TOUCHSTONE
RESEARCH LABORATORY, LTD.

PRODUCTION OF AL MMC CASES FOR IM TESTING

Brian Gordon, Senior Program Manager
Touchstone Research Laboratory

NDIA Insensitive Munitions and Energetic Materials Technology Symposium
May 11 – 14, 2009

TOUCHSTONE®

Outline

- **Technology Overview**
  – Touchstone Research Laboratory
  – Metal Prepreg Technology
  – Materials
  – Al MMC Lamina Properties
  – Al MMC Process Background
- **Al MMC Cylinder Production**
  – MMC Design Tool Calibration and Validation
  – Validation Testing
  – IM and Static Firing Test Cylinders
- **Conclusions and Future Work**

TOUCHSTONE
Imagination. Invention. Innovation.
TOUCHSTONE RESEARCH LABORATORY, LTD.

Touchstone is an award-winning supplier of advanced materials, composites, materials testing, industrial problem solving, and outsourced R&D services to commercial and government customers.

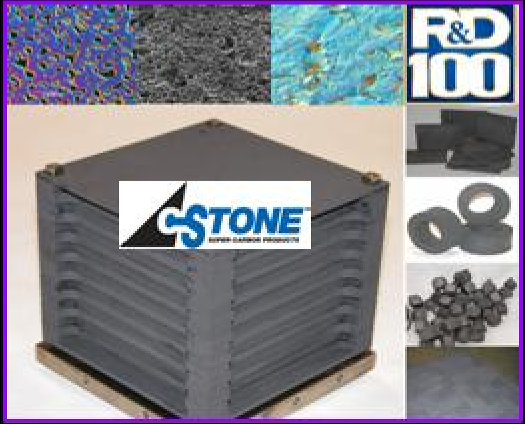
Material Testing

Outsourced R&D

Industrial Problem Solving

Advanced Composites

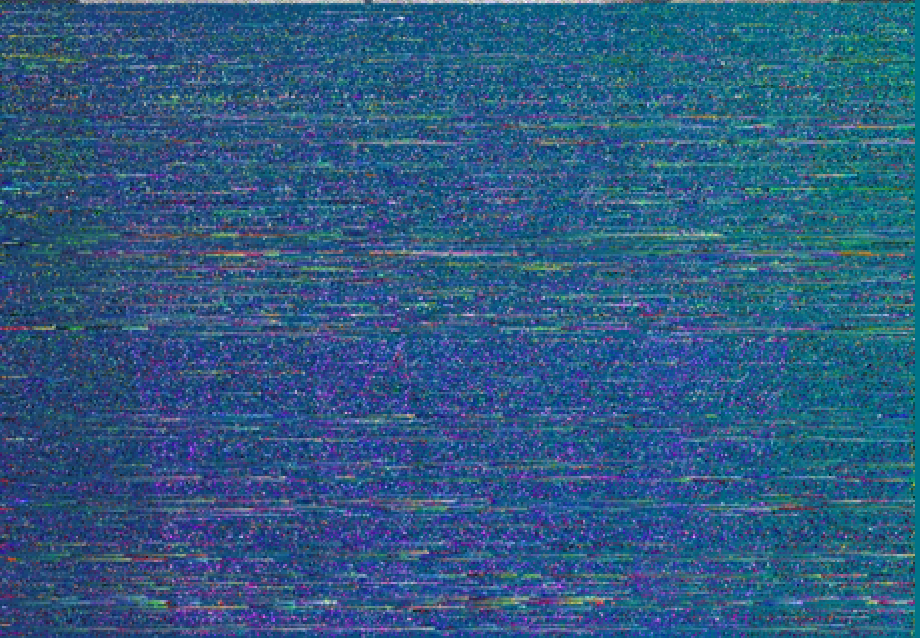
Products



Premier Product Development Company in WV

www.trl.com

Metal Prepreg Technology



Tape Width – 0.25 to 1.50”
Tape Thickness – 0.007 to 0.020”
Tubing – 0.25” OD, 0.015” wall
Angle – 0.375” per leg, 90° angle
Other sizes and shapes possible

