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Conference & Exhibition

Re-Certification and Equivalency Test Results for IM7/8552-1 Following Extended Freezer Storage

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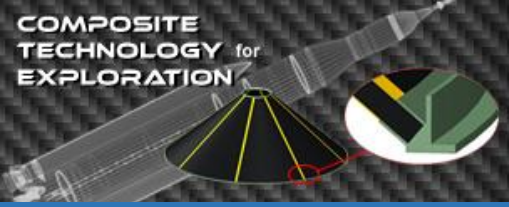


Composite Technology for Exploration- Project Background

Motivation

- Composite joints can account for very significant increases in cost and weight. In addition, improvements are needed in analytical capabilities required to predict failure modes in composite structures.

Technical Objectives

- The Composites Technology for Exploration (CTE) project will advance composite technologies for future light-weight NASA exploration missions.
  - CTE targets bonded joint technology for Space Launch System scale (8.4m diameter) hardware.

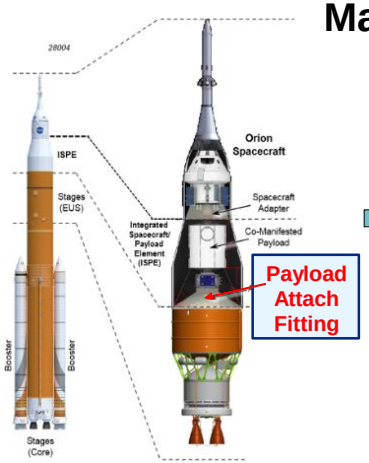
- To advance composite technologies CTE will develop and demonstrate critical composite joint technologies through materials, design, analyses, manufacturing, test, and test correlation efforts.

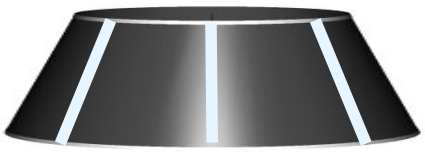
- CTE project will develop, demonstrate and document a tailoring approach to enable reducing composite discontinuities factor of safety from the current 2.0 (NASA-STD-5001) targeting 1.5 to 1.8

Utilization of Acreage Panels

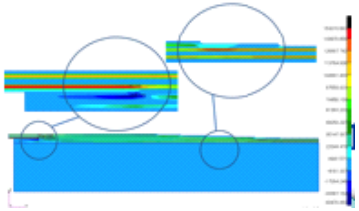
CTE Technology Plan

Material characterization studies

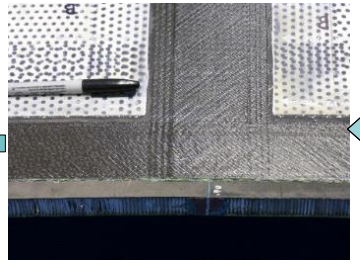




Acreage sizing and joint trade studies



Detailed joint analysis



Joint manufacturing process development

Joint Sub-element tests

Jointed panel tests and analyses correlations

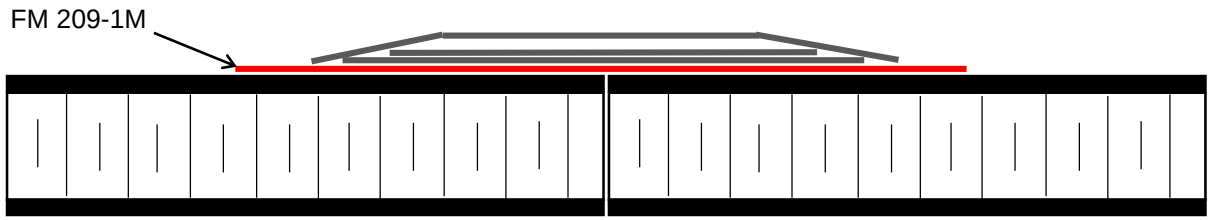
Utilizing personnel from MSFC, LaRC, GRC, GSFC, and KSC

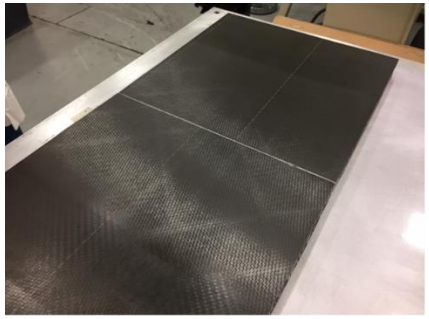
Bonded Joint Pathfinder

Fabrication of sandwich structures for bonding trials underway.

