

M6X00408

by Nathan Louis Doyle

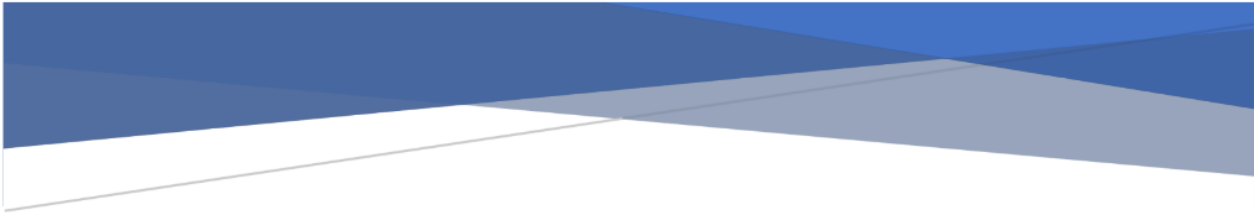
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ADVANCED COMPUTATIONAL METHODS

M6X00408

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Executive Summary



During the flight of an apache helicopter, a high stress concentration is experienced on the tail rotor blades when conducting a finite element analysis on the lift. It is also observed that centrifugal forces, result in a continual displacement at the end of the blade which may lead to possible fatigue. Even though the report produces a set of results, research has shown that many limitations exist that need to be factored into to any future studies. These include alternative materials, weather systems and vibration from the aircraft. The findings in this report show that the stiffness and natural frequency of the blades is reduced when an additional component is added, but it must be recognised that the study does not research the correct location, size and material of this extra feature. It does, however, provide a useful insight into an under-researched area.



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1. Introduction



An apache helicopter is comprised of two rotors that purpose is to transport the aircraft from one location to the next. The large main rotor has the function of producing lift that moves the helicopter, whilst the tail rotors purpose is to oppose friction created from the main rotor. This report uses finite element analysis to understand forces occurring on the tail rotor blades.

FEA is an effective tool in understanding a components response to an external force. The software allows for a detailed analysis of stress concentration on all areas of the component as well as studying the strain and displacement, when a force is applied. In the case of an apache helicopter, FEA can be used to understand the stresses involved in the tail rotor when in operation.



The report will investigate how centrifugal and lift forces act on the blades as well as understanding the natural frequencies that occur. Research will be gathered to explore the loading conditions that need to be considered and these will be used to help the FEA analysis to create images for this report. It is likely that considerations need to be made on time and accuracy with loading conditions such as mesh sizes so that the FEA can produces images quickly without compromising on producing inaccurate results. After the analysis, recommendations will be suggested to improve the study, along with areas that may need to be investigated further due to limitations with the software or lack of knowledge.

2. Research of Design and Loading Conditions

The tail rotor is an essential component of a helicopter and is explained by Singh, et al., (2008) as being able to perform numerous tasks in such as counteracting the torque created by the main rotor, yaw control and controlling the helicopter. Without it the helicopter would become incredible unstable and may lead to total failure. Zhong, et al., (2018) adds excessive noise induced by the rotor creates acoustic fatigue and additional vibration, places limitations on its performance and safety.

2.1 Design

The tail rotor blades design are continually evolving with the continually added focus on safety, quality and flight performance. Once in flight, the blades are designed with three degrees of rotation known as flapping, lagging and feathering. These design features are crucial in reducing the cyclic bending stresses, pitching torques and vibrations in rotation (Zaharia, 2015). Figure 1 illustrates the degrees of movement in the blades.

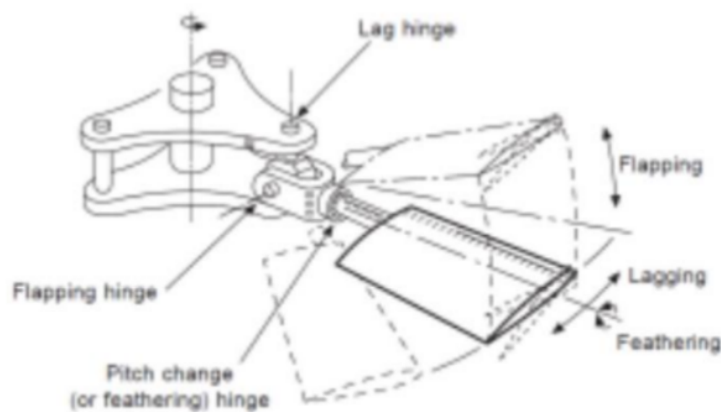


FIG. 1. Degrees of freedom (Zaharia, 2015).

