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Reverse Engineering Of An Automotive Wind Tunnel Composite Fan Blade

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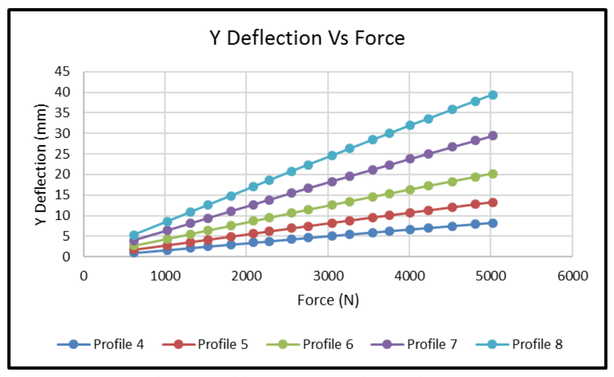

Graph 1 stiffness results of testing

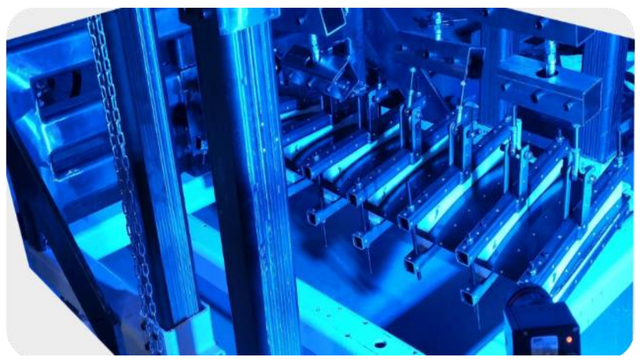

Figure 1 whiffletree rig testing blade stiffness

Introduction

F1 Customer commissioned *Lentus Composites* to perform a reverse engineering investigation to determine design criteria and manufacturing process for a like for like replacement wind tunnel blade. This was entrusted to the author to fulfil the commission.

The project entailed carrying out stiffness and vibration dynamic testing of the current original blade to identify its performance and design targets. These are used to define the new blade design. FEA and design optimisation was used to determine a composite laminate and structure to match the performance of the current blade.

Aims

A review of data from available literature, together with results from testing the original blade supported a scheme of work devised with design targets to develop the replacement blade (Table 1).

Table 1 scheme of work

No.	Task	Description/Notes
1	Create CAD model of the current blade	
2	Calculate blade loading and distribution	The methods developed in the literature review are used to calculate both the aerodynamic and centrifugal loadings
3	Design testing rig	The loadings found from the calculations are used to design a whiffletree stiffness testing rig
4	Stiffness testing	Carry out the testing to find the current blade stiffness
5	Tap testing	Using a combination of using LDV and a single accelerometer testing rig to find the current blade modes
6	Mass testing	Measure the current blade to find the total mass and the centre of gravity
7	Develop FEA model	Develop the methodology of how to model the blade
8	Develop blade design	
9	Develop blade laminate	

The principle tasks were

- Investigate the current blade loading
- Identify blade performance requirements
- Test current blade performance
- Identify achievable design targets for the new blade
- Build FEA methodology and create FEA model
- New blade design to achieve design targets

Methodology

A whiffletree was designed to load, test and assess stiffness of the current blade (Figure 1). Graph 1 are the results of that testing and shows how the displacement defines the stiffness criteria of the new blade. To find the 1st mode shape and frequency of the blade, LDV testing was carried out (Figure 2). From that testing, the design targets were determined. The FEA model was developed after carrying out parameter studies. The studies validated the results of the FEA model by matching results with coupon testing (Figure 3).

Table 2 design targets of the new blade determined from the methodology

No.	Target	Value
1	New Design To Match Current Blade Stiffness	Match the values from testing
2	Design To Cope With Centrifugal Loading At MAX Rotor RPM	Value to be calculated
3	Total Blade Mass	To be the same
4	New Design To Match 1st Mode Frequency	To match the current blade
5	New Design To Match 1st Mode Shape	Bending Mode
6	The CoG Z distance	Z To Be No More Than Current Blade
7	Steel Foot Stress To Be Half Of Material Yield Point	Depending On Material
8	Composite Strain	Be Below 3000 Microstrain

Final Design

The final design comprised:

1. Steel Foot
2. Foam Core
3. UD Laminate
4. Full Blade Laminate
5. Steel Sleeves
6. Shroud Foam Core
7. Shroud Composite Skin

Table 3 is evaluating the performance of the final design against the design targets.

However, further development is required to solve a composite bonding stress issue between the foot and foam core joint (see Figure 5).