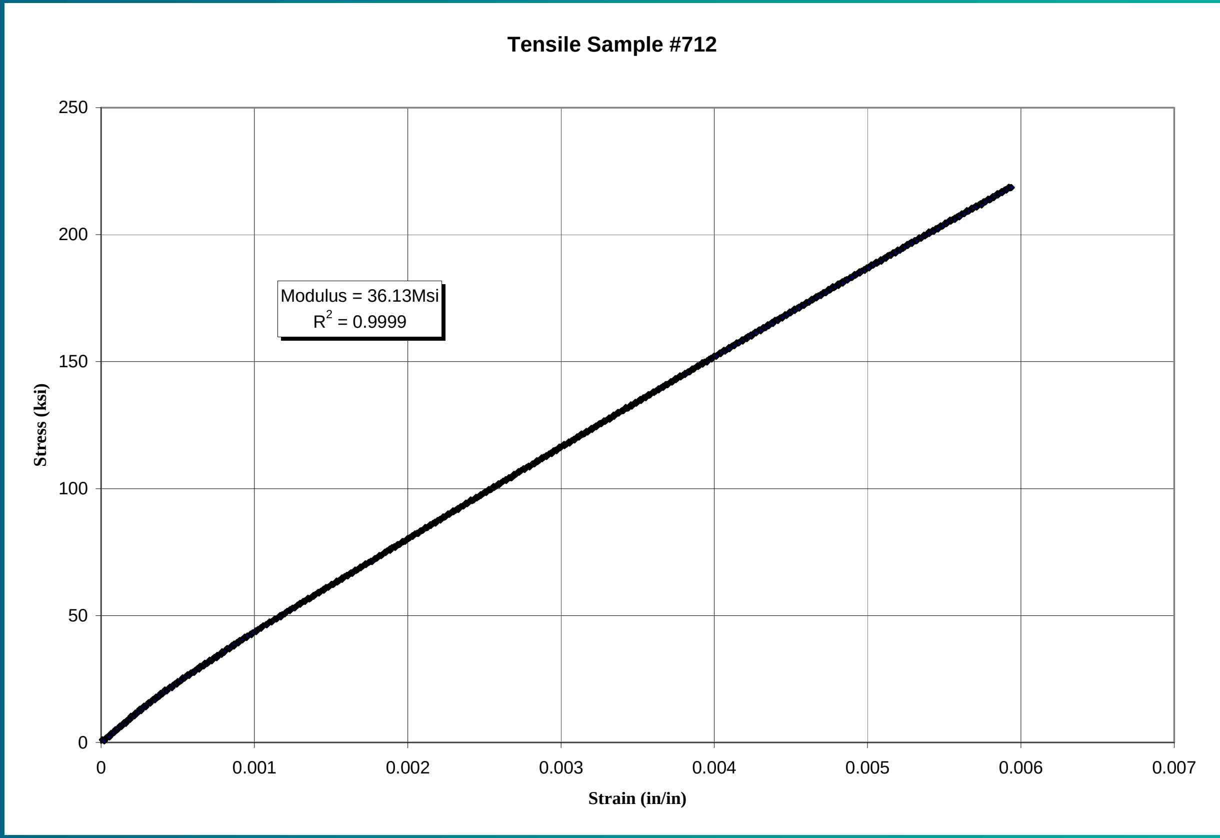
Fiber and Matrix Typical Properties

Property	Units	Fiber	Matrix
Chemical Composition	wt. %	>99 Al_2O_3	99.99 Al
Melting Point	°C °F	2000 3632	660 1220
Filament Diameter	µm in (10^{-4})	10-12 4-5	-
Crystal Phase		α- Al_2O_3	-
Density	g/cm^3 lb/in^3	3.9 0.141	2.7 0.098
Tensile Strength	MPa ksi	3100 450	40-50 6-7
Tensile Modulus	GPa Msi	380 55	62 9
Elongation	%	0.7-0.8	50-70
Thermal Expansion (100-1100°C)	ppm/°C ppm/°F	8.0 4.4	25 14

Metal Prepreg Tape Properties

	V_f	Density (lb/in³)	Width (in)	Thickness (in)	F_1^{tu} (ksi)	E_1^t (Msi)	ε_1^{tu} (%)
Mean	0.50	0.119	0.377	0.0134	210	33	0.63

Material = Al_2O_3 fibers in pure Al
Temperature = RT
Environment = Air
Direction = [0]



Standard Tape:

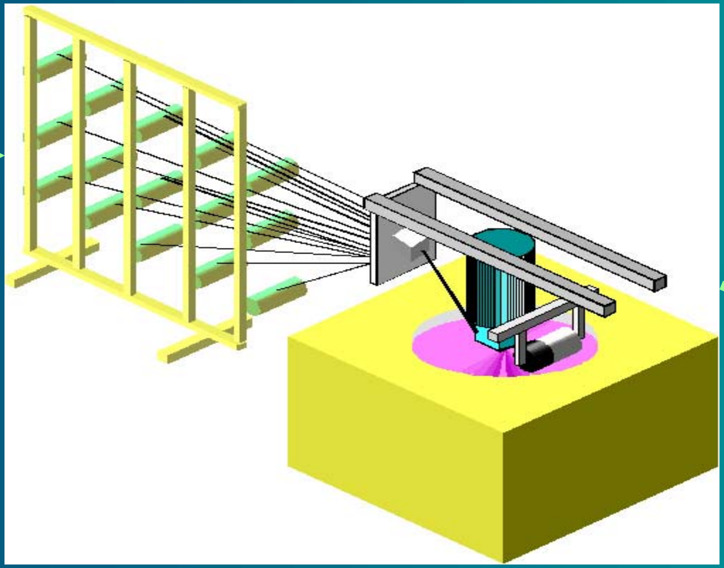
Fiber volume of 50%

Width of 0.5 inch

Thickness of 0.015 inch

Properties similar to steel but with the weight of aluminum

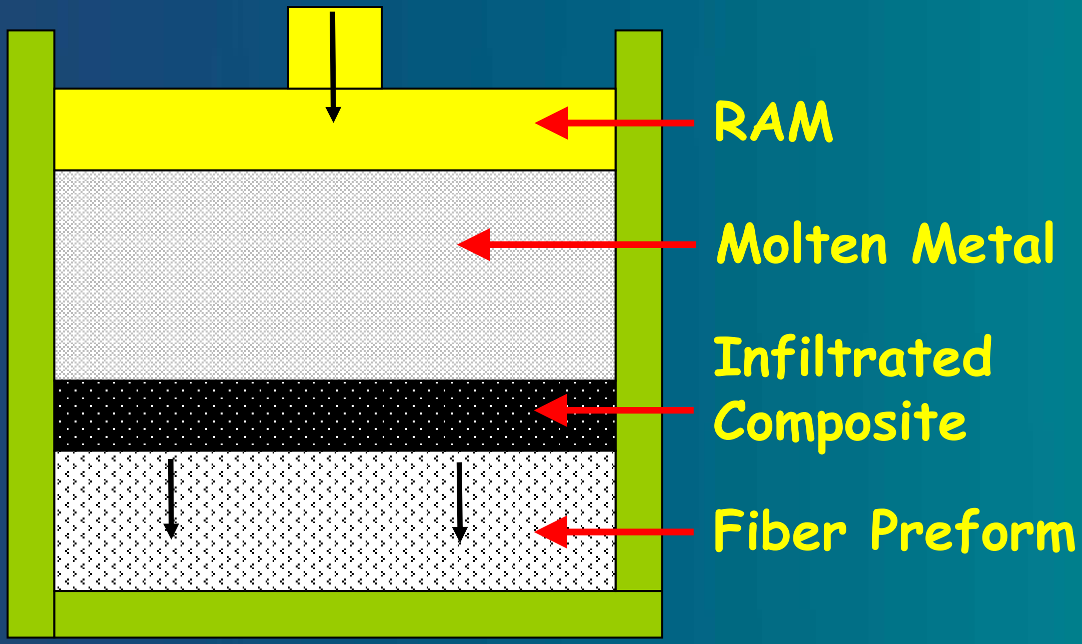
Metal Prepreg Filament Winding



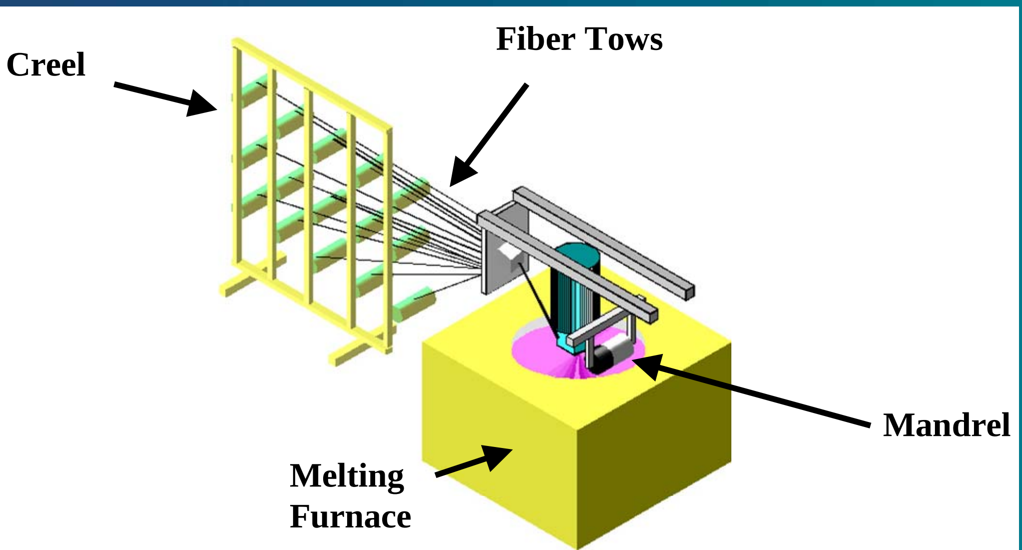
- **Analogous to PMC wet winding**
  - Based on MetPreg metal prepreg technology
  - Spools of fiber are put on creel
  - Tension is built into each tow
  - Fiber bundle is dipped into the liquid matrix (molten aluminum) to impregnate
  - Impregnated fiber bundle is laid onto the mandrel

Low-cost, flexible processing for MMCs

Casting vs. Filament Winding for MMCs



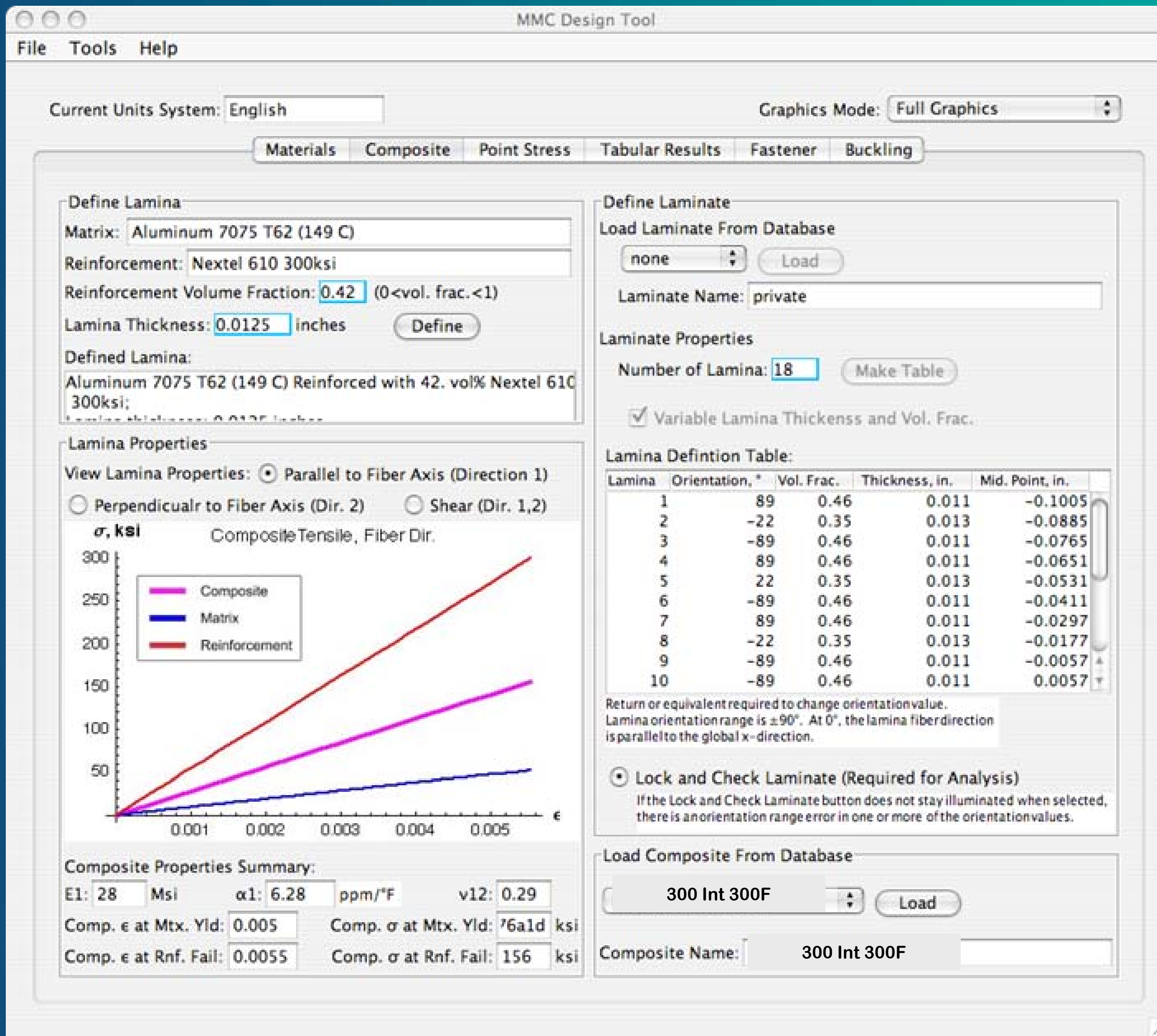
- **Pressure or squeeze casting is a multi-step process**
  - Wind preform
  - Load mold
  - Melt metal
  - Infiltrate preform



- **MMC filament winding is one step**
  - Aluminum is kept molten in furnace
  - Fibers are infiltrated and wound in a continuous process
  - Mandrel is removed from finished part after winding

