NASA/CR—2008-215233

Intelligent Engine Systems

Smart Case System

Ming Xie
General Electric Aircraft Engines, Cincinnati, Ohio

May 2008

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1. Cost Modeling

The objective of this task was to expand affordability modeling software developed under a previous program. The scope involved reviewing and extracting mathematical algorithms from prior cost models for bodies of revolution using hand lay-up and braid process models.

UDRI, Ufkes Engineering, and Ohio University analyzed GE compiled shop floor data for the F110, F414, and GEnx. Equations were developed that relate geometry and other attributes to process time for the following:

Hand Layup	Tool Prep	Assemble Flange Shoes/Cull Plate
Wind	Assemble Tool	Seal Flange Shoes
Cure	Demold/Debag	Apply Resin System (RFI)
Load Autoclave	Trim	Post Cure
Bag	Cut/Kit	Hot Debulk
	Crossover	Debulk

UDRI, Ufkes Engineering, and Ohio University analyzed CAI MathSpecs in order to develop routines for additional processes for which no shop floor data was available. Equations that estimate process time were developed for the following additional processes:

RTM	Press Mold
VARTM	Paste Bond

The developed equations were reviewed with Ufkes Engineering and Ohio University. The equations were delivered to Ohio University for incorporation into a Java-based software user interface.

The cost modeling system easily and accurately estimates the cost of axisymmetric composite parts for jet engines. The system models a variety of composite materials, application and curing processes as well as a wide variety of part features. The guiding principle behind the system was to allow design engineers to estimate the cost impact of their decisions early. Some of the factors (besides the geometry) that influence the cost of a part are: form of the material, the application process, and the cure process.

The software allows the engineer to enter the rough dimensions of a part and determine the manufacturing approach that produces the most cost effective design.

The estimates are calculated using a bottoms-up approach. The cost of each component and process of the part is estimated and summed. Bottoms-up estimates mimics the actual method used by finance departments to determine actual costs. Therefore, they tend to be the most accurate type of estimates. The tool also provides an extensive breakdown of the cost drivers for the part to help the engineer understand where cost saving opportunities exists.

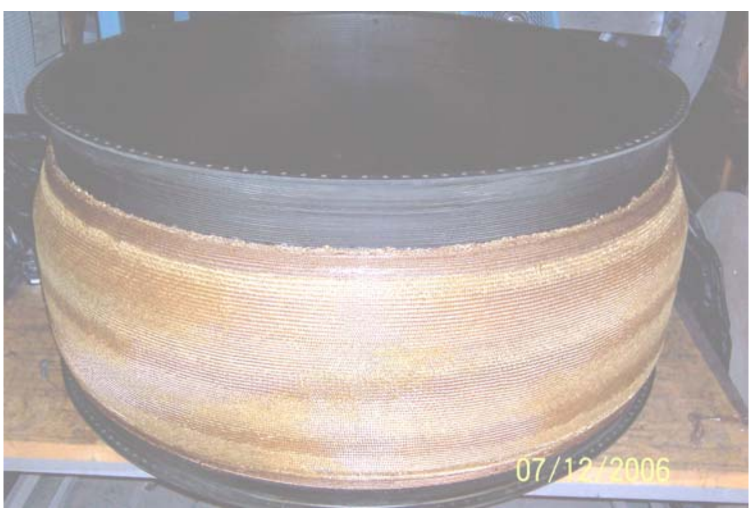
The system uses an automated method to associate the part attributes to process attributes. Thus, changing a single dimension on the part will simultaneously update the cost of the material, as well as the tool prep, application, debulk, cure, and machining times. This allows users to estimate the cost of a complicated part within minutes and more importantly see the effect of alternatives in seconds.

The cost elements were developed by experts from GE, Ohio University, University of Dayton and Ufkis Engineering. The elements were calibrated using actual manufacturing data from GE and validated using existing parts. The estimates of these parts were within 5% of the actual costs. Finally, the system has been used to investigate various manufacturing approaches to a commercial fan case and military ducts and cases.

2. Health Monitoring

A composite softwall fan containment case, with Zylon containment belt, was fabricated in a previous Prop21 program task. It was used in the current program to study the structure health monitoring methodology using several techniques.

The following picture shows the softwall containment case.



It was instrumented with a sensor package consisting of eight accelerometers and 39 ink grid sensors which were applied with conductive ink consisting of PR24LHT carbon nanofibers and Epon 862 epoxy. The fan case was shipped to NASA Glenn for impact testing and orbit testing. The sensor layout for the engine case is shown below in Figures 1 and 2.

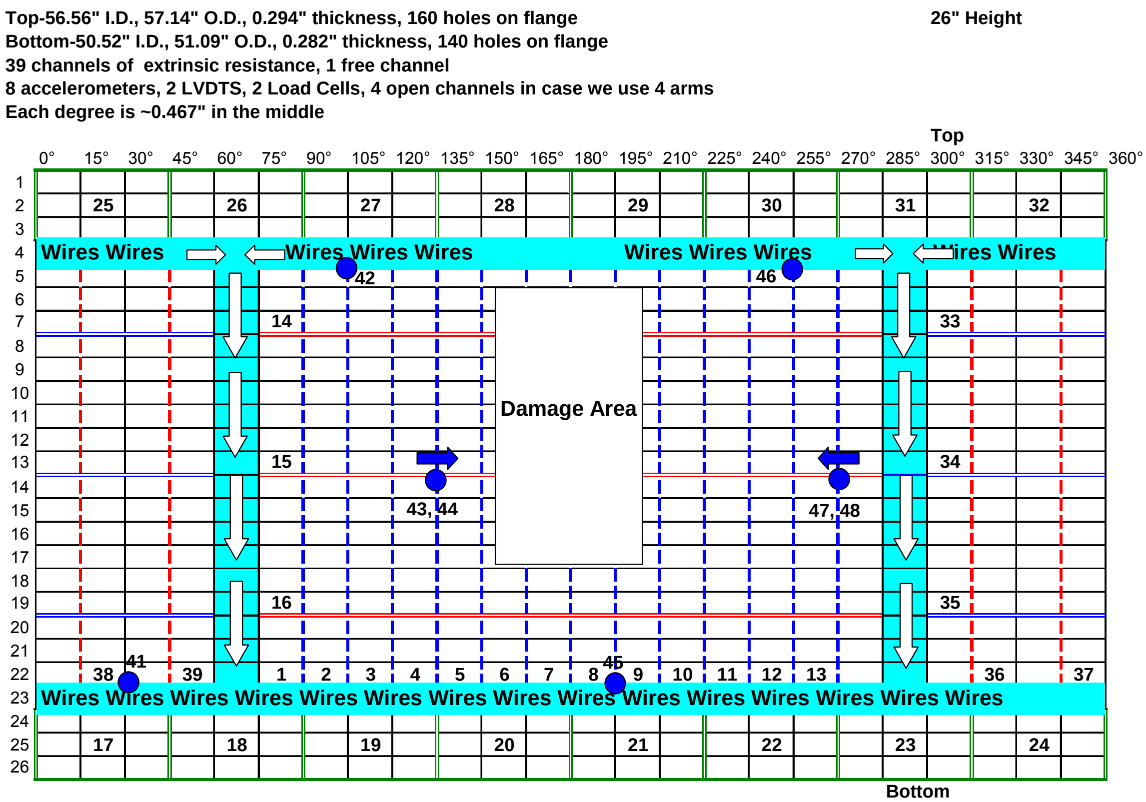


Figure 1. Sensor lay-out for GE composite fan case.

Figure 2. Fan case undergoing senor check

NASA Glenn will conduct the impact test in October under a different program. Test fixture design is currently in progress.

3. Nano reinforcement - Ballistic testing

UDRI has produced nano fiber and particle toughened composite panels for ballistic impact tests. The following panels have been produced first –

Panel #1 - virgin material (T700S/5208) without any nano enrichments;
Panel #2 - with 10 grams functionalized nano carbon fiber per square meter;
Panel #3 - with 20 grams functionalized nano carbon fiber per square meter;
Panel #4 - with 30 grams functionalized nano carbon fiber per square meter

Each panel has 30 layers of T700S triax braid. The final trimmed panel was 24"x24".

Ballistic impact tests have been performed on the above four (4) panels and great containment performance has been observed.

More ballistic panels were produced soon based on the experimental results. A total of ten composite laminates were prepared using braided reinforcements (Sigmatex, T700SC 12K, 50C). Laminates were prepared by first dispersing nanoparticles into the resin then filming the resin to an appropriate thickness to yield a composite with approximately 55 fiber vol%. The ballistic panels listed in Table 1 were made and delivered. Table 2 lists some of the additional information associated with the panels. The nanofillers used were ASI's carbon nanofiber PR24LHT-XT-OX and nano-clay I.30E

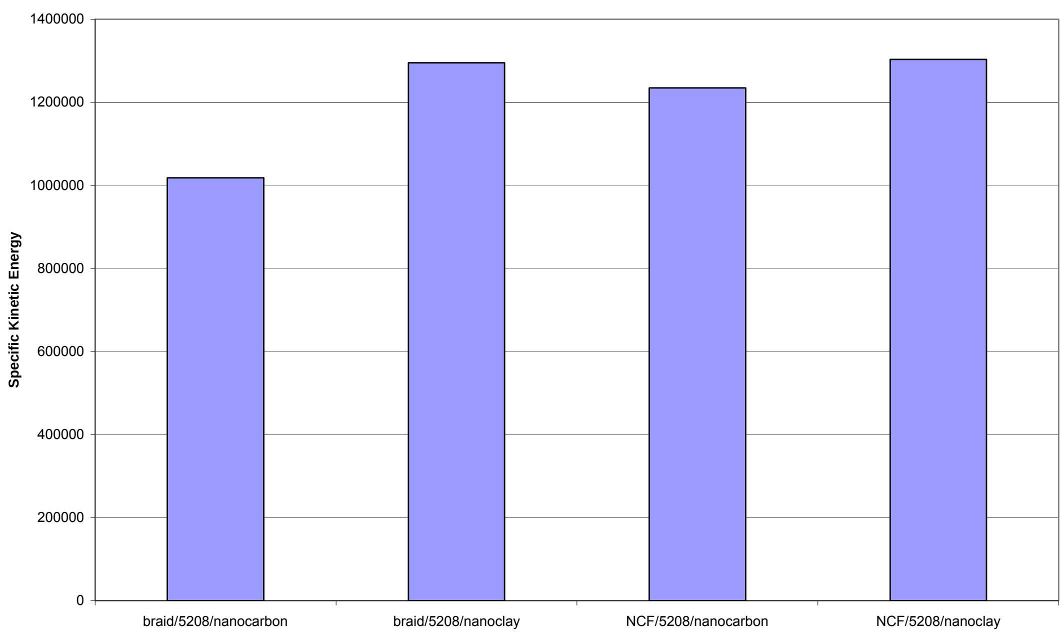
Panel	Fabric	Resin	Plies	Panel Size	Lay-up
1	Braid	5208	30	24" x 24"	First 15 layers (tool side) 10 gsm UDRI #172, last 15 layers have no nano
2	Braid	5208	30	24" x 24"	First 15 layers (tool side) 10gsm I.30E, last 15 layers have no nano
3	Braid	5208	6	24" x 24"	10 gsm UDRI #172 (PR24LHT-XT-OX)
4	Braid	5208	6	24" x 24"	10 gsm UDRI #172
5	Braid	5208	6	24" x 24"	10 gsm UDRI #172
6	Braid	5208	6	24" x 24"	10 gsm UDRI #172
7	Braid	5208	6	24" x 24"	10 gsm I.30E
8	Braid	5208	6	24" x 24"	10 gsm I.30E
9	Braid	5208	6	24" x 24"	10 gsm I.E30
10	Braid	5208	6	24" x 24"	10 gsm I.E30

Table 1. Ballistic Panels.

