Def Sci J, Vol 38, No. 4, October 1988, pp 333-340

# Applied Technology in Gas Turbine Aircraft Engine Development

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## INTRODUCTION

At General Electric (GE*) Aircraft Engines the primary emphasis is on producing engines that meet each customer's unique performance, reliability and life cycle cost requirements. The latest advanced technology is incorporated only if it contributes to those goals. Over the years, this approach has brought GE power plants an international reputation for being the most advanced, reliable, and cost effective engines in their power and thrust classes. In fact, engines like the T700 and F404 deliver the performance, reliability, maintainability and availability so important to their users because of the major technological improvements of the last few decades.

Today, these engines are being installed in military aircraft in the United States, as well as in many Asian and European countries. For example, after outstanding service in the F/A-18 aircraft, the F404 has been upgraded with advanced technology and has been selected to power the prototype of the Indian Light Combat Aircraft (LCA). GE has delivered the mock-up of that engine to the Aeronautical Development Agency and is on schedule to deliver the first ground test engine later this year.

T700 and F404 users are beneficiaries of GE's balanced design philosophy and commitment to the technological innovation it requires. As a result, during the past few decades, GE engineers and scientists have made important gains in applying advances in engineering technology and in materials and processes to aircraft engine components and parts.

Engineers have been able to increase system performance significantly while at the same time being responsive to growing customer demands for reduced life cycle

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Received 4 May 1988

* GE (USA) is not connected with the English company of a similar name.

cost, longer engine life, greater reliability and increased maintainability. Efforts to meet performance objectives have emphasized more effective and more efficient techniques for increasing cycle pressure ratio, raising temperatures and improving component efficiency. During the last 20 years, core engine pressure ratio has steadily climbed from between 6 and 8 to over 20. Higher temperature and pressure ratios have been made possible chiefly because of improved blade, vane, rotor, combustor and shroud materials and from new cooling schemes.

The outlook for continuing technology development is also very promising. For example, GE engineers have already designed and tested the new GE38 family of 5,000 shaft horsepower (3730 kW) turboshaft and turboprop engines whose advanced state-of-the-art materials and design concepts deliver further performance efficiency and cost effectiveness improvements. Growth versions of the F404 and other advanced fighter engines are also taking advantage of new technology in components now under development.

Because current models of GE engines like the F404 and the T700 feature modular design, their users will be able to utilise many future technology improvements at far lower cost, a fact which promises much greater flexibility than had once been thought feasible.

At GE Aircraft Engines designers and materials experts work cooperatively with scientists and engineers at GE's Corporate Research and Development Centre Currently, developmental efforts are focused in such areas as :

i) Large structural castings to simplify components,
ii) Polymeric composites for light weight and strength,
iii) Improved methods for determining heat transfer, and
iv) Coatings and surface treatments to prolong component life.

In each of these areas, efforts are already producing important benefits

## 2. STRUCTURAL INVESTMENT CASTINGS

During the past ten years, GE has more than doubled its use of investment castings in aircraft engines. Today, many structural components such as frames and casings are being routinely produced with investment casting processes. In fact, many components which once comprised scores of intricate, fabricated or forged/machined pieces are now thought of as single parts. The reasons are straight forward.

Investment casting can produce intricately shaped engine parts to specification with an accuracy and dependability heretofore thought unrealistic. In fact, because casting frequently means a single part can replace components comprised of scores of intricate, discrete pieces, the process by definition eliminates machining and assembly as well as the time and costs associated with them. For example, the swirl frame (Fig. 1) in GE's T700 engine consists of nearly a hundred separate pieces which are today being replaced by a single investment casting (Fig. 2). The process also permits the cost-efficient incorporation of highly-tailored alloys.

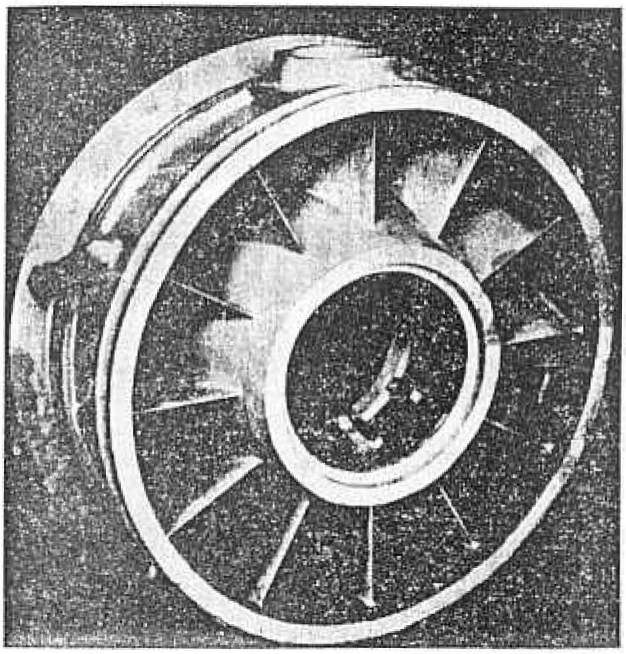

**Figure 1.** The new T700 swirl frame consists of a single investment casting replacing the scores of discrete, individual parts which used to be required for the component. By definition investment casting eliminates maching and assembly as well as the time and costs associated with them.