MMC Design Tool Model Calibration and Validation

Virginia Tech/Aerojet MMC Design Tool



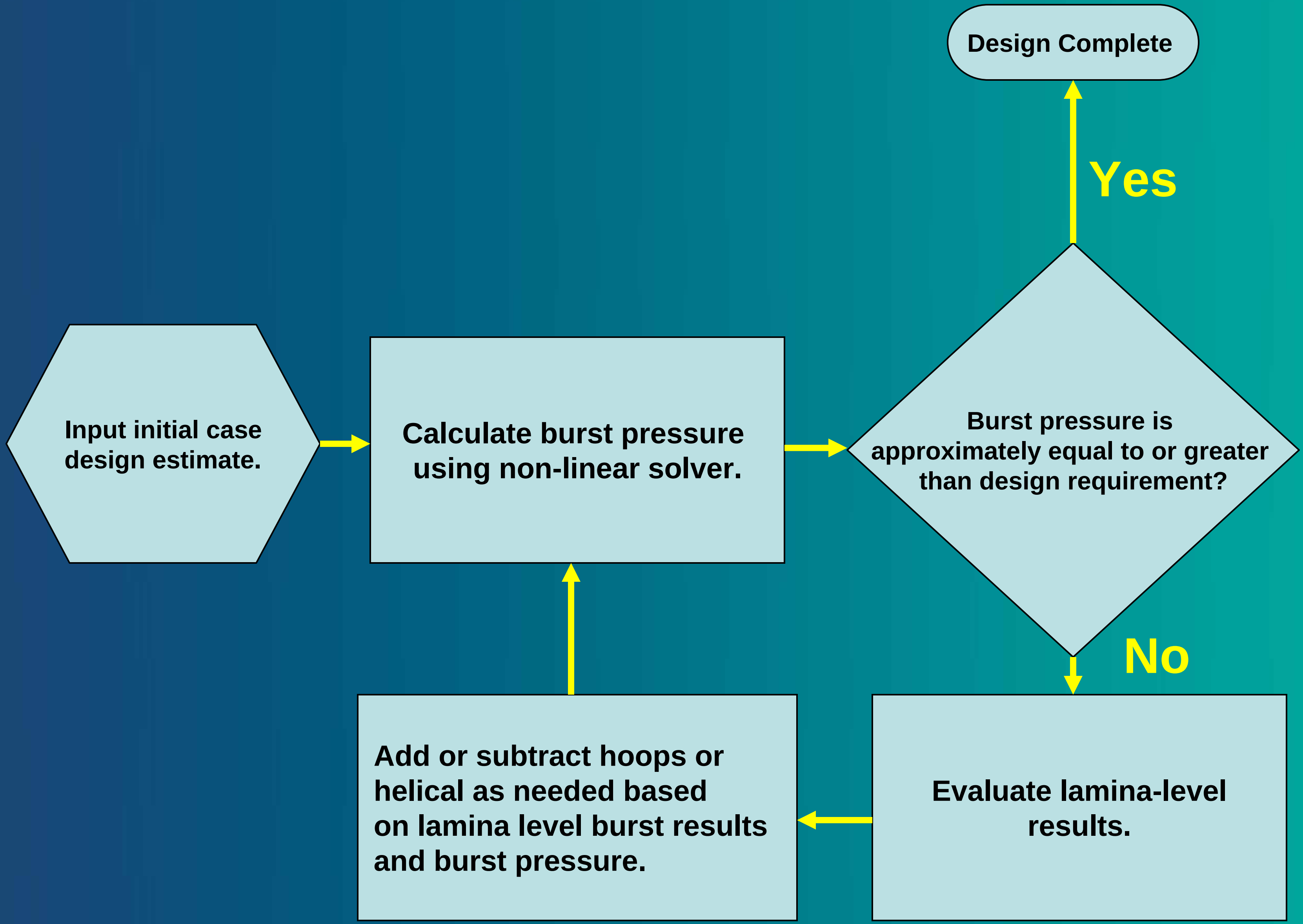
Calibrate to Experimental Values

- Calculated mean N_y was 7030 lb/in for 4-inch diameter hoop-only cylinders $N_y = P \times r$
- Model uses a non-linear point-stress analysis to determine lamina stresses
- Stress in the fiber direction for this load is 249 ksi
- This value was put back into the model and used to predict burst pressure for a 6-ply ±45/90/90/±45 lay-up
- Prediction was within 4% of experimental value

Cylinder Laminate	Assumed Fiber Strength (ksi)	Predicted Burst Pressure (psi)	Actual Burst Pressure (psi)	% Diff
$[90]_4$	249	2813	2812	0
±45/90/90/±45	249	3250	3393	-4

Production of Validation Test Cylinders

Case Design Using the MMC Design Tool

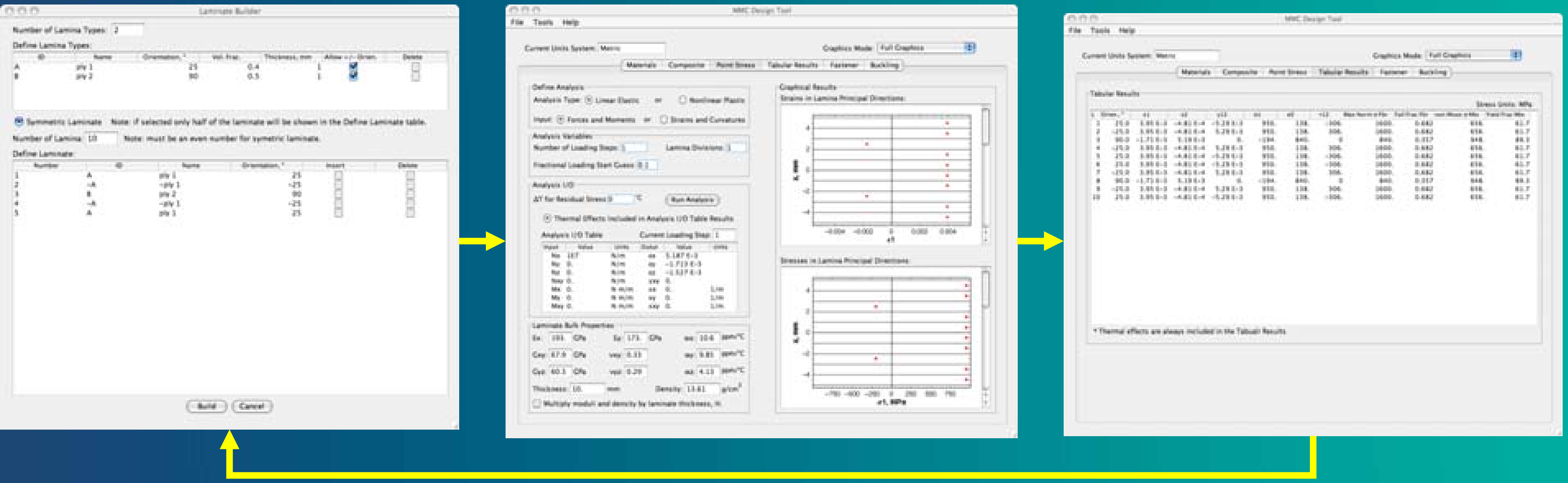


Iterative Case Design Decision Loop

Laminate Builder - Modify Lay-up

Nonlinear Solver - Calculate Burst Pressure

Lamina-level Results - Determine Modifications



Step #1 – Laminate Builder

Laminate Builder

Number of Lamina Types: 2

Define Lamina Types:

ID	Name	Orientation, °	Vol. Frac.	Thickness, mm	Allow +/− Orien.	Delete
A	ply 1	25	0.4	1	☑	☐
B	ply 2	90	0.5	1	☑	☐

◉ Symmetric Laminate   Note: if selected only half of the laminate will be shown in the Define Laminate table.

