N86-11291

CURRENT AND FUTURE ENGINE APPLICATIONS OF Gr/PI COMPOSITES

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The application of organic matrix composites to gas turbine engine components has been the subject of numerous Government and company funded programs since the 1960's.

The possibility of significant weight reductions, performance improvements and lower component costs have made the organic matrix composites extremely attractive to aircraft engine designers. But very little of this potential has been incorporated into production engines over the years even though a significant number of components have been designed, fabricated and tested. Some of the reasons behind the slow rate of incorporation include the following:

A. Criticality - Since the engines are responsible for providing the power to achieve and maintain flight, the engine components must be designed and fabricated with materials that are extremely reliable. Composite materials have suffered from lack of cost effective, reliable non-destructive inspection methods for determining the integrity of small, complex shaped parts. To compensate for the inspection uncertainties, larger safety margins are often employed which result in reduced benefits.

B. Temperatures - Gas turbine engine components generally operate at higher temperatures than the airframe components.

   The thermal environment of a typical military gas turbine engine (Figure 1) is such that only parts near the front of the engine and on the outside of the engine operate at sufficiently low temperatures to be considered for organic matrix composites.

   The development of the polyimide matrix materials, such as PMR-15, has significantly expanded the potential number component applications because of the 550 to 600°F capability of this material.

C. Small component size - Most of the low temperature engine components are small in size and have extremely tight dimensional tolerances. As a result the fabrication methods must often employ compression molding which can have high tooling costs.

This is especially important during the development phase of an engine when designs may change rapidly. The small component sizes also make it very difficult to achieve the desired ply patterns in the thin sections and at attachment locations. This leads to design compromise in weight and cost.

D. Small production volumes - The world market for gas turbine engines is not very large and as a result the economies of large scale production are rarely achieved. The turbine engine industry capital investment in metal working equipment represents a momentum that is difficult to overcome. Retooling for composite materials fabrication represents a major long-term investment that has been difficult to rationalize.

E. Interfacing with metal components - Composite materials operate most efficiently in simple uniaxial or biaxial stress fields. At attachment locations the high stress concentrations are not easily accommodated which complicates the composite design and increases the cost. The other attachment problem that must often be overcome is the mismatch in coefficients of thermal expansion between composite materials and metals. The special metal part designs to accommodate the composite material properties often results in high costs and hence a reduction in the benefits which could result from the use of composite materials.

DISCUSSION

The weight advantage that can be obtained with the graphite/polyimide (Gr/PI) composites is a direct result of the high specific strength (strength/density) (Figure 2) and high specific modulus. While it would appear that weight reductions of 50% or more are obtainable over titanium alloy components, in practice because of the larger safety margins used and more complex and heavier attachment areas, the composite component weight savings is typically only 10 to 25%. These savings can be quite significant if the components are large as is the case with the high bypass ratio turbofan engines (Figure 3). Since these engines are best suited to low mach number operation on transport and bomber type aircraft, the inlet temperature are low enough ($<$ 250°F) for epoxy matrix composites to be used for the fan outer ducts. The inner ducts and cowlings operate at higher temperature because they are closer to the turbomachinery. These are a prime candidate for polyimide matrix materials such as PMR-15.

In the low bypass ratio augmented turbofan engines (Figure 4) that are best suited to fighter aircraft very few of the components operate at temperatures low enough for epoxy matrix composites. The number of components which are suited to the application of polyimide composites is quite significant, however. Using a maximum sustained operating temperature capability of 600°F with short term excursions to 650°F for the PMR-15 polyimide matrix material, the applications shown in Figure 4 have been defined.

Under a Navy sponsored program, both TRW and CHI fabricated (during the 1975-1977 time period) external engine components for evaluation on the F100 engine. The resin matrices used included NR-150B2, PMR-15 and Rhodia's K601 bismaleimide system. Figure 5 shows some of the components evaluated.

The cover plates, of both PMR-15 and NR-150B2 with chopped glass fiber, experienced compression creep at elevated temperature under the design bolt load. The unlined oil transfer tube, Kerimid 601 with chopped HT-5 fiber, was structurally adequate, but experienced seepage of hydraulic oil under 400 psig pressure. The oil tank brackets of chopped glass (with selective continuous reinforcement) with both NR-150B2 and PMR-15 matrices passed the required structural tests. Cost and weight reduction potential was demonstrated for these small components. Another small box bracket, not shown, was successfully engine tested for over 600 hours.

