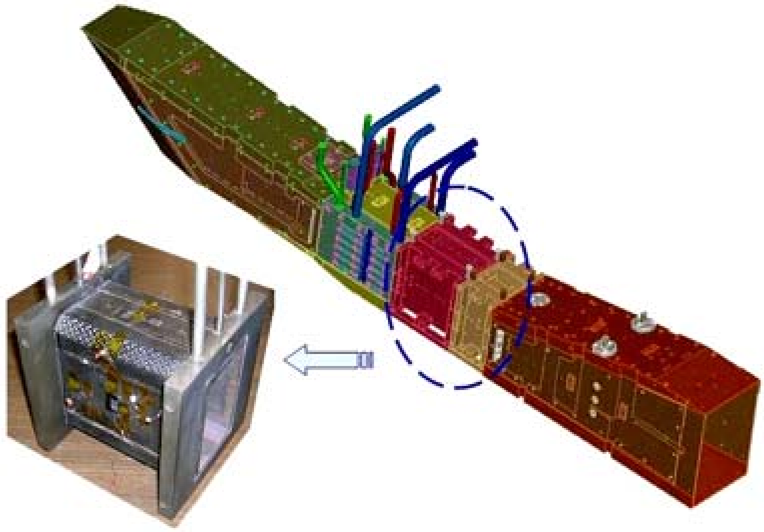
High-Temperature Polymer Composites Tested for Hypersonic Rocket Combustor Backup Structure

Significant component weight reductions are required to achieve the aggressive thrust-to-weight goals for the Rocket Based Combined Cycle (RBCC) third-generation, reusable liquid propellant rocket engine, which is one possible engine for a future single-stage-to-orbit vehicle. A collaboration between the NASA Glenn Research Center and Boeing Rocketdyne was formed under the Higher Operating Temperature Propulsion Components (HOTPC) program and, currently, the Ultra-Efficient Engine Technology (UEET) Project to develop carbon-fiber-reinforced high-temperature polymer matrix composites (HTPMCs). This program focused primarily on the combustor backup structure to replace all metallic support components with a much lighter polymer-matrix-composite- (PMC-) titanium honeycomb sandwich structure (refs. 1 to 3).

On the basis of literature and database analyses and scouting feasibility studies, a Glenn-developed second-generation polymerization of monomeric reactants (PMR) polyimide resin (PMR-II-50) composite reinforced with a carbon fiber (M40J) was considered for the high-temperature facesheet of the sandwich structure that required substantial stiffness to contain deflections in the combustor. Challenges were raised because of the severe rocket engine environments--including the extremely high power density, temperature extremes (up to 600 °F), high thermal gradients, severe thermal shock under humid conditions (maximum heat-up rate ~250 °F/sec), extreme fluid flow rates and pressure changes (from 0 to 100 psi over approximately 100 sec), reactive propellants and complex dynamics, and geometric restriction of the rectangular combustion chamber design. Finally, the significant mismatch of the thermal expansion between the combustor inner metal jacket and PMC facesheet was another challenge to the design and manufacturing of this sandwich structure.

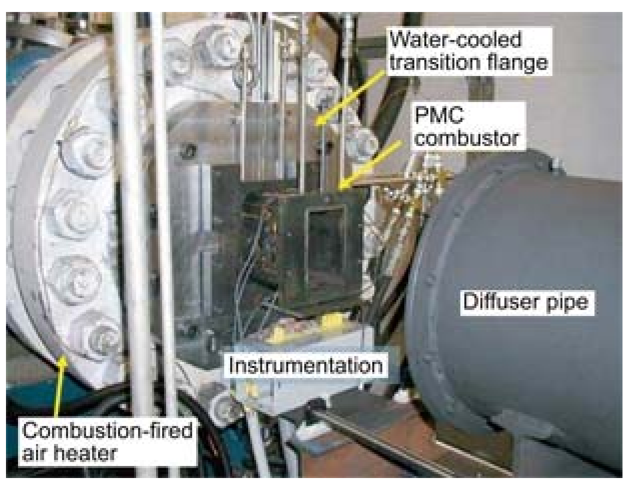
A multiteam collaboration was established to validate and optimize the use of the dissimilar materials. The tasks performed in this validation included evaluating the PMC structure-process-property relations, understanding the performance durability for both coupons and subcomponents, applying high-temperature adhesive bonding and surface treatments, performing finite element modeling for various component configurations as a function of thermal- and pressure-loading conditions, optimizing the design and manufacturing of the subscale and full-scale structures, and conducting a full-scale engine simulation of the complete combustor. This building-block approach was adopted for a successful integration of all these materials into the PMC combustor support structure. Risks were minimized through extensive design analysis, testing of the PMC panels and Pathfinder sandwich panels, and fabricating demonstrators.



Artist's rendering of typical all-metal A5 RBCC engine and photograph of the PMC-supported combustor.

Long description of figure 1. Newly designed lightweight combustor with polymer matrix composite backup support structure. Several thermocouples and strain gauges are mounted on the polymer matrix composite surfaces for hot-fire testing

During the design of the lightweight support structure (see the preceding illustration), PMC corner clips were added to stabilize combustor wall deflections. The combination of thicker adhesive layers and optimized postcure conditions improved bond strength, which significantly reduced the thermal expansion mismatch and the components' residual stresses. The hot-fire testing of the HTPMC combustor support structure for the RBCC engine was successfully conducted at ATK-General Applied Science Laboratory (GASL) (see the following photograph). This testing concluded a 3-year collaboration between Glenn and Boeing.



Hot-fire test setup of the PMC-supported combustor at GASL.

Long description of figure 2. Hot-fire test setup of the high-temperature polymer matrix composites combustor support structure for the rocket-based combined-cycle engine in Leg 1 at General Applied Science Laboratory. Photograph shows combustion-fired air heater, instrumentation, water-cooled transition flange, PMC combustor, and diffuser pipe.

The support structure successfully survived a total of eight hot-fire test runs: that is, it met the design specifications by withstanding up to 50-psig chamber pressure at 285 °F PMC temperature under 4000 °F combustion gas with 10 ft/sec and 1450-psia water cooling for durations of 40 to 60 sec. The Computer Aided Tap Tester nondestructive evaluation verified the structural integrity of the PMC facesheets, core, and bondlines before and after each hot-fire test. Significant weight reductions were achieved. A Boeing Company tradeoff study indicated that replacing the all-metal support structure with the PMC-titanium honeycomb structure afforded a weight savings of up to 77 percent and an overall combustor weight savings of ~25 percent.

In addition to satisfying an important technical milestone, this activity is noteworthy because it constitutes a number of firsts. This was the first application for Rocketdyne of an HTPMC in a space propulsion component. Successful completion of this test will enable Rocketdyne to explore other applications for HTPMCs in their engines. It was also the first time that a full-scale PMC structure had been tested at GASL. Experience gained from this testing will enable GASL to more easily test similar structures.

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