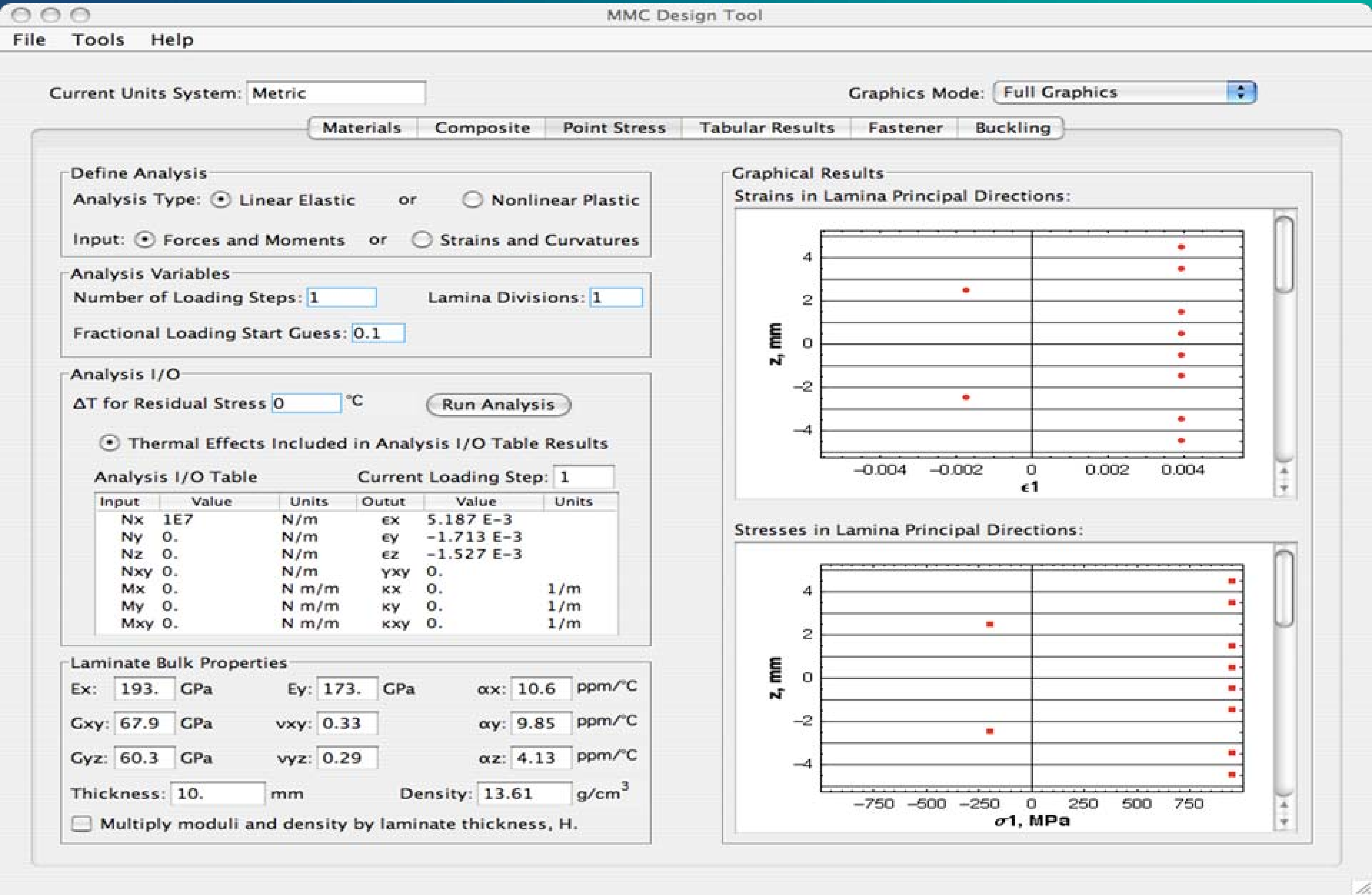
Number of Lamina: 10   Note: must be an even number for symetric laminate.

Define Laminate:

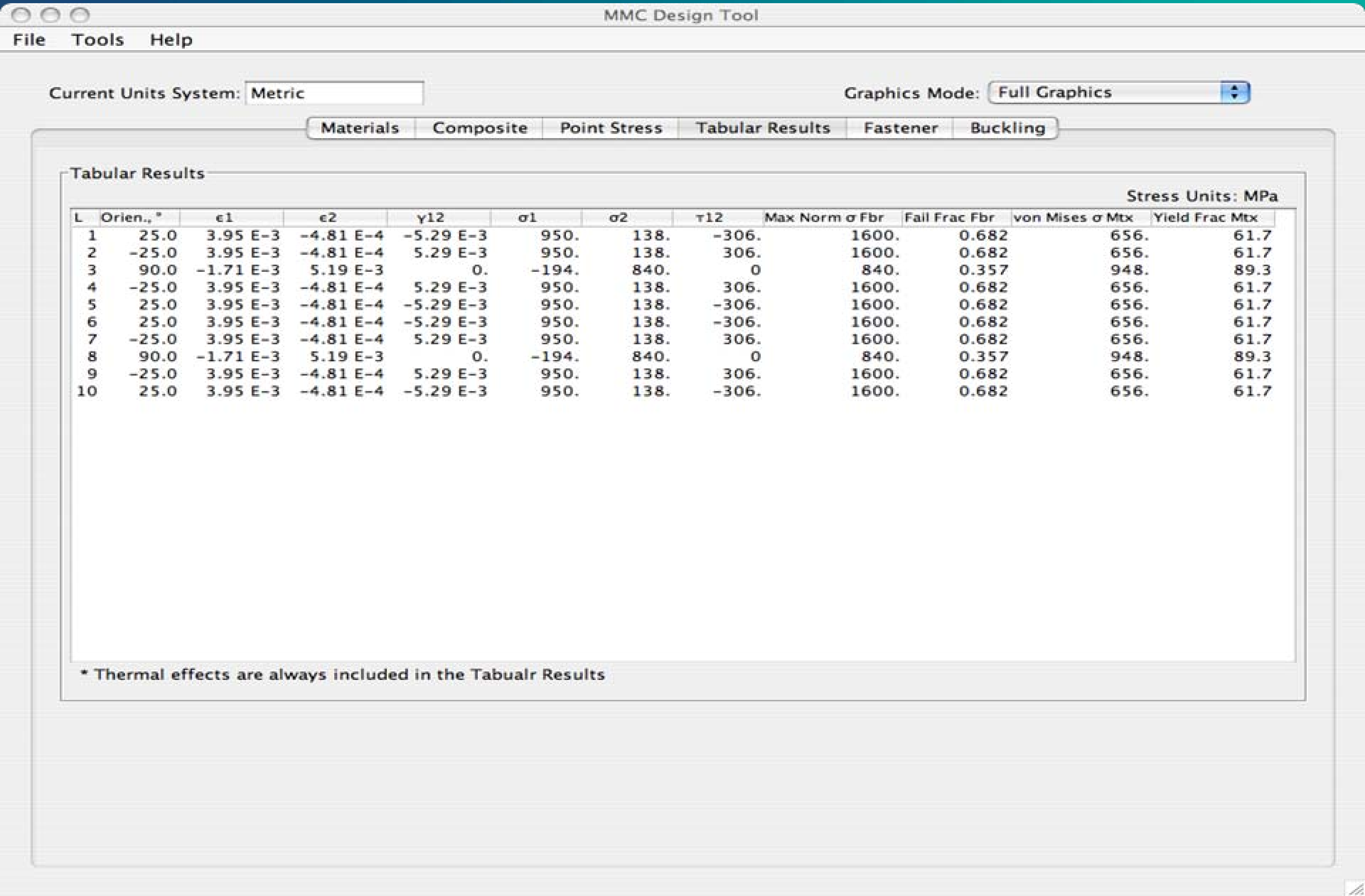
Number	ID	Name	Orientation, °	Insert	Delete
1	A	ply 1	25	☐	☐
2	−A	−ply 1	−25	☐	☐
3	B	ply 2	90	☐	☐
4	−A	−ply 1	−25	☐	☐
5	A	ply 1	25	☐	☐