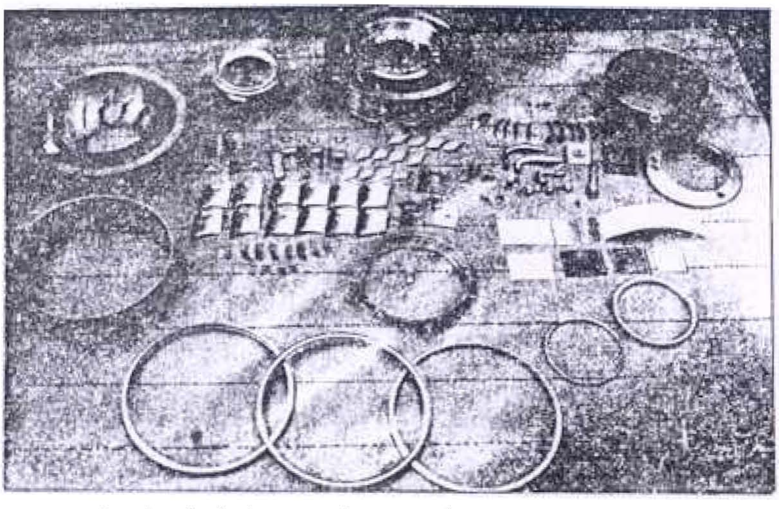

**Figure 2.** One hundred pieces nearly are used to assemble the original T700 swirl frame. Those pieces are replaced by a single investment casting in a new T700 swirl frame which GE Aircraft Engines is incorporating into the powerplant.

GE Aircraft Engines is projecting that by the mid 1990's about 40 per cent of the weight of most of its engines will involve investment-cast parts. Already GE fighter engines typically use several hundred investment castings.

Despite rapid and remarkable work in the area, considerable progress remains to be made. Investment casting for aircraft engines demands very exacting conformance to exceedingly precise specifications and extraordinarily high degrees of metallurgical integrity. GE is currently emphasizing the analytical techniques of computer-aided design and computer-aided engineering to accelerate development of increasing precision in ever more automated investment casting processes.

Investment Casting Simulation Software (ICSS) is used to reduce the time consuming trial-and-error methods the casting industry has traditionally used to aid in identifying critical foundry designs and parameters which represent major contributing factors to casting integrity. ICSS also simulates solidification of molten alloys. Such modelling promises accurate prediction of the solidification course and identification of a casting's propensity for producing various degrees of defect.

## 3. POLYMERIC COMPOSITES

Composites are perhaps the fastest growing materials in aerospace. Already widely used by airframe manufacturers and for non-structural parts in aircraft engines, they are just beginning to be incorporated for structural applications in aircraft engines. For instance, the F404 will use a composite outer duct (Fig. 3) in future production. Also, the new GE36 unducted fan engine will use composites for its fan blades.

