ROLLS-ROYCE'S WIDE CHORD FAN BLADE - THE NEXT GENERATION

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Abstract

Rolls-Royce has designed and developed a unique, highly efficient lightweight fan for civil engine applications in the thrust range 22000 lbs to over 90000 lbs. These wide chord fan designs are hollow and snubberless, and have applied innovative metal forming, metal joining and inspection techniques.

First generation wide chord fan blades entered service in the RB211-535E4 powered Boeing 757 in 1984. The technology has since been applied to the IAE V2500 engine for the Airbus Industries A320 and the McDonnell Douglas MD90 aircraft, and the RB211-524 G/H powerplants for Boeing 747 and 767 aeroplanes. This fan design utilises a fabrication of two external titanium alloy panels and an internal titanium alloy honeycomb core joined by Activated Diffusion Bonding.

The design and corresponding manufacturing technologies for larger fans in the higher thrust Trent series of aeroengines have now evolved to enable Rolls-Royce to specify an even lighter fan blade with enhanced cost and quality control advantages by exploiting solid-state diffusion bonding for joining the fabrication and superplastic forming to develop the supporting internal core. These second generation wide chord fan blades have been subjected to intensive pre-certification integrity and durability tests which have verified design and mechanical integrity and, most importantly have demonstrated the maturity of the manufacturing processes.

1. Introduction

The fan in modern "high by-pass ratio" civil turbofan engines must deliver a high level of performance over a wide range of operating conditions. Its primary design requirement is to minimise fuel consumption by maximising the propulsive force generated from the power supplied by the turbine. Weight, cost, noise, foreign object impact resistance and mechanical integrity under fatigue conditions are other essential design considerations.

Titanium '92
Science and Technology
Edited by F.H. Froes and I. Caplan
The Minerals, Metals & Materials Society, 1993

Conventional fan blades are manufactured from solid titanium alloy forgings and are designed with mid-span snubbers to counteract aerodynamic instability (Figure 1a). However, the snubbers impede the supersonic airflow causing a loss in aerodynamic performance with corresponding penalties in fuel consumption. Rolls-Royce has, therefore, removed the snubber from the fan to provide the most aerodynamically efficient aerofoil, increased its chord for natural stability, and reduced the number of blades per assembly by approximately a third (Figure 1b). This has been achieved at reduced weight by designing a hollow wide chord fan blade with an internal supporting core which can satisfy severe operational requirements. (References 1,2)

Its position at the front of the engine demands that the fan is capable of developing sufficient power for aircraft safety after suffering impacts, predominantly by birds, during take-off. Certification regulations require an engine to be capable of ingesting groups of 1½lb birds with subsequent continual running at a minimum of 75% power. Also, an engine must be capable of a safe shut-down after the ingestion of 4lb birds. Fan blades are subjected to low cycle fatigue stresses during every flight and to high cycle fatigue stresses from air intake disturbances at specific flight conditions. Stresses within the component have, therefore, to be maintained within established limits in order to guarantee adequate fatigue life.

To satisfy these design criteria, Rolls-Royce has developed hollow wide chord fan blades with low density cores for enhanced aerodynamic efficiencies as well as component lightness and mechanical integrity. The constructions of the designs are shown schematically in Figure 2. For both fabrications, the external titanium alloy skins are separated and supported by an internal titanium alloy core. Panel/ panel joints and core/panel joints must exhibit parent material properties to withstand the effects of impact and fatigue. In the latest design, the established honeycomb core is superseded by a superplastically formed corrugation which allows the production of a lighter construction with reduced manufacturing costs.

2. Wide Chord Fan Manufacturing Technologies

Innovative metal forming, metal joining and inspection techniques have been developed by Rolls-Royce for the manufacture of its wide chord fan blades. First generation designs have been manufactured as a fabrication of external titanium alloy panels and an internal titanium alloy honeycomb core joined by a liquid-phase diffusion bonding process, Activated Diffusion Bonding (reference 3). The latest designs and corresponding manufacturing methods for Trent fan blades have now evolved to exploit solid-state diffusion bonding for joining the fabrication and superplastic forming for the development of the internal corrugated core.