Panel	Film Thickness
1	13 mils
2	13.5 mils, 13 mils
3	13 mils
4	13 mils
5	13 mils
6	13 mils
7	13.5 mils
8	13.5 mils
9	13.5 mils
10	13.5 mils

Table 2. Resin film thickness for ballistic panels.

Some of the representative ballistic impact test results are shown in the following chart.



4. Nano reinforcement – Flanges

UDRI has supplied some nano resin film for process trial to fabricate composite flanges. Epoxy 5208 films were made for use with T700 braid to yield a composite with a target 65% fiber volume. Two batches (2000g each) were made with 5 gsm functionalized and with 10 gsm functionalized nanofibers (PR24LHT-XT-OX). The films were cut to 15" x 12" x 12 mils. Each set of films was delivered.

Composite flange sectors were made using the above nano enriched resin films and shown in the following picture.

5. Nano reinforcement – Localized reinforcement

In this subtask, nano enriched composite panels were fabricated by UDRI. The 12 panels are made up of various fabrics and Cycom 5208 resin with various nano-fillers. The following table contains the panel ID for the combinations of fabric, filler, thickness and dimensions for each of the panels. The fabrics include a T700SC 12K non-crimp fabric (NCF) with an areal weight of 750 GSM, a T700SC 24K 2x2 twill with a areal weight of 900 GSM, and T700SC lay flay braid with an areal weight of 550 GSM. Multiple areal weight resin films were made in order to target 63% fiber volume for each fabric and the respective panels. The panels were fabricated by interleafing layers of resin and layers of fabric. If in the table a panels is listed as having 30 plies that indicates there were 30 plies of fabric and 30 plies of resin.

Panel ID	Fabric/Resin	Nano	Lay-up	Dim	Plies
GEPS22807-1	Braid 5208	none	Axial alligned	10”x10”	30
GEPS22807-2	Briad 5208	none	Axial alligned	18”x18”	6
GEPS22807-3	Braid 5208	Nanocarbon fiber 10GSM	Axial alligned	10”x10”	30

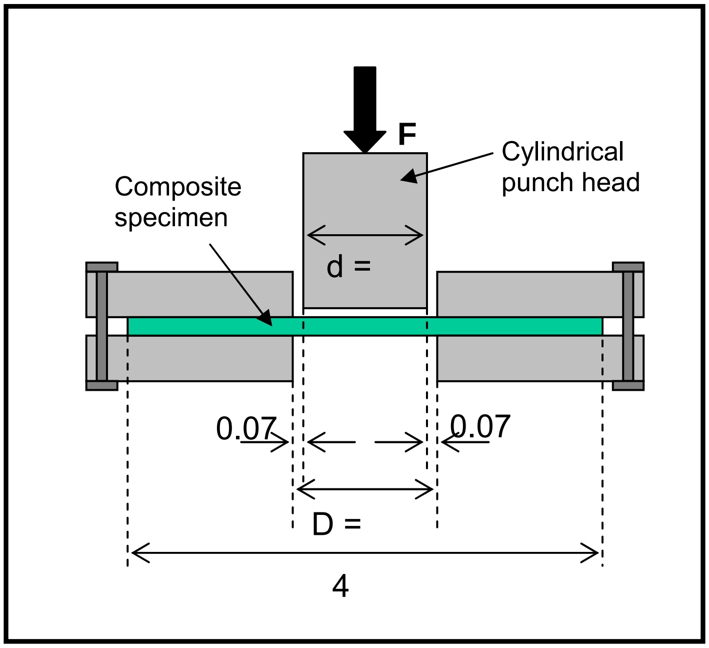
GEPS22807-4	Braid 5208	Nanocarbon fiber 10 GSM	Axial alligned	18”x18”	6
GEPS22807-5	Braid 5208	Func. nanocarbon fiber 10 GSM	Axial alligned	10”x10”	30
GEPS22807-6	Braid 5208	Func. nanocarbon fiber 10 GSM	Axial alligned	18”x18”	6
GEPS22807-7	Braid 5208	Nanoclay 20 GSM	Axial alligned	10”x10”	30
GEPS22807-8	Braid 5208	Nanoclay 20 GSM	Axial alligned	18”x18”	6
GEPS22807-9	24K weave	none	(0,45,45,0)4	10”x10”	16
GEPS22807-10	24 K weave 5208	none	0,45,45,0	18”x18”	4
GEPS22807-11	NCF 5208	none	Axial alligned	10”x10”	20
GEPS22807-12	NCF 5208	none	Axial alligned	18”x18”	4

The panel thicknesses and cured ply thickness (CPT) were measured for each completed panel. Density, acid digestion and microscopy were performed on each panel. The thicknesses of the completed panels are listed in Table 2. These thicknesses were measured using a 1/4” diameter flat-flat probe on a digital micrometer.

Table 2 Laminate thickness measurement results.

Panel ID	Average Thickness	CPT
GEPS22807-2	0.105”	0.0175”
GEPS22807-4	0.105”	0.0175”
GEPS22807-10	0.100”	0.0250”
GEPS22807-12	0.082”	0.0205”

The punch shear test was later conducted to quantify the thru-thickness shear capability. The test set up is shown in the following figure.



6. Acoustic Evaluation

Acoustic panel fabrication trial has started at RL Industries. Micrographs of a trial composite laminate processed by RL Industries where taken, and evaluated for porosity. This effort showed 12% porosity in the laminates, and pointed toward a processing issue rather than fiber resin compatibility.

More small processing trial panels were made at RL Industries and the process was closely monitored. Insufficient time for the release of volatiles was identified as a problem.

TGA and Rheology of the phenolic resin are to be performed to identify the amount and time of volatiles coming off the resin, and the gel time of the resin. The resin is to be placed in the oven and observed for volatile release.

Phenolic J2027L was mixed with 3% Phencat 382 and a clay loading of I.30E was added to yield a loading of 20 gsm. Films were cut to 24" x 12" x 0.004" and were delivered to Dave Bentley at RL Industries. The films were purposely made thin and at a high loading so that RL Industries could use a VARTM process to make the panels.

UDRI performed relative acoustic transmission loss testing on seven panels manufactured by RL industries as part of Task 6. After testing all panels, a 2” layer of foam was adhered to two of the panels and tested again. This test is a relative measure of the capability of a panel of material to reduce the acoustic transmission from one area to another.

The results of the test provide a relative ranking of various panels and do not provide absolute transmission loss values applicable to any general configuration.

The facility for this testing consists of a reverberant room and a quiet room separated by a door. The facility is illustrated in Figure 1. In the door is a cutout panel, which is replaced by panels of the acoustic materials being tested. A speaker was used to generate white noise in specific frequency bands at nominally 100 dB in the reverberant room. Microphones on either side of the panel (one in the reverberant room and one in the quiet room) were used to measure the sound level.

The tips of the random incidence microphones were positioned 6.0 inches from the surface of the panel and were pointed at the center of the panel. The microphones were calibrated to 114.0 decibel (dB) at 10.0 Pascals. All data were acquired at 75±3 °F.

A Bruel&Kjaer digital Fourier analyzer was used to compute sound level as a function of frequency from the microphone measurements. Acoustic pressure as a function of time was recorded by the Fourier analyzer and converted, using a Fast Fourier Transform, to acoustic pressure as a function of frequency. Sixteen frequency-domain samples were averaged to obtain each data point listed in the results.

The total pressure in each frequency band was then computed based on the average frequency-domain spectrum for each microphone. The total level of each microphone was recorded in dB, and the difference between microphone readings represents the acoustic reduction across the panel.

The test results are summarized in Figure 2.

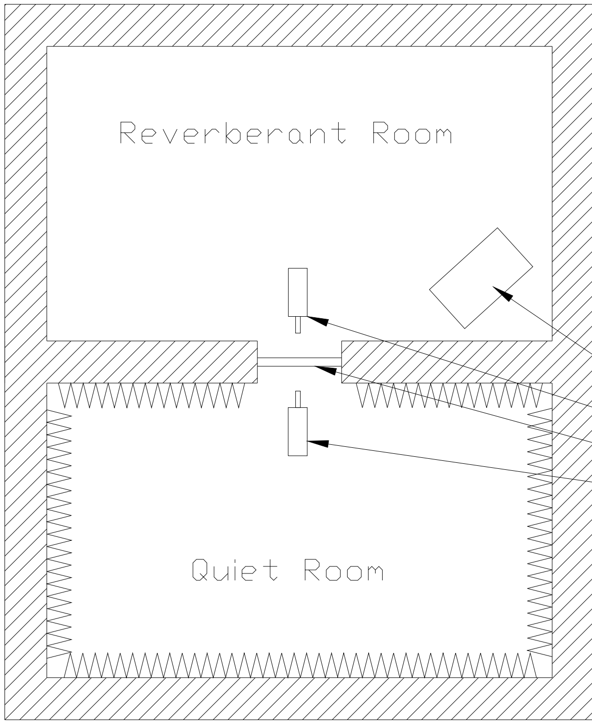


Figure 1. Schematic of Test Room (View Looking Downward)