- Capitalize lessons learned from composite crew module.
- Performing process optimization to minimize voids.
- Preliminary evaluation of damage detection.

Top View





a.) Pre cured Acreage

b.) Surface Preparation

c.) Pre-preg Splice

Introduction

- In 2015, the Composites for Exploration Upper Stage (CEUS) Project and procured a significant amount of prepreg.
- The material selected was IM7/8552-1, a variant of the IM7/8552 prepreg used to populate a National Center for Advanced Materials Performance (NCAMP) database.
- The CEUS successor program, Composites Technology for Exploration (CTE), kicked off in 2017 with the remaining CEUS prepreg planned for use.
- The IM7/8552-1 prepreg was recertified through an in-house defined set of pass/fail criteria then evaluated for equivalency to the NCAMP database.
- Over the course of recertification and equivalency panel fabrication, the time of freezer storage ranged from 19 – 23 months.
- Panels for recertification and equivalency tests were fiber placed at NASA Marshall Space Flight Center (MSFC) and NASA Langley Research Center (LaRC).

Manufacturing Facilities

Panels were fabricated by fiber placement at NASA Langley Research Center and NASA Marshall Space Flight Center.

Established a processing specification to ensure consistency across remote manufacturing sites.

Test Matrix for Material Re-Certification

The material end-user has the flexibility to define its recertification test matrix, but should interrogate resin-dominated composite properties and retention of material processability.

Panel	Lay-up	Test Standard	Batches	Panels/ Batch	Panel Total	Specimen/ Panel	Specimen Total
Compression Strength and Modulus	$[0]_{12}$	SACMA SRM 1	2	1	2	5	10
Fiber Volume	$[0]_{12}$		2	1	2	5	10
Short Beam Shear	[45/0/-45/90]3s	ASTMD2344	2	1	2	5	10
Tg by DMA	[45/0/-45/90]3s	ASTM D7028	2	1	2	2	4

Minimum required values were determined statistically through application of the t-test. The t-test is a statistical tool used to calculate a confidence interval for data comparison; providing a probability that data will fall into a given range.

A broader range imparts an increased probability that a data-point will fall between upper and lower bounds. The 95% confidence interval is a widely accepted conservative value.

Re-Certification Test Data

This recertification effort provided a 12 month extension in freezer life of the material for use within the CTE project. The 12 month extension was deemed appropriate for a non-flight project. Past programs have shown excellent property retention in this material following extended freezer life and out time conditions.

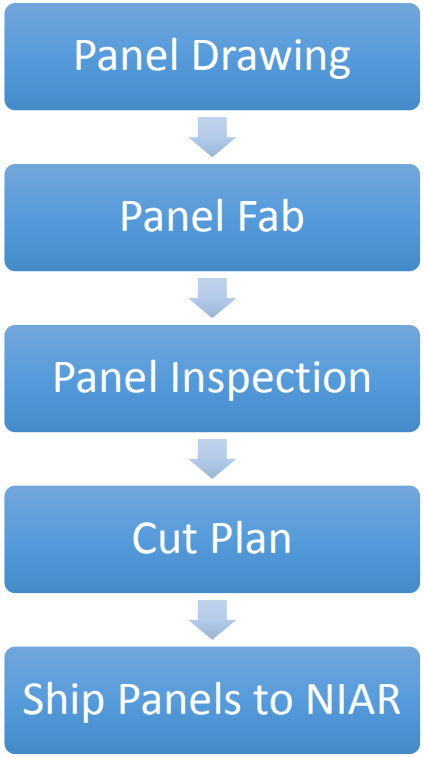
Test- Lamina	Lay-up	Hexcel-1	Hexcel-2	Hexcel-3	Hexcel-4	Pass Re-Cert (Min Value, 95% conf)	CTE ReCert Measured Value	Comments
Compression Strength (ksi)	$[0]_{12}$	274	230	293	258	221	Avg. 224 ksi	LaRC: 216 MSFC: 225 MSFC: 231
Compression Modulus (msi)	$[0]_{12}$	21.5	21.5	21.3	21.0	20.95	Avg. 21.17 msi	LaRC: 21.12, MSFC: 20.68, MSFC: 21.71
CEUS Data								
Short Beam Shear (ksi)	$[45/0/-45/90]_{3s}$	12.45 (GRC)	12.03 (LaRC)	12.40 (MSFC)		11.72	Avg. 11.76 ksi	LaRC: 12.59 MSFC: 11.49 MSFC: 11.19
Glass Transition Temp. (^{o}C), E' shoulder in DMA	$[45/0/-45/90]_{2s}$	192, 191 (GRC)	194, 191 (LaRC)	190°C, 194°C (MSFC)		191	Avg. 189^{o}C	
Fiber Volume (%)	$[45/0/-45/90]_{2s}$	56.6 (MSFC)	58.4 (LaRC)			56.2	57.2%	