In 1976 work was initiated under company funded programs on the F100 exhaust nozzle external flap. The early prototype flaps were fabricated by a number of suppliers, including Composites Horizons, General Dynamics, Grumman and Hamilton Standard Division (HSD) of United Technologies. The HSD flaps were fabricated using the HMS/NR-160B2 system and are shown in Figure 6. A full set (15 pieces) has been flight tested on an F-15 aircraft at Edwards AFB. The high time part has collected over 700 total operating hours and 430 flight hours. This work led to a subsequent AF program (F33615-78-C-5099) in which a total of 52 parts were fabricated by Hamilton Standard from C-6000/NR-150B2. A schematic of the flap design is shown in Figure 7. These flaps have also accumulated a significant number of flight hours. Fifteen have 108 hours at EAFB and another set has collected 18 hours in a F-15 at NASA Hugh C. Dryden Flight Test Center (Figure 8). No significant difficulties have been encountered with any of these flaps and the two sets from the AF program will continue to be flight tested.

This latter design demonstrated a 22% weight reduction. Switching from the now-unavailable duPont NR-150B2 polyimide to the PMR-15 resin system and incorporating automated cutting and stacking under AF contract F33615-78-C-5218 has resulted in the composite flap being a cost effective alternative to the bill-of-material metal flap.

In 1979 P&WA performed static structural tests on three F100 Gr/PI augmentor ducts (Figure 9). These were fabricated by Rohr Industries (AS/703), Composite Horizons (C-6000/PMR-15), and General Dynamics (C-6000/NR-150B2). All the flanges were titanium, only the barrel was of composite. Weight savings, despite the fact that no design iterations were permitted, were 10 and 15% for the RI and CHI ducts. The Rohr duct passed all static structural tests and plans have been made to conduct sea level tests of the duct on a P&WA engine this year.

The CHI duct passed all of the static tests except for that portion involving an internal pressurization of the duct. In an attempt to extend maximum thermal performance, an elevated temperature posture was employed which induced matrix microcracking. The microcracking lead to gas leakage through the wall which made this duct unsuitable for subsequent engine testing.

It is clear that the usage of organic matrix composites in gas turbine engines is rapidly gaining acceptance. As a result of the current activities, the usage will increase rapidly in the later portion of the 1980's and early 1990's. This is shown schematically in Figure 10. As confidence is gained, through the successful application of composites, continued growth will occur which will have a beneficial effect on future engine weight, cost and performance.

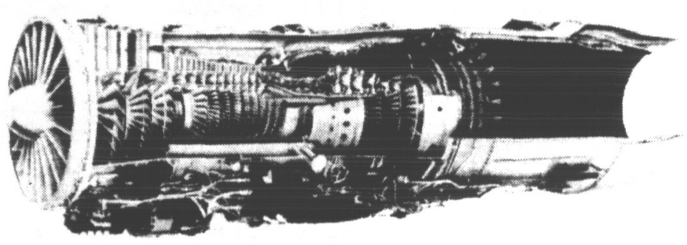

Figure 1. - F100 turbofan engine.

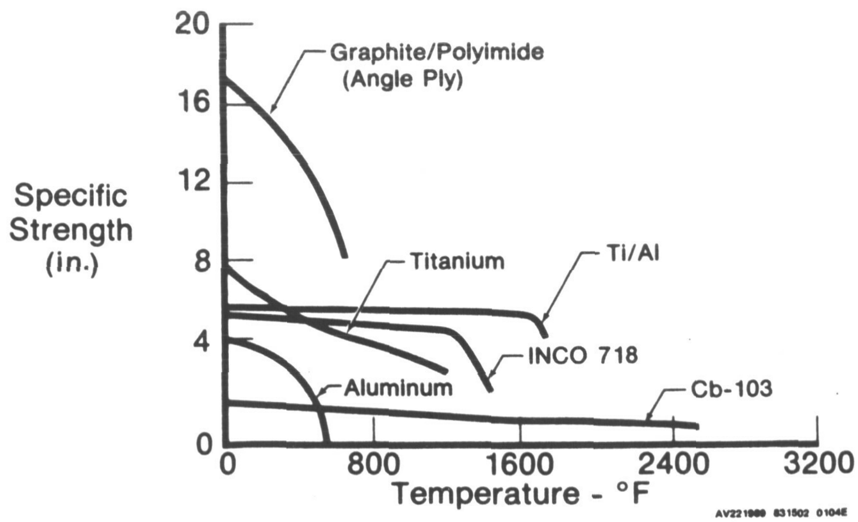

Figure 2. - Specific strength versus temperature.