The tail rotor is viewed by Zaharia, (2015) as being a vital component to an helicopter, therefore it is imperative that it is manufactured with the correct material. Shanyavskiy & Toushentsov, (2016) suggest that an aluminium alloy 2014, is a suitable material due to its high tensile stress, corrosion resistant and

being extremely light weight. According to Hansen, (2005) the apache helicopters blades are required to be efficient and light, yet strong, due to the overall structures weight being over 5000kg.

2.2 Mesh Size

Prior to an analysis, the blade is divided into numerous subsystems known as finite elements that are interconnected by points known as nodes. These are specific points within the finite element where variables such as stress, strain and displacement are to be calculated. The accuracy of the analysis depends on the number of these elements (Vanam, et al., 2012). According to Shih, (2011) a greater coarse mesh density will provide a quicker set of results which will be less accurate, whereas a finer arrangement may take long to assemble results but the accuracy will be high. In Vargiu, et al. view, (2017) a balance needs to be met based on the application of the product. A set of results need to be gained, whereby a high accuracy is achieved in a relatively short time. Below is a table comparing the time taken for various mesh sizes of the tail motor blade.

Mesh Size	Total Elements	Time Taken  6
1mm	515256	00.01.17s
2mm	75687	00.00.40s
3mm	5902	00.00.21s
10mm	1288	00.00.02s
20mm	383	00.00.01s

Table. 1. Table justifying mesh sizes.

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The table justifies using a mesh size of 3mm, whereby there is a balance of many elements used in a relatively short time. Future analysis can research into applying different mesh densities over areas of higher stress that could reduce computing time but still give accurate results where needed. The analysis on this is deemed reasonable as it is an extremely important decision in any FEA study.

2.3 Centrifugal Force

This is a force that acts on the tail rotor, arising from the circular motion of the blades around their centre. It is known as an inertial force and is directed outwards from a rotating body from its central axis (Clausen & Wood, 2013). As established by Badiru, (2010) the centrifugal force is given by the formula -

$$F = m\omega^2 r$$

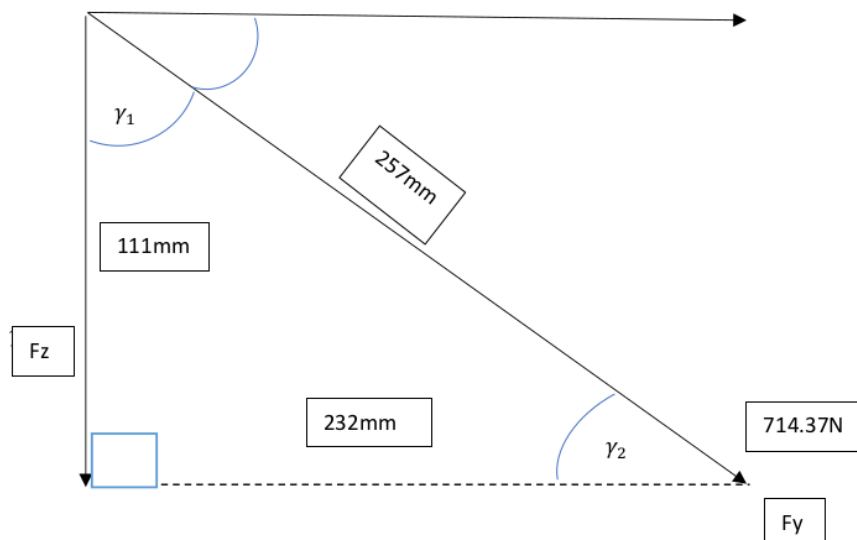
In Bishop's view, (2011) the tail rotor rotates at an rpm of 1419 and this is usually in a 6:1 ratio with the main rotor. Barakos & Han, (2017) agrees with the ratio of 6:1 but suggests that the rpm of the tail motor is lower at 1189. For the purpose of the report, 1189rpm is used.

$$F = 0.192 \times 124.51^2 \times 0.192$$

Symbol	Meaning	Result
F	Centrifugal Force	714.37 Newtons
m	Mass	240×10^{-3} Grams
ω	Angular Velocity	124.51 Rads/s
r	Radius	0.192 Metres

Table. 2. Table of centrifugal force results.