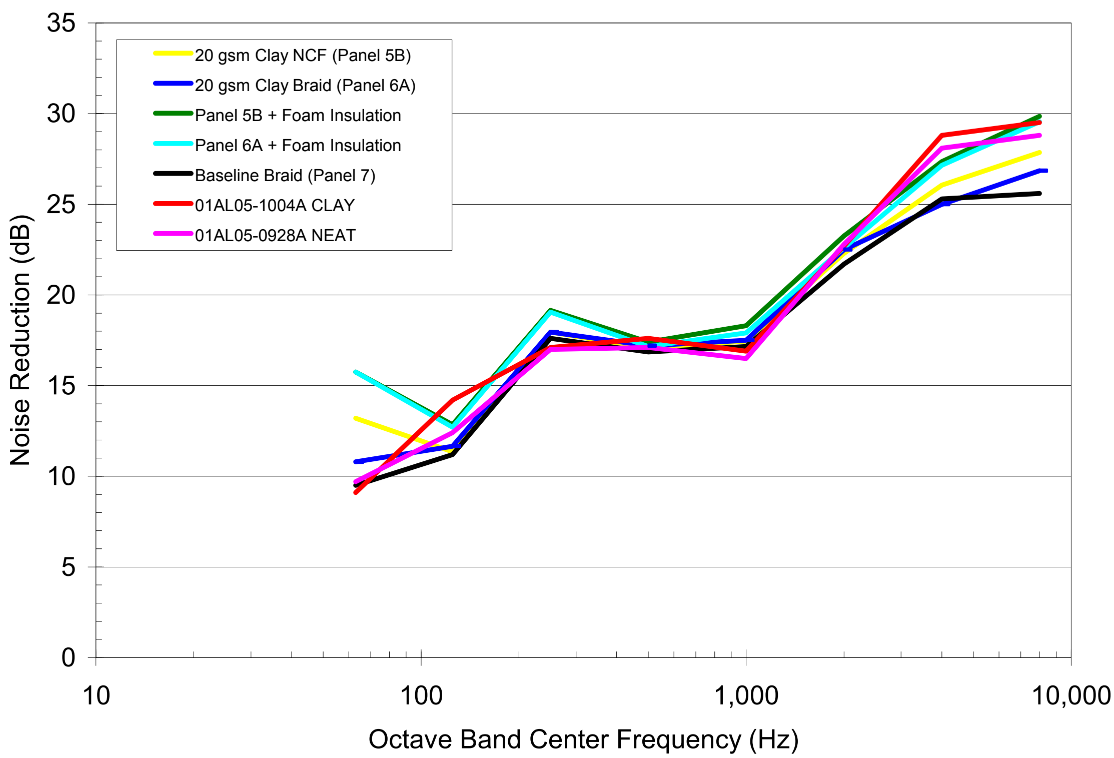
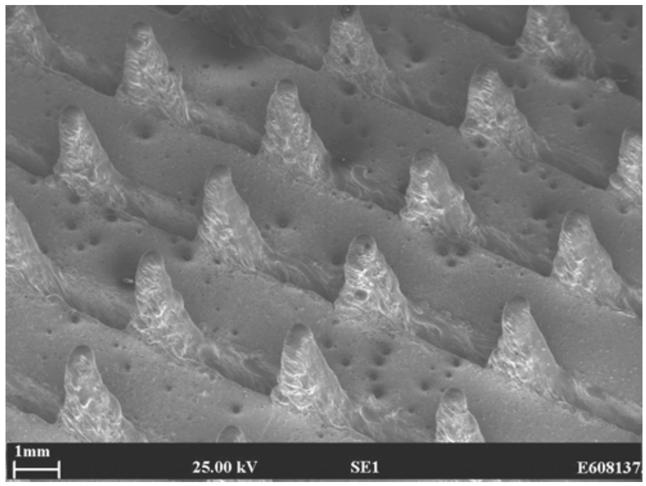


Figure 2. Summary of acoustic results for the various laminate configurations.

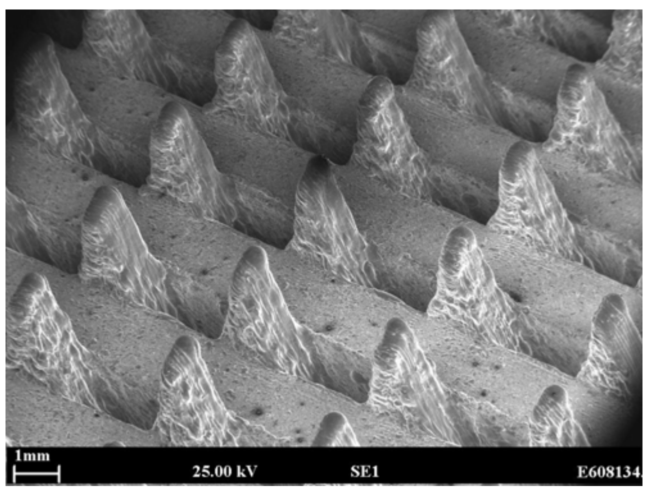
7. Metal to Composite Attachment

Metal joint specimens is being fabricated and a typical metallic surface treatment is shown in the following.

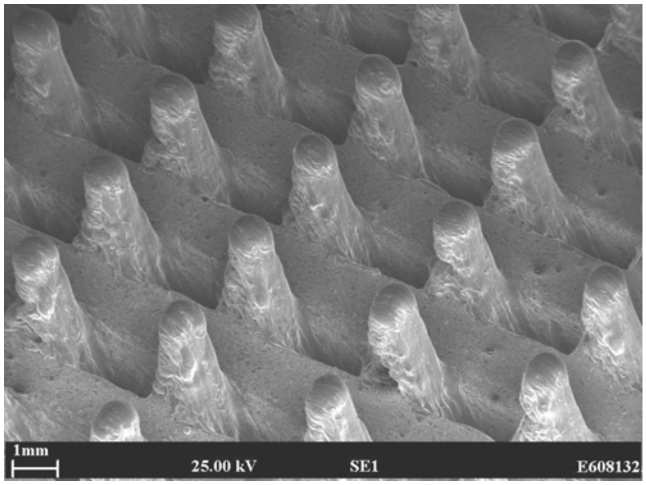
<u>Treatments in Aluminum 7075</u>



E608137 AAH11

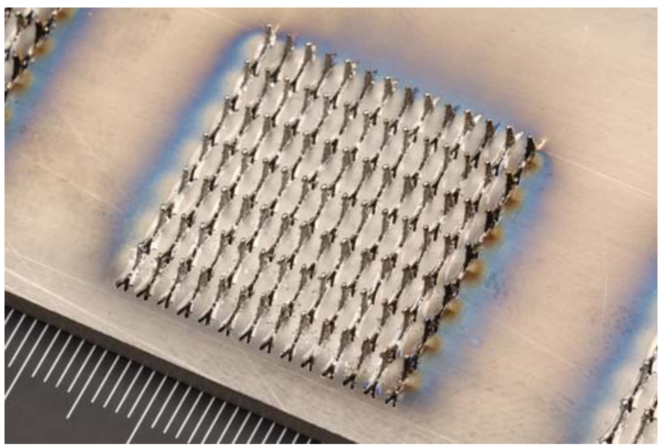


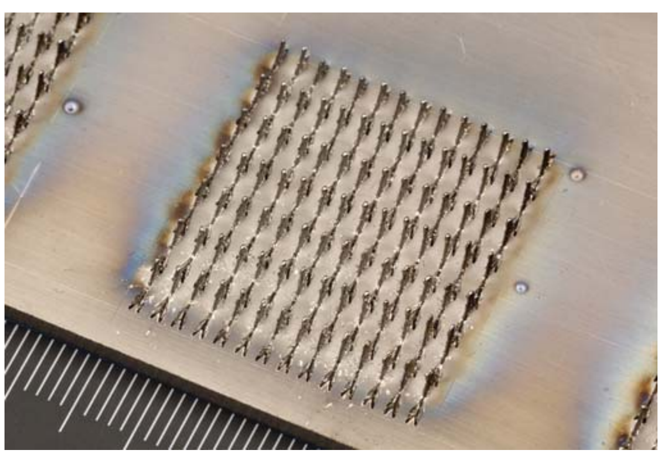
E608134 AAH15



E606132 AAH19

Treatments in Titanium 6/4


DSC6879


DSC6888

A set of aluminum and titanium plates with an arrangement of projections or teeth were evaluated for improvement in lap shear strength. A single lap configuration was used with the composite consisting of AS4/8HS fabric and epoxy resin. An appropriate surface treatment was applied to each metal plate before bonding.

Test results are provided in Tables 1 and 2. Representative failure modes are shown in Figures 1 and 2. All of the teeth on the titanium adherends were still intact following testing. Most of the teeth on the aluminum adherends actually sheared off during test.

Test Coupon Number	Tooth Density (grid size)	Tooth Angle	Test Temp.	Coupon Width (in.)	Overlap (in.)	Overlap Area (in²)	Max. Load (lbs.)	Lap Shear Stength (psi)	Comments
55	4 x 4	20°	RT (Dry)	1.016	1.00	1.016	2142	2108	All teeth remain; negligible fiber from Gr/Ep on Ti
56	4 x 4	20°	RT (Dry)	1.016	1.00	1.016	2026	1994	All teeth remain; negligible fiber from Gr/Ep on Ti
57	4 x 4	20°	RT (Dry)	1.014	1.00	1.014	2152	2122	All teeth remain; negligible fiber from Gr/Ep on Ti
							Average =	**2075**	
46	4 x 4	85°	RT (Dry)	0.996	1.00	0.996	2465	2475	All teeth remain; negligible fiber from Gr/Ep on Ti
47	4 x 4	85°	RT (Dry)	1.015	1.00	1.015	2408	2372	All teeth remain; negligible fiber from Gr/Ep on Ti
48	4 x 4	85°	RT (Dry)	1.005	1.00	1.005	2524	2511	All teeth remain; negligible fiber from Gr/Ep on Ti
							Average =	**2453**	
50	7 x 7	20°	RT (Dry)	1.020	1.00	1.020	2175	2132	Portion of Gr/Ep surface ply sheared at joint
51	7 x 7	20°	RT (Dry)	1.020	1.00	1.020	2150	2108	Portion of Gr/Ep surface ply sheared at joint
52	7 x 7	20°	RT (Dry)	1.020	1.00	1.020	2326	2280	Portion of Gr/Ep surface ply sheared at joint
							Average =	**2173**	
42	7 x 7	85°	RT (Dry)	1.005	1.00	1.005	2760	2746	Surface ply of Gr/Ep sheared at joint
43	7 x 7	85°	RT (Dry)	1.020	1.00	1.020	2948	2890	Surface ply of Gr/Ep sheared at joint
44	7 x 7	85°	RT (Dry)	1.020	1.00	1.020	2951	2893	Surface ply of Gr/Ep sheared at joint
							Average =	**2843**	

Table 1. Titanium bonded to graphite/epoxy laminate.

Test Coupon Number	Tooth Density (grid size)	Tooth Angle	Test Temp.	Coupon Width (in.)	Overlap (in.)	Overlap Area (in²)	Max. Load (lbs.)	Lap Shear Stength (psi)	Comments
94	4 x 4	20°	RT (Dry)	1.013	1.03	1.043	1458	1398	All but 1 tooth sheared off
95	4 x 4	20°	RT (Dry)	1.013	1.03	1.043	2256	2163	All but 2 teeth sheared off
96	4 x 4	20°	RT (Dry)	1.010	1.03	1.040	1939	1864	All but 2 teeth sheared off
							Average =	**1808**	
82	4 x 4	85°	RT (Dry)	1.012	1.03	1.042	1775	1703	All but 1 tooth sheared off
83	4 x 4	85°	RT (Dry)	1.015	1.03	1.045	2435	2330	All but 1 tooth sheared off
84	4 x 4	85°	RT (Dry)	1.015	1.03	1.045	1520	1455	All but 1 tooth sheared off
							Average =	**1829**	
91	7 x 7	20°	RT (Dry)	1.015	1.03	1.045	1927	1844	All but 4 teeth sheared off
92	7 x 7	20°	RT (Dry)	1.013	1.03	1.043	2033	1949	All teeth sheared off
93	7 x 7	20°	RT (Dry)	1.015	1.03	1.045	1808	1730	All but 1 tooth sheared off
							Average =	**1841**	
87	7 x 7	85°	RT (Dry)	1.012	1.03	1.042	2073	1989	All teeth sheared off
88	7 x 7	85°	RT (Dry)	1.003	1.03	1.033	2385	2309	All teeth sheared off
89	7 x 7	85°	RT (Dry)	1.007	1.03	1.037	2442	2355	All teeth sheared off
							Average =	**2218**	

Table 2. Aluminum bonded to graphite/epoxy laminate.

