FILAMENT WINDING TECHNOLOGY – EXAMPLE OF AN INTEGRAL ENGINE NOSE CONE

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OVERVIEW

The demand for economic airborne vehicles drives the design of aircraft and engine structures into the usage of high performance materials and optimised design solutions.

The BR715 engine nose cone is an example of using the superior properties of composite materials in conjunction with a dedicated manufacturing process to achieve a component that fulfils the diverse requirements. The new single-piece design concept of the nose cone replaces a two-piece component to further improve the in-service performance.

To achieve such component, the following requirements had to be considered:

- Infinite life under normal operation conditions
- Resistance against bird strike
- Resistance against erosion

Based on results of Rolls-Royce Deutschland research activity in cooperation with University of Technology Dresden and composite specialist East-4D, a nose cone concept was developed to production standard that addresses these requirements.

The backbone of the new concept is the application of automated filament winding technology that allows the economic manufacturing of the integral nose cone design. This process, initially applied to manufacture simple shaped contours, was adopted to enable the creation of the complex contour of the nose cone allowing a unique design of the component. Due to the optimised process the automated manufacturing is highly effective and allows significant cost reduction compared to original hand lay-up manufacturing.

1. COMPONENT INTRODUCTION

To initiate the thermodynamic cycle in a turbojet engine, the breathed-in air is compressed by the first stage of fan blades. To cover the fan disc and to allow a smooth air path into the engine, a nose cone is fitted to the engine spool (see [FIG 1]).

Such nose cone is subject to centrifugal loading due to the engine shaft rotation as well as to erosion and foreign object damage.

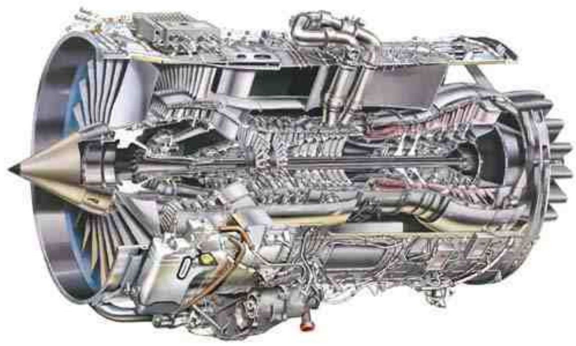

FIG 1. Section through BR715 engine

Since the malfunction of the nose cone results in imbalance of the engine rotor up to the extreme of a possible engine shut-down, the reliability of the component is essential for the engine operation.

2. COMPONENT DESIGN

2.1. Geometry

The nose cone in general has a conical shape with an angle defined by the air flow requirements towards the fan stage. The tip of the nose cone is formed by a rubber tip to prevent ice formation and built-up. To attach the nose cone to the fan shaft a rectangular flange is incorporated that allows bolting. To protect the bolt holes from damage, shouldered metallic inserts are incorporated. The airwashed surface of the nose cone is protected by an elastic coating. [FIG 2] shows the general design of the nose cone.

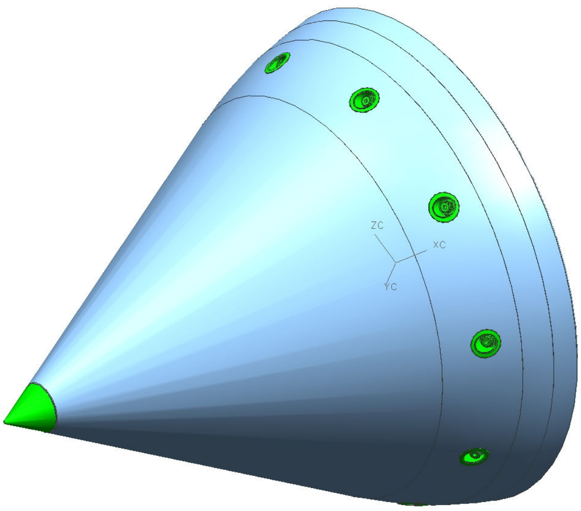

FIG 2. Nose cone external shaping

2.2. Composite Lay-up

The component is designed to withstand normal operation conditions that are rotational speed along with the fan shaft and a thermal loading due to the different temperature of the fan air stream. Furthermore the nose cone is subject to foreign object with a bird strike as an extreme event.