IM7/8552-1 Equivalency Tests

Purpose

- Demonstrate equivalency to existing NCAMP database
- Leverage database to reduce coupon testing.

Panels for Equivalency Fabricated, Inspected and Shipped to NIAR for Mechanical Tests



Equivalency Pass-Fail Metrics

- Different matrix materials were used in this work and the NCAMP database; i.e. 8552-1 vs. 8552.
- Reported data has been normalized to a cured ply thickness (CPT) of 0.0072 inch.
- This material was aged beyond the recommended freezer life. Prepreg had been stored below 0°C for 19-23 months at the time of panel fabrication.
- Any tests failing statistically by 1% or less were considered a 'pass'.
- Any tests that failed because measured data was higher than qualification data was considered a 'pass'.
- Any test that passed by the modified CV method was considered a 'pass'.
- Data is presented as Pass/Fail. The relative severity of a failure is given by the below chart.

Description	Modulus	Strength
Mild Failure	% fail ≤ 4%	% fail ≤ 5%
Mild to Moderate Failure	4% < % fail ≤ 8%	5% < % fail ≤ 10%
Moderate Failure	8% < % fail ≤ 12%	10%< % fail ≤ 15%
Moderate to Severe Failure	12% < % fail ≤ 16%	15% < % fail ≤ 20%
Severe Failure	16% < % fail ≤ 20%	20% < % fail ≤ 25%
Extreme Failure	20% < % fail	25% < % fail

Lamina Test Data

	RTD		ETW	
Test/ Center	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL
Longitudinal Tension $[0]_6$				
NCAMP				
Strength (ksi)	362.7 (16.1)		333.5 (38.8)	
Modulus (Msi)	23.0 (0.8)		24.0 (0.6)	
CTE-MSFC				
Strength (ksi)	371.6 (20.8)	Pass	354.4 (49.7)	Pass
Modulus (Msi)	22.4 (0.3)	Pass	22.7 (1.0)	Pass
CTE-LaRC				
Strength (ksi)	359.8 (8.4)	Pass	341.2 (12.4)	Pass
Modulus (Msi)	21.8 (0.3)	Pass	22.1 (0.3)	Mild Failure
Longitudinal Compression $[0]_{14}$				
NCAMP				
Modulus (Msi)	20.0 (1.4)		20.4 (1.8)	
CTE-MSFC				
Modulus (Msi)	20.5 (0.6)	Pass	20.7 (0.5)	Pass
CTE-LaRC				
Modulus (Msi)	19.9 (0.4)	Pass	19.6 (0.3)	Pass

Lamina Test Data

	RTD		ETW	
Test/ Center	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL
Transverse Tension $[0]_{11}$				
NCAMP				
Strength (ksi)	9.3 (0.9)		3.5 (0.2)	
Modulus (Msi)	1.3 (0.04)		0.8 (0.04)	
CTE-MSFC				
Strength (ksi)	10.4 (1.4)	Pass	3.1 (0.8)	Pass
Modulus (Msi)	1.3 (0.02)	Pass	0.9 (0.1)	Pass
CTE-LaRC				
Strength (ksi)	11.3 (0.7)	Pass	3.3 (0.3)	Pass
Modulus (Msi)	1.2 (0.01)	Pass	0.8 (0.03)	Pass
Transverse Compression $[0]_{11}$				
NCAMP				
Strength (ksi)	41.4 (1.9)		19.0 (1.0)	
Modulus (Msi)	1.4 (0.1)		1.2 (0.1)	
CTE-MSFC				
Strength (ksi)	39.6 (0.7)	Pass	18.8 (0.3)	Pass
Modulus (Msi)	1.4 (0.01)	Pass	1.0 (0.04)	Moderate Failure
CTE-LaRC				
Strength (ksi)	37.7 (1.3)	Mild Failure	17.9 (0.9)	Mild Failure
Modulus (Msi)	1.4 (0.02)	Pass	1.0 (0.03)	Moderate Failure