Build   Cancel

Step #2 – Calculate Burst Pressure



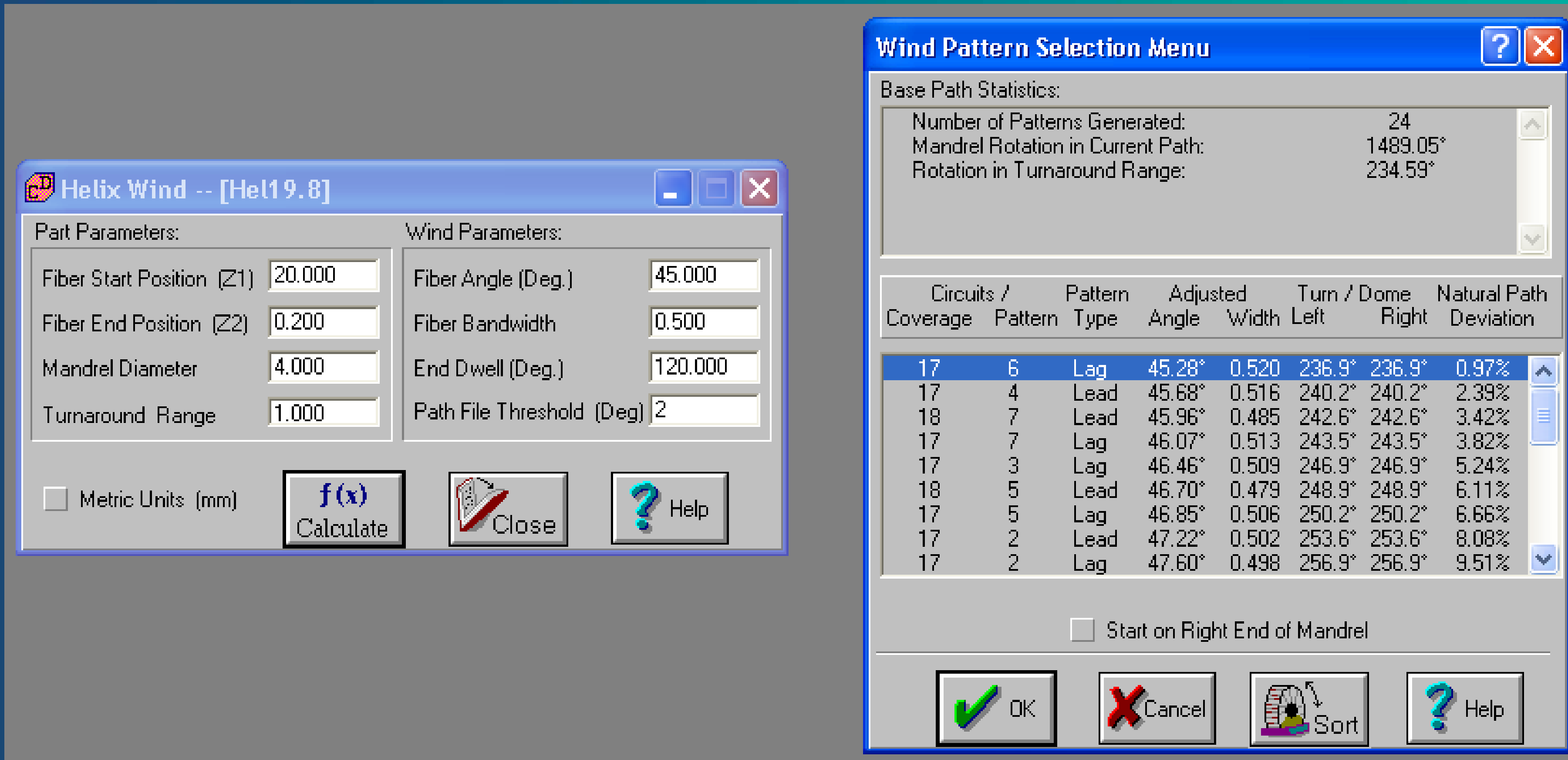
Step #3 – Review Lamina Level Results



L	Orien., *	ε1	ε2	γ12	σ1	σ2	τ12	Max Norm σ Fbr	Fail Frac Fbr	von Mises σ Mtx	Yield Frac Mtx
1	25.0	3.95 E-3	-4.81 E-4	-5.29 E-3	950.	138.	-306.	1600.	0.682	656.	61.7
2	-25.0	3.95 E-3	-4.81 E-4	5.29 E-3	950.	138.	306.	1600.	0.682	656.	61.7
3	90.0	-1.71 E-3	5.19 E-3	0.	-194.	840.	0	840.	0.357	948.	89.3
4	-25.0	3.95 E-3	-4.81 E-4	5.29 E-3	950.	138.	306.	1600.	0.682	656.	61.7
5	25.0	3.95 E-3	-4.81 E-4	-5.29 E-3	950.	138.	-306.	1600.	0.682	656.	61.7
6	25.0	3.95 E-3	-4.81 E-4	-5.29 E-3	950.	138.	-306.	1600.	0.682	656.	61.7
7	-25.0	3.95 E-3	-4.81 E-4	5.29 E-3	950.	138.	306.	1600.	0.682	656.	61.7
8	90.0	-1.71 E-3	5.19 E-3	0.	-194.	840.	0	840.	0.357	948.	89.3
9	-25.0	3.95 E-3	-4.81 E-4	5.29 E-3	950.	138.	306.	1600.	0.682	656.	61.7
10	25.0	3.95 E-3	-4.81 E-4	-5.29 E-3	950.	138.	-306.	1600.	0.682	656.	61.7