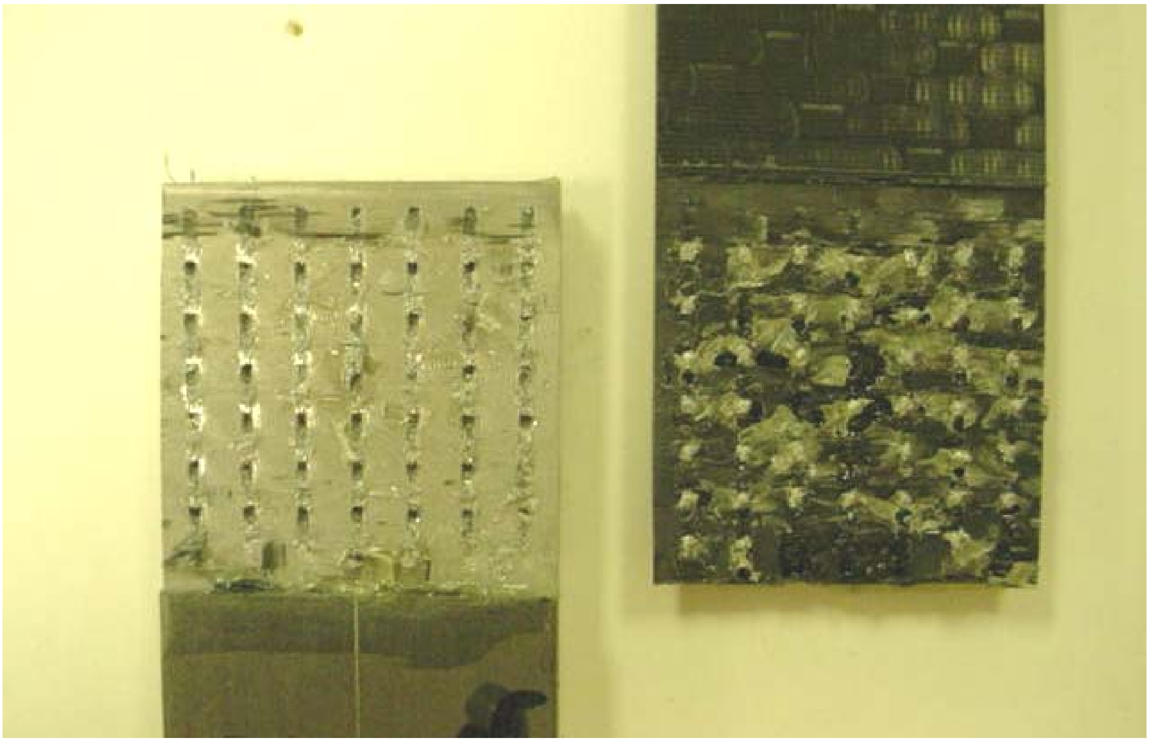


Figure 1. Post-test photographs of aluminum (7 x 7 grid of teeth) and composite adherends. Teeth on aluminum shorn off; shorn aluminum embedded in composite substrate.

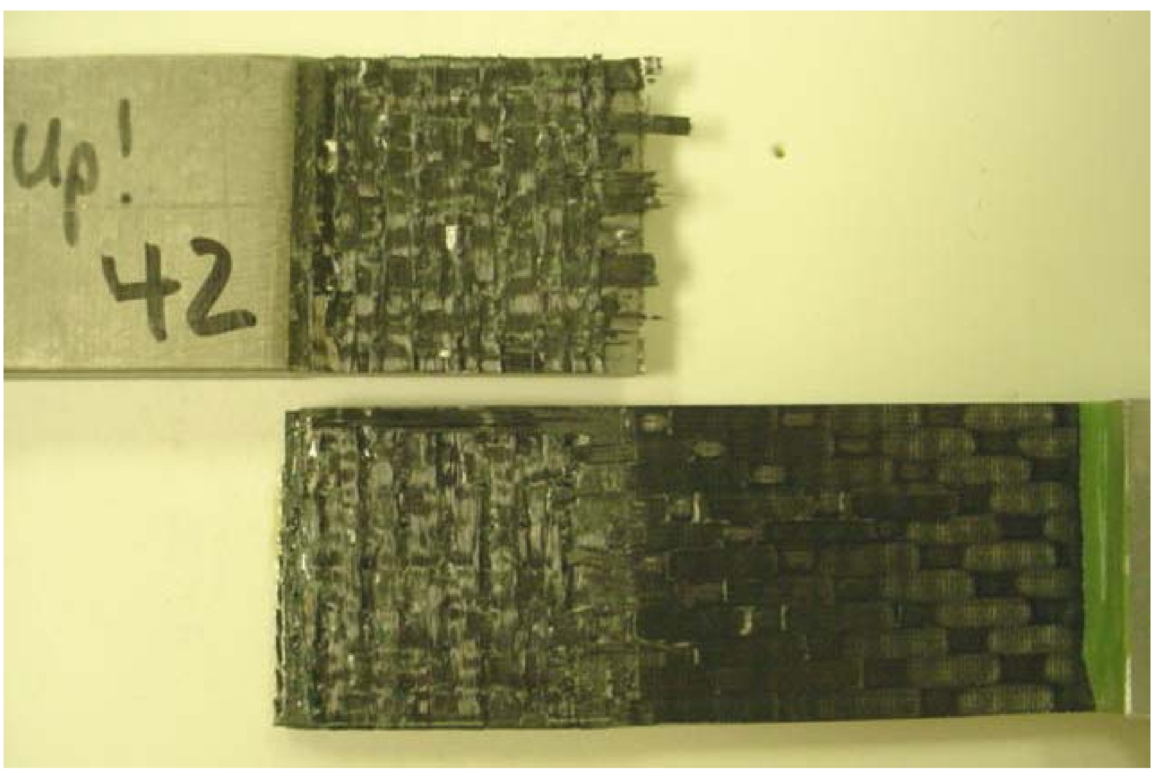
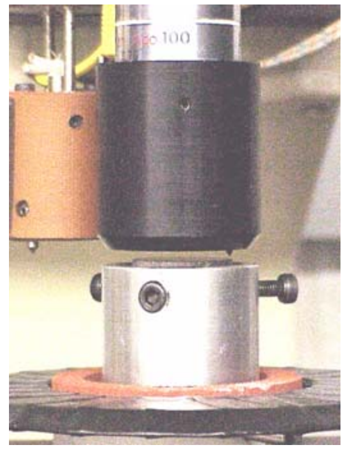


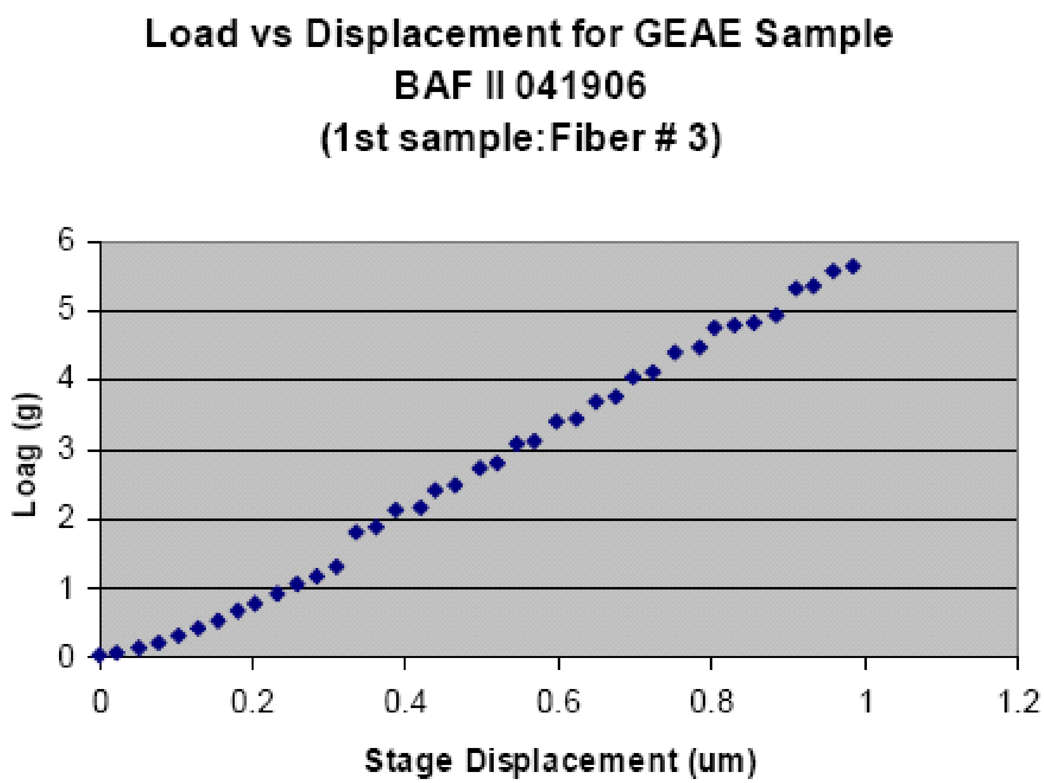
Figure 2. Post-test photograph of Titanium/composite lap shear coupon. Surface ply of composite sheared off during test and remained with titanium.

8. Composite Fiber Sizing

Michigan State University performed fiber indentation test on a composite material systems.



A carbon/epoxy composite material system was tested and the following curve shows the interfacial shear load-displacement relationship.



9. Abradable Panels

A study was conducted to evaluate the ability to disperse PR24LHT (U172) carbon nanofiber into Ultem thermoplastic and to evaluate any change in physical properties. The Ultem was dried at 150 °C in a vacuum oven for 4 hours and premixed by hand. A HAAKE extruder was used to prepare Ultem/U172 (8 wt%) nanocomposites. A fracture surface of Ultem/U172 was obtained to study the dispersion of nanofiber in the matrix and the adhesion using HR-SEM as shown in Figure 1. The nanofiber was uniformly dispersed in the resin. However, relatively long fibers were pulled out from the matrix when the sample was fractured which indicated that the adhesion between the fibers and the matrix was not very strong.

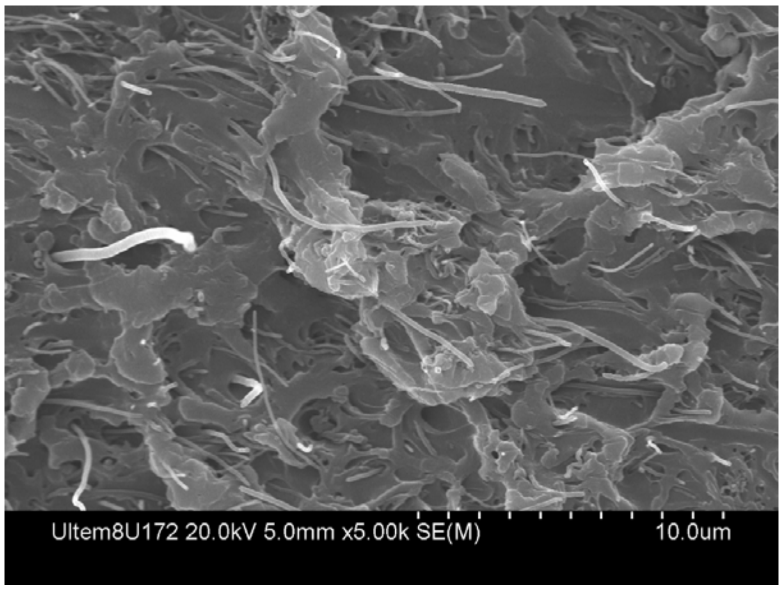


Figure 1. SEM image of the fractured surface of Ultem/U172.