Even though the centrifugal force has been calculated, it is required to find how much of the force is exerting in the Z and Y axis of the blade.



$$\gamma_1 = \sin^{-1} \frac{111}{257} \quad \text{8}$$

$$\gamma_1 = 25.6^\circ$$

$$\gamma_2 = 180 - 90 - 25.6$$

$$\gamma_2 = 64.4^\circ$$

$$F_z = F \cos \gamma_2$$

$$F_z = 714.37 \cos(64.4)$$

$$F_z = 309\text{N}$$

$$F_y = F \cos \gamma_1$$

$$F_y = 714.37 \cos(25.6)$$

$$F_y = 644\text{N}$$

2.4 Lift Force

The lift force of the tail rotor is required to counteract the torque generated from the friction in the main rotors shaft. Vigano, et al., (2011) state that the main rotor blades are held by a complex elastomeric bearing that creates drag, pitches and flaps, therefore due to the complexity of calculating friction, the tail rotors lift force will be examined instead. Figure 2 illustrates the forces acting on the apache. According to Barakos & Han, (2017) the apache helicopters tail rotors provides lift of 1189rpm or 19.82Hz.

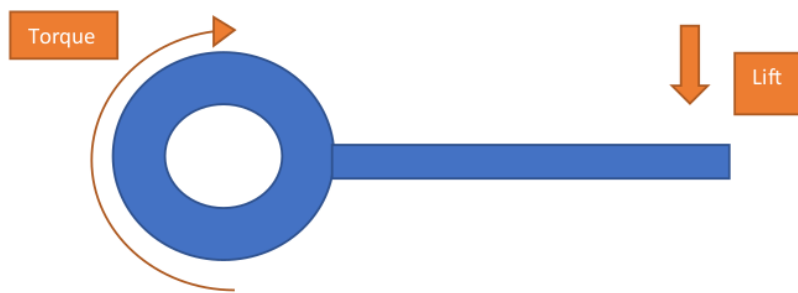


FIG. 2. Forces acting on helicopter (Doyle, 2019).

The extent of lift relies on several factors such as density, area, lift coefficient and velocity (Benson, 2018). These can be displayed in the following equation.

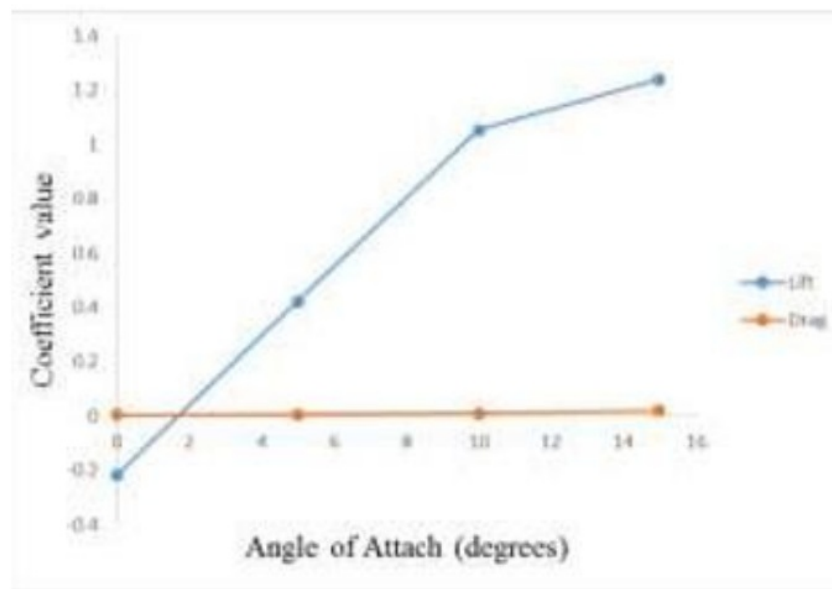
$$L = \frac{1}{2} \rho v^2 A C_L$$

ρ (Density)
V (Velocity)
A (Area of Blade)
C_L (Coefficient of Lift)
L (Lift)

Table. 3. Table of units for lift equation.

Coefficient of Lift

The ability of a component to create lift through a liquid is known as its lift coefficient and is dependent on the shape and angle of attack (Kent, 2007). Caplan & Gardner, (2007) explain that the lift coefficient increased with the angle of attack up to a value of 1.25 (Figure 3) and this is further supported by Manohar & Ramkissoon, (2016) whereby a blades lift coefficient reaches 1.25 and reverts back to zero.



5. Resolution(-)

FIG. 3. Graph showing coefficient of lift (Caplan & Gardner, 2007).

Velocity

When rotating, the velocity is dependent on the location on the blade (Figure 4), therefore, it will be assumed that the velocity will be uniformly distributed across the entire blade.