Lamina Test Data

	RTD		ETW	
Test/ Center	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL
In-Plane Shear $[45/-45]_{3s}$				
NCAMP				
0.2% Offset Strength (ksi)	7.8 (0.2)		3.3 (0.2)	
5% Offset Strength (ksi)	13.2 (0.2)		5.5 (0.2)	
Modulus (Msi)	0.68 (0.02)		0.306 (0.01)	
CTE-MSFC				
0.2% Offset Strength (ksi)	7.2 (0.1)	Mild Failure	3.6 (0.1)	Pass
5% Offset Strength (ksi)	12.7 (0.2)	Pass	5.9 (0.1)	Pass
Modulus (Msi)	0.63 (0.01)	Mild Failure	0.344 (0.01)	Pass
CTE-LaRC				
0.2% Offset Strength (ksi)	7.2 (0.04)	Mild Failure	3.5 (0.1)	Pass
5% Offset Strength (ksi)	12.6 (0.04)	Pass	5.8 (0.1)	Pass
Modulus (Msi)	0.63 (0.01)	Mild Failure	0.341 (0.01)	Pass

Pristine Laminate Test Data

	RTD		ETW	
Test/Project/ Center	Normalized Data	PASS/FAIL	Normalized Data	PASS/ FAIL
Un-notched Tension $[45/0/-45/90]_{2s}$				
NCAMP				
Strength (ksi)	104.7 (7.3)		112.5 (5.6)	
Modulus (Msi)	8.4 (0.5)		8.0 (0.4)	
CTE-MSFC				
Strength (ksi)	104.8 (2.0)	Pass	112.7 (5.2)	Pass
Modulus (Msi)	8.1 (0.1)	Pass	7.9 (0.2)	Pass
CTE-LaRC				
Strength (ksi)	106.5 (1.9)	Pass	113.9 (2.7)	Pass
Modulus (Msi)	7.9 (0.1)	Pass	7.8 (0.1)	Pass
Un-notched Compression $[45/0/-45/90]_{2s}$				
NCAMP				
Strength (ksi)	87.0 (8.1)		57.7 (6.4)	
Modulus (Msi)	7.9 (0.4)		7.1 (0.1)	
CTE-MSFC				
Strength (ksi)	82.9 (2.9)	Pass	61.3 (4.2)	Pass
Modulus (Msi)	7.4 (0.2)	Pass	7.4 (0.1)	Pass
CTE-LaRC				
Strength (ksi)	82.5 (3.9)	Pass	61.1 (1.3)	Pass
Modulus (Msi)	7.4 (0.1)	Pass	7.2 (0.1)	Pass