The Trent wide chord fan blade is manufactured as a fabrication of three sheets of the titanium alloy, Ti-6Al-4V. An inhibiting compound is applied to the mating faces of the external panels in a pattern derived from the developed design for the internal corrugated core. Diffusion bonding can then occur at all surfaces which are not coated with the inhibitor. The three-piece fabrication is selectively joined in a custom-built high temperature pressure vessel under computer control. Appropriate process control guarantees the generation of diffusion bonds with parent material mechanical properties (reference 4) and develops the microstructure shown in Figure 4.

The manufacturing sequence then exploits the inherent superplasticity of these fine-grained titanium alloys. The cavity of the diffusion bonded construction is inflated at elevated temperature between appropriately contoured metal dies using an inert gas to expand the core by superplastic forming whilst simultaneously developing accurately the blade's external aerodynamic profile in terms of radial bow, axial camber and aerofoil twist. This process is carried out in customised presses in a computer-controlled operation to guarantee the strict tolerances necessary for component temperature distribution as well as the strain-rate of the internal core.

Considerable experimentation has been carried out to establish diffusion bonding and superplastic forming as viable manufacturing technologies for critical hollow aeroengine component designs. Second generation wide chord fan blades also benefit significantly from reduced manufacturing costs due to their simplified manufacturing sequence.

To satisfy the stringent product assurance standards required for the service environment, all hollow wide chord fan blades are critically inspected for component integrity using a variety of sophisticated non-destructive techniques supplemented by conventional methods. In particular, Rolls-Royce has specifically developed and refined ultrasonic and radiographic techniques for the assessment of solid-state diffusion bonds and structures developed by superplastic forming. This in turn has enabled the manufacturing processes to be fully understood and matched with the requirements of the design specification.

Rolls-Royce has commissioned a unique manufacturing module with special-to-product plant and equipment for the production of wide chord fan blades (Figure 3). The operation also benefits from the implementation of systems engineering principles for the effective manufacture of high quality components.

3. Wide Chord Fan Integrity

First generation wide chord fans have been in service since 1984 and have accumulated over five million hours of Rolls-Royce exclusive operational experience. Second generation wide chord fan blades for the Trent series of aeroengines have now been subjected to intensive engine and rig component tests which have verified the design and associated manufacturing technologies. These test programmes have been successfully completed, and have confirmed metallurgical integrity as well as the maturity of the enabling manufacturing processes, diffusion bonding and superplastic forming.

A series of single-arm and bladed rotor bird ingestion tests has been carried out using Trent demonstrator wide chord fan blades. This programme has demonstrated that the airworthiness requirements have been significantly exceeded. Figure 5 demonstrates the 8lb bird ingestion capability of the second generation wide chord fan design at maximum climb ratings. Impact damage is confined to local distortion in the strike area with no metal loss.

Diffusion bonded and superplastically formed Trent wide chord fan blades have been subjected to fatigue testing in both low cycle and high cycle modes. Groups of components have been repeatedly accelerated to maximum speed in a large vacuum rig until failure is induced to determine low cycle fatigue endurance. Fan blade behaviour under high cycle conditions has been measured on a static flap vibration rig to stress levels determined from engines subjected to severe cross wind conditions. This fatigue test programme has demonstrated that the second generation fan design exceeds the capability of the initial design standard with its established integrity and service record.

4. Summary

First generation wide chord fan designs have demonstrated reduced fuel consumption and increased resistance to component and engine damage over five million hours of Rolls-Royce exclusive operational experience. Second generation wide chord fans have now been specified for the higher thrust-rated Trent aeroengines with inherent weight and cost advantages. This latest design exploits diffusion bonding and superplastic forming, and has successfully completed component integrity and durability testing. The Trent series of powerplants has been launched for Airbus Industries A330 and the Boeing 777. They are also available to power the McDonnell Douglas, MD12.