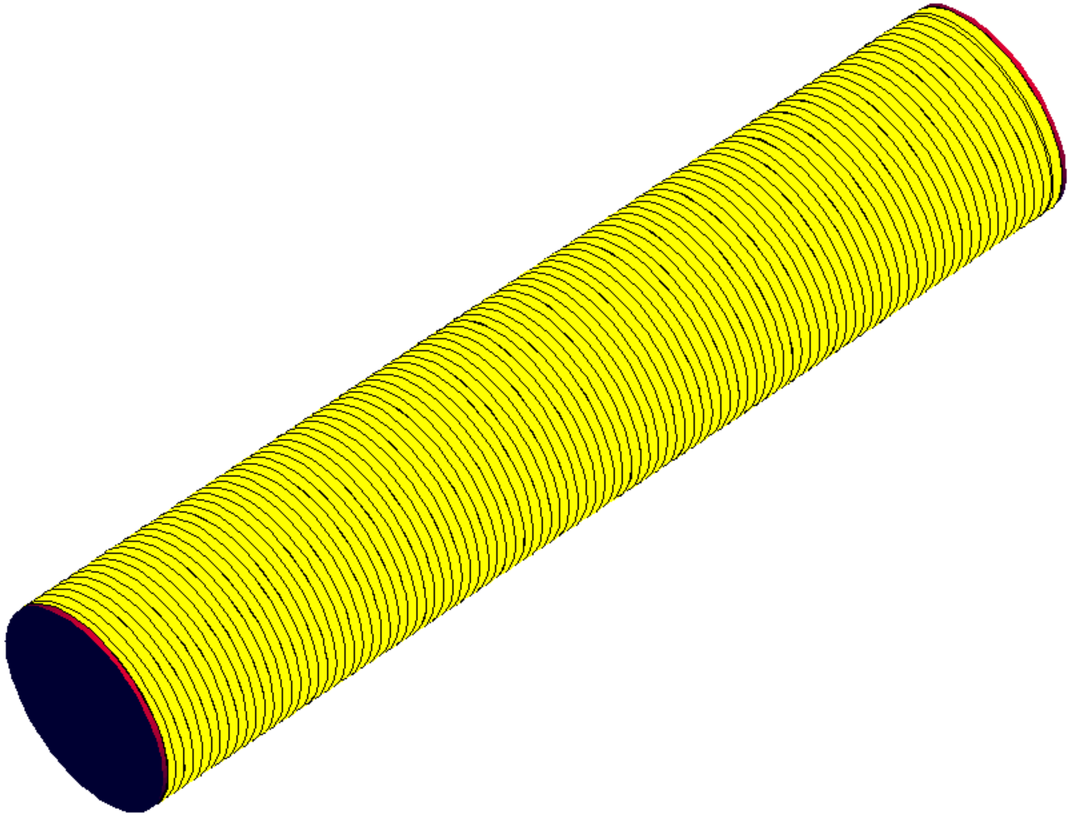
* Thermal effects are always included in the Tabualr Results

Pattern Development

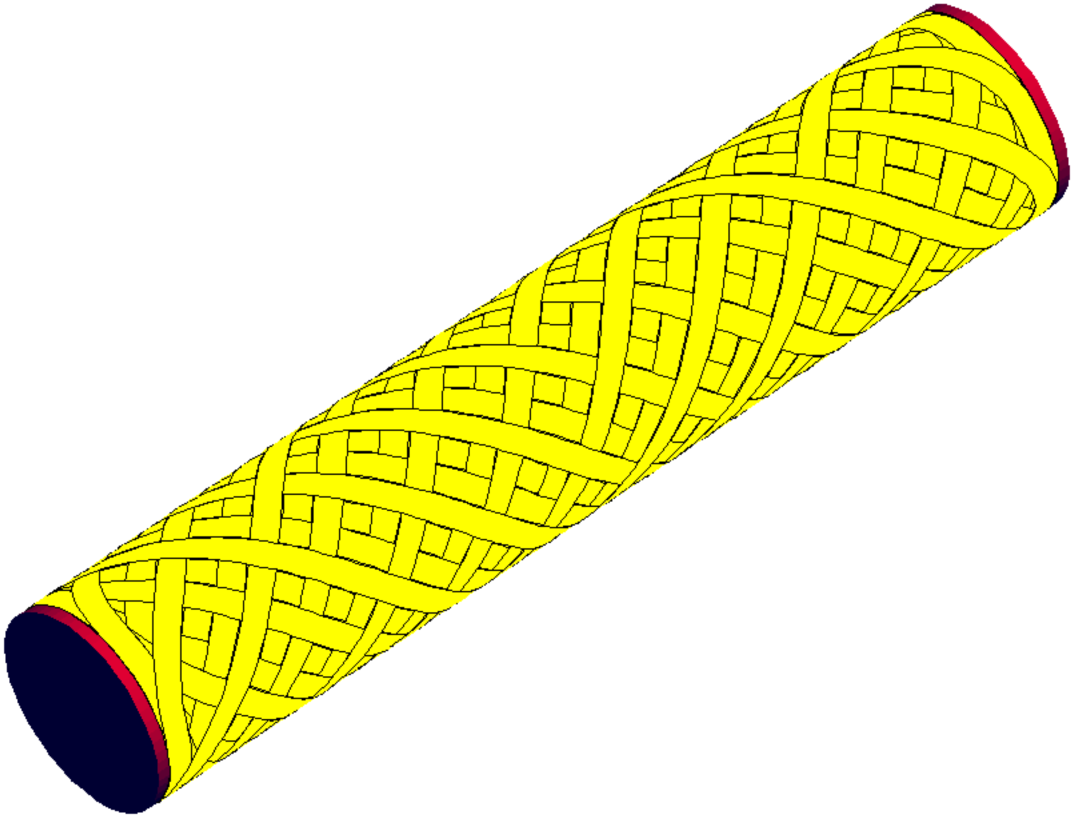


- **Pattern files are created for each ply or layer**
- **Hoop ply patterns require the input of the mandrel diameter, pattern length, and fiber bandwidth**
- **Helical layer patterns require these same inputs plus the fiber angle, parameters that deal with the reversal of the fiber direction on each end, and choosing the circuits/coverage and circuits/pattern**

