STRESS FREE TEMPERATURE TESTING AND CALCULATIONS ON OUT-OF-AUTOCLAVE COMPOSITES

SAMPE Conference
Long Beach, CA
May 6-9, 2013

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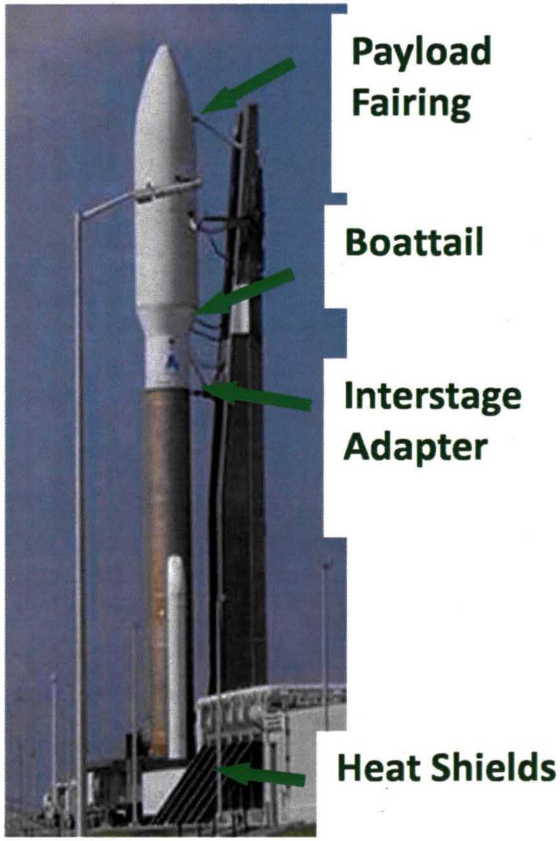
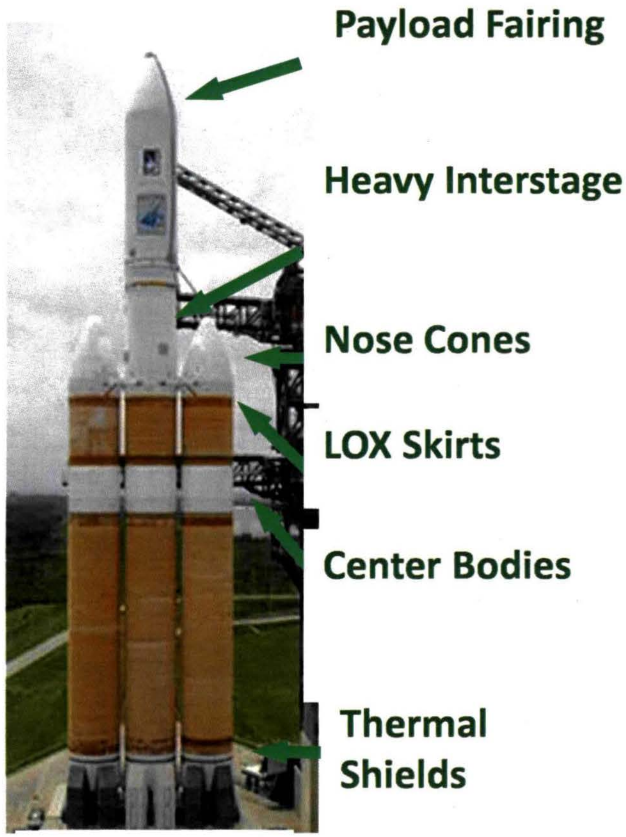
Agenda/Outline

- Background on Composites for Exploration
- Test Panel Fabrication
- Stress Free Temperature Testing
- Results and Analysis
- Conclusion
- Questions

Aerospace Applications

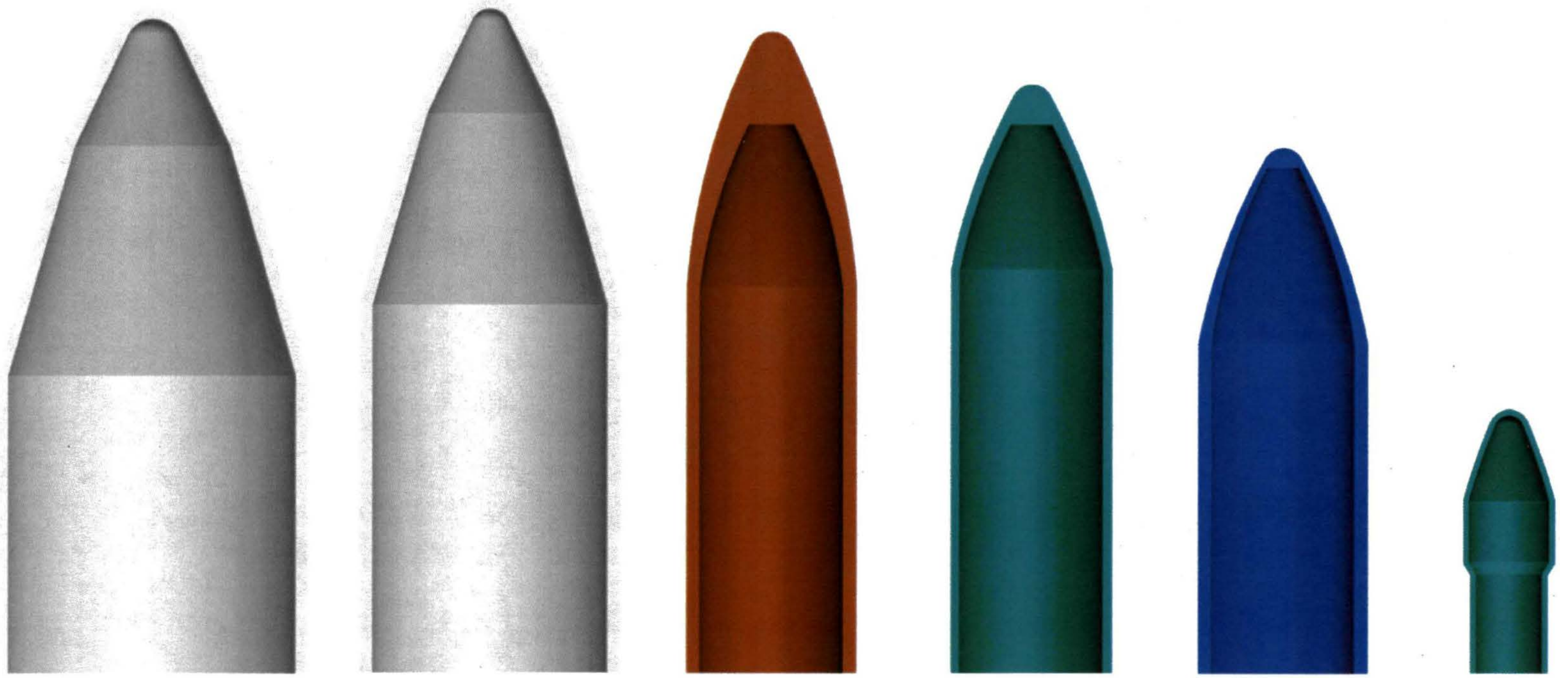


Atlas V



Delta IV

Fairing Size Comparison



Vehicle	Ares V	Ares V	Atlas V	Delta IV	Ariane	Delta II
Dia	10 m	8.4 m	5.4 m	5.1 m	5.4 m	3 m
Area	~561 m^2	~493 m^2	~311 m^2	~277 m^2	~254 m^2	~63 m^2

Composites for Exploration

- Advancement of composite systems for large primary structures, by developing a composite payload fairing for heavy lift vehicle
- Demonstrate 25-30 percent weight savings and 20-25 percent cost savings for composite compared to metallic payload fairing structures
- Material Requirements
  - Out of Autoclave cure required due to size of structure
  - Maximum cure temperature of 177°C due to tooling temperature restrictions
  - High operating temperature to reduce amount of thermal protection needed