To cope with the above loading while maintaining a lightweight structure, composite material was chosen for the nose cone. The laminate lay-up was developed to suit the different areas of the cone

- high impact resistance and strength to the bird strike scenario in the main cone body
- resistance to the installation bolt clamp load
- high stiffness and strength in the flange to withstand centrifugal load while maintaining the aero contour

Based on material and impact test a material choice for a hybrid fibre arrangement was taken. This hybridisation combines equal portion of impact resisting glass fibres with high stiffness and strength of carbon fibres. The hybrid fibres are then infiltrated with epoxy resin during an RTM process.

To address the structural integrity during bird strike continuous fibres are arranged in cross ply orientation over the airwashed surface. Due to the surface´s conical shape the fibre orientation is changing with the axial extent of the nose cone. This is driven by the geodesic line the fibres take on that cone. In the flange area the continuous cross angled fibres of the outer surface are supported by circumferential fibres that force the fibre placement into the flange corner. These circumferential fibres take the main operation loading and provide a strong mounting interface to the fan shaft. The section wise arrangement of continuous cross-ply and circumferential fibres is shown in [FIG 3].

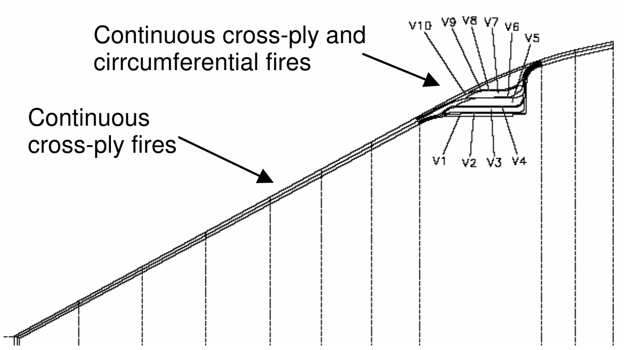

FIG 3. Laminated arrangement

2.3. Manufacturing

Previous composite nose cone designs were based on the heritage of prepreg technology. To reduce the manufacturing effort and with it the component costs, an automated process is required for that manufacturing. Since the nose cone is an axisymmetric part the filament winding technology was chosen for manufacturing. At manufacturer East-4D in Dresden a 5-axis winding machine (see [FIG 4]) is available allowing a precise lay-up of the dry fibres. This winding head allows the combined use of glass and carbon fibres in a continuous procedure. To meet the demand of the BR715 fleet operators East-4D introduced a unique double-mandrel tooling concept.

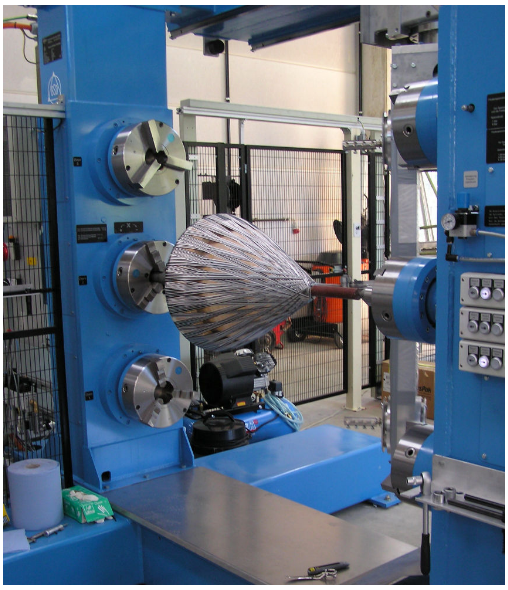

FIG 4. Automated filament winding

Prior to component definition winding simulation was used to allow the best fibre orientation and stacking sequence (see [FIG 5]). This allows an accurate definition of the laminate for design purposes as well as for the structural analysis.

