Application and Testing of High Temperature Composite Materials

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Background

Due to light weight and high strength design requirements, carbon fiber re-enforced plastics have rapidly been finding more uses in several areas of structural design. However, their low operating temperatures severely limit their use. In extreme temperature environments, alternatives have typically been relatively heavy metals or extremely expensive ceramic composites. Recently, experimental materials have been developed in an attempt to make high temperature ceramic composites more affordable. Still, experience with these new materials is limited. In order to implement these materials confidently, testing needs to be performed to understand the thermo-mechanical properties.

Application

The goal is to eventually validate a material called Pyrosic 4686 as a viable alternative to inconel 625 for the exhaust duct of a Honeywell TPE331-10 turboprop engine. The engine is typically mounted in aircraft such as the Predator-B/MQ-9/Reaper UAV (unmanned aerial vehicle). Pyrosic is a silicon-carbide fiber impregnated with a ceramic resin. The advantage is dramatic weight savings.

Material Comparison

	Inconel	PyroSic	% Difference	
Density, ρ [g/cm³]	8.0	2.0	-75.0	
Tensile Strength, [MPa]	215.0	250.0	16.3	Inconel Property @ Yield
Thermal Conductivity, K [W/m·K]	21.5	0.9	-95.8	Inconel Property @ 500 °C
Coefficient of Thermal Expansion, CTE [µm/m·K]	18.7	3.0	-84.0	Inconel Property @ 0-650°C

http://www.pyromeral.com/doc/jec-magazine-nb53-dec-2009.pdf

Engineering Properties of Steels, Philip D. Harvey, editor, American Society for Metals, Metals Park, OH, (1982).

Handbook of Stainless Steels, Donald Peckner and I. M. Bernstein, McGraw-Hill Book Company, New York, NY, (1977)

Metals Handbook, Howard E. Boyer and Timothy L. Gall, Eds., American Society for Metals, Materials Park, OH, 1985.

Metals Handbook, 10th ed., vol. 1, ASM International Handbook Committee., ASM International, Materials Park, OH, (1990)

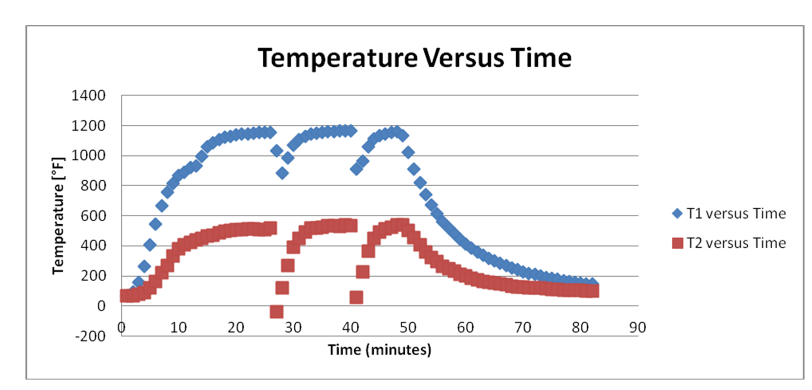
Description	Current Weight [lb]	PyroSic Weight [lb]	Weight Reduction [lb]
Primary Exhaust Duct	21.8	14.0	7.8
Primary Insulation Blanket	7.6	0.0	7.6
Secondary Duct	12.4	4.4	8.0
Exhaust Shield	4.5	1.6	2.9
Total Assembly	46.3	20.0	26.3
		Ballast Reduction [lb]	33.3
		Total Reduction [lb]	**59.6**

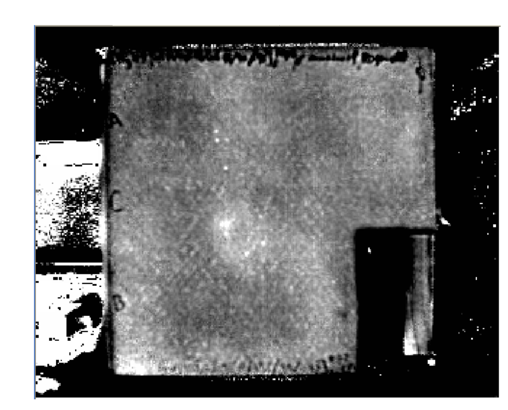
Concerns

- Material's reaction to extreme temperature gradients
  - Hot exhaust gasses inside(1200°F)
  - low ambient temperatures outside (-40°F)
- Material's ability to act as a thermal insulator compared to the previous design's insulation blanket

Thermal Shock Testing

- To address the extreme temperature gradient concern, panels of Pyrosic were tested with an infrared heater on one side and blasts of liquid nitrogen on the other
- Created a worst case scenario of thermally induced stresses

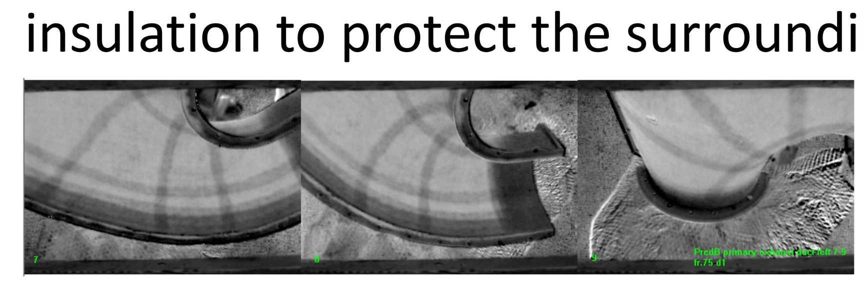


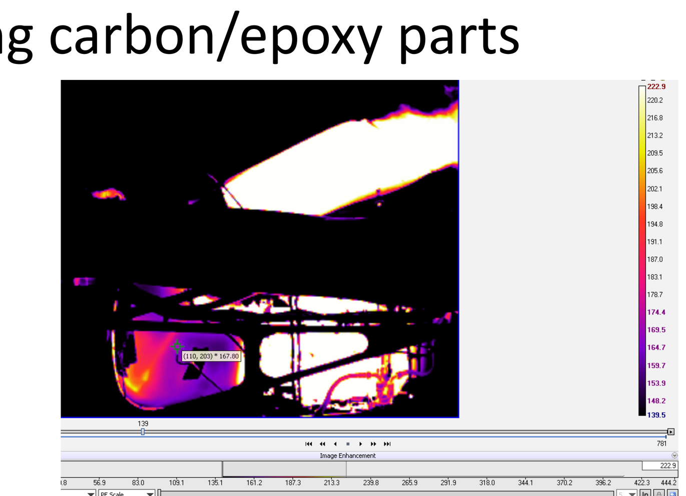


- No structural degradation was detectable
- No de-lamination of plies was found
- An examples of a pulse thermography image from after the testing is shown above on the right.

Prototype Testing

- Total of 72 testing hours logged on an engine to date
  - Pulse thermography Inspection every 25 hours indicates no de-laminations have developed
- A combination of thermocouple measurements and active thermography indicates the first design has insufficient thermal insulation to protect the surrounding carbon/epoxy parts





Pulse thermography of primary duct after 50 hours of testing(above).
Active thermography of duct assembly during engine run (right).

Conclusions/Future Testing

Testing has proven that the mechanical properties of Pyrosic withstand the expected conditions. However, the thermal properties of the design's cross section are not sufficient. In order to reduce the number of costly prototype iterations, a heated wind tunnel has been designed and fabricated to simulate the exhaust conditions. This will allow for testing of small panels with different coatings, blankets, and thicknesses ; thus, providing the means to determine if a configuration has the enough thermal resistance.