Materials

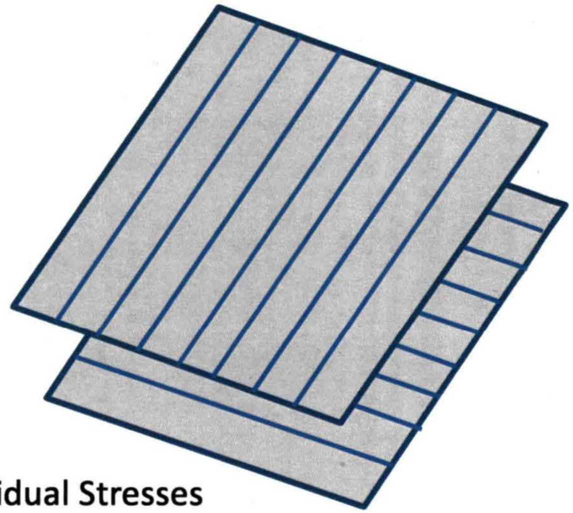
- Out of Autoclave IM7/Bismaleimide (BMI) Prepreg Unitapes
  - **Renegade:** RM3004 developed to be cured at 191 °C (vendor did not recommend cure below 185 °C)
  - **Stratton Composites:** AR4500 developed to be cured at 191 °C
  - **Tencate:** RS8-OOA developed to be cured at 177 °C

Residual Stress in Composite Panels

Residual stress due to thermal mismatch between the matrix and the fiber

$$\sigma_A = \frac{1}{d_A}\left(\frac{(\alpha_B - \alpha_A)\Delta T}{\frac{1-\nu_A}{d_A E_A} + \frac{1-\nu_B}{d_B E_B}}\right)$$

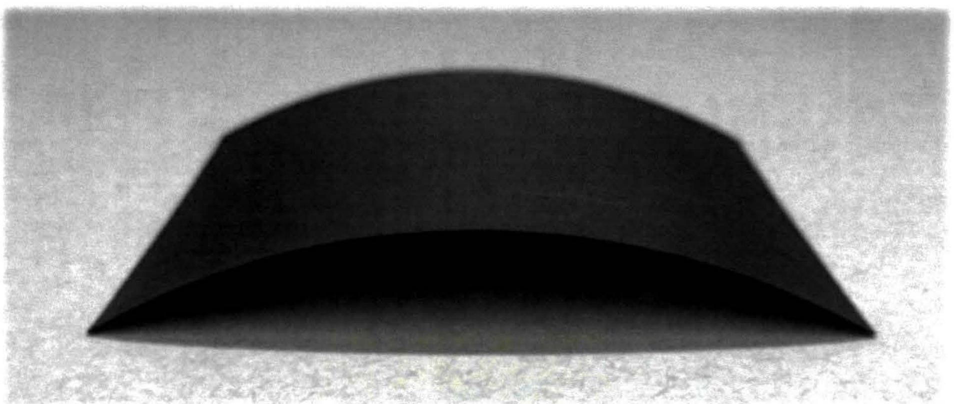
d = layer thickness
α = Coefficient of Thermal Expansion
$\Delta T = T_{SF} - T$
T_{SF} = Stress Free Temperature
T = Current Temperature
ν = Poisson's Ratio
E = Young's Modulus



Ref: McGinnis, Arthur J.; Watkins Thomas R.; and Jagannadham K., "Residual Stresses in a Multilayer System of Coatings," JCPDS-International Centre for Diffraction Data, 1999. pp 443-454.

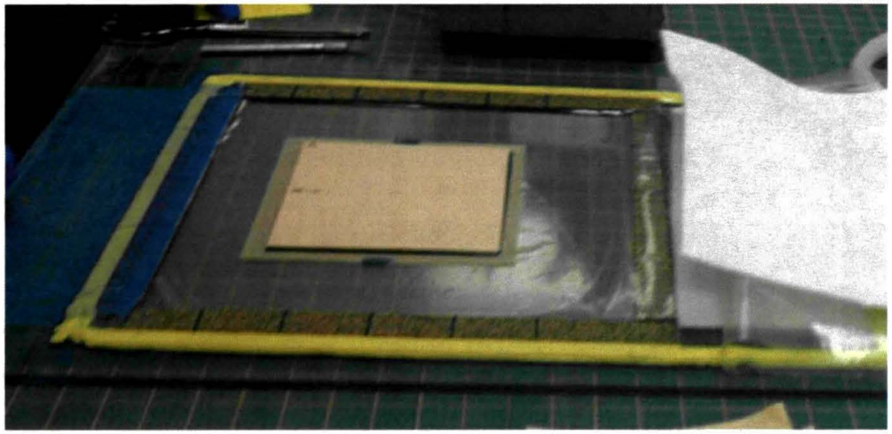
Test Panel Configuration

- Asymmetric Panels (2 ply [0,90])
  - Room Temperature, Dry (Desiccator for 24 hours)
  - Environmental Exposure (Humidity Chamber at 75% RH and 32°C for 7-10 days)
  - Each panel is 15.2 cm X 15.2 cm