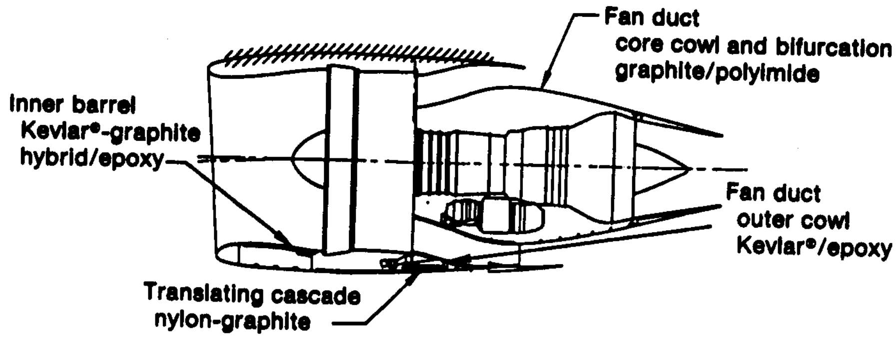

Figure 3. - Organic matrix composite applications in large turbofan engines.

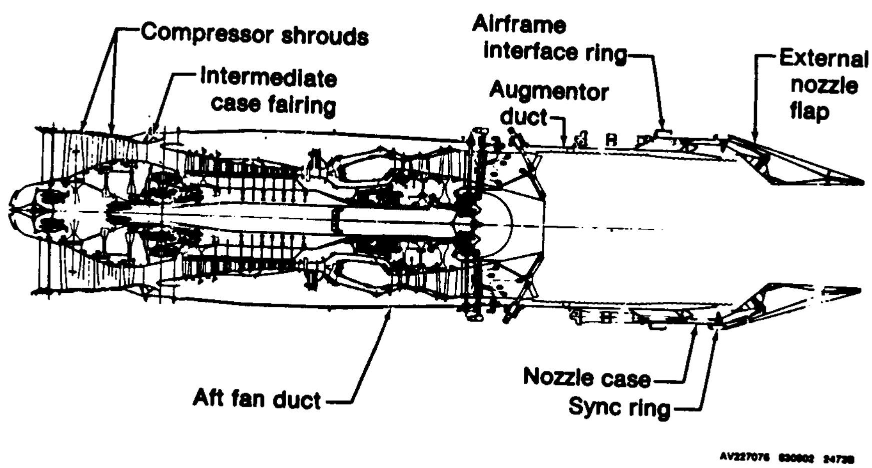

Figure 4. - Organic matrix composite applications in augmented turbofan engines.

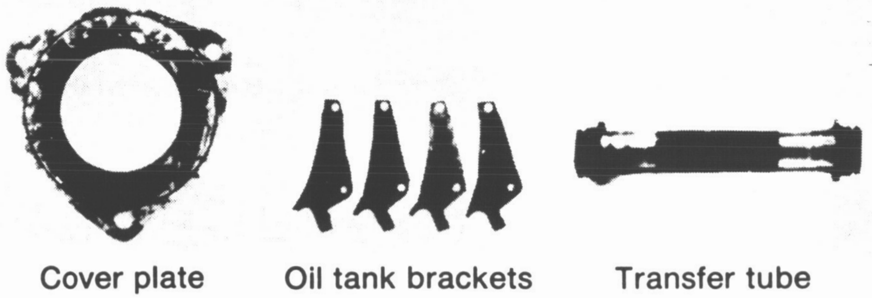

Figure 5. - External engine composite components.

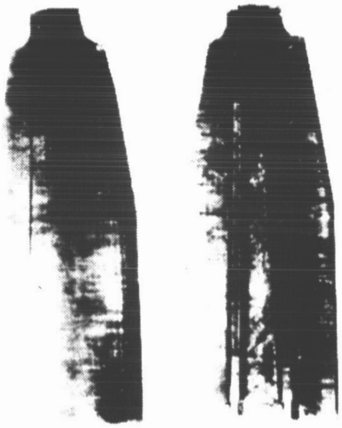

Figure 6. - Prototype composite external nozzle flap.

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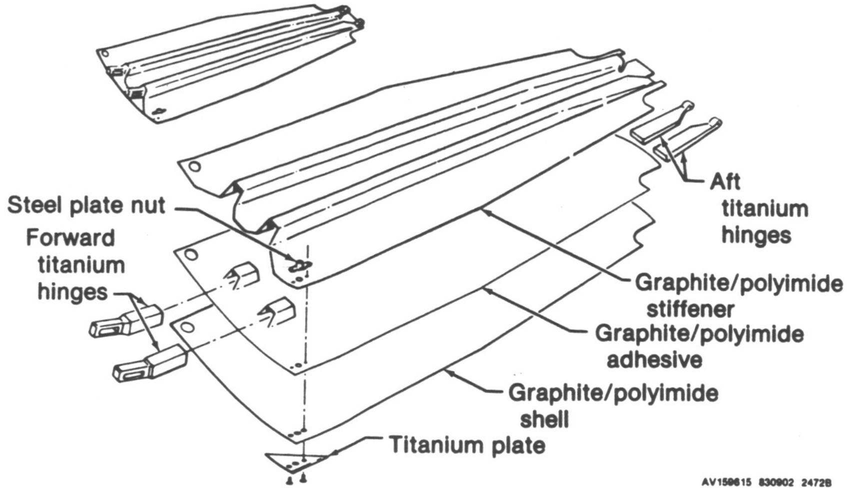

Figure 7. - Schematic of F100 composite nozzle flaps.