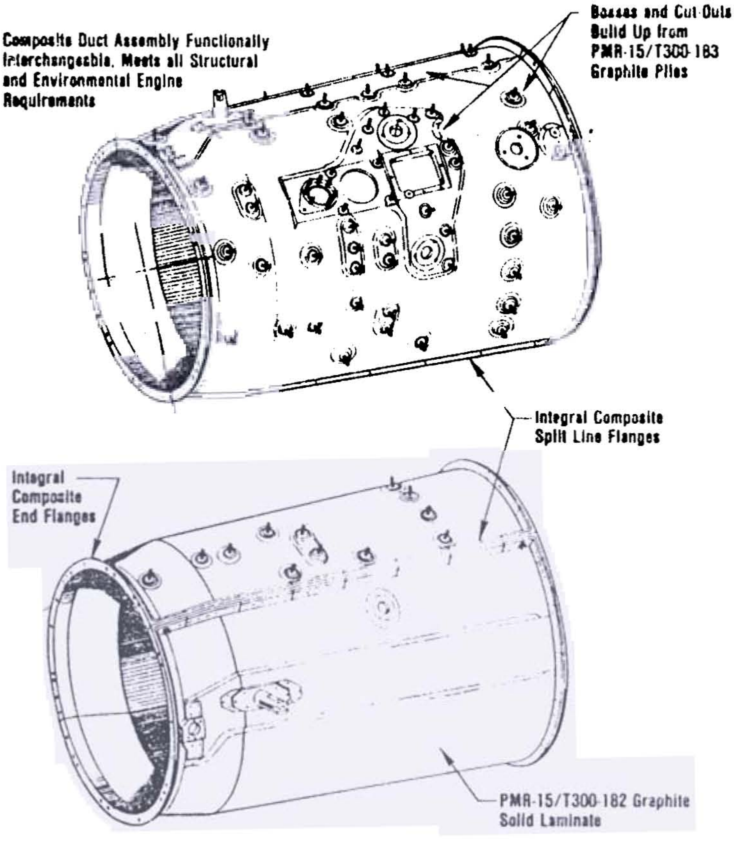

**Figure 3.** F404 engine composite outer duc

Composed of two or more distinct, but compatible substances, a composite is essentially a new material which exploits the best properties of its parent substances. In a typical composite, metal, ceramic, glass aramid or carbon fibres are joined by a binder, usually a high temperature-resistant resin. In many respects, the resulting composite possesses properties superior to the metal it is designed to replace. For example, strength-to-weight ratios of some advanced composites are two to seven times better than those of titanium or steel. The F404 outer bypass duct being developed from a resin composite, is both stronger and lighter than the titanium duct it will replace.

An experimental duct has successfully completed more than 1,000 hours of accelerated mission testing and has been static-tested at 210 per cent of the maximum design manoeuvre load without any sign of damage.

GE's work in composites includes techniques for inspecting aircraft engine components made of the new materials. Two particularly promising inspection techniques, ultrasound and computer-aided tomography, represent applications of technology widely used for medical diagnostic purposes.

Using ultrasound involves submerging a composite part in what can be a very large water tank. Sound waves pass without distortion through the water. When they reach a part, they emit sound waves of a predictable density and pattern which are attenuated by any defect in the composite material. Delamination or lack of adhesion between carbon/glass/epoxy parts is one such defect that can be detected by ultrasound inspection.

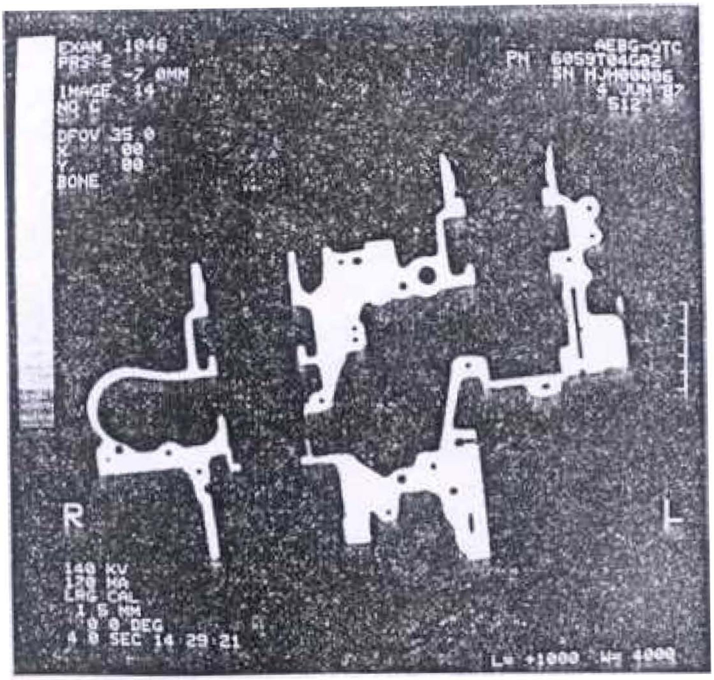

**Figure 4.** GE Medical Systems' CAT-scan technology can provide a clear picture of the intricate interior of aircraft engine parts like the one shown above without damage to the exterior of the part.

Computer-aided tomography, or CAT-scanning, is used to detect defects in objects with strongly curves external surfaces (Fig. 4). Using conventional CAT-scan hardware developed by GE in its Medical Systems Group, Aircraft Engines has been able literally to look inside composite parts and components to analyse conformance to specification. A major advantage of CAT-scan technology for inspecting aircraft engines is that it provides a very precise picture of the inside of a part or component in a process that is totally non-destructive.

## 4. IMPROVED METHODS FOR DETERMINING HEAT TRANSFER

Turbine airfoils experience a tough environment. While operating in a jet engine the airfoils get so hot they glow bright red. In fact, if they were not cooled, they would melt very quickly as the gas temperature inside a jet engine is several hundred degrees hotter than the melting point of the sophisticated metal alloy from which the airfoil is made.