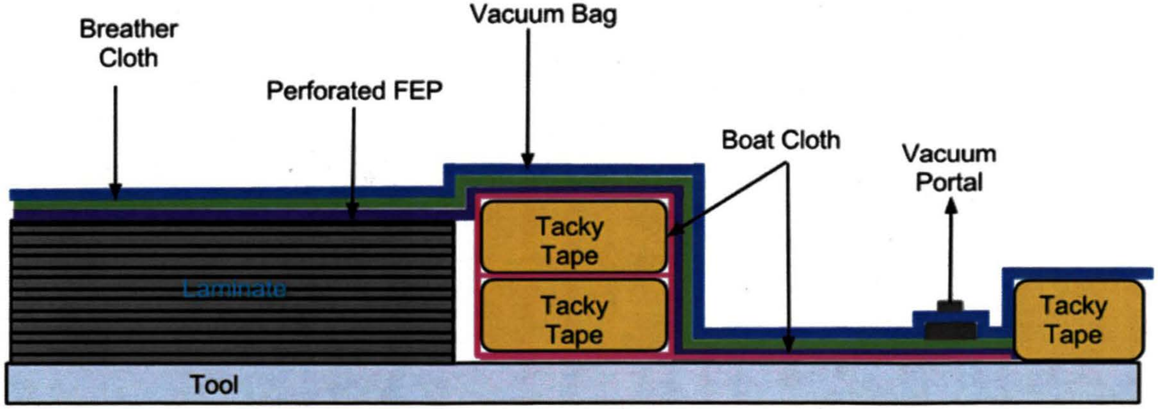


IM7/BMI Panel Fabrication

Hand Lay Up Method

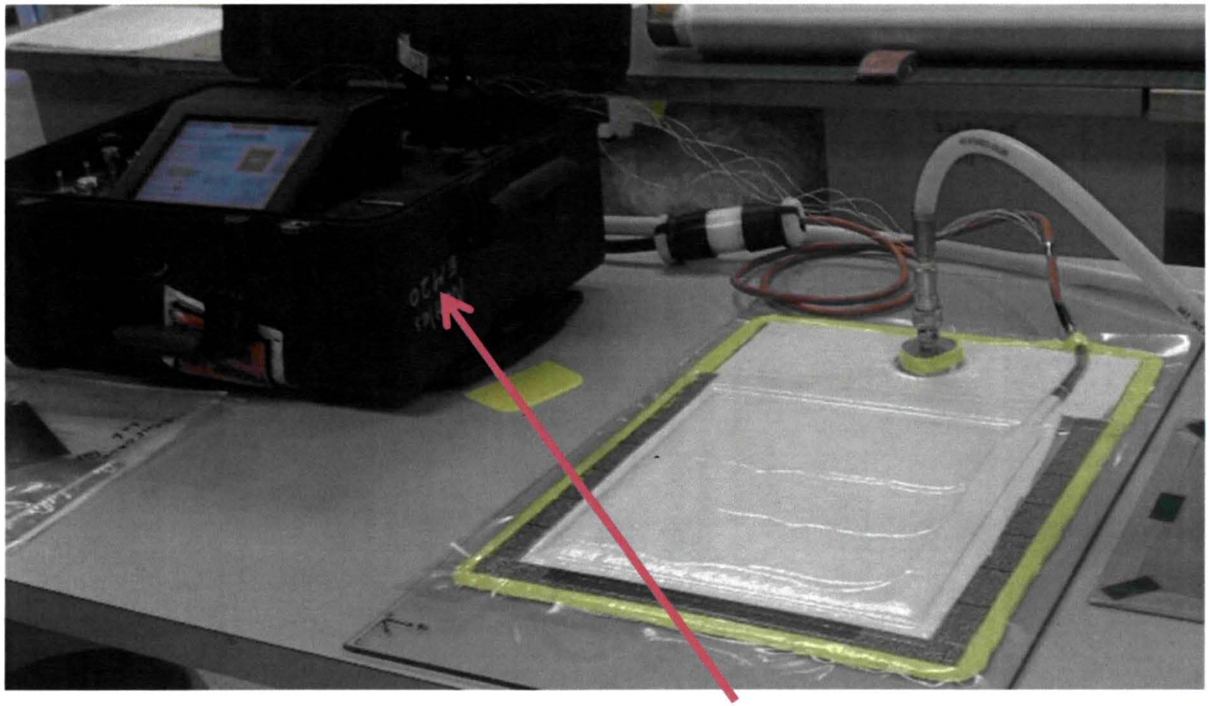


Example of Bagging Schedule



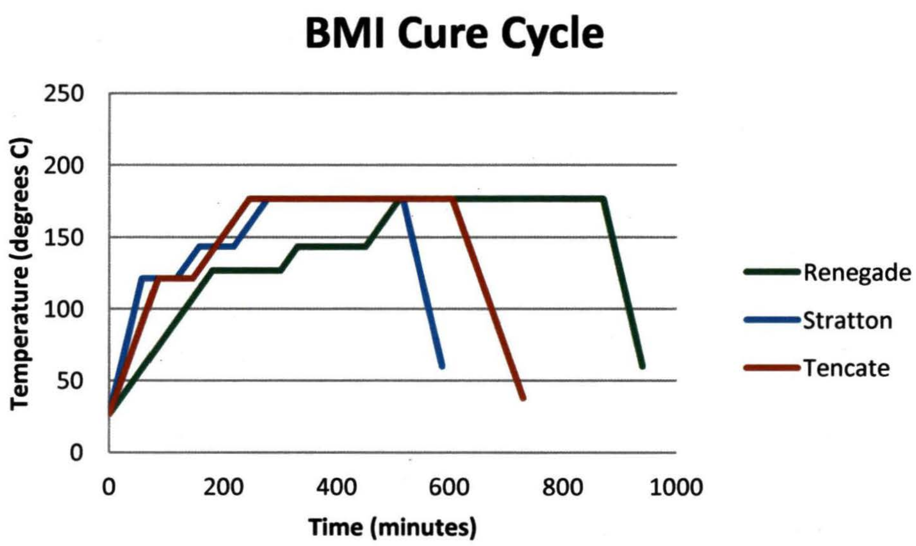
Heated Debulk

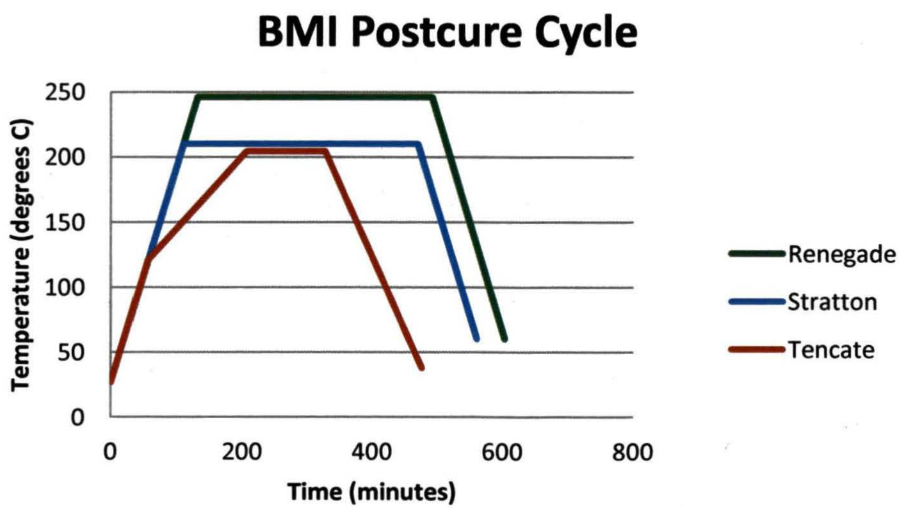
Heated debulk used to simulate the heat and pressure applied by the Automated Fiber Placement Tool



Heated Debulk Using a Hot Bonder

BMI Panel Cure Cycles

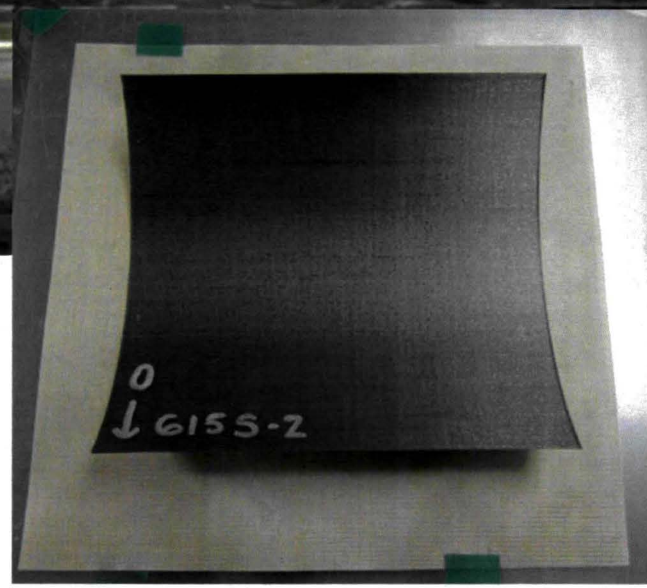




Oven Cure of Panel Under Vacuum

BMI Free Standing Post Cure

Panels in the oven for a free standing post cure



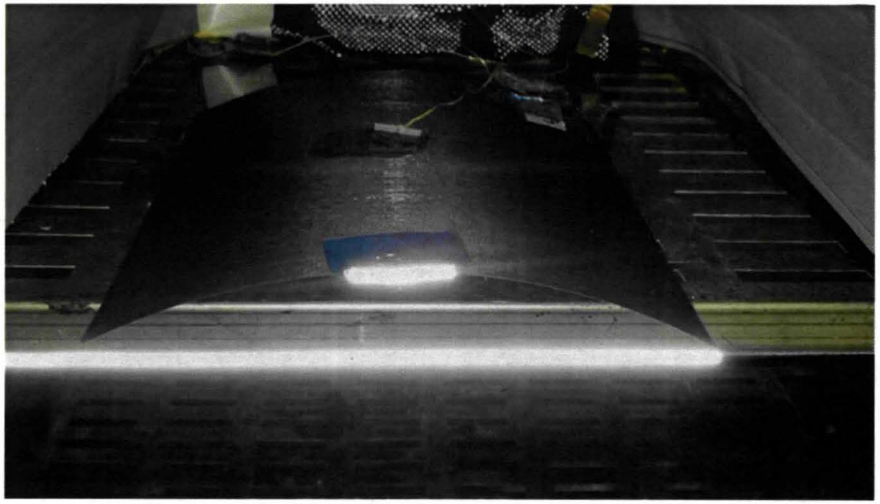
Fully Cured Panel

Test Panel Configuration

PANEL	MANUFACTURER	SET	HEATED DEBULK TEMP (DEG C)	CONDITION	% WEIGHT GAIN
615-R1	Renegade	1	40	Environmental	
615-R2	Renegade	1	40	Room Temp, Dry	
615-S1	Stratton	1	40	Environmental	0.651
615-S2	Stratton	1	40	Room Temp, Dry	
615-T1	Tencate	1	30	Environmental	0.445
615-T2	Tencate	1	30	Room Temp, Dry	
630-R1	Renegade	2	60	Environmental	0.894
630-R2	Renegade	2	60	Room Temp, Dry	
630-S1	Stratton	2	60	Environmental	
630-S2	Stratton	2	60	Room Temp, Dry	
630-T1	Tencate	2	60	Environmental	0.493
630-T2	Tencate	2	60	Room Temp, Dry	