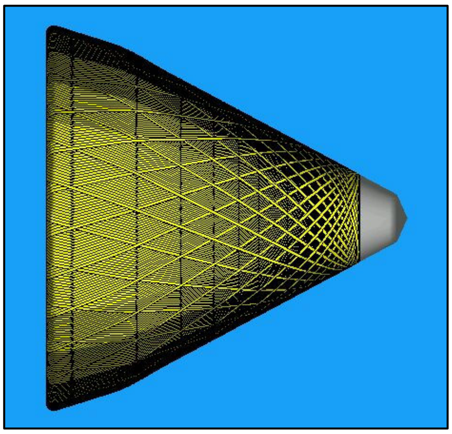

FIG 5. Simulated filament winding pattern

3. MATERIAL CHARACTERISATION

For the structural analysis of the component the material properties and behaviour have to be evaluated. Therefore a test program was established to determine the orientation dependent properties of the hybrid laminate. For testing tubular specimen, shown in [FIG 6] were manufactured with the identical processing route as defined for the production nose cone. These specimens are winded to have a uniform cross ply laminate.

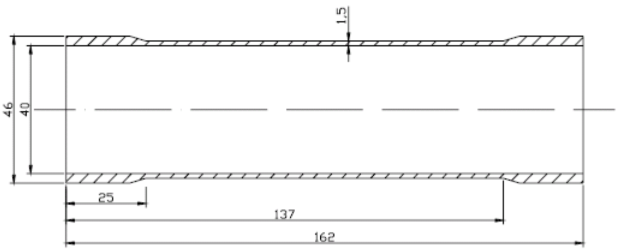

FIG 6. Tubular specimen for laminate test

For material characterisation tensile ultimate and fatigue tests were performed on different laminate orientations to reflect the loading scenario within the component. By statistical methodology a sound basis was established for the elastic behaviour and strength. [FIG 7] documents the stress-strain-curve in dependency of the fibre volume fraction. The sensitivity to that parameter was considered to reflect possible local variations of the fibre volume fraction within the cone.

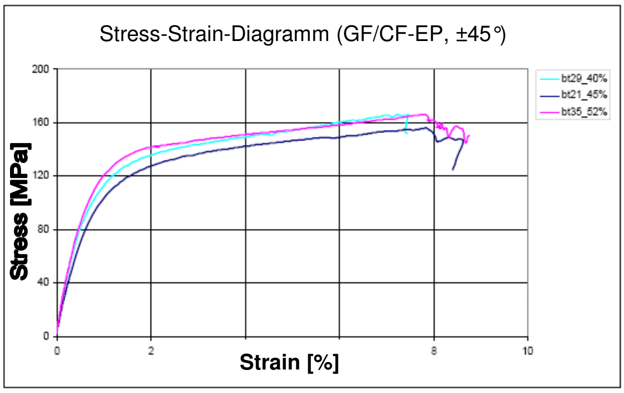

FIG 7. Stress-strain-curve in dependency of the fibre volume fraction

This procedure establishes the data basis for the orthotropic laminate. To analyse the relative thick laminate in the flange area the full set of anisotropic material properties is required. Using the classic laminate theory the test data is broken down into the properties of the material micro level and rebuilt up to the macro level using the extended laminate theory.

4. COMPONENT ANALYSIS

To prove the strength of the nose cone under operation conditions and to achieve component certification a finite element analysis was performed incorporating the laminate lay-up as defined by the winding simulation. This model combines 2D- and 3D-sections to reflect the different property sets (see [FIG 8]). While the plain cone body implements the orthotropic behaviour of a shell of revolution, the flange is separated into radial sections of quasi uniform lay-up.