DMA tests of Ultem and its nanocomposite were carried out and the results are shown in Figure 1. The storage moduli of both samples changed at about 226 °C. The addition of nanofibers did provided an approximate 10% improvement in modulus retention near the Tg. The increases of loss modulus and the width of the loss modulus peak indicated that the addition of CNFs affected the formation of crystallization of Ultem. These results matched DSC studies.

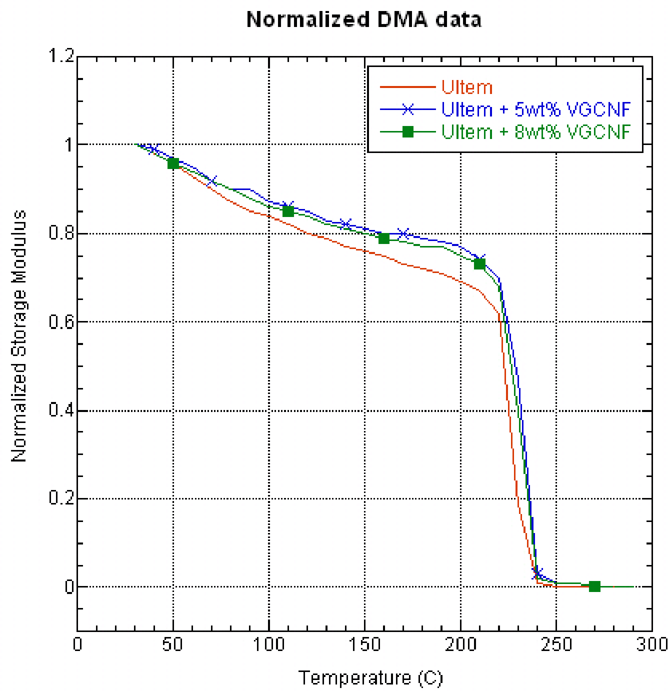
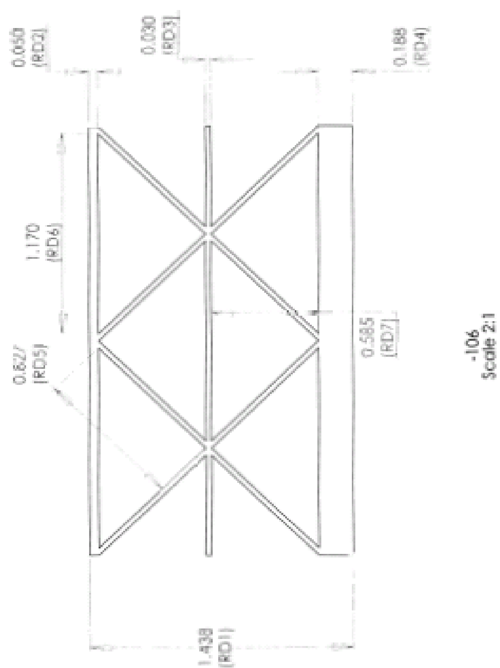
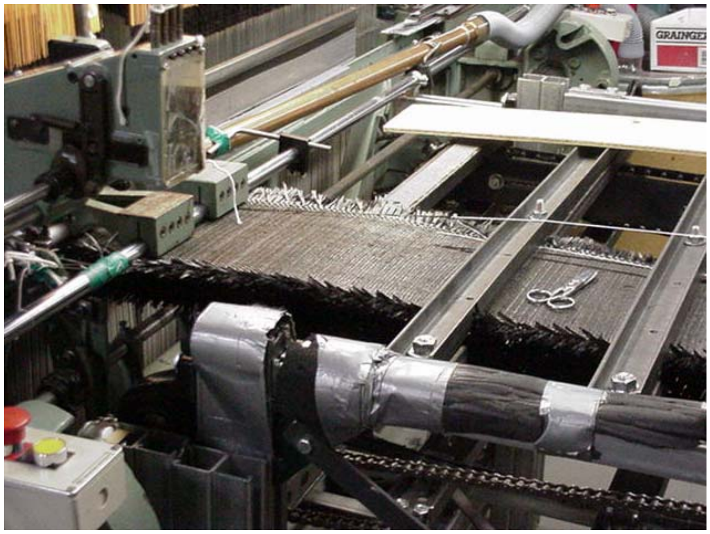


Figure 1. Normalized DMA data – Ultem, Ultem + nanofiber nanocomposites.

Bally Ribbon Mills fabricated 3D woven composite panels as potential candidate for trench filler substrate structure on fan case. The 3D woven preform design and 3D weaving process are shown in the following pictures.





10. Material Property Testing

Nano enriched material property panels are designed to study the material property change due to nano fiber enrichment.

Property	Test Method	Quantity	Test Details
0 Degree Compression Modulus, Strain-to-Failure, Flexural Strength	ASTM D 6272 - Third Point Loading	3	Load specimen beyond ultimate load; load until specimen fractures, load plateaus, or test fixture prohibits further displacement. Strain gage on compression surface & center point deflectometer on tension side
60 or 90 Degree Compression Modulus, Strain-to-Failure, Flexural Strength	ASTM D 6272 - Third Point Loading	3	Load specimen beyond ultimate load; load until specimen fractures, load plateaus, or test fixture prohibits further displacement. Strain gage on compression surface & center point deflectometer on tension side
0 DegreeTensile Modulus, Strength, Strain-to-Failure & Poisson's Ratio	ASTM D 3039 Tension	3	Load specimen until specimen is separated into 2 pieces; may require reloading specimen following initial catastrophic failure. Biaxial Strain Gage
60 or 90 Degree Tensile Modulus, Strength, Strain-to-Failure & Poisson's Ratio	ASTM D 3039 Tension	3	Load specimen until specimen is separated into 2 pieces; may require reloading specimen following initial catastrophic failure. Biaxial Strain Gage
In-plane Shear Modulus and Strength	ASTM D 7078 V-Notch Rail Shear	3	If variation on D 7078 is desired it will be specified. For example, loading beyond ultimate load.
Punch Shear; SPR = 1.1	Univ of Del Quasi-Static	4	Test Fixture can be provided by GE if necessary. Test Methodology to be provided, which includes loading beyond ultimate load to plateau load or fixed punch displacement. Proposing to run two specimens in standard set-up and two specimens with a 1/2" thick rigid foam backing covering open span region of test fixture. Considering Foam backing to reduce flex of specimen, although it may increase flex if foam compresses and provides more space for specimen to flex.
Apparent Interlaminar Shear Strength	ASTM D 2344 Short Beam Strength	5	Four Point Bend Methodology. Span to Depth Ratio of ~8:1. Five specimens to allow for exploratory tests with two specimens
Translaminar Fracture Toughness	ASTM E 1922 Edge Notch Tension	4	Pin Loaded - likely will tab specimen ends to avoid compression delamination around loading pins. a/W ratios of 0.25 and 0.33 to be measured
Translaminar Fracture Toughness	Center Notch Tension	4	Clamp loaded in the same manner as a D 3039 tension test. a/W ratios of 0.25 and 0.33 to be measured. Testing methodology to be specified.

A series of T700 composite laminates were fabricated with nano-modified 5208 and PR520 epoxy resin as shown in Table 1. Mechanical testing of several laminates is reported under Task 14 while the rest were shipped to GE Aviation for testing. We noticed that the PR520 has a solvent resistance issue with acetone. This issue is apparent with or without nanofillers. The nanofiber used in this study is PR24LHT-XT.

Panel ID	Resin	Panel Description
GE060207-A	5208	T700 Braid-7 plies x 24" x 24" 10 gsm nonfunctionalized nanofiber
GE060207-B	5208	T700 Braid-7 plies x 24" x 24" 10 gsm functionalized nanofiber
GE060207-C	PR520	T700 12k Weave-6 plies x 24" x 24" 10 gsm nonfunctionalized nanofiber
GE060207-D	PR520	T700 12k Weave-6 plies x 24" x 24" 10 gsm functionalized nanofiber
GE060207-E	PR520	T700 0/60/-60 NCF-5 plies x 24" x 24" 10 gsm nonfunctionalized nanofiber
GE060207-F	PR520	T700 0/60/-60 NCF-5 plies x 24" x 24" 10 gsm functionalized nanofiber
GE060207-G	PR520	T700 0/60/-60 NCF-5 plies x 24" x 24" 10 gsm nanokevlar with MY720W
GE060207-H	PR520	T700 0/60/-60 NCF-5 plies x 24" x 24" 10 gsm I.30E nanoclay

Table 1. Panels made for mechanical testing.

10.1 COMPRESSION RESULTS

Nine compression test coupons (i.e., three in the laminate 0°-orientation, three in the laminate 60°-orientation, and three in the laminate 90°-orientation) were extracted from both of the T700-braid/5208 test laminates and tested at room temperature-ambient conditions. The tension coupons were 0.500”-wide by 5.50”-long, and were surface ground to final coupon dimensions to ensure perpendicular and parallel ends and edges. It should be noted here, however, that no grinding was performed on the coupon thickness. The bag surfaces of the coupons were such that grinding to a uniform thickness would have resulted in significant amounts of surface ply tow fibers being ground away to achieve a uniform (±0.001”) thickness.

Although the specimens were not truly flat, back-to-back uniaxial strain-gages was applied to the coupons. Gages were applied to the bag surfaces of the specimens to identify gross buckling situations. For all tests, a crosshead speed of 0.05”/minute was used.

Tables 1 and 2 present the results from the combined-loading compression tests on the two 5208 test laminates.

