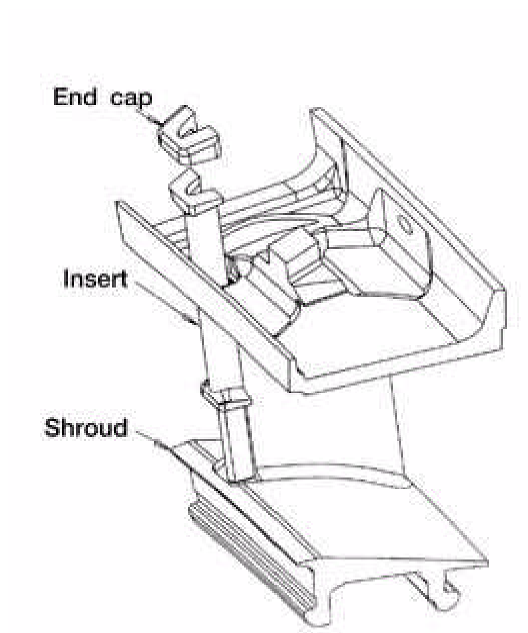
Turbine Airfoil With CMC Leading-Edge Concept Tested Under Simulated Gas Turbine Conditions

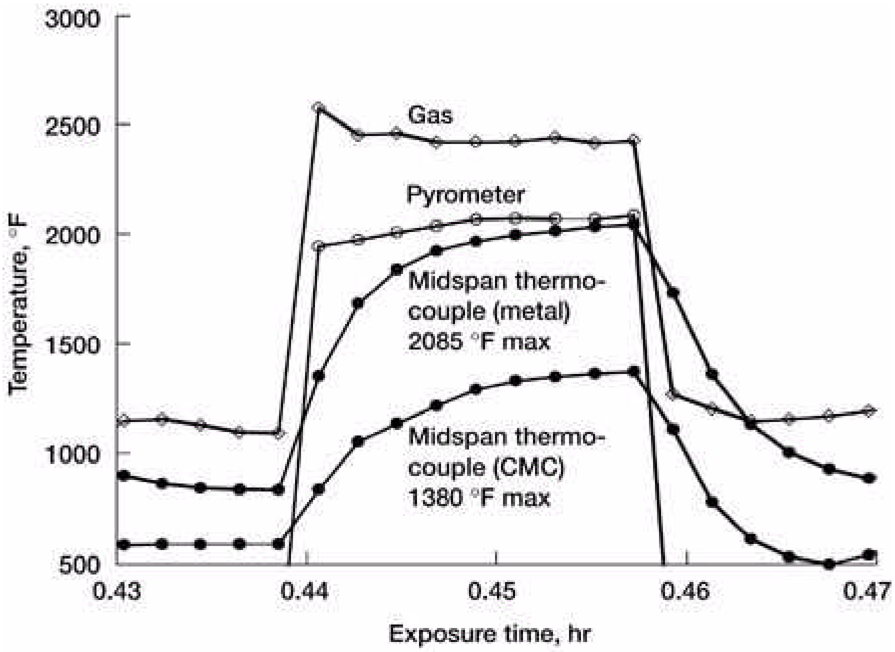
Silicon-based ceramics have been proposed as component materials for gas turbine engine hot-sections. When the Navy's Harrier fighter experienced engine (Pegasus F402) failure because of leading-edge durability problems on the second-stage high-pressure turbine vane, the Office of Naval Research came to the NASA Glenn Research Center at Lewis Field for test support in evaluating a concept for eliminating the vane-edge degradation. The High Pressure Burner Rig (HPBR) was selected for testing since it could provide temperature, pressure, velocity, and combustion gas compositions that closely simulate the engine environment. The study focused on equipping the stationary metal airfoil (Pegasus F402) with a ceramic matrix composite (CMC) leading-edge insert and evaluating the feasibility and benefits of such a configuration. The test exposed the component, with and without the CMC insert, to the harsh engine environment in an unloaded condition, with cooling to provide temperature relief to the metal blade underneath.



Airfoil with integrated CMC leading-edge concept.

The insert was made using an AlliedSignal Composites, Inc., enhanced HiNicalon (Nippon Carbon Co. LTD., Yokohama, Japan) fiber-reinforced silicon carbide composite (SiC/SiC CMC) material fabricated via chemical vapor infiltration. This insert was 45-mils thick and occupied a recessed area in the leading edge and shroud of the vane. It was designed to be free floating with an end cap design. The HPBR tests provided a comparative evaluation of the temperature response and leading-edge durability and included cycling the airfoils between simulated idle, lift, and cruise flight conditions. In addition, the airfoils were air-cooled, uniquely instrumented, and exposed to the exact set of internal and external conditions, which included gas temperatures in excess of 1370 °C (2500 °F).

In addition to documenting the temperature response of the metal vane for comparison with the CMC, a demonstration of improved leading-edge durability was a primary goal. First, the metal vane was tested for a total of 150 cycles. Both the leading edge and trailing edge of the blade exhibited fatigue cracking and burn-through similar to the failures experienced in service by the F402 engine. Next, an airfoil, fitted with the ceramic leading edge insert, was exposed for 200 cycles. The temperature response of those HPBR cycles indicated a reduced internal metal temperature, by as much as 600 °F at the midspan location for the same surface temperature (2100 °F). After testing, the composite insert appeared intact, with no signs of failure on either the vane's leading or trailing edge. Only a slight oxide scale, as would be expected, was noted on the insert.



Temperature response during HPBR test cycle of the baseline metal airfoil in comparison to that equipped with the CMC leading-edge insert.

Overall, the CMC insert performed similarly to a thick thermal barrier coating. With a small air gap between the metal and the SiC/SiC leading edge, heat transfer from the CMC to the metal alloy was low, effectively lowering the temperatures. The insert's performance has proven that an uncooled CMC can be engineered and designed to withstand the thermal up-shock experienced during the severe lift conditions in the Pegasus engine. The design of the leading-edge insert, which minimized thermal stresses in the SiC/SiC CMC, showed that the CMC/metal assembly can be engineered to be a functioning component.

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