GE designers use a combination of materials, coatings and cooling air to enable airfoils to survive this hostile environment. Cooling air flows through the complex passage-ways inside the airfoil, and exits through a myriad of holes in the airfoil surface to give an efficient exploitation of flow cooling capacity by a combination of convective, conductive, impingement and film cooling mechanisms. Its effect is enhanced by features like turbulators, rough projections as small as a hundredth of an inch high on the walls of the internal passages.

Present and future requirements for jet engines will continue to push the state-of-the-art for higher operating temperatures. The upper limit in the temperature the engine can handle is a function of both material properties at the elevated temperatures and the effectiveness of the cooling techniques. At any given temperature, engine performance can be gained by reducing the volume of air used for cooling engine components and allowing this air to do useful work through the engine. As operating temperatures increase and cooling air is reduced, the need for innovative designs becomes limiting.

Within GE's heat transfer groups, computational techniques have been modernised and automated, so that heat transfer analysis and cooling designs are completed much more quickly. Jet engine design, however, is largely an empirical science with computational techniques relying on previous test data. To facilitate new and innovative designs, the empirical performance data on which performance is based must be made available rapidly and accurately. GE's heat transfer groups are developing new methods for experimentally measuring heat transfer, including large-scale models and rotating liquid crystal displays.

Experimental wooden and plastic test rigs have been devised which produce adequate flexibility for testing a range of turbulated passage geometries to provide a parametric envelope covering the range required for current and future engine designs and to maintain Reynolds number and parametric similarity and ease of measurement by being built in very large scale.

A joint GE-Northeastern University program is currently studying the effects of rotational forces on heat transfer coefficients in airfoil cooling passages.

## 5. COATINGS

Even if jet aircraft were used only under ideal conditions, parts inside their engines would wear from the incredibly brutal temperatures and stresses inside the powerplant itself. In reality, however, jet aircraft compound the problem because they travel anywhere, passing through salt spray and desert dust, even taking off and landing from muddy runways or pitching decks. In short, jet engine parts have to be designed and built for use under the worst conditions anyone can imagine. Parts are coated to help them take it. Some coatings have been specifically developed and applied to reduce wear produced when parts rub against one another. Others aim at countering erosion from ingestion of foreign particles such as sand.

Hard coatings reduce impact damage between abutting engine parts. Softer materials are used to minimise fretting and galling wear in parts that can rub against one another. It is common to coat fan and compressor surfaces with carbides, compounds like titanium nitride, aluminium oxide, chrome oxide or solid film lubricants like epoxy resins. A proprietary triballoy coating can be thermally sprayed to create a hard, wear-resistant coating that is typically used on rotating shafts, blade interlocks, and vane ledges.

The fan and the compressor wear from actual ingestion of foreign particles. In fact, some of the new graphite/epoxy and polyamide materials used in these parts to meet other design requirements are particularly prone to erosion from salt, sand, and dust. GE Aircraft Engines is developing metallic and intermetallic erosion-resistant coatings to protect such parts. Work has emphasized chemical deposition processes and sprayed carbides, the latter of which have produced good results. For example, in initial operation of a CFM56 re-engined, older type of aircraft, the low ground clearance of the inlet caused the engine to ingest excessive runway dust. The result was rather severe compressor airfoil erosion. The problem was solved by applying a commercially available sprayed carbide coating. The coating was easy to apply and has performed well in service aboard the aircraft.

While in this particular instance the sprayed carbide coating has been successful, such approaches may not offer optimal solutions in all applications because they create relatively rough surfaces on the parts they coat. A physical-vapour-deposited coating system applied by sputtering, cathodic arc deposition or other similar process may represent a more elegant solution. Work in this area is progressing rapidly.

We recognise that optimal coatings for today's engine materials and designs might be easier and faster to develop were erosion mechanisms themselves better understood. To address this basic knowledge limitation, GE Aircraft Engines has been conducting detailed scanning electron microscope studies. Analysis of this work is producing important data on the differences in the erosion process within various materials and on coating degradation prior to particle penetration.

## 6. CONCLUSION

New technology can improve our engines, but solid engineering is still the guiding principle at GE. New materials and applications of developing technology will continue to be applied to the F404 engine family as an integral step in the growth plans for the engine. Such technological innovations assure that the F404 will remain the world's premier fighter and attack engine well into the 21st century.

## ACKNOWLEDGEMENTS

The author would like to express his gratitude and appreciation to Guy V. Andrews, John H. Starkweather, Samuel D. Spring, Leo Buchakjian, Srini R. Gowda, Kory O. Rogus, Chris Johns and Robert V. Hillery for their technical contributions to GE and to material for this paper, some of which has been previously published in The Leading Edge, a publication of the General Electric Company (USA). A special note of appreciation is made to Dr. Frederic F. Ehrich, of The Leading Edge editorial board, whose assistance in the preparation of this paper has been invaluable.