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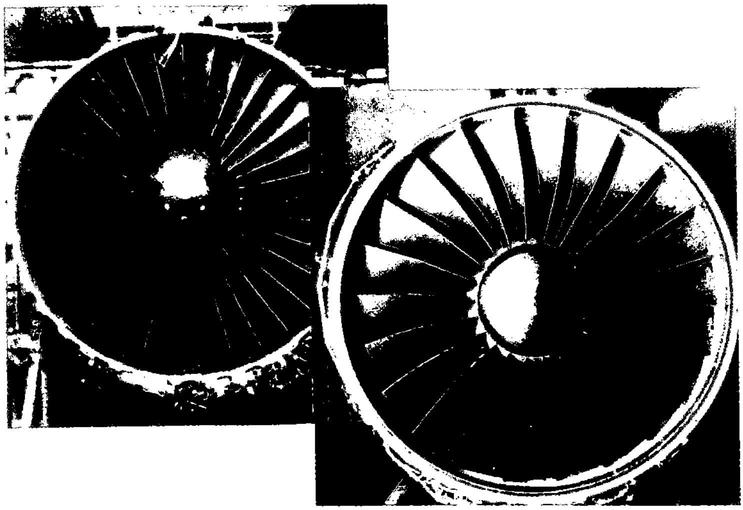
Acknowledgements

The authors wish to thank Rolls-Royce plc for permission to publish this paper. They would also like to recognise the contributions made by many colleagues at Barnoldswick and Derby to the developments reported.