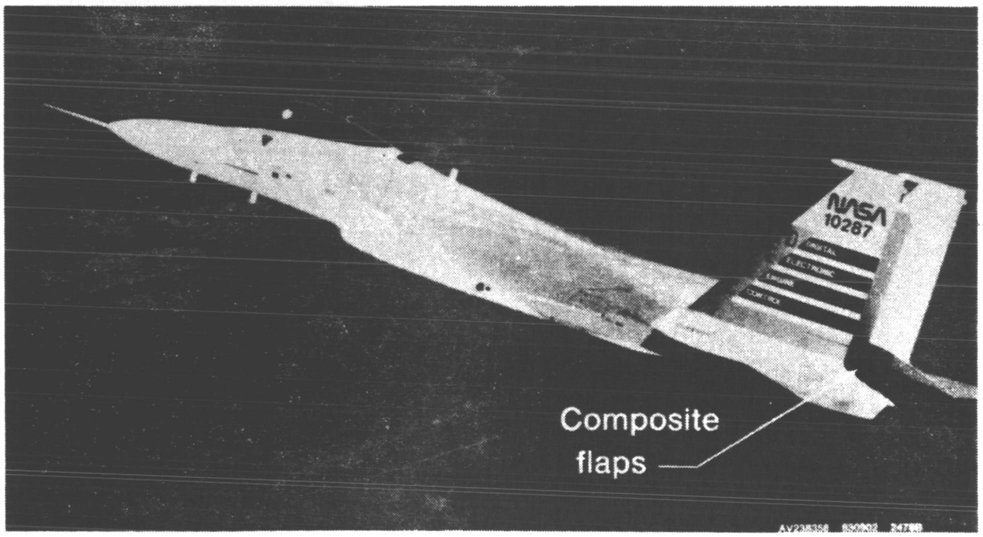

Figure 8. - Graphite/polyimide composite. External flaps on NASA F-15.

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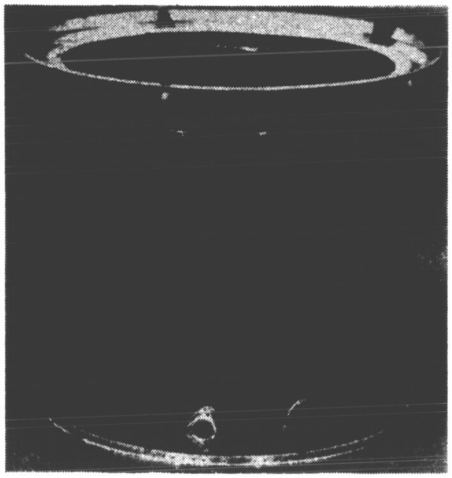

Figure 9. - Gr/PI composite augmentor duct.

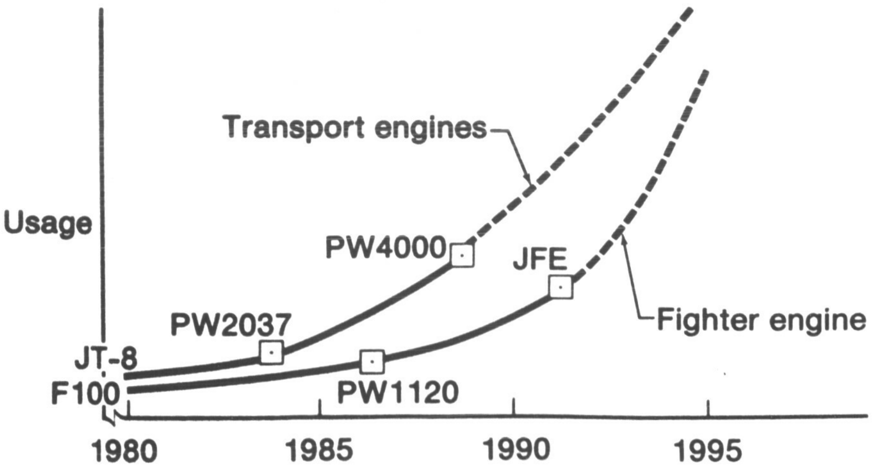

Figure 10. - Composite usage in engines is increasing.

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