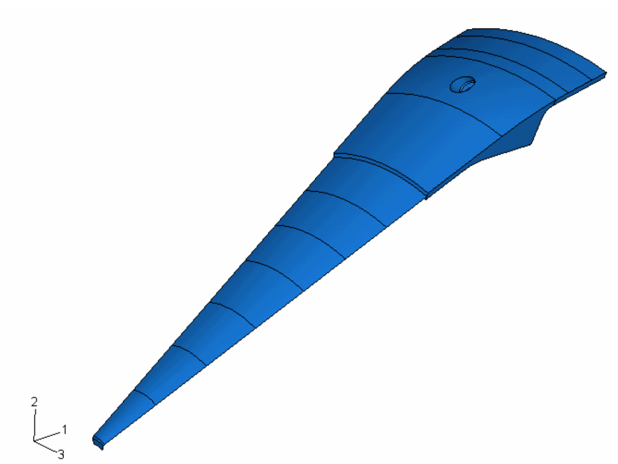

FIG 8. Simplified geometry for analysis

Applying a sequence of loading ranging from installation to different operation conditions the fatigue spectrum was analysed in terms of laminate stresses. [FIG 9] illustrates the stress distribution in the highest loaded flange area.

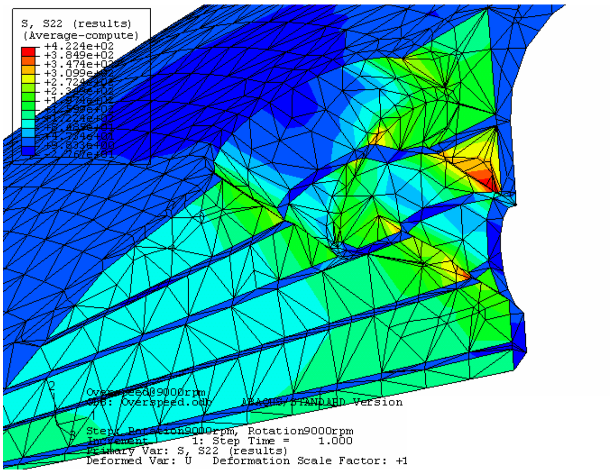

FIG 9. Hoop stress distribution in the highest loaded flange region

5. COMPONENT TEST

To validate the structural analysis and to support the certification strategy, a number of full component tests were performed. These tests included

- Medium bird strike (bird mass = 2.5 lbs) @ 450 m/sec onto cone body
- Large bird strike (bird mass = 6 lbs) @ 450 m/sec onto flange region
- Overspeed test (130% of max operation)

[FIG 10] documents the high speed impact of the bird onto the rotating nose cone.

Prior to test all nose cones were inspected for manufacturing defects. Computer tomography proved the excellent quality of the component laminate. The same inspection and additional cut-ups proved the damage free condition after testing.

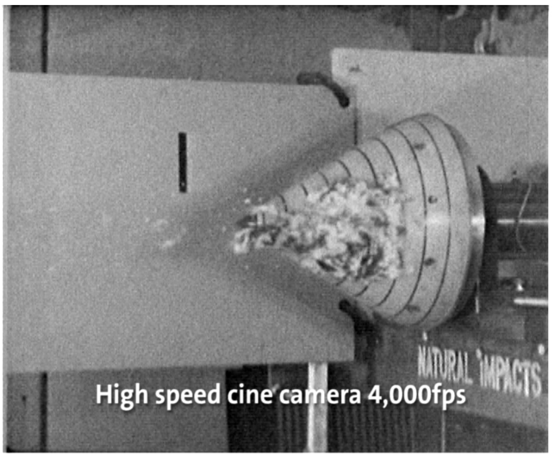

FIG 10. Nose cone during bird strike

6. CONCLUSION

Passing the development process of the novel nose cone concept a number of innovations were introduced into the component design

- Double mandrel tooling concept
- Hybrid fibres of glass and carbon
- 3D material characterisation for thick laminate

By proving its structural capability by analysis and test this design forms the baseline for a novel family of nose cones in future applications.

Having introduced the new design to the BR715 fleet in 2006 the design shows best performance under service conditions and contributes to customer satisfaction.

7. REFERENCES

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