Open Hole Laminate Test Data

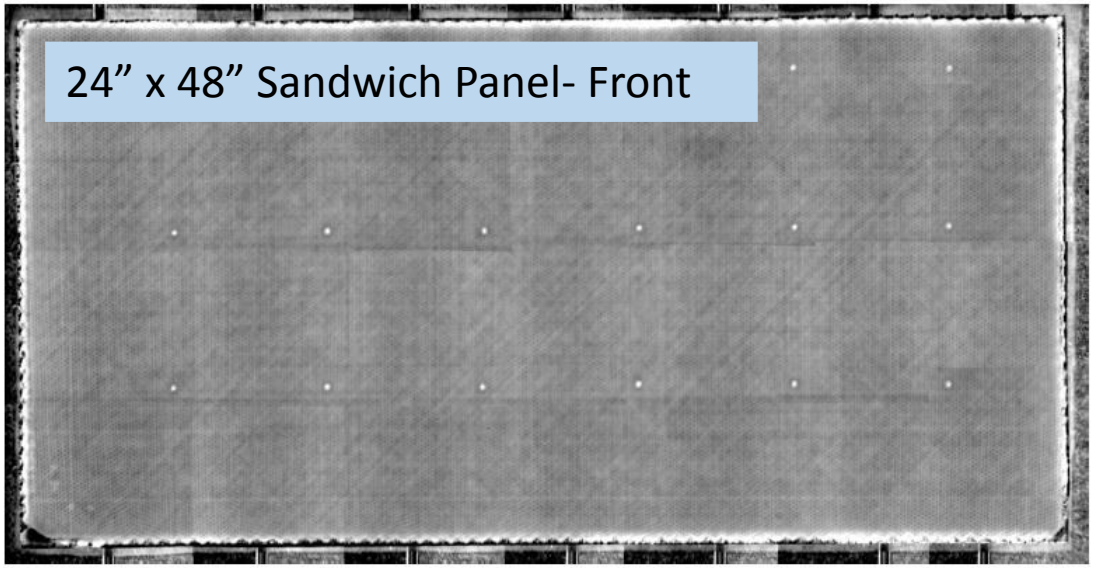
	RTD		ETW	
Test/ Center	Normalized Data	PASS/FAIL	Normalized Data	PASS/ FAIL
Open Hole Compression $[45/0/-45/90]_{3s}$				
NCAMP Strength (ksi)	49.1 (3.7)		35.5 (1.4)	
CTE-MSFC				
Strength (ksi)	47.9 (3.3)	Pass	37.1 (1.9)	Pass
CTE-LaRC				
Strength (ksi)	47.7 (1.6)	Pass	36.0 (1.0)	Pass
Open Hole Tension $[45/0/-45/90]_{2s}$				
NCAMP Strength (ksi)	59.0 (4.0)		67.0 (2.9)	
CTE-MSFC				
Strength (ksi)	63.8 (2.7)	Pass	68.3 (3.0)	Pass
CTE-LaRC				
Strength (ksi)	63.8 (4.7)	Pass	69.1 (1.1)	Pass
Filled Hole Tension $[45/0/-45/90]_{2s}$				
NCAMP Strength (ksi)	65.9 (4.9)		70.3 (2.3)	
CTE-MSFC				
Strength (ksi)	67.7 (2.2)	Pass	71.6 (1.9)	Pass
CTE-LaRC				
Strength (ksi)	68.0 (2.4)	Pass	71.8 (2.3)	Pass
Single Shear Bearing $[45/0/-45/90]_{2s}$				
NCAMP 2% Strength (ksi)	109.9 (5.5)		88.1 (8.9)	
CTE-MSFC				
2% Strength (ksi)	128.6 (3.1)	Pass	104.1 (3.9)	Pass
CTE-LaRC				
2% Strength (ksi)	125.7 (2.6)	Pass	97.7 (4.7)	Pass

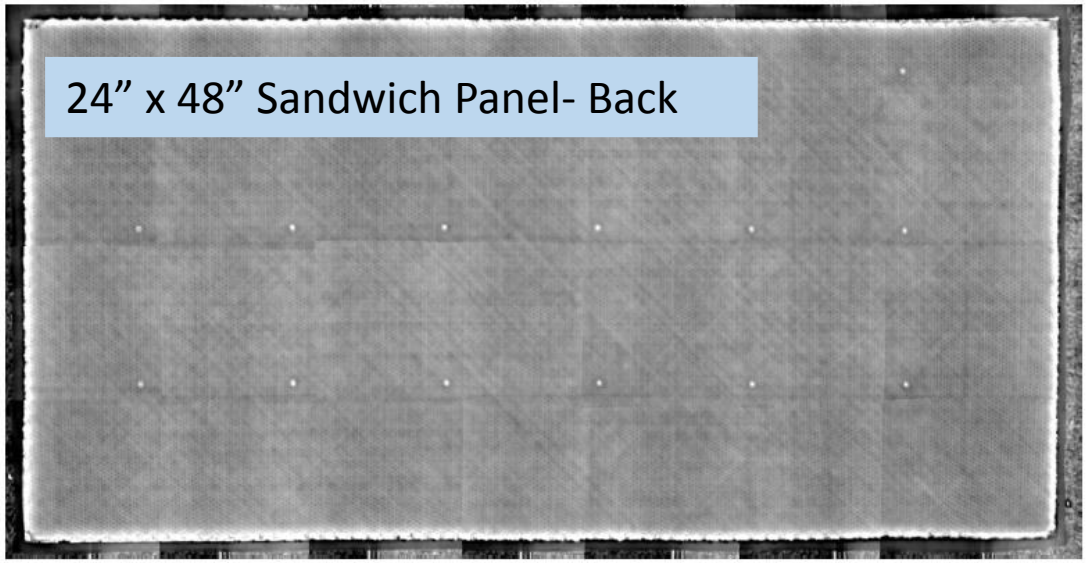
Material Performance- Flash Thermography

