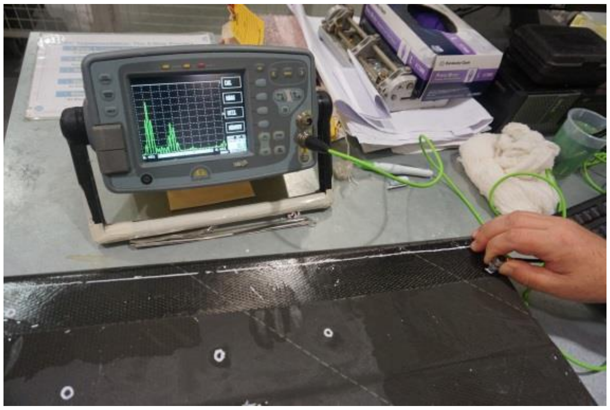


Figure D.6-11. Standard showing strong intermediate reflection with significant back-wall signal attenuation.

Figure D.6-12. Standard showing smaller intermediate reflection with back-wall signal attenuation.

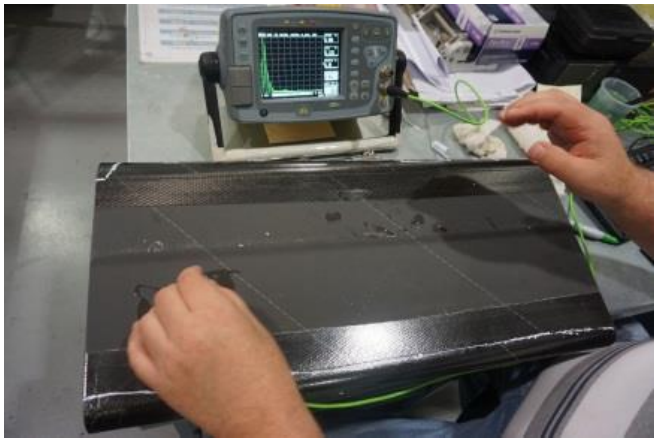


Figure D.6-13. Standard showing complete back-wall signal loss.

The range of defects addressed included Porosity, disbonds, wrinkles, and Marcels, and FOD. Wrinkles are particularly difficult to define in that they are visually evident on the surface but are usually not able to be characterized for depth or severity without destructive dissection. The wrinkle specimens showed loss of back wall signal but their severity is only evident by viewing the specimen cross section that bisected a representative wrinkle. Likewise distinguishing porosity clusters from disbonds or delaminations can be challenging and determining their precise depth locations and footprint is often limited by the inspection equipment and part geometry with conics presenting unique conditions that reflect signals away from their source. Figures D.6-14, D.6-15, D.6-17, and D.6-18 show visual microscopic definition of various defects taken from the polished edges of the standards. Figure D.6-16 shows a macro close-up of an external wrinkle. These can be correlated with the NDT techniques employed for the inspection of the Standards.

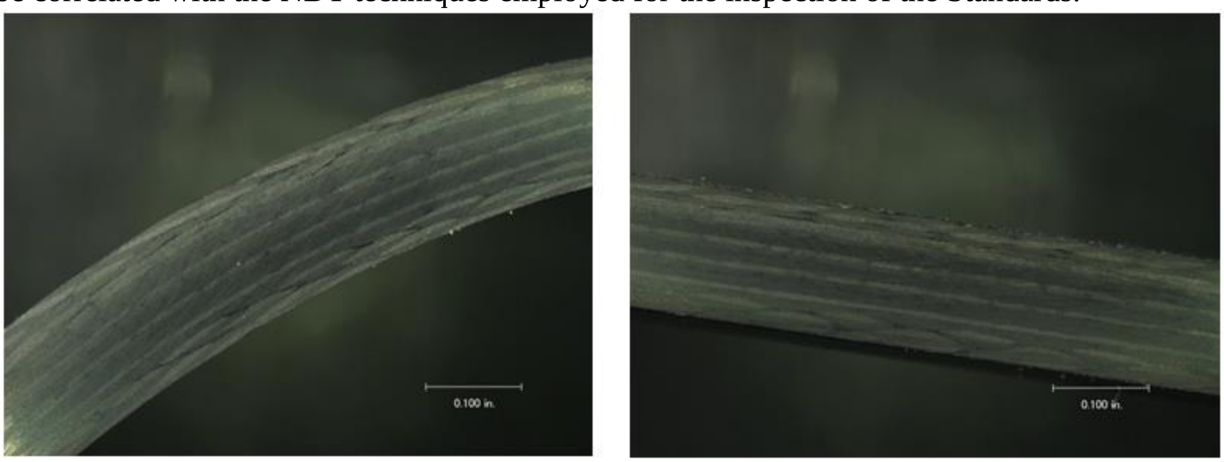


Figure D.6-14. NASA-005-Tube-Standard 001 and 002 defect free.