Stress Free Temperature Testing

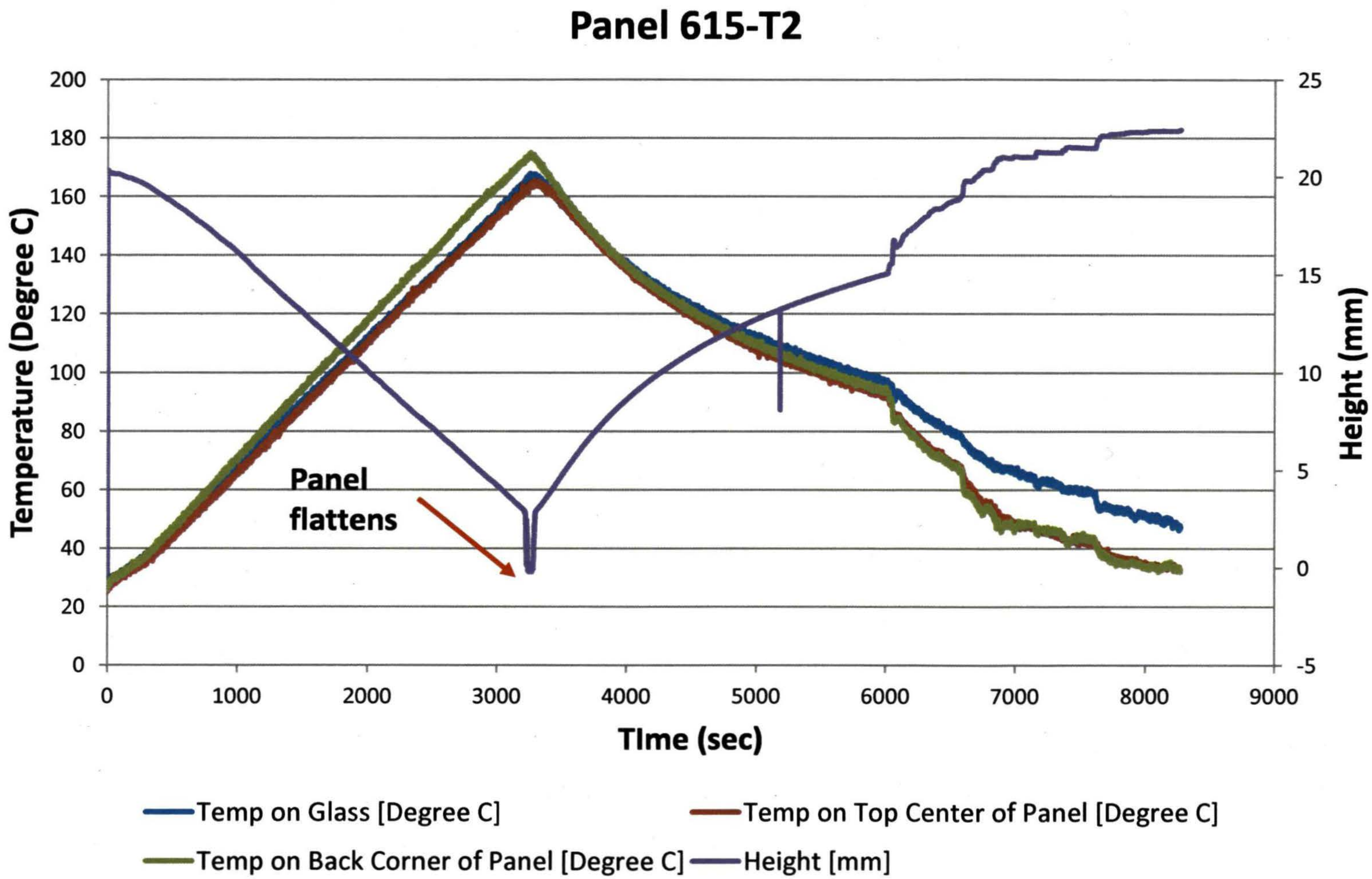
- Asymmetric panel flattens as it is heated
  - Thermocouples measured panel temperature
  - Reflective tape and a laser extensometer measured distance from the top of the curvature to the glass plate



Video of Panel Flattening

- Will insert video (630R2)