Panel:	CTE057-MSFC-8
Plies:	8 (facesheets)
Layup:	$[+45/90/-45/0]_s$
Prepreg:	IM7/8552-1 (1/2" slit tape)
Core:	1", 3.1 pcf, 3/16", 5056
Core Splice:	None
Film Adh.	FM209-1M
Test:	Flatwise tension (ASTM C297)
Test Speed:	.02 in/min

Inspection Settings

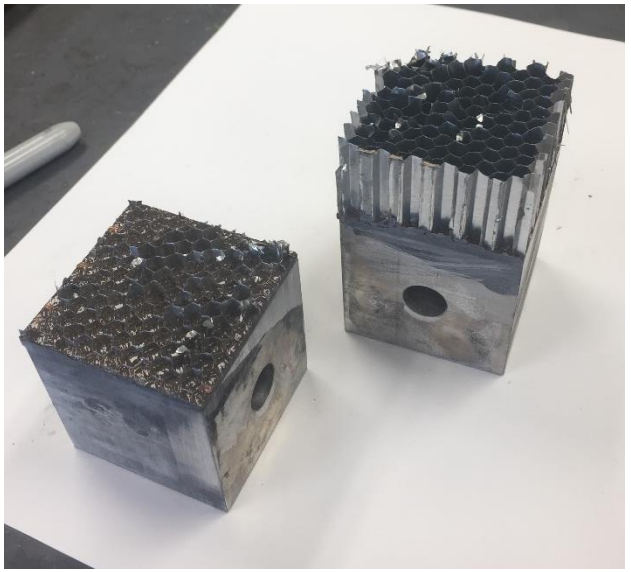
Capture Software	EchoTherm 8
Image Size	640 x 512
Capture Frequency	24 Hz
Flash Duration	Full
Flash Delay	0 milliseconds
Flash Frame	10
TSR Skip Frames	1





Material Performance- Flatwise Tension

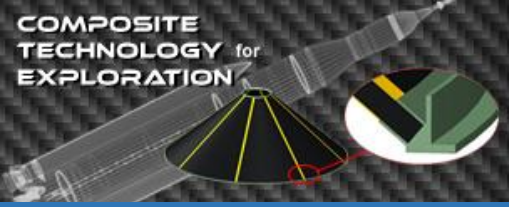
Panel: CTE057-LaRC-1
Plies: 8 (facesheets)
Layup: $[+45/90/-45/0]_s$
Prepreg: IM7/8552-1 (1/4" slit tape)
Core: 1", 3.1 pcf, 3/16", 5056
Core Splice: None
Film Adh. FM209-1M
Test: Flatwise tension (ASTM C297)
Test Speed: .02 in/min



Specimen	Width (in)	Length (in)	Peak Load (lb)	Failure	F^{ftu} (psi)
1	2.0	2.0	3939.328	Core	984.8
2	2.0	2.0	3911.276	Core	977.8
3	2.0	2.0	3871.922	Core	968.0
4	2.0	2.0	3827.068	Core	956.8
5	2.0	2.0	3862.994	Core	965.7
6	2.0	2.0	3874.614	Core	968.7
Mean	2.0	2.0	3881	-	970
St. Dev.	0.0	0.0	39	-	9.8
CoV	0.0	0.0	1.01	-	1.01

Re-Certification and Equivalency Summary

- Under RTD conditions, panels fabricated from IM7/8552-1 following 19 months to 23 months of freezer storage, passed most equivalency metrics; with the exceptions being in-plane shear and transverse compression. Statistically mild failures were observed for these properties. Under ETW conditions, the aged material failed the metric for equivalency only in longitudinal tensile modulus, and transverse compression strength and modulus.
- Tensile modulus, transverse compression and shear are resin dominated properties and a decline would be expected for ‘aged’ material. The marginal knock-down in shear performance was consistent with that measured for recertification.
- NDE indicated sandwich panels fabricated from this material were well consolidated.
- Flatwise tension tests failed in core, no face-sheet failures.