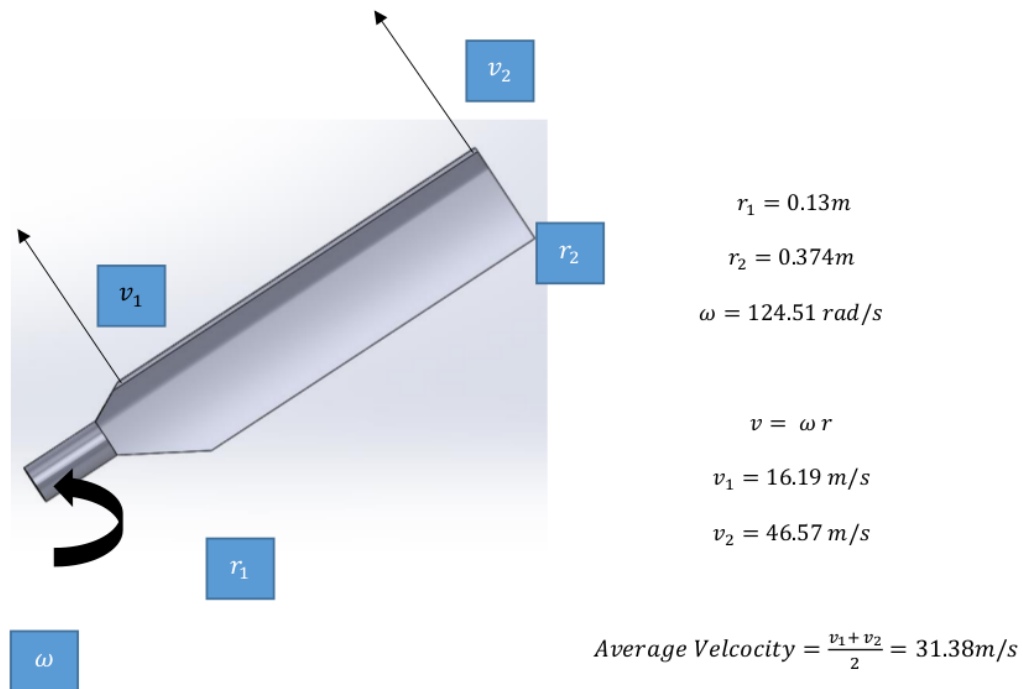


FIG. 4. Forces acting on blade.

The results show that the average velocity acting across the blade is 31.38 m/s . If you combine this with the density of air being 1.285 kg/m^3 and the area of the blade being 0.04 m^2 (Bansal, 2005), then you have a lift force as follows-

$$L = \frac{1}{2} \times 1.285 \times 31.38^2 \times 0.04 \times 1.25$$

$$L = 31.43 \text{ N}$$

The lift force does not consider any drag that is caused by the air around the blades. Further analysis needs to be taken to investigate how the drag could affect the lift force and other analysis featured in the report.



3. FEA Models, Analysis and Recommendations

Using Finite Element Analysis in solid works, the blade will be tested with forces that will occur within its normal operation. These include centrifugal forces, natural frequencies and lift forces.

3.1 Natural Frequency

Every component has natural vibration known as its natural frequency and this is the frequency a body oscillates at without any driven force occurring. The natural frequency of the blades is 19.82hz. A forced frequency occurs when an additional force or body is added to a component and it can induce severe vibration if it resonates the same as the component's natural frequency (Rao, 1999). Here are figures showing four modes of rotation, with and without a central shaft.

Mode Shape 1

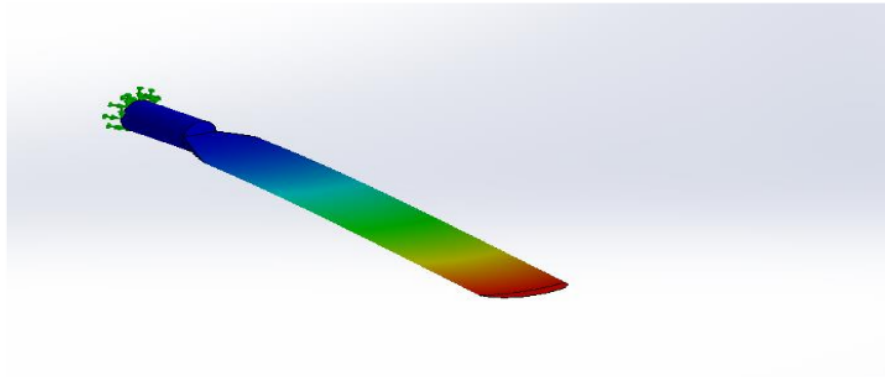


Fig. 5. First mode analysis (Doyle, 2019).