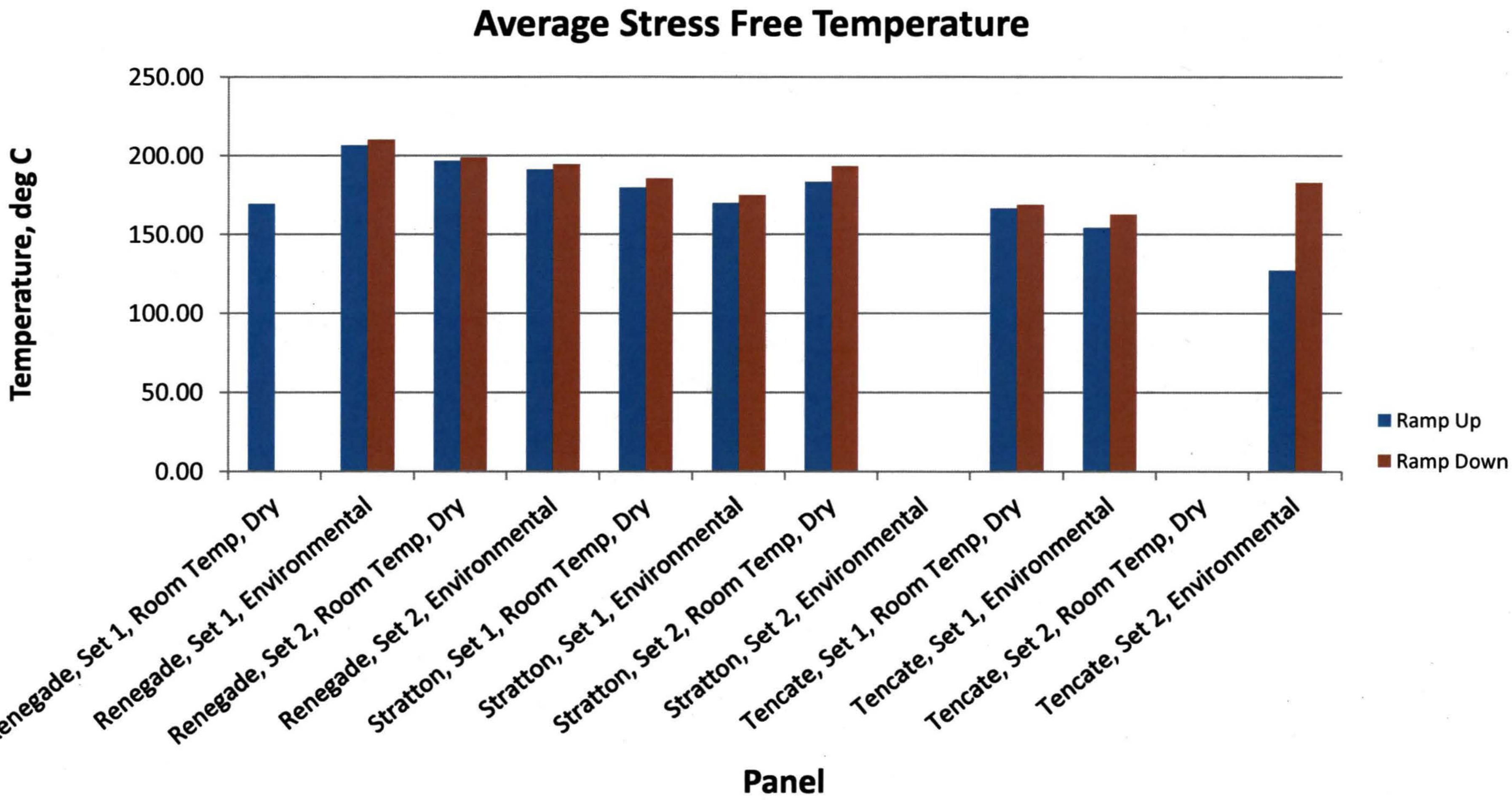
Testing Profile



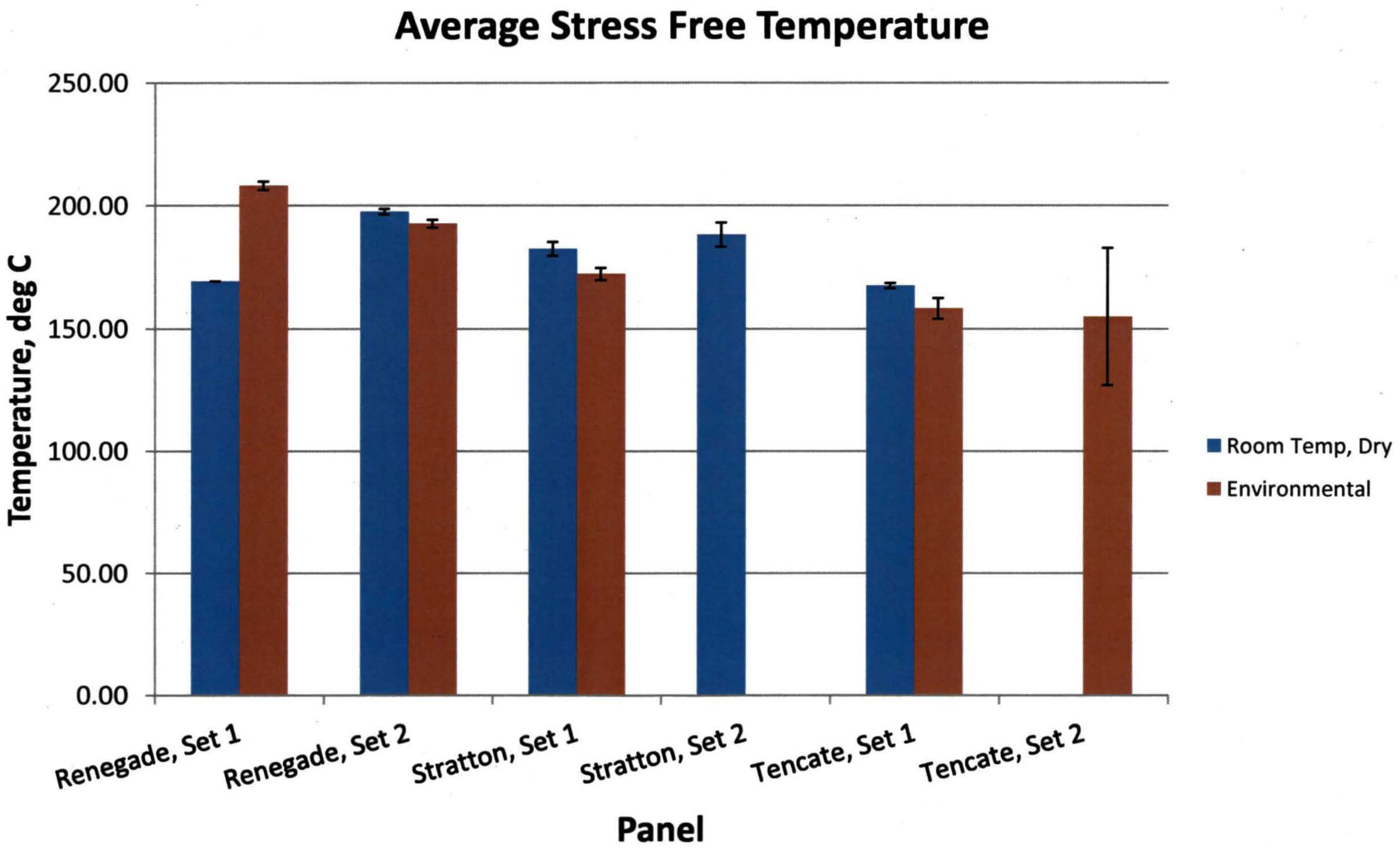
Results

PANEL NUMBER	PANEL DESCRIPTION				AVG STRESS FREE TEMP ON PANEL (degree C)
615-R1	Renegade	Set 1	Environmental	Ramp Up	206.44
				Ramp Down	209.89
630-R1		Set 2	Environmental	Ramp Up	191.06
				Ramp Down	194.31
615-R2		Set 1	Room Temp, Dry	Ramp Up	169.33
630-R2		Set 2	Room Temp, Dry	Ramp Up	196.50
				Ramp Down	198.72
615-S1	Stratton	Set 1	Environmental	Ramp Up	169.72
				Ramp Down	174.72
615-S2		Set 1	Room Temp, Dry	Ramp Up	179.58
				Ramp Down	185.25
630-S2		Set 2	Room Temp, Dry	Ramp Up	183.25
				Ramp Down	193.06
615-T1	Tencate	Set 1	Environmental	Ramp Up	154.17
				Ramp Down	162.44
630-T1		Set 2	Environmental	Ramp Up	127.03
				Ramp Down	182.75
615-T2		Set 1	Room Temp, Dry	Ramp Up	166.47
				Ramp Down	168.61

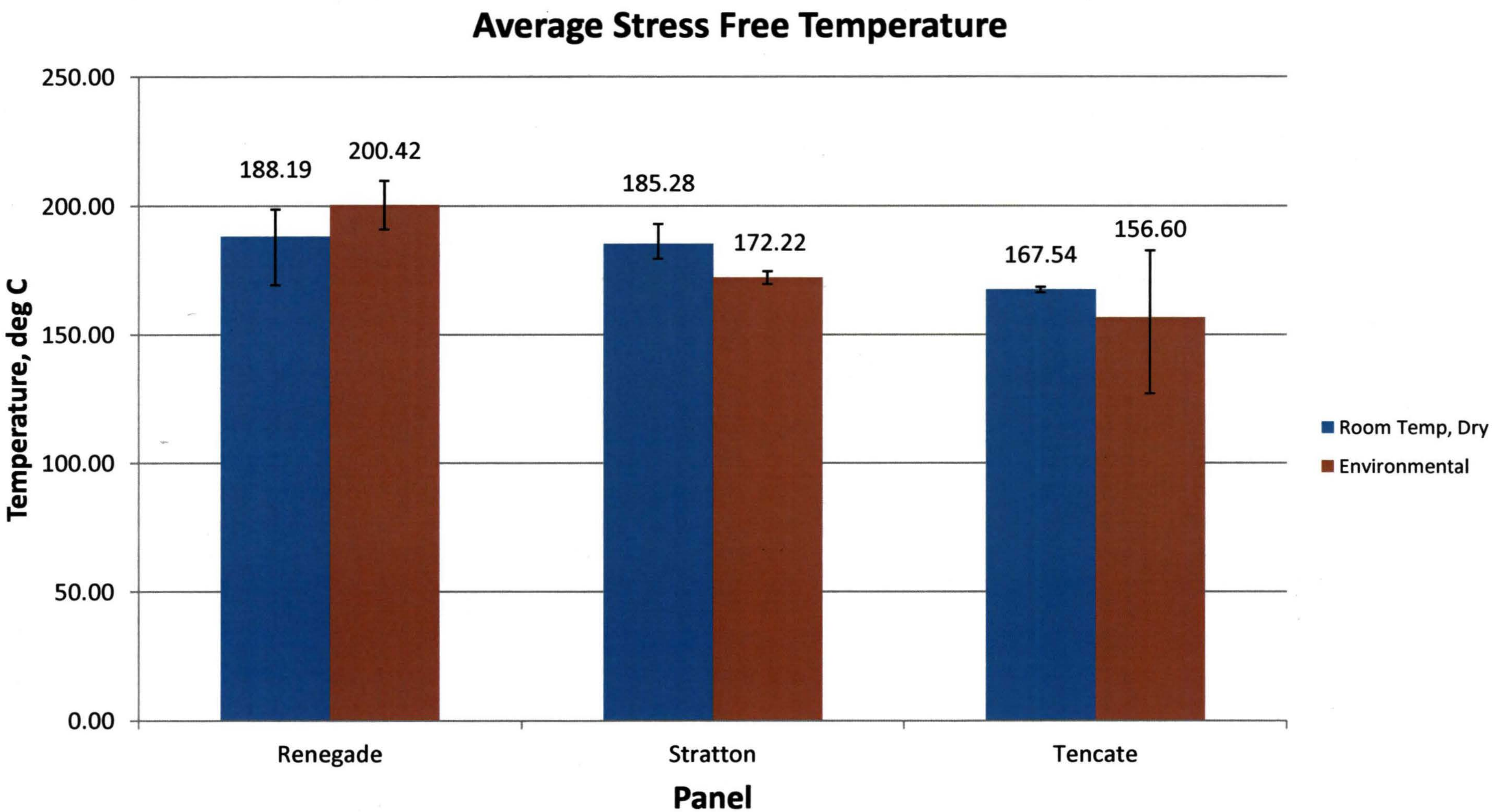
Ramp Up vs. Ramp Down



Room Temperature, Dry vs. Environmental – Each Panel



Room Temperature, Dry vs. Environmental - Averaged



Summary

- Stress free temperatures were determined by heating asymmetric panels
- This can be used to determine the residual stress
- Environmental exposure does have an effect on the stress free temperature
- There is a correlation between the recommended cure temperature and the stress free temperature

Composites for Exploration

CoEx Project Manager
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Materials and Manufacturing Co- Leads
Larry Pelham, Marshall Space Flight Center
Dr. Jim Sutter, Glenn Research Center

Materials Subtask Lead
Dr. Sandi Miller, Glenn Research Center

KSC CoEx POC
Anne Caraccio, Kennedy Space Center
Sarah Cox, Kennedy Space Center

Supporting Kennedy Space Center Team Members
Dr. LaNetra Tate*, Susan Danley,
Jeffrey Sampson, Brian Taylor

* Former KSC CoEx POC and Repair Subtask Lead, currently Detailed to NASA HQ/NIST