Table 1

Combined-Loading Compression Results for T700 Braid/5208 with Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-A]

Test: Combined Loading Compression (ASTM D6641) — **Tested By:** R. Glett

Material: T700 Braid/5208 with Carbon Nano Fibers (10 gsm) — **Panel I.D.:** WP-062807-A

Coupon I.D. No.	Test Coupon Orientation	Test Cond.	Avg. Thick. (in.)	Avg. Width (in.)	Avg. Cross-Sxnl. Area (in²)	Max. Load (lbs.)	Compression Strength (ksi)	Tool Side Modulus (Msi)	Bag Side Modulus (Msi)	Test Date	Notes
A-0C-1	Laminate 0°	RT [Dry]	0.1842	0.499	0.0920	4629	50.32	5.20	5.04	27-Aug-07	[1,2]
A-0C-2	" "	RT [Dry]	0.1798	0.501	0.0901	4980	55.27	5.36	5.25	27-Aug-07	[1,2]
A-0C-3	" "	RT [Dry]	0.1780	0.502	0.0894	4805	53.75	4.86	5.29	27-Aug-07	[1,2]
						Average =	**53.11**	**5.14**	**5.19**		
						Std. Dev.=	**2.54**	**0.26**	**0.13**		
						C.o.V. =	**4.8%**	**5.0%**	**2.6%**		
A-60C-1	Laminate 60°	RT [Dry]	0.1790	0.501	0.0897	2715	30.27	5.71	4.68	27-Aug-07	[1,2]
A-60C-2	" "	RT [Dry]	0.1771	0.500	0.0885	2549	28.80	5.07	5.12	27-Aug-07	[1,2]
A-60C-4	" "	RT [Dry]	0.1786	0.499	0.0892	2852	31.97	4.87	5.69	27-Aug-07	[1,2]
						Average =	**30.35**	**5.22**	**5.16**		
						Std. Dev.=	**1.59**	**0.44**	**0.51**		
						C.o.V. =	**5.2%**	**8.4%**	**9.8%**		
A-90C-1	Laminate 90°	RT [Dry]	0.1657	0.500	0.0829	2598	31.34	4.77	5.65	27-Aug-07	[1,2]
A-90C-2	" "	RT [Dry]	0.1675	0.500	0.0837	2559	30.57	5.01	5.36	27-Aug-07	[1,2]
A-90C-3	" "	RT [Dry]	0.1640	0.499	0.0818	2588	31.64	4.95	5.37	27-Aug-07	[1,2]
						Average =	**31.18**	**4.91**	**5.46**		
						Std. Dev.=	**0.55**	**0.12**	**0.16**		
						C.o.V. =	**1.8%**	**2.5%**	**3.0%**		

Notes:

(1) Test Speed = .05 in./min.

(2) "Modulus" computed between 1000 and 3000 μ-strain.

Table 2

Combine-Loading Compression Results for T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-B]

Test: Combined Loading Compression (ASTM D6641) **Tested By:** R. Glett
Material: T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) **Panel I.D.:** WP-062807-B

Coupon I.D. No.	Test Coupon Orientation	Test Cond.	Avg. Thick. (in.)	Avg. Width (in.)	Avg. Cross-Sxnl. Area (in²)	Max. Load (lbs.)	Compression Strength (ksi)	Tool Side Modulus (Msi)	Bag Side Modulus (Msi)	Test Date	Notes
B-0C-1	Laminate 0°	RT [Dry]	0.1868	0.500	0.0934	4287	45.90	5.54	5.50	27-Aug-07	[1,2]
B-0C-2	" "	RT [Dry]	0.1851	0.500	0.0926	3955	42.71	5.16	5.58	27-Aug-07	[1,2]
B-0C-3	" "	RT [Dry]	0.1879	0.500	0.0940	3330	35.43	5.09	4.46	27-Aug-07	[1,2]
						Average =	**41.35**	**5.26**	**5.18**		
						Std. Dev. =	**5.37**	**0.24**	**0.62**		
						C.o.V. =	**13.0%**	**4.6%**	**12.1%**		
B-60C-1	Laminate 60°	RT [Dry]	0.1802	0.500	0.0901	3096	34.36	5.68	4.49	27-Aug-07	[1,2,3]
B-60C-2	" "	RT [Dry]	0.1777	0.500	0.0889	3037	34.16	5.42	4.61	27-Aug-07	[1,2,3]
B-60C-3	" "	RT [Dry]	0.1764	0.500	0.0883	3408	38.60	4.47	5.30	27-Aug-07	[1,2,3]
						Average =	**35.71**	**5.19**	**4.80**		
						Std. Dev. =	**2.50**	**0.64**	**0.44**		
						C.o.V. =	**7.0%**	**12.3%**	**9.1%**		
B-90C-1	Laminate 90°	RT [Dry]	0.1821	0.500	0.0911	2227	24.45	4.07	4.76	27-Aug-07	[1,2]
B-90C-2	" "	RT [Dry]	0.1814	0.500	0.0907	2148	23.68	4.30	4.57	27-Aug-07	[1,2]
B-90C-3	" "	RT [Dry]	0.1759	0.500	0.088	2207	25.08	4.38	4.60	27-Aug-07	[1,2]
						Average =	**24.40**	**4.25**	**4.64**		
						Std. Dev. =	**0.70**	**0.16**	**0.10**		
						C.o.V. =	**2.9%**	**3.8%**	**2.2%**		

Notes:
(1) Test Speed = .05 in./min.
(2) "Modulus" computed between 1000 and 3000 μ-strain.
(3) % Bending greater than 10% @ 2,000 με

10.2 FLEXURAL RESULTS

Six flexure test coupons (i.e., three in the laminate 0°-orientation and three in the laminate 60°-orientation) were extracted from both of the T700-braid/5208 test laminates and tested at room temperature-ambient conditions. The flexure coupons were 2.00"-wide by 8.0"-long, and were tested in accordance with the procedures described in ASTM D6272. A span-to- thickness ratio of 32 was used for the support span, and loading was at one-third the span. The test coupons were positioned in the fixture such that the tool surface of the coupons were in compression and the bag surfaces were in tension.

A uniaxial strain-gage was applied to the compression surfaces of the coupons and an LVDT was used to measure mid-span deflection during each test. For all tests, a crosshead speed of 0.35"/minute was used.

Tables 1 through 4 present the results from the four-point flexure tests on the two 5208 test laminates.

Table 1
0° Flexural Results for T700 Braid/5208 with Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-A]

Test: 4-Pt. Flex; ASTM D6272 (L/D = 32, 1/3L Loading) **Specimen Orientation**: Laminate 0° **Tested By:** J. Chumack
Material: T700 Braid/5208 with Carbon Nano Fibers (10 gsm) **Panel I.D.** = WP-062807-A

Test Coupon Number	Test Cond.	Mid Coupon Width (in.)	Mid Coupon Thick. (in.)	Max. Load (lbs.)	Ultimate Flexural Strength (Ksi)	Flexural Modulus (Msi)	Compression Modulus (Msi)	m, slope of Load vs. Deflection (lbs/in)	LVDT Deflection @ Max Load (in.)	MTS Disp. @ Max Load (in.)	Strain @ Max Load (%)	Date Tested	Remarks
A-0F-1	RT [Dry]	2.005	0.183	764.2	67.04	4.75	4.89	1358.9	0.673	0.603	1.686	31-Jul-07	[1]
A-0F-2	RT [Dry]	2.005	0.175	808.8	77.58	5.04	5.11	1261.5	N/A	0.648	1.573	01-Aug-07	[1,2]
A-0F-3	RT [Dry]	2.005	0.181	742.3	66.56	4.94	5.11	1369.2	0.650	0.583	1.555	01-Aug-07	[1]
				Average	**70.39**	**4.91**	**5.04**						
				Std. Dev.	**6.23**	**0.15**	**0.13**						
				C.o.V. (%)	**8.85%**	**3.03%**	**2.52%**						

Remarks:
(1) Crosshead speed = 0.35"/min., Support Span = 5.89"
(2) Deflection exceeded capacity of LVDT. A deflection of 0.726" was recorded at a load of 767.4 lbs.

Table 2
60° Flexural Results for T700 Braid/5208 with Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-A]

Test: 4-Pt. Flex; ASTM D6272 (L/D = 32, 1/3L Loading) **Specimen Orientation**: Laminate 60° **Tested By:** J. Chumack
Material: T700 Braid/5208 with Carbon Nano Fibers (10 gsm) **Panel I.D.** = WP-062807-A

Test Coupon Number	Test Cond.	Mid Coupon Width (in.)	Mid Coupon Thick. (in.)	Max. Load (lbs.)	Ultimate Flexural Strength (Ksi)	Flexural Modulus (Msi)	Compression Modulus (Msi)	m, slope of Load vs. Deflection (lbs/in)	LVDT Deflection @ Max Load (in.)	MTS Disp. @ Max Load (in.)	Strain @ Max Load (%)	Date Tested	Remarks
A-60F-1	RT [Dry]	2.003	0.189	617.4	50.82	4.51	4.71	1421.3	0.502	0.455	1.203	01-Aug-07	[1]
A-60F-2	RT [Dry]	2.004	0.184	612.0	53.13	4.85	5.49	1411.8	0.482	0.437	1.023	01-Aug-07	[1]
A-60F-3	RT [Dry]	2.005	0.181	514.8	46.16	4.95	5.28	1372.8	0.406	0.367	0.917	01-Aug-07	[1]
				Average	**50.04**	**4.77**	**5.16**						
				Std. Dev.	**3.55**	**0.23**	**0.40**						
				C.o.V. (%)	**7.09%**	**4.88%**	**7.82%**						

Remarks:
(1) Crosshead speed = 0.35"/min., Support Span = 5.89"

Table 3
0° Flexure Results for T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-B]

Test: 4-Pt. Flex; ASTM D6272 (L/D = 32) **Specimen Orientation**: Laminate 0° **Tested By:** J. Chumack
Material: T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) **Panel I.D.** = WP-062807-B

Test Coupon Number	Test Cond.	Mid Coupon Width (in.)	Mid Coupon Thick. (in.)	Max. Load (lbs.)	Ultimate Flexural Strength (Ksi)	Flexural Modulus (Msi)	Compression Modulus (Msi)	m, slope of Load vs. Deflection (lbs/in)	LVDT Deflection @ Max Load (in.)	MTS Disp. @ Max Load (in.)	Strain @ Max Load (%)	Date Tested	Remarks
B-0F-1	RT [Dry]	1.999	0.185	829.2	71.39	4.78	5.00	1409.4	N/A	0.651	1.776	01-Aug-07	[1,2]
B-0F-2	RT [Dry]	2.004	0.186	802.8	68.20	4.67	4.96	1402.8	N/A	0.694	1.962	01-Aug-07	[1,3]
B-0F-3	RT [Dry]	2.000	0.183	808.0	71.05	4.95	5.03	1414.3	N/A	0.721	2.087	01-Aug-07	[1,4]
				Average	**70.21**	**4.80**	**5.00**						
				Std. Dev.	**1.75**	**0.14**	**0.04**						
				C.o.V. (%)	**2.49%**	**2.97%**	**0.70%**						

Remarks:
(1) Crosshead speed = 0.35"/min., Support Span = 5.89"
(2) Deflection exceeded capacity of LVDT. A deflection of 0.702" was recorded at a load of 804.9 lbs.
(3) Deflection exceeded capacity of LVDT. A deflection of 0.717" was recorded at a load of 753.9 lbs.
(4) Deflection exceeded capacity of LVDT. A deflection of 0.694" was recorded at a load of 797.7 lbs.