Back-Up

Equivalency- Data Relative to CEUS

	CTE		CEUS		CTE		CEUS	
	RTD		RTD		ETW		ETW	
Test/ Center	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL
Longitudinal Tension $[0]_6$								
MSFC								
Strength (ksi)	371.6 (20.8)	Pass	397.1 (2.7)	Pass	354.4 (49.7)	Pass	366.5 (3.5)	Pass
Modulus (Msi)	22.4 (0.3)	Pass	22.6 (0.3)	Pass	22.7 (1.0)	Pass	22.8 (1.6)	Pass
LaRC								
Strength (ksi)	359.8 (8.4)	Pass	381.7 (14.2)	Pass	341.2 (12.4)	Pass	358.1 (3.7)	Pass
Modulus (Msi)	21.8 (0.3)	Pass	22.4 (2.4)	Pass	22.1 (0.3)	Mild Failure	23.2 (1.6)	Pass

Equivalency- Data Relative to CEUS

	CTE		CEUS		CTE		CEUS	
	RTD		RTD		ETW		ETW	
Test/Project/ Center	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std dev.)	PASS/ FAIL	Normalized Data (std dev.)	PASS/FAIL	Normalized Data (std dev.)	PASS/ FAIL
Un-notched Tension $[45/0/-45/90]_{2s}$								
MSFC								
Strength (ksi)	104.8 (2.0)	Pass	107.4 (1.5)	Pass	112.7 (5.2)	Pass	110.9 (2.5)	Pass
Modulus (Msi)	8.1 (0.1)	Pass	8.1 (1.2)	Pass	7.9 (0.2)	Pass	7.9 (1.6)	Pass
LaRC								
Strength (ksi)	106.5 (1.9)	Pass	108.0 (1.4)	Pass	113.9 (2.7)	Pass	116.1 (2.4)	Pass
Modulus (Msi)	7.9 (0.1)	Pass	8.2 (2.0)	Pass	7.8 (0.1)	Pass	8.0 (1.8)	Pass
Un-notched Compression $[45/0/-45/90]_{2s}$								
MSFC								
Strength (ksi)	82.9 (2.9)	Pass	95.0 (3.3)	Pass	61.3 (4.2)	Pass	60.3 (2.8)	Pass
Modulus (Msi)	7.4 (0.2)	Pass	7.7 (0.5)	Pass	7.4 (0.1)	Pass	7.5 (1.2)	Pass
LaRC								
Strength (ksi)	82.5 (3.9)	Pass	92.2 (2.3)	Pass	61.1 (1.3)	Pass	56.4 (7.5)	Pass
Modulus (Msi)	7.4 (0.1)	Pass	7.6 (1.3)	Pass	7.2 (0.1)	Pass	7.4 (0.8)	Pass

Equivalency- Data Relative to CEUS

	CTE		CEUS		CTE		CEUS	
	RTD		RTD		ETW		ETW	
Test/ Center	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std dev.)	PASS/ FAIL	Normalized Data (std. dev.)	PASS/ FAIL	Normalized Data (std dev.)	PASS/ FAIL
Open Hole Compression $[45/0/-45/90]_{3s}$								
MSFC								
Strength (ksi)	47.9 (3.3)	Pass	47.5 (3.7)	Pass	37.1 (1.9)	Pass	33.2 (2.7)	Mild Failure
LaRC								
Strength (ksi)	47.7 (1.6)	Pass with Mod CV	47.1 (2.9)	Pass	36.0 (1.0)	Pass	32.2 (2.4)	Mild Failure
Open Hole Tension $[45/0/-45/90]_{2s}$								
MSFC								
Strength (ksi)	63.8 (2.7)	Pass	64.1 (2.6)	Pass	68.3 (3.0)	Pass	69.4 (3.4)	Pass
LaRC								
Strength (ksi)	63.8 (4.7)	Pass	62.4 (1.8)	Pass	69.1 (1.1)	Pass	69.0 (2.4)	Pass