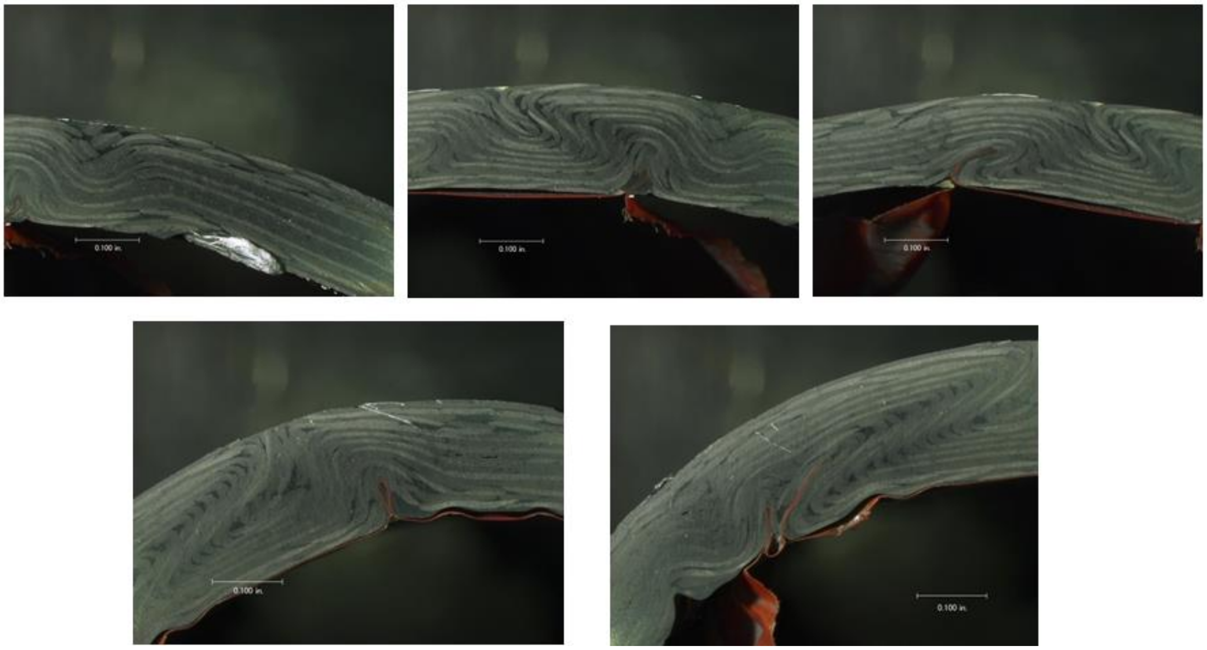


Figure D.6-15. NASA-005-Tube-Wrinkle 001 and 002.

Figure D.6-16. Close-up of wrinkle surface on OML of NASA-005-Tube-Wrinkle-001.

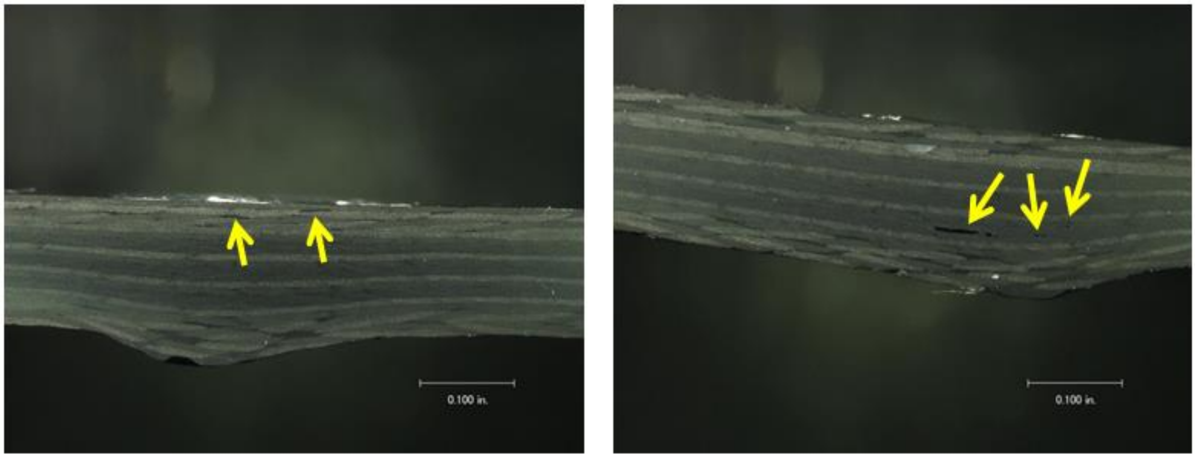


Figure D.6-17. NASA-005-Tube-Porosity 001 and 002.