Mode shape 2

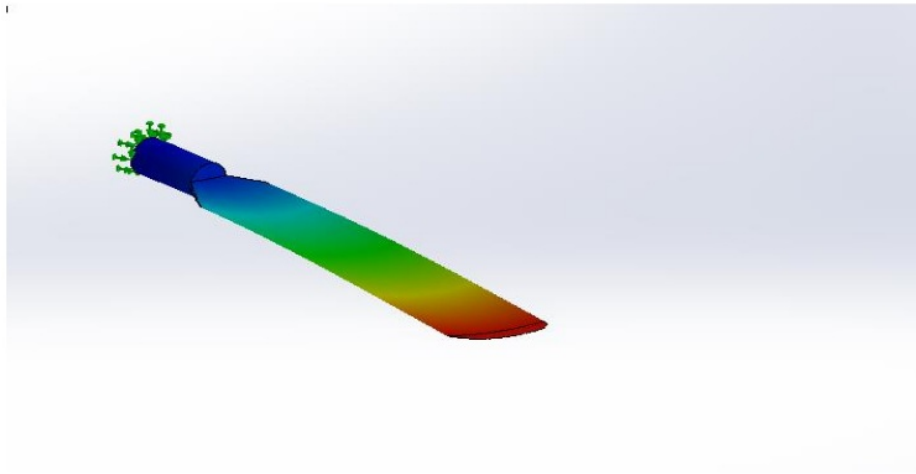


Fig. 6. Second mode analysis (Doyle, 2019).

Mode shape 3

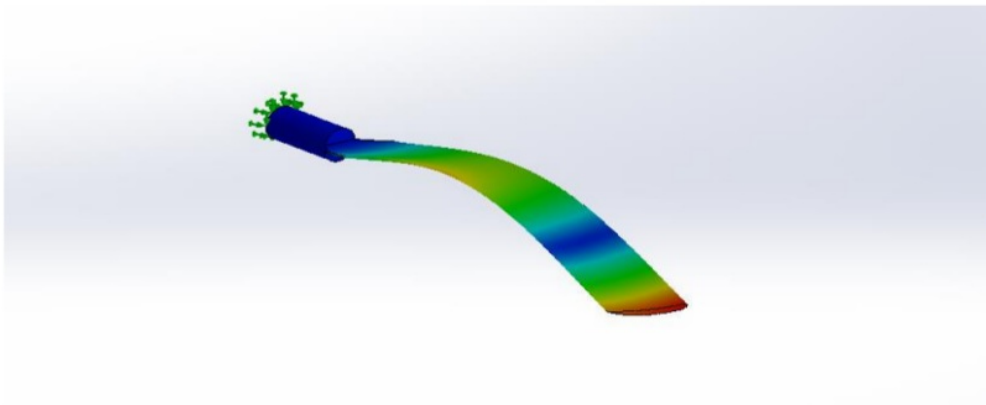


Fig. 7. Third mode analysis (Doyle, 2019).

Mode shape 4

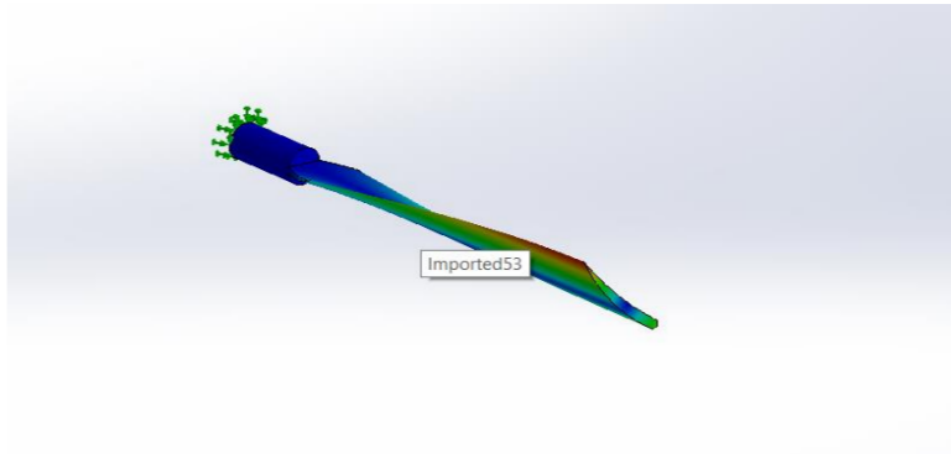


Fig. 8. Fourth mode analysis (Doyle, 2019).