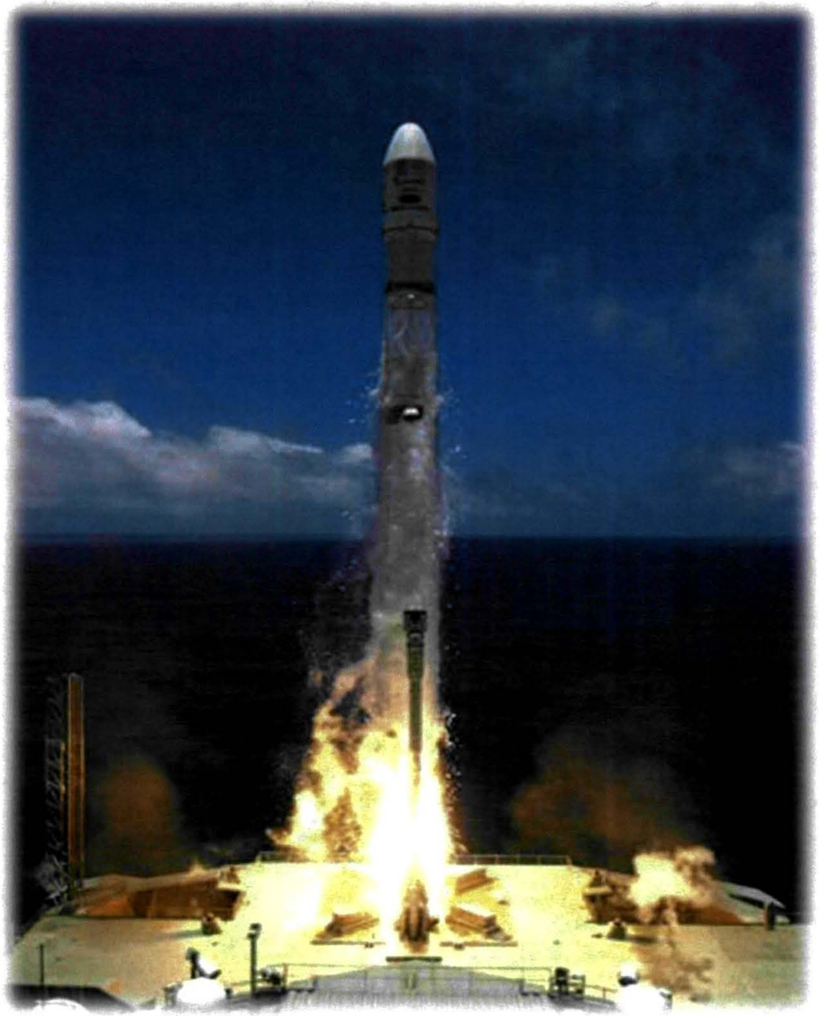
QUESTIONS?