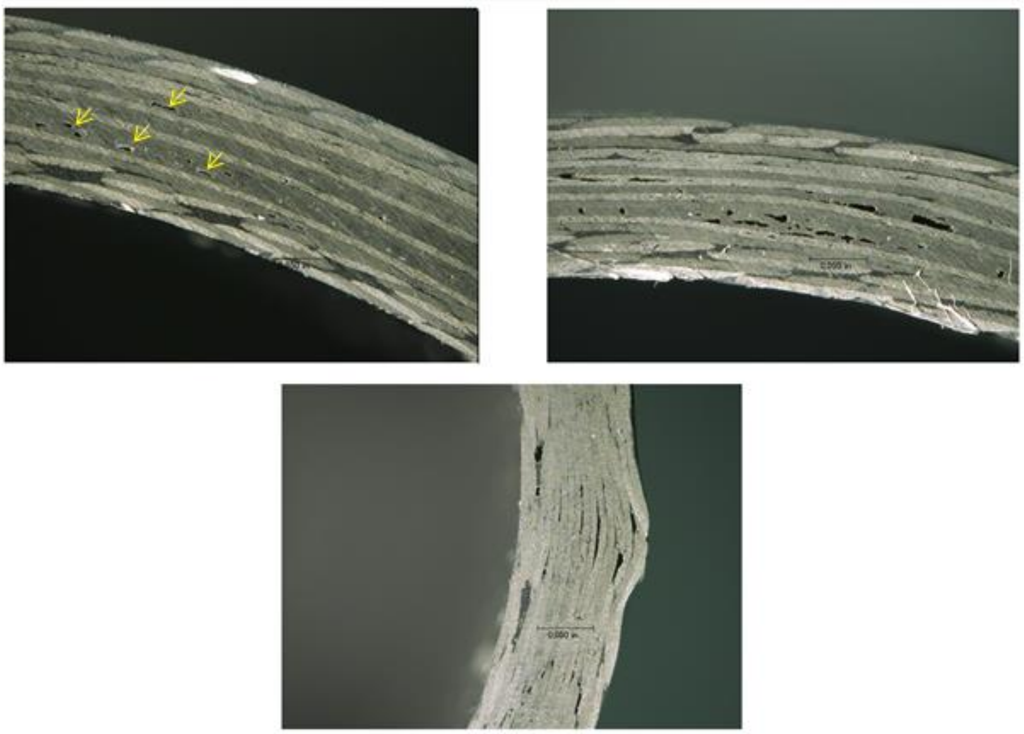


Figure D.6-18. NASA-005-Tube-Porosity 003 and 004 show porosity of varying degrees.

Characterization methods used in this IDIQ task were conventional hand scan ultrasonic inspection, supplemented by visual examination and dissection. The standards are available for ACC tasks to explore more comprehensive inspection techniques that can add to the fidelity of understanding the depth and severity of each kind of defect. One such candidate NDT technology is micro CT scan, but current technology would have to be demonstrated on the NDT standards, then modified to apply to long (>20 feet) closed tubular shapes. The standards delivered under this contract for future study by the NASA ACC Program or for round-robin testing is shown in Figures D.6-19 through D.6-22, with top and bottom views shown in each figure. The reference standards are marked with a paint pen, showing areas on the specimens where loss of back wall or intermediate defects were detected. A Mylar template map of defects documented by Sikorsky is provided for each defect specimen to facilitate any blind round-robin studies that may choose to remove actual markings on the parts.