Mode Shape	Natural Frequency
1	48.329Hz
2	230.99Hz
3	315.75Hz
4	440.84Hz

Table. 4. Table results of natural frequency.

The next set of results incorporates the inclusion of a second component that is the central shaft of the propeller blade and this is constrained instead of the blade.

Mode shape 1

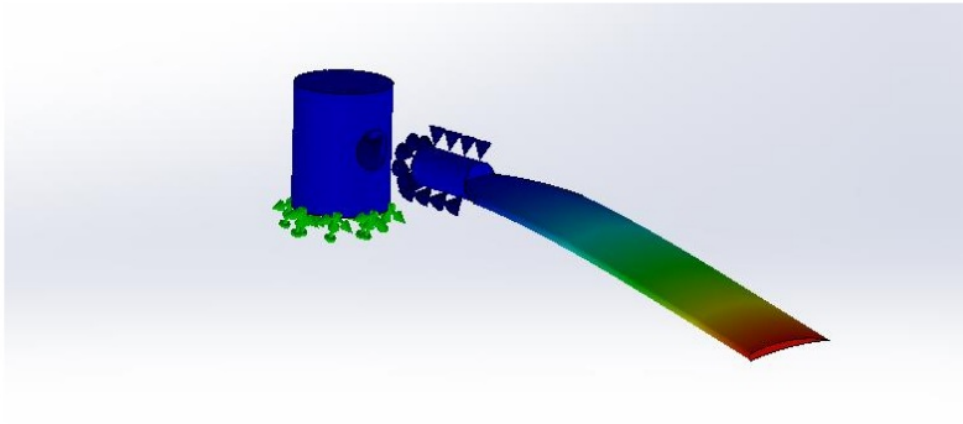


Fig. 9. First mode using rigid connection (Doyle, 2019).

Mode Shape 2

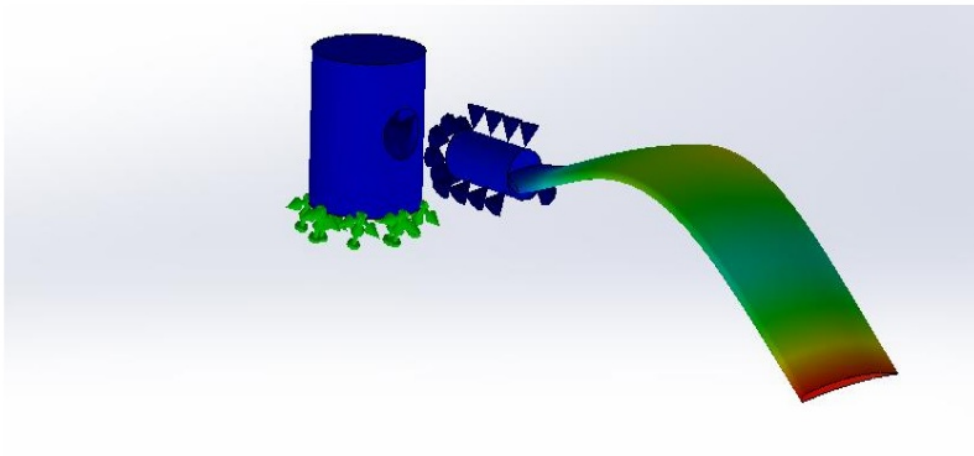


Fig. 10. Second mode using rigid connection (Doyle, 2019).

Mode Shape 3

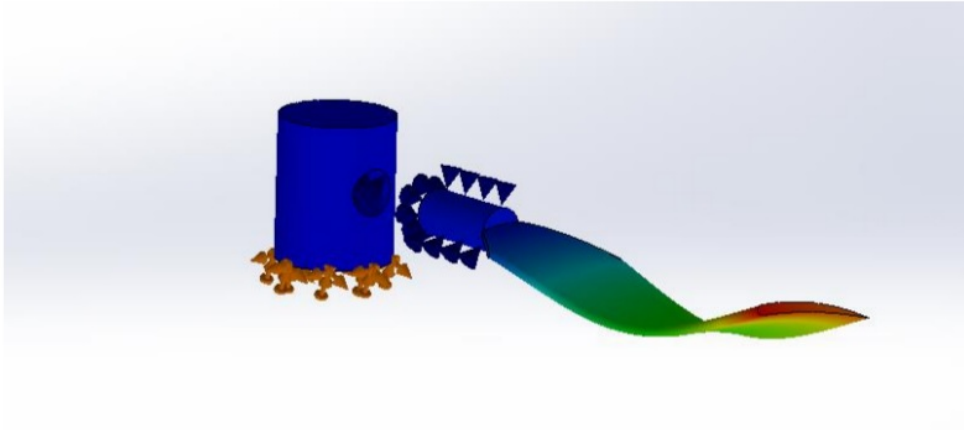


Fig. 11. Third mode using rigid connection (Doyle, 2019).