Preview of the Winding Patterns

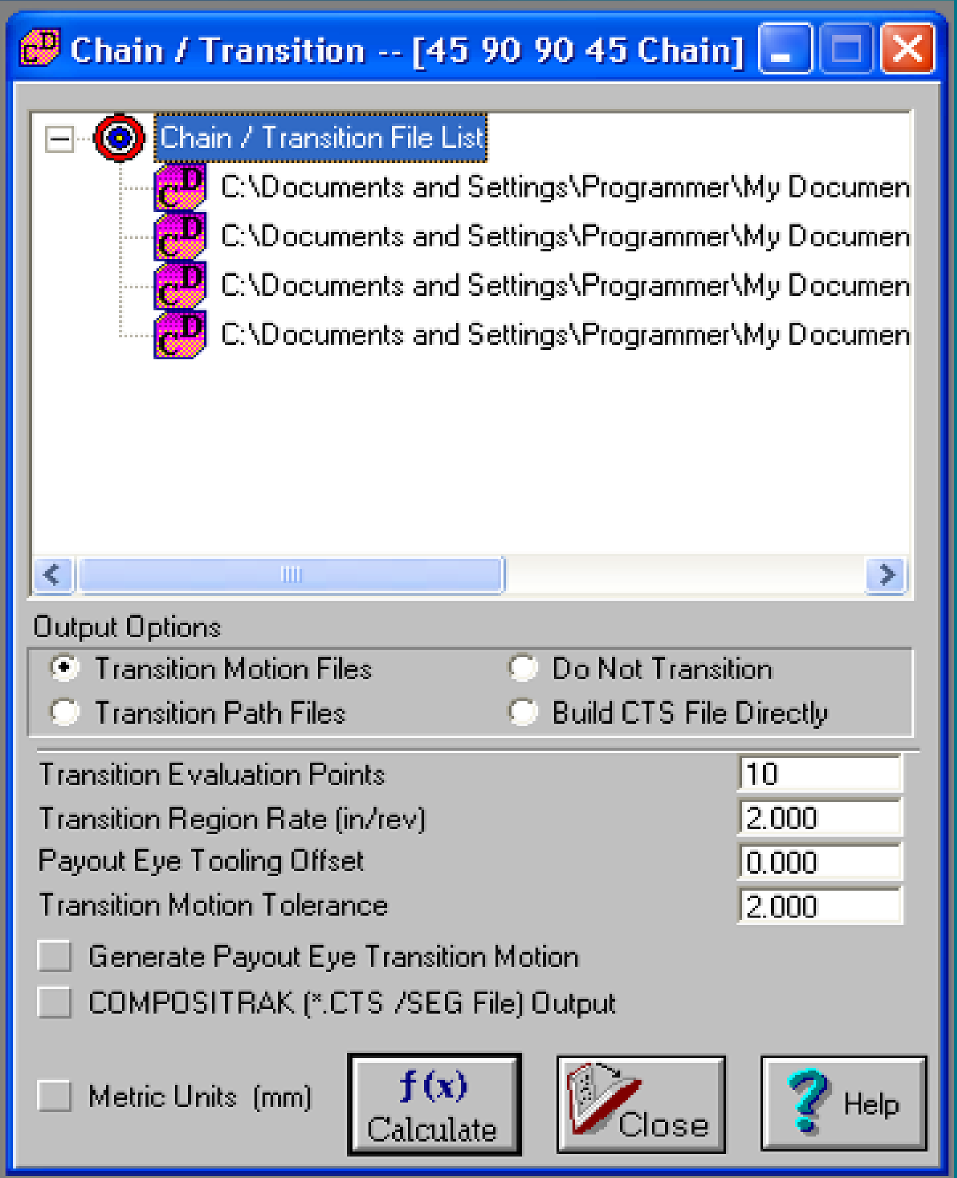


Check for pattern coverage



Check for coverage and smoothness of turns on ends

Combining Individual Patterns Into Chain Pattern



- Individual patterns are linked together in a chain wind to ensure smooth transitions between segments
- The pattern is “filtered” to level out any acceleration spikes in the machine motion

Validation Test Results

SUMMARY DATA	Cyl 1	Cyl 2
Test Date	28-Feb-08	19-Jan-08
Test Temp., (°F)	~77	~77
Wall Thickness, in	0.220	0.233
Fiber Vol. Fraction	0.404	0.385
Burst Pressure, psi	3331	3277
Ultimate Hoop Stress, ksi	39.8	39.2
Hoop Elastic Modulus, Msi	20.0	5.0
Hoop Strain at Failure, %	0.33	1.14
Ultimate Axial Stress, ksi	19.9	19.6
Axial Elastic Modulus, Msi	30.0	7.0
Axial Strain at Failure, %	0.06	0.26

- **Wall thickness of nearly ¼" with a lay-up of 90/±45/ ±45/90/ ±45/ ±45/90**
- **Hoop fiber failure achieved**
- **Consistent properties with the exception of some strain data anomalies**

Production of IM and Static Fire Test Cylinders

Al MMC Cylinder Production

Conclusions

- MMC filament winding process has been further demonstrated through the production of nine 6-inch OD x 15-inch long cylinders with ~0.25-inch wall thickness
- MMC Design Tool and burst test results were successfully used to design cylinders for IM and static fire testing
- Tests completed thus far indicate that Al MMC motor cases will be better than steel cases against BI and FI
- Al MMC cases may be better than steel in FCO as well, but the first test was not conclusive and another test is being planned
- The response to SCO should be no worse than current designs, the most difficult threat to mitigate, and there is the potential for incorporating unique closure designs specifically geared towards SCO mitigation

Future Work

- **Currently implementing a 3rd axis on the filament winding machine which should allow cylinders with thinner walls to have higher burst pressures**
- **Additional scale-up to make cylinders with lengths up to six feet is being planned**
- **A method for NDI/NDE will need to be developed**
- **End closure processing and attachment point designs will also need to be developed**

Questions?

Visit Touchstone Research Laboratory on the Web

www.trl.com ***www.metpreg.com***

E-mail: metpreginfo.com