Table 4
60° Flexure Results for T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-B]

Test: 4-Pt. Flex; ASTM D6272 (L/D = 32) **Specimen Orientation**: Laminate 60° **Tested By:** J. Chumack
Material: T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) **Panel I.D.** = WP-062807-B

Test Coupon Number	Test Cond.	Mid Coupon Width (in.)	Mid Coupon Thick. (in.)	Max. Load (lbs.)	Ultimate Flexural Strength (Ksi)	Flexural Modulus (Msi)	Compression Modulus (Msi)	m, slope of Load vs. Deflection (lbs/in)	LVDT Deflection @ Max Load (in.)	MTS Disp. @ Max Load (in.)	Strain @ Max Load (%)	Date Tested	Remarks
B-60F-1	RT [Dry]	2.005	0.185	690.3	59.25	4.73	4.85	1398.1	0.558	0.504	1.365	01-Aug-07	[1]
B-60F-2	RT [Dry]	2.005	0.188	776.9	64.57	4.68	4.99	1453.5	0.637	0.575	1.496	01-Aug-07	[1]
B-60F-3	RT [Dry]	2.005	0.190	587.8	47.83	4.46	4.80	1430.9	0.448	0.408	1.046	01-Aug-07	[1]
				Average	**57.22**	**4.62**	**4.88**						
				Std. Dev.	**8.55**	**0.14**	**0.10**						
				C.o.V. (%)	**14.95%**	**3.02%**	**2.00%**						

Remarks:
(1) Crosshead speed = 0.35"/min., Support Span = 5.89"

10.3 SHORT BEAM SHEAR

Shortbeam shear test coupons were extracted from each of the eight (8) test laminates and tested at room temperature-ambient conditions. The coupons were tested in accordance with the procedures described in ASTM D2344, with the following notable exceptions: (1) four-point bend, third-point loading was used as opposed to the conventional three-point bend set-up cited in ASTM D2344, (2) a span-to-depth ratio of 9:1 was employed, and (3) the coupons were 1.00”-wide as opposed to the typical 0.250”-width called out in ASTM D2344.

When testing the shortbeam shear coupons, the bag surfaces of the coupons were positioned in the test fixture such that they were in tension during the tests. For all tests, a crosshead speed of 0.05”/minute was used.

Tables 1 through 8 present the test results from the short-beam shear testing.

Table 1
Shortbeam Shear Results for T700 Braid/5208 with Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-A]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
A-S1	0.189	0.999	1.705	0.038	793.8	3.15	ILS
A-S2	0.189	1.001	1.705	0.039	740.0	2.93	ILS
A-S3	0.187	1.001	1.705	0.038	717.9	2.88	ILS
A-S4	0.188	1.001	1.705	0.038	710.3	2.83	ILS
A-S5	0.191	1.001	1.705	0.038	751.7	2.95	ILS
					Avg. =	**2.95**	
					Std. Dev. =	**0.12**	
					CoV =	**4.20%**	

“ILS” = Interlaminar Shear

Table 2
Shortbeam Shear Results for T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-B]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
B-S1	0.188	1.000	1.705	0.037	740.3	2.95	ILS
B-S2	0.191	1.001	1.705	0.037	769.0	3.02	ILS
B-S3	0.193	1.001	1.705	0.033	736.1	2.86	ILS
B-S4	0.192	1.000	1.705	0.037	751.9	2.94	ILS
B-S5	0.188	1.001	1.705	0.036	731.1	2.91	ILS
					Avg. =	**2.94**	
					Std. Dev. =	**0.06**	
					CoV =	**1.98%**	
"ILS" = Interlaminar Shear							

Table 3
Shortbeam Shear Results for T700-12K Weave/PR520 with Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-C]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
C-S1	0.134	1.003	1.260	0.022	578.6	3.23	ILS
C-S2	0.136	1.003	1.260	0.023	662.0	3.65	ILS
C-S3	0.136	1.003	1.260	0.027	759.7	4.19	ILS
C-S4	0.135	1.002	1.260	0.022	668.7	3.70	ILS
C-S5	0.135	1.003	1.260	0.023	652.0	3.60	ILS
					Avg. =	**3.67**	
					Std. Dev. =	**0.34**	
					CoV =	**9.28%**	
"ILS" = Interlaminar Shear							

Table 4
Shortbeam Shear Results for T700-12K Weave/PR520 with Functionalized Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-D]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
D-S1	0.144	1.003	1.260	0.019	490.9	2.56	ILS
D-S2	0.144	1.002	1.260	0.020	487.2	2.53	ILS
D-S3	0.144	1.001	1.260	0.018	478.3	2.49	ILS
D-S4	0.146	1.001	1.260	0.020	476.6	2.45	ILS
D-S5	0.144	1.003	1.260	0.020	509.8	2.64	ILS
					Avg. =	**2.53**	
					Std. Dev. =	**0.07**	
					CoV =	**2.89%**	
"ILS" = Interlaminar Shear							

Table 5
Shortbeam Shear Results for T700 [0/60/-60] NCF/PR520 with Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-E]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
E-S1	0.136	1.001	1.143	0.047	275.3	1.52	ILS
E-S2	0.128	1.000	1.143	0.011	280.1	1.64	ILS
E-S3	0.121	1.000	1.143	0.013	303.3	1.88	ILS
E-S4	0.119	1.001	1.143	0.028	261.5	1.65	ILS
E-S5	0.120	1.000	1.143	0.013	288.8	1.81	ILS
E-S6	0.133	1.000	1.143	0.021	267.2	1.51	ILS
					Avg. =	**1.67**	
					Std. Dev. =	**0.15**	
					CoV =	**9.10%**	
"ILS" = Interlaminar Shear							

Table 6
Shortbeam Shear Results for T700 [0/60/-60] NCF/PR520 with Functionalized Carbon Nano Fibers (10 gsm)
[Panel I.D. = WP-062807-F]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
F-S1	0.125	1.001	1.143	0.029	273.5	1.64	ILS
F-S2	0.133	1.000	1.143	0.011	282.4	1.59	ILS
F-S3	0.134	1.000	1.143	0.021	297.7	1.67	ILS
F-S4	0.130	1.000	1.143	0.019	282.3	1.63	ILS
F-S5	0.139	1.001	1.143	0.009	313.3	1.69	ILS
F-S6	0.119	1.001	1.143	0.022	249.1	1.57	ILS
					Avg. =	**1.63**	
					Std. Dev. =	**0.04**	
					CoV =	**2.71%**	
"ILS" = Interlaminar Shear							

Table 7
Shortbeam Shear Results for T700 [0/60/-60] NCF/PR520 with Nano Aramid Fibers (10 gsm)
[Panel I.D. = WP-062807-G]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
G-S1	0.121	1.000	1.143	0.023	297.0	1.85	ILS
G-S2	0.132	1.001	1.143	0.017	316.9	1.80	ILS
G-S3	0.137	1.001	1.143	0.010	294.0	1.60	ILS
G-S4	0.133	1.001	1.143	0.010	260.9	1.47	ILS
G-S5	0.123	1.001	1.143	0.022	266.6	1.63	ILS
G-S6	0.117	1.000	1.143	0.014	318.2	2.04	ILS
					Avg. =	**1.67**	
					Std. Dev. =	**0.15**	
					CoV =	**9.10%**	
"ILS" = Interlaminar Shear							

Table 8
Shortbeam Shear Results for T700 [0/60/-60] NCF/PR520 with Nano Clay Particles (10 gsm)
[Panel I.D. = WP-062807-H]

Coupon I.D. No.	Coupon Thickness (inch)	Coupon Width (inch)	Support Span (inch)	Displacement @ Max. Load (inch)	Maximum Load (lbs.)	Shortbeam Shear Strength (ksi)	Failure Mode
H-S1	0.138	1.000	1.143	0.021	652.3	3.56	ILS
H-S2	0.130	1.000	1.143	0.025	779.2	4.50	ILS
H-S3	0.120	1.000	1.143	0.023	624.5	3.91	ILS
H-S4	0.129	1.000	1.143	0.020	599.7	3.49	ILS
H-S5	0.132	1.000	1.143	0.021	790.2	4.48	ILS
H-S6	0.116	1.000	1.143	0.025	757.4	4.88	ILS
					Avg. =	**4.14**	
					Std. Dev. =	**0.57**	
					CoV =	**13.70%**	
"ILS" = Interlaminar Shear							

10.4 TENSION RESULTS

Six straight-sided tension test coupons (i.e., three in the laminate 0°-orientation and three in the laminate 60°-orientation) were extracted from both of the T700-braid/5208 test laminates and tested at room temperature-ambient conditions. The tension coupons were 1.00"-wide by 10.0"-long, and were tested in accordance with the procedures described in ASTM D3039.

No gripping tabs were used on these coupons. A biaxial (0°/90°) strain-gage was applied to the tool surface of each of the coupons. For all tests, a crosshead speed of 0.05"/minute was used.

Tables 1 through 4 present the results from the tension tests on the two 5208 test laminates.

Table 1

0° Tensile Results for T700 Braid/5208 with Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-A]

Test: Straight-Sided Tension (ASTM D3039) **Specimen Orientation.**: Laminate 0° **Tested By:** D. Byrge
Material: T700 Braid/5208, 10 gsm nano carbon fiber **Panel I.D.** = WP-062807-A

Test Coupon Number	Test Conditions	Cross-Sectional Area (in²)	Max. Load (lbs.)	Ultimate Tensile Strength (Ksi)	Tensile Modulus (Msi)	Failure Strain (%)	Poisson's Ratio	Date Tested	Remarks
A-0T-1	RT [Dry]	0.1781	15,732	88.33	5.24	1.60	0.34	03-Aug-07	[1,2]
A-0T-2	RT [Dry]	0.1807	15,668	86.71	5.34	1.89	0.29	06-Aug-07	[1,2]
A-0T-3	RT [Dry]	0.1807	15,691	86.83	6.29	1.43	0.37	06-Aug-07	[1,2,3]
			Average =	**87.29**	**5.62**	**1.64**	**0.33**		
			Std. Dev. =	**0.90**	**0.58**	**0.23**	**0.04**		
			CoV (%) =	**1.03%**	**10.31%**	**14.18%**	**12.12%**		

Remarks:
(1) "Tensile Modulus" computed between 500 and 2500 μ-strain.
(2) Reported "Poisson's Ratio" represents slope (best-fit line) of transverse vs. longitudinal strain plot between 500 and 2500 longitudinal μ-strain
(3) Longitudinal gage failed prior to specimen fracture; "Failure Strain" extrapolated from Load vs. Strain plot.

Table 2

60° Tensile Results for T700 Braid/5208 with Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-A]

Test: Straight-Sided Tension (ASTM D3039) **Specimen Orientation.**: Laminate 60° **Tested By:** D. Byrge
Material: T700 Braid/5208, 10 gsm nano carbon fiber **Panel I.D.** = WP-062807-A

Test Coupon Number	Test Conditions	Cross-Sectional Area (in²)	Max. Load (lbs.)	Ultimate Tensile Strength (Ksi)	Tensile Modulus (Msi)	Failure Strain (%)	Poisson's Ratio	Date Tested	Remarks
A-60T-1	RT [Dry]	0.1832	12,146	66.30	5.27	1.16	0.23	06-Aug-07	[1,2,3]
A-60T-2	RT [Dry]	0.1838	11,689	63.60	6.20	1.03	0.38	06-Aug-07	[1,2,3]
A-60T-3	RT [Dry]	0.1871	11,479	61.35	5.52	1.26	0.32	07-Aug-07	[1,2]
			Average =	**63.75**	**5.66**	**1.15**	**0.31**		
			Std. Dev. =	**2.48**	**0.48**	**0.12**	**0.08**		
			CoV (%) =	**3.89%**	**8.50%**	**10.03%**	**24.35%**		

Remarks:
(1) "Tensile Modulus" computed between 500 and 2500 μ-strain.
(2) Reported "Poisson's Ratio" represents slope (best-fit line) of transverse vs. longitudinal strain plot between 500 and 2500 longitudinal μ-strain
(3) Longitudinal gage failed prior to specimen fracture; "Failure Strain" extrapolated from Load vs. Strain plot.