Mode Shape 4

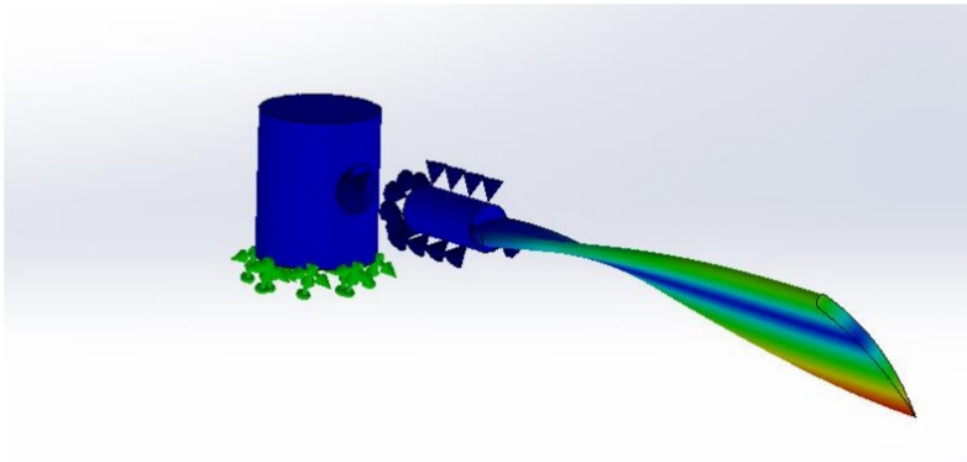


Fig. 12. Fourth mode using rigid connection (Doyle, 2019).

Mode Shape	Natural Frequency (Hz)
1	29.13
2	201.43
3	270.19
4	325.8

Table. 5. Table results of natural frequency.

The results clearly demonstrate that the inclusion of the additional component has reduced the blades natural frequency in each of the modes. This reduction in natural frequency is expected because the additional component has reduced the structures overall stiffness (Leung, 2012). To obtain the frequency in a component the equation is given below-

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

Given that K represents the stiffness, an increase will raise the natural frequency (Carrella, et al., 2008), therefore, the design of the shaft is critical to stop the frequency reaching the blades 19.82Hz. If this was to occur, it will stimulate uncontrollable vibration in the blades. The FEA analysis has assumed the dimensions of the central shaft, along with the material and size. It has not considered the type of fit required between the blade and the shaft as well as the necessary bearings needed. The design and shape are critical to maintain a high natural frequency to avoid excess vibration. It therefore recommended, that a full analysis be initiated to solely concentrate on the central shaft and its interaction with the blade. A full review of potential materials needs to be instigated so that the most efficient combination can be selected to improve the apaches tail motor design and increase or maintain the stiffness.