Table 3 evaluating new blade performance against design targets

No.	Target	Value	Pass?	Acceptable?	Why?/Notes
1	New Design To Match Current Blade Stiffness	Match the values from testing	No	Yes	The blade stiffness was only at worst 9% stiffer. The performance is to be discussed with the customer to reach an agreement.
2	The Design To Cope With Centrifugal Loading At MAX Rotor RPM	Value to be calculated	Yes		Composite not failing under load, but safety factors to be discussed with the customer.
3	Total Blade Mass	Same as current	Yes		The total mass came out as over. Mass is over but can be controlled with back plate.
4	New Design To Match 1st Mode Frequency	Same as current	Yes		
5	New Design To Match 1st Mode Shape	Bending Mode	Yes		
6	The CoG Z distance	Z To Be No More Than current blade	Yes		The Z came out below. The customers are aware that because this value is not the exact same the blades will need to be changed in pairs.
7	Steel Foot Stress To Be Half Of Material Yield Point	Depending On Material	No	Yes	Not thought to have a major effect, but to be discussed with the customer.
8	Composite Strain	Be Below 3000 Microstrain	No	Yes	In one confined spot, to be discussed with customer.

Please note that sensitive information has been withheld from this poster to not breach customer NDA

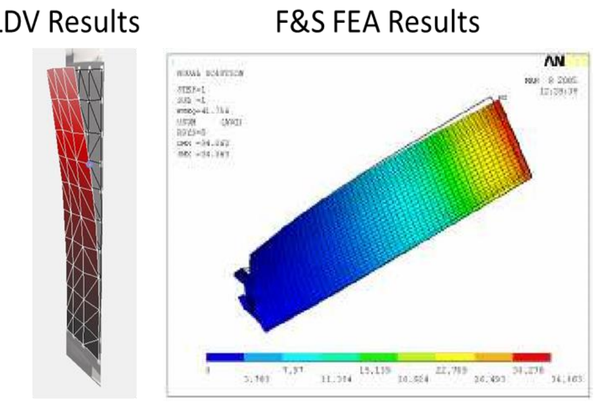

Figure 2 LDV & F&S results of the 1st mode shape

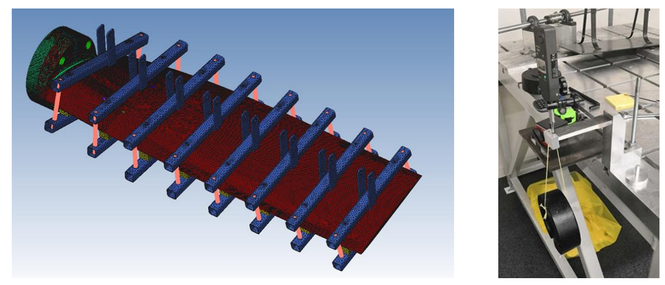

Figure 3 blade FEA model and coupon for validation studies

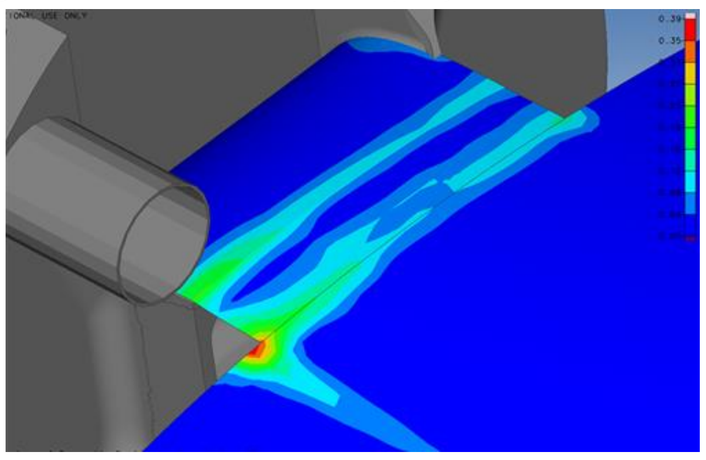

Figure 5 composite interlaminor shear stress failure index

Conclusions

The new blade design achieves the required targets. However, further work is needed to solve the bonding stress issue. Also the performance and reserve factors need to be discussed with the customer prior manufacturing a prototype for testing.

Acknowledgements

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References

Hyson, G. (2018, September 12). Fan Blade FEA Results. (G. Spring-Benyon, Interviewer)

Mattews, F. L., & Rawlings, R. D. (1994). *Composite Materials Engineering And Science.* North America: CRC Press LLC.

NASA. (1998). *Design and Manufacture of Wood Blades for Windtunnel Fans.* Gloucester: NASA.

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