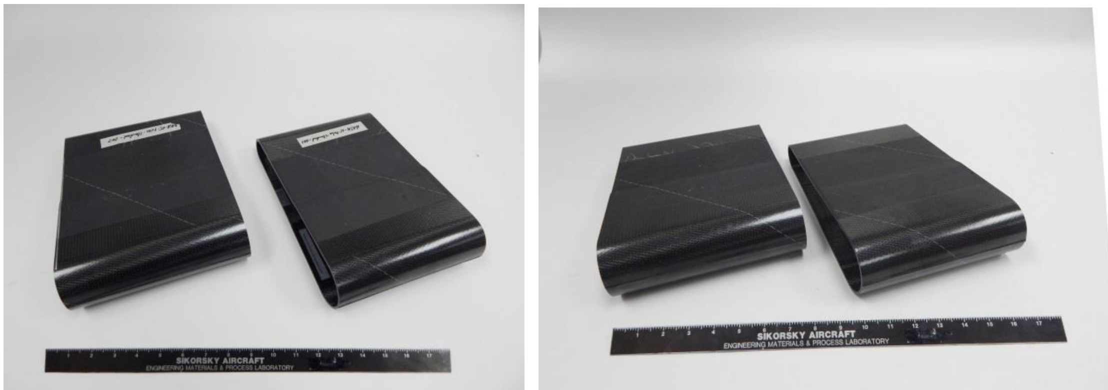


Figure D.6-19. NASA-005-STANDARD-001 and -002.

Figure D.6-20. NASA-005-Wrinkle-001 and -002.

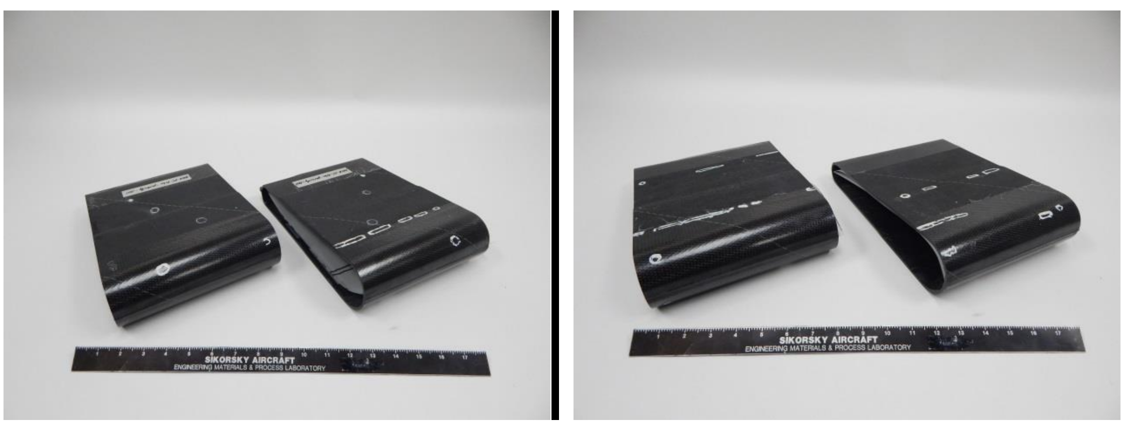


Figure D.6-21. NASA-005-Porosity-001 and -002.

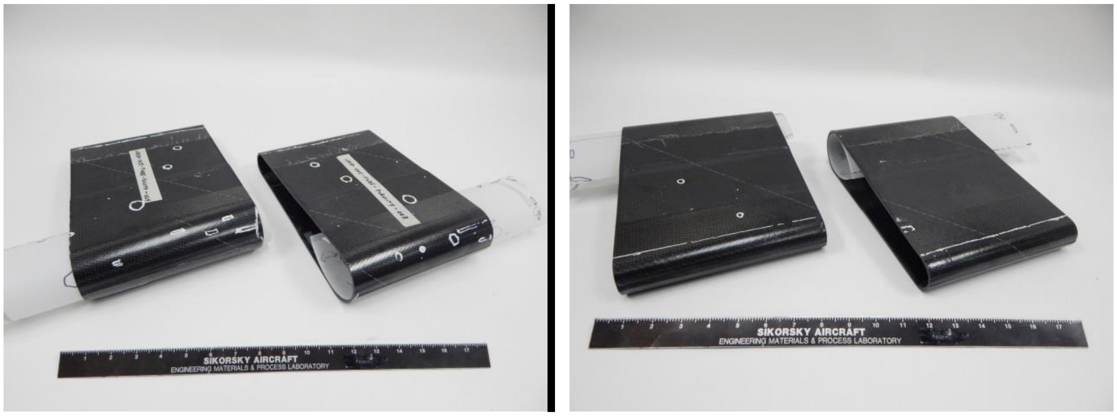


Figure D.6-22. NASA-005-Porosity-003 and -004.

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14. ABSTRACT
This Handbook is a guidance document that facilitates the selection of appropriate Nondestructive Evaluation (NDE) techniques and provides recommended protocols for detecting and characterizing common flaw types in complex composite structures. It seeks to reduce the time required to develop qualified inspection processes for composite aircraft structures during the development, certification, and manufacturing phases by providing a reference that helps minimize trial and error and provides guidance on best practices, techniques, and settings, for specific flaw types and geometries.

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