BACK UP

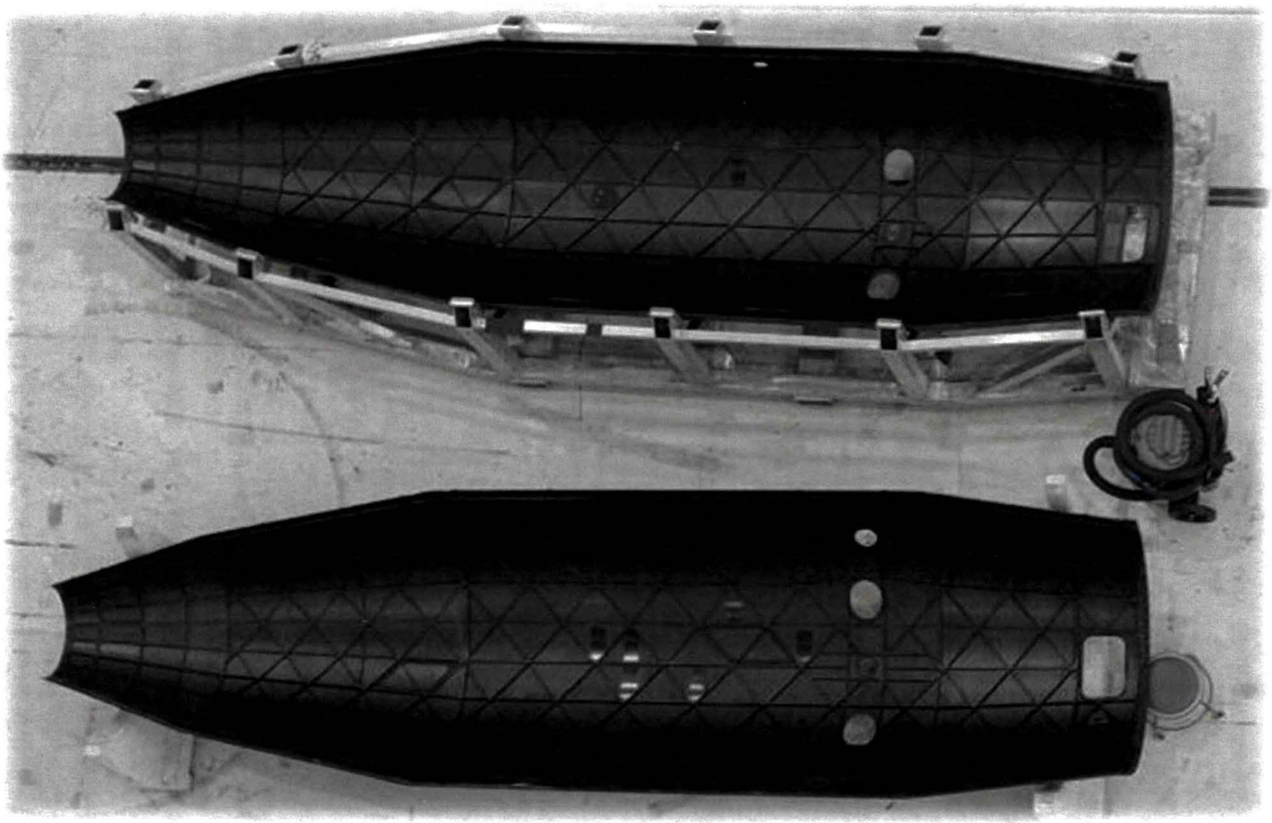
Sea Launch Payload Accommodations

Composite Faring
4.15 m dia
10.5 m long

Composite
Payload Structure

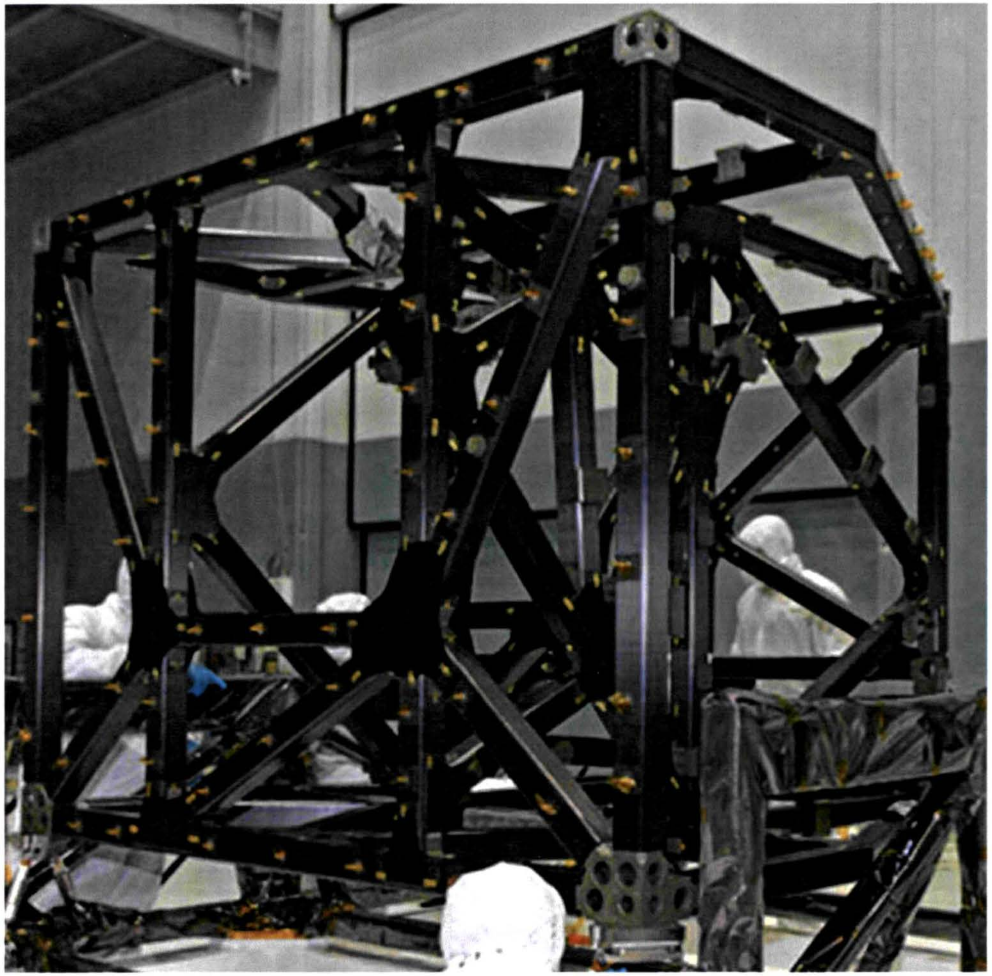


Minotaur Payload Fairing
AFRL development with Orbital Sciences



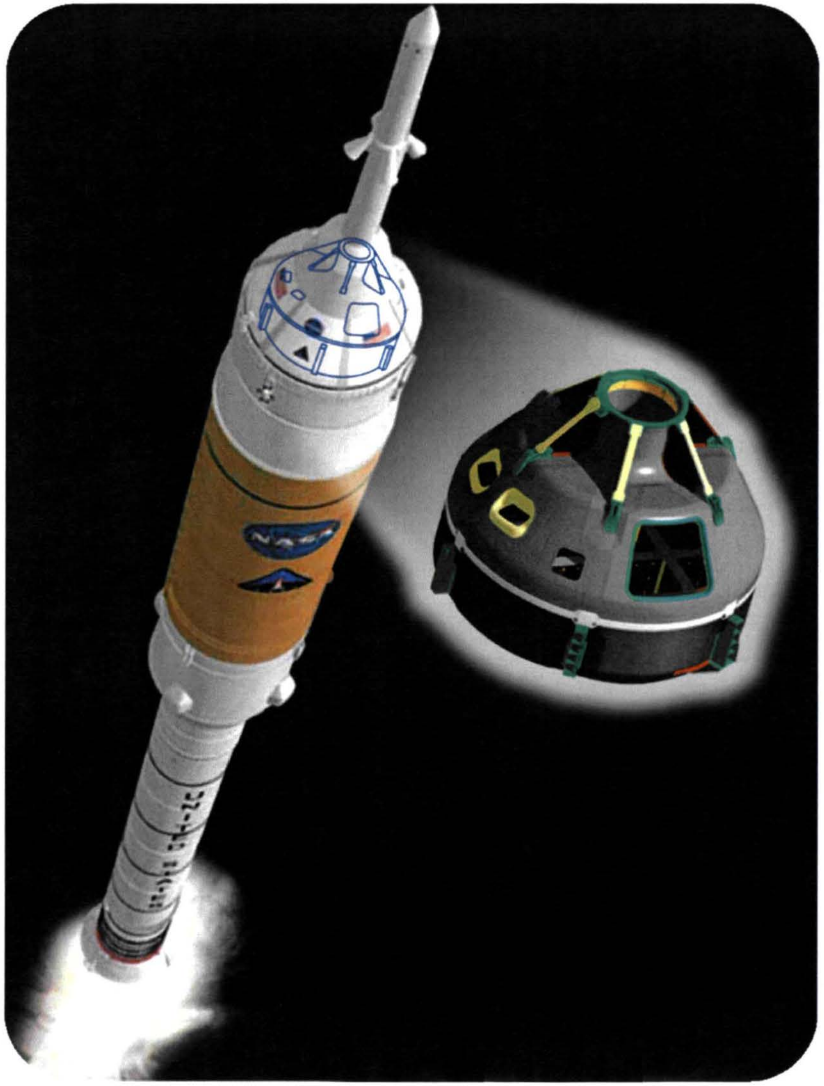
1.55 m diameter
Launched in 2006

Integrated Science Instrument Module



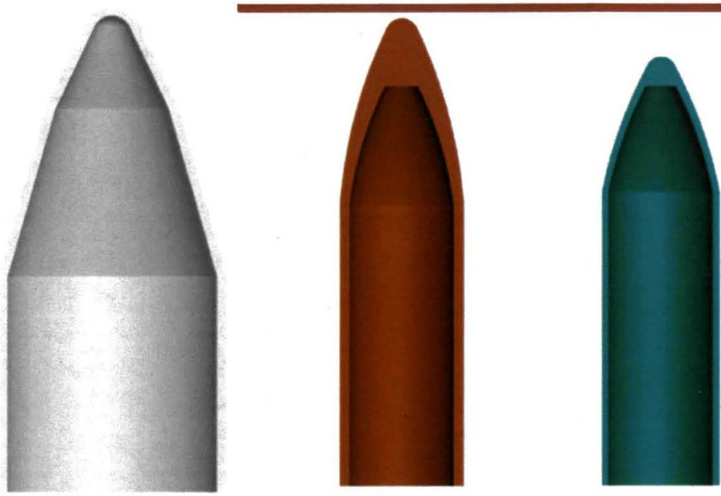
- **Protoflight hardware developed for James Webb Space Telescope and to be flown on an Ariane V**
- **Technology highlights**
  - **Cryogenic joints**
  - **Hybrid laminates for near-zero coefficient of thermal expansion operating at cryogenic temperatures**
- **Benefit: reduced thermal distortion**

NASA Composite Crew Module



- **Combined Sandwich and Solid Laminate Construction**
- **Solid Laminate**
  - **Tunnel**
  - **Main Parachute Attach**
- **Sandwich Panels**
  - **Ceiling**
  - **Conic section**
  - **2.5-cm-thick aluminum core**
- **IML and OML Facesheets Symmetric**

Composites for Exploration Project



Vehicle	Heavy Lift	Atlas V	Delta IV
Dia	10 m	5.4 m	5.1 m
Area	~561 m^2	~311 m^2	~277 m^2

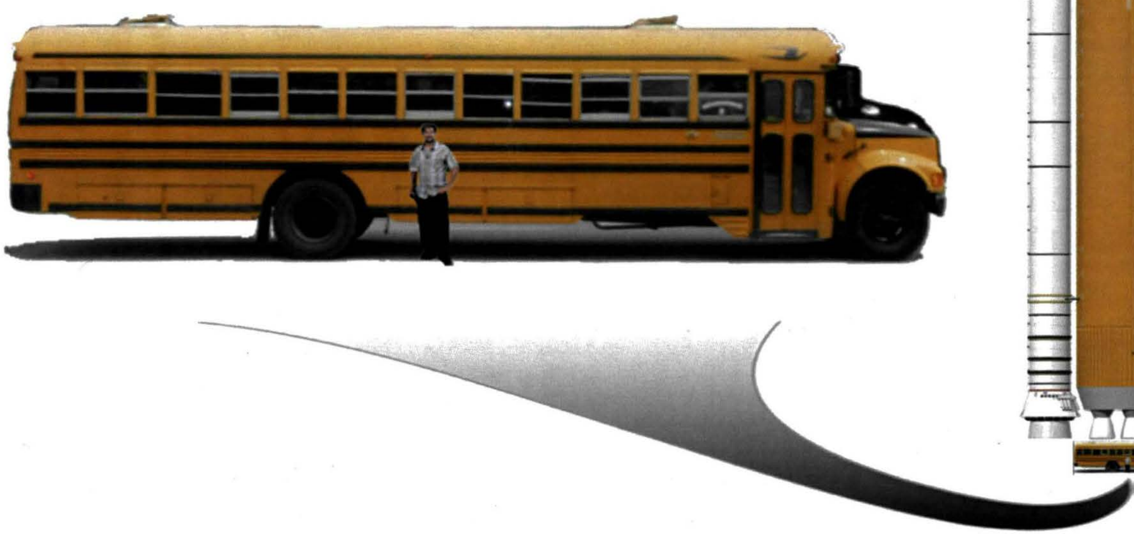
CoEx Thrust	SOA
Panels for 10-m-dia. barrels	No composites experience at this scale
Automated manufacturing	Limited to 7-m-dia. barrels
OoA* technologies	Maturing for aerospace quality
Design database	Not demonstrated for 10-m-dia. barrels