(a) RB211-535C
Snubbered Fan

(b) RB211-535 E4
Wide Chord Fan

Figure 1 - Fan Blade Designs

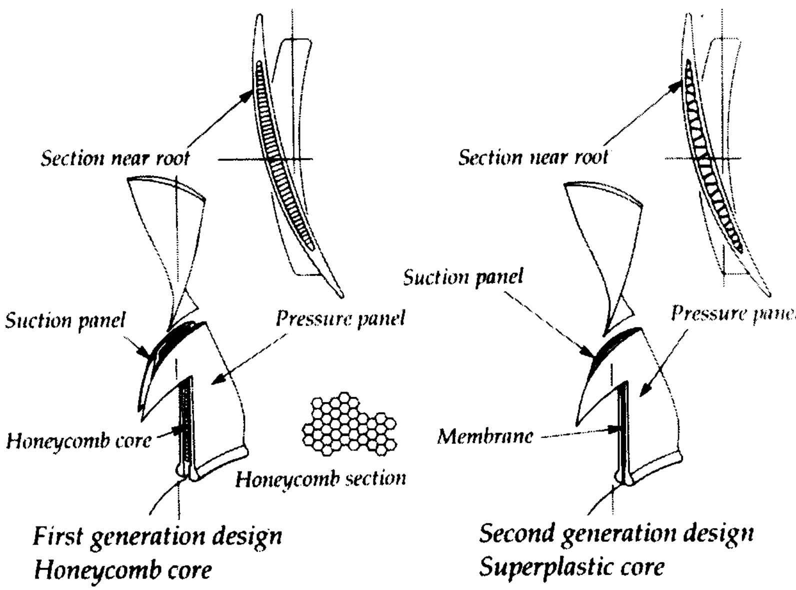


Figure 2 - Construction of Rolls-Royce Wide Chord Fan Blades

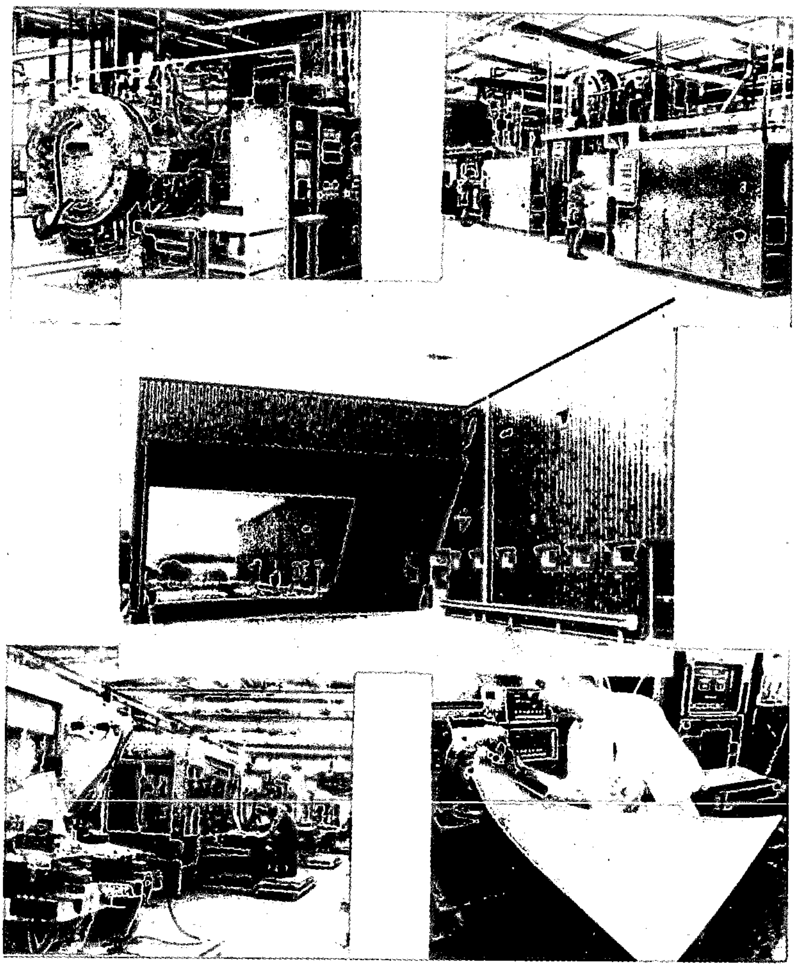
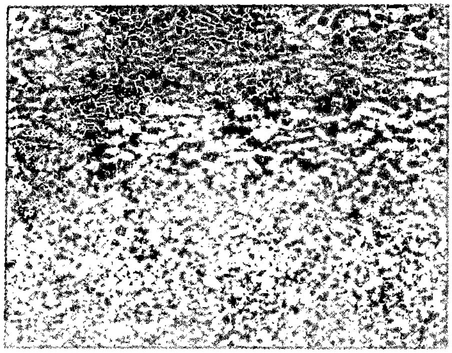


Figure 3 - Wide Chord Fan Blade
Manufacturing Module



Joint Line

0,2mm

Figure 4 - Solid State Diffusion Bond
Ti-6Al-4V

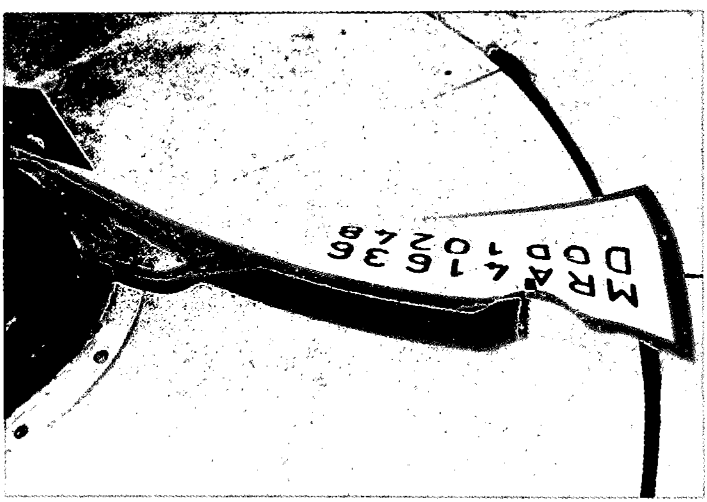


Figure 5 - Trent Fan Blade after 8lbs Bird
Ingestion Test