Table 3

0° Tensile Results for T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-B]

Test: Straight-Sided Tension (ASTM D3039) **Specimen Orientation.**: Laminate 0° **Tested By:** D. Byrge
Material:T700 Braid/5208, 10 gsm functionalized nano carbon fiber **Panel I.D.** = WP-062807-B

Test Coupon Number	Test Conditions	Cross-Sectional Area (in²)	Max. Load (lbs.)	Ultimate Tensile Strength (Ksi)	Tensile Modulus (Msi)	Failure Strain (%)	Poisson's Ratio	Date Tested	Remarks
B-0T-1	RT [Dry]	0.1904	17,994	94.51	5.79	1.68	0.41	07-Aug-07	[1,2]
B-0T-2	RT [Dry]	0.1876	16,652	88.76	6.64	1.66	0.38	07-Aug-07	[1,2]
B-0T-3	RT [Dry]	0.1837	14,730	80.19	5.69	1.57	0.30	07-Aug-07	[1,2]
			Average =	**87.82**	**6.04**	**1.64**	**0.36**		
			Std. Dev. =	**7.21**	**0.52**	**0.06**	**0.06**		
			CoV (%) =	**8.21%**	**8.64%**	**3.58%**	**15.65%**		

Remarks:
(1) "Tensile Modulus" computed between 500 and 2500 μ-strain.
(2) Reported "Poisson's Ratio" represents slope (best-fit line) of transverse vs. longitudinal strain plot between 500 and 2500 longitudinal μ-strain.
(3) Longitudinal gage failed prior to specimen fracture; "Failure Strain" extrapolated from Load vs. Strain plot.

Table 4

60° Tensile Results for T700 Braid/5208 with Functionalized Carbon Nano Fibers (10 gsm) [Panel I.D. = WP-062807-B]

Test: Straight-Sided Tension (ASTM D3039) **Specimen Orientation.**: Laminate 60° **Tested By:** D. Byrge
Material:T700 Braid/5208, 10 gsm functionalized nano carbon fiber **Panel I.D.** = WP-062807-B

Test Coupon Number	Test Conditions	Cross-Sectional Area (in²)	Max. Load (lbs.)	Ultimate Tensile Strength (Ksi)	Tensile Modulus (Msi)	Failure Strain (%)	Poisson's Ratio	Date Tested	Remarks
B-60T-1	RT [Dry]	0.1851	12,340	66.67	5.52	1.25	0.43	07-Aug-07	[1,2,3]
B-60T-2	RT [Dry]	0.1832	13,717	74.87	5.17	1.57	0.24	07-Aug-07	[1,2,3]
B-60T-3	RT [Dry]	0.1854	12,141	65.49	4.96	1.59	0.24	07-Aug-07	[1,2,3]
			Average =	**69.01**	**5.22**	**1.47**	**0.30**		
			Std. Dev. =	**5.11**	**0.28**	**0.19**	**0.11**		
			CoV (%) =	**7.40%**	**5.42%**	**12.98%**	**36.16%**		

Remarks:
(1) "Tensile Modulus" computed between 500 and 2500 μ-strain.
(2) Reported "Poisson's Ratio" represents slope (best-fit line) of transverse vs. longitudinal strain plot between 500 and 2500 longitudinal μ-strain.
(3) Longitudinal gage failed prior to specimen fracture; "Failure Strain" extrapolated from Load vs. Strain plot.

11. Process Modeling Tool for High Temperature Composites

High Temperature Composite Systems like PMR15 involve in-situ chemical reactions that produce significant amounts of volatiles. Generation of these gases pose special challenges to consolidation of the composite parts. Temperature, pressure and vacuum cycle must be designed carefully to avoid bleeding too much resin by early pressure application or porosity due to lack of consolidation. Simple models have been developed in past programs at GE that simulate the generation of volatiles, imidization, flow, consolidation and final curing of a plaque in an autoclave process. These models provide a quick method of evaluating process scenarios based on material rheo-kinetic properties.

They can be very helpful in developing process cycles for new materials and accelerate material and component development programs significantly. In this program, these simple process simulation models were incorporated into a Microsoft Excel based tool. The consolidation models were recoded in object orient format as dynamic linked library, capable of communicating with Microsoft Excel. A GUI was created within Excel to specify the model geometry, material properties and processing conditions. The user inputs comprise of ply dimension, initial conditions, and processing cycle such as temperature, pressure, vacuum and their respective time duration. The material properties are specified and stored in a table form.

Figure 1 shows a screen shot of the input definition screen of the Excel based process modeling tool. The plotting capabilities of Excel are used to display overlay graphs to visualize modeling outputs such as degree of cure, resin viscocity and glass transition temperature, material compaction, volume fraction of constituents etc. The model outputs are automatically generated in Excel chart format, once results are computed. Multiple results can be cross plot in an overlay format for better comparisons. Figures 2 and 3 show typical variation of cure, Tg and resin viscocity during the consolidation process.

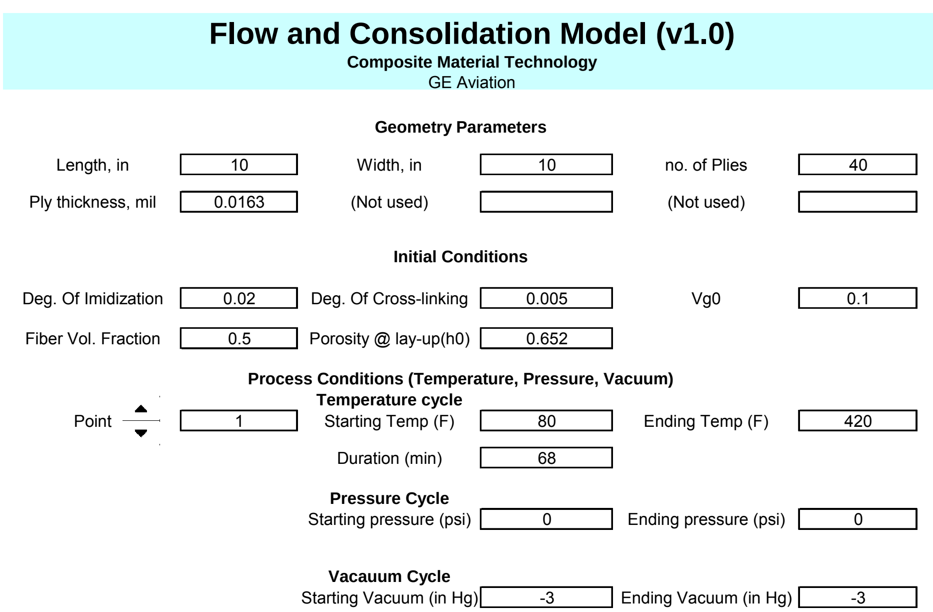


Figure 1: GUI showing input screen for the Excel based PMC process modeling tool.

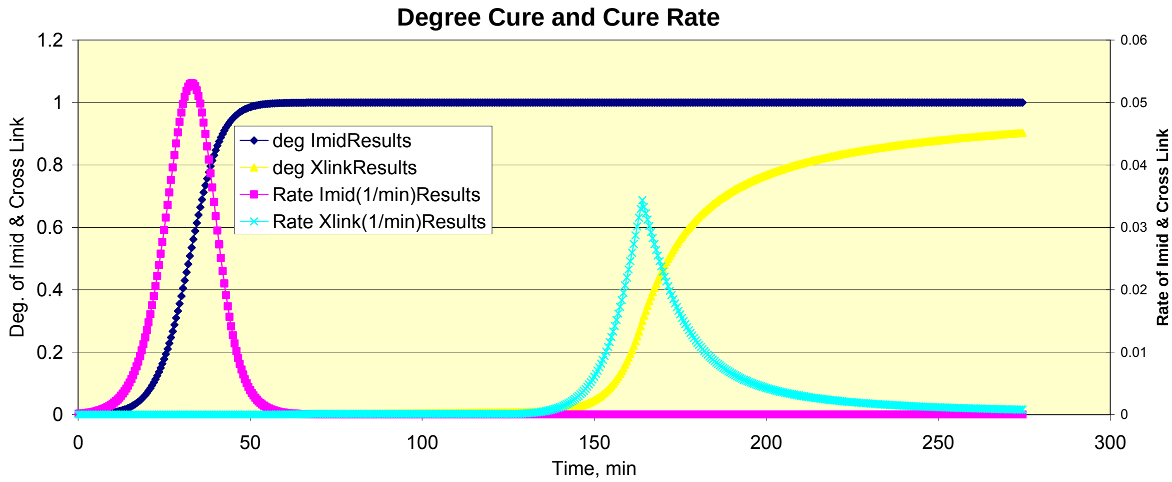


Figure 2: Predicted variation of “Degree of Cure” and “Cure Rate” for high temperature PMC during the consolidation/cure process.

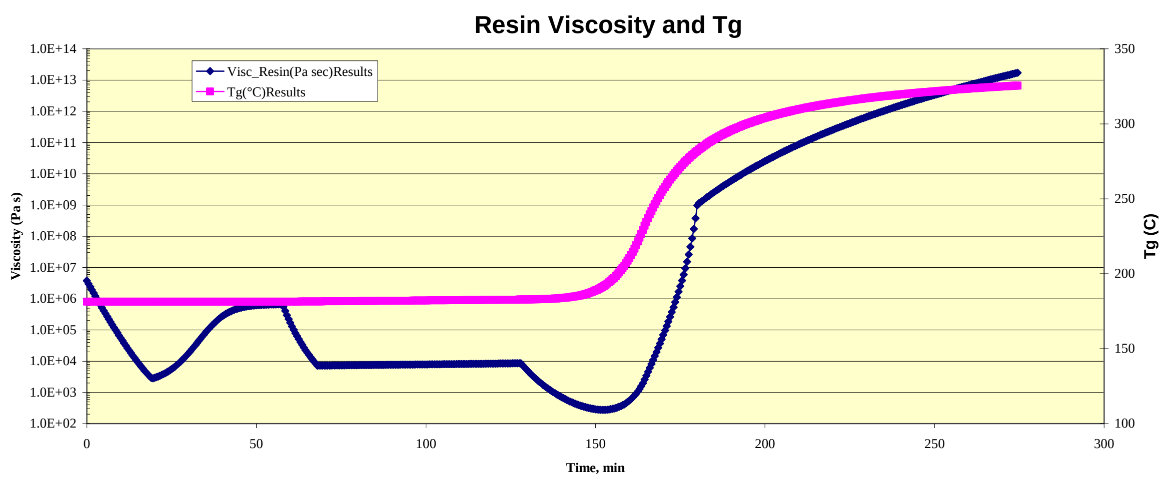


Figure 3: Predicted variation of “Resin Viscocity” and “Glass Transition Temperature” for high temperature PMC during the consolidation/cure process.

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14. ABSTRACT
A high bypass jet engine fan case represents one of the largest, heaviest single components in an engine. In addition to supporting the inlet and providing the fan flowpath, the most critical function is the containment of a failed fan blade. In this development program, a lightweight, low-cost composite containment case with diagnostic capabilities was developed, fabricated, and tested. The fan case design, containment methods, and diagnostic concepts evaluated in the initial Propulsion 21 program were improved and scaled up to a full case design.

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