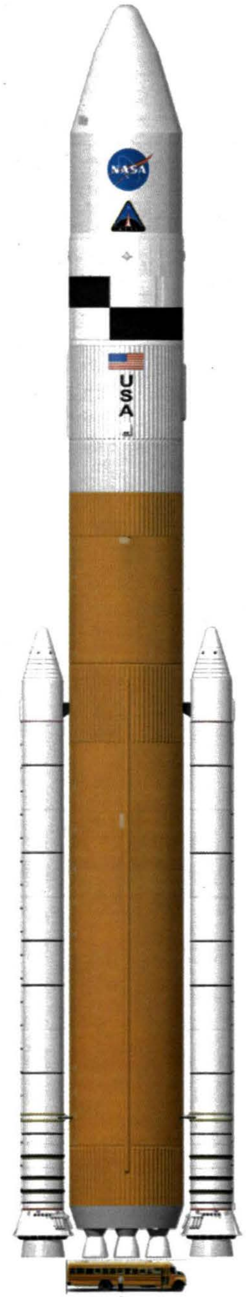
Demonstrate 25-30 percent weight savings and 20-25 percent cost savings for composite compared to metallic payload fairing structures

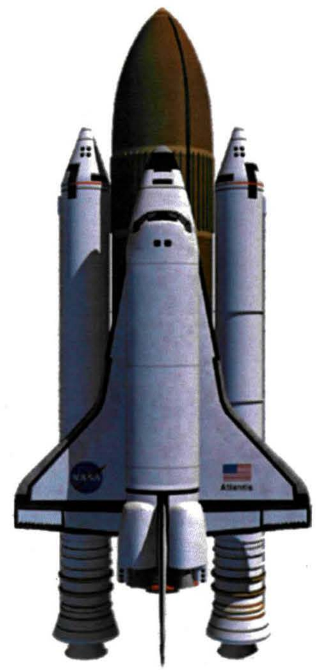
***out of autoclave**

Size Comparisons

Composite structures for heavy lift launch vehicles will be the largest composite aerospace structures ever built!

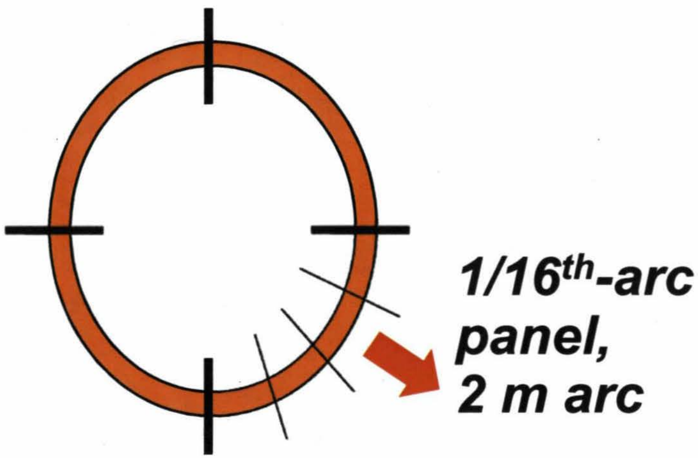


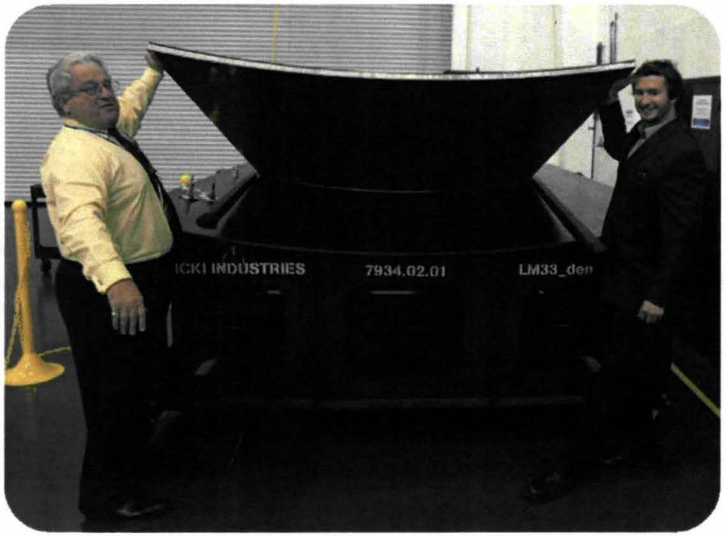




Manufacturing Summary

- Manufacturing plans are being guided by modeling of fabrication processes
- NASA fabrication of 1/16th-arc panels is first step to fabricating larger structures

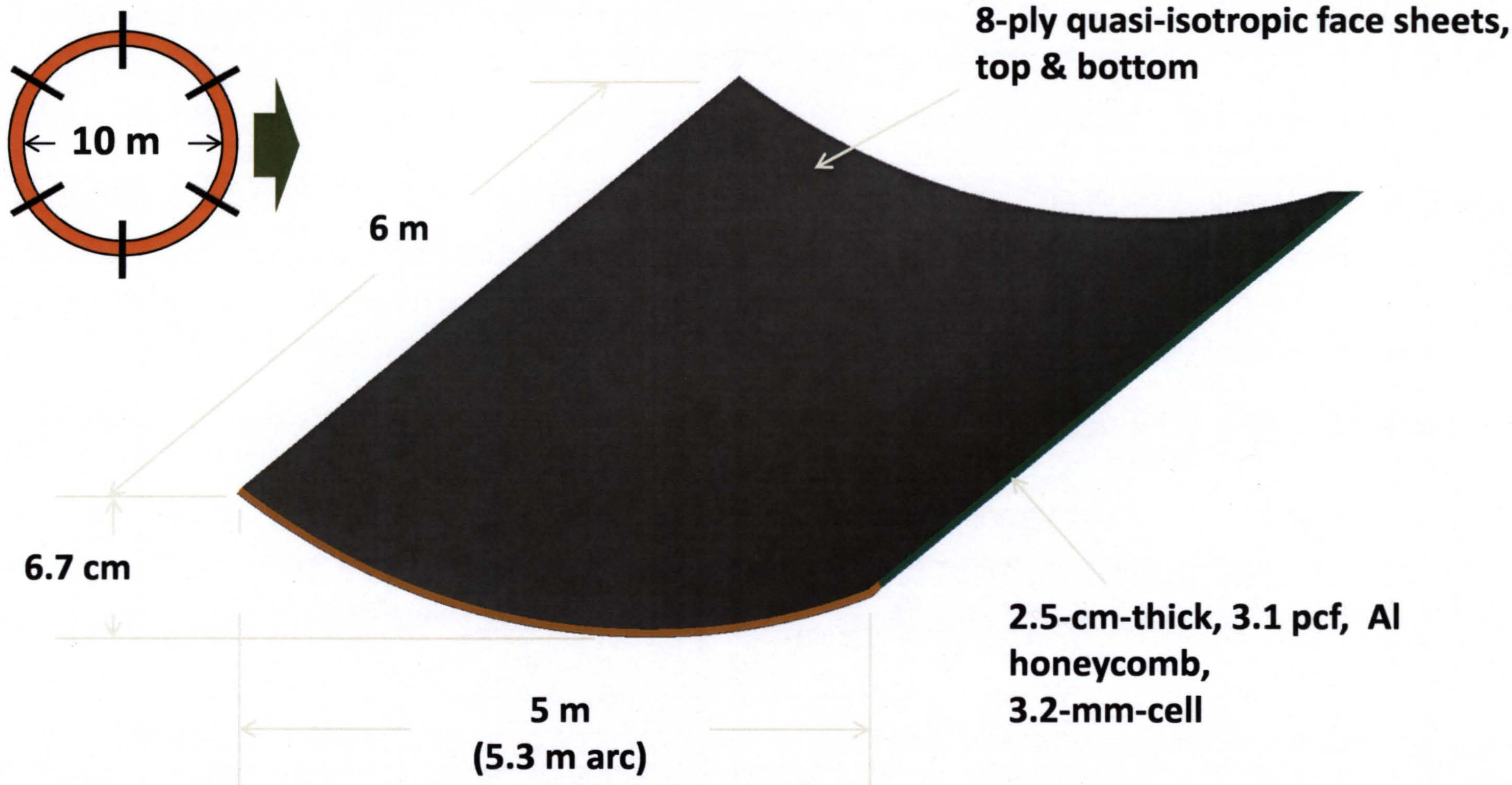




1/16th-Arc Panel Tool Fabrication

Preliminary 1/6th-Arc Panel

not to scale



1/6th – Arc Panel Fabrication