Good

3.2 Lift Force

3. BCs (-)

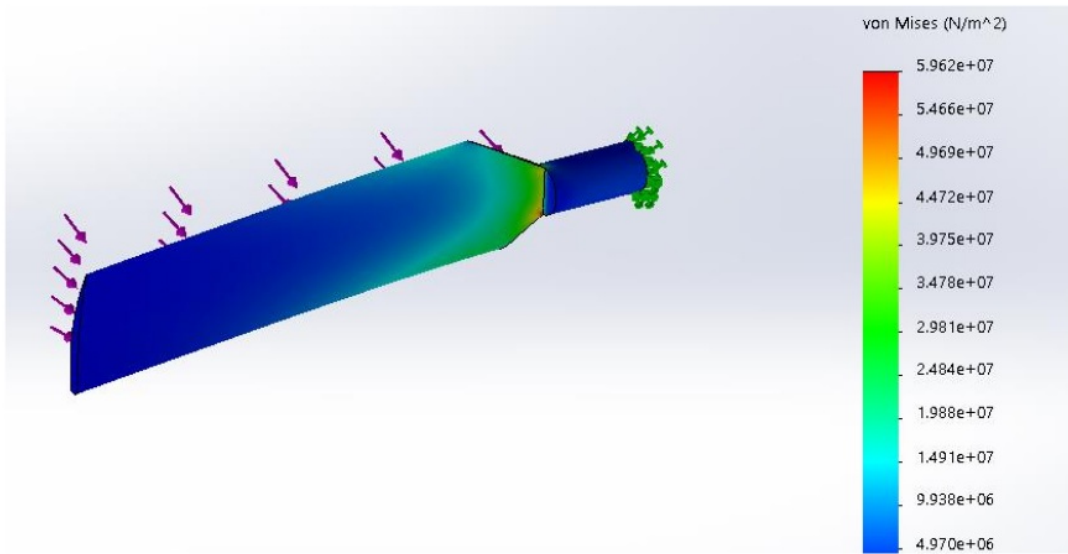


Fig. 13. FEA of lift force (Doyle, 2019).

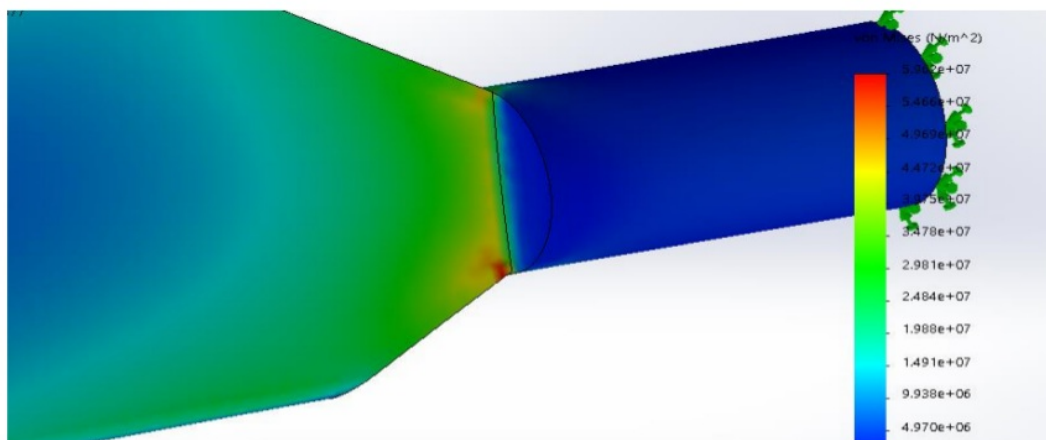


Fig. 14. FEA stress concentration (Doyle, 2019).

The two figures above display the stresses on the blade after the lift force has been applied. It is seen that there is an area of high stress concentration on the blade at a stress of 59620000 N/m^2 , however, due to the material yield strength being 96509800 N/m^2 , the component is not going to start yielding and deform. If the stress concentration had been higher than the material yield strength, a redesign such as fillets or ribs or material change should be considered. Figure 15 and 16 show the effect a fillet has made to reduce the stress concentration on the component. The stress has been significantly reduced to 2954000 N/m^2 .

12

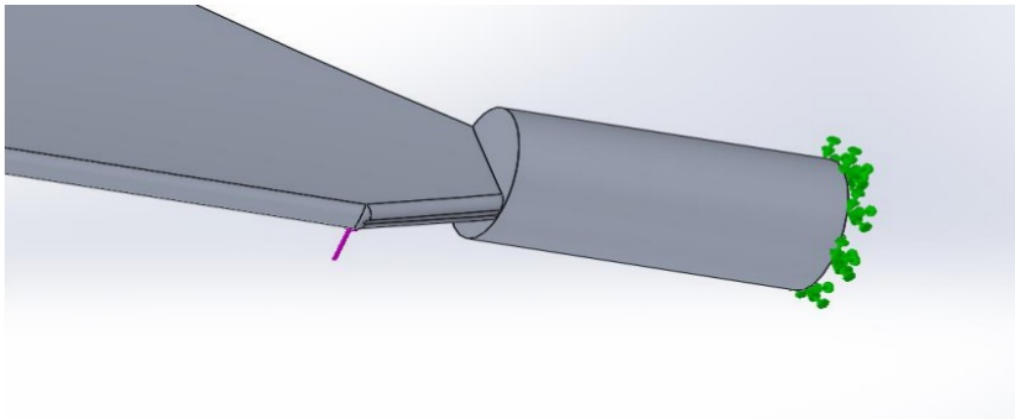


Fig. 15. Modified part to reduce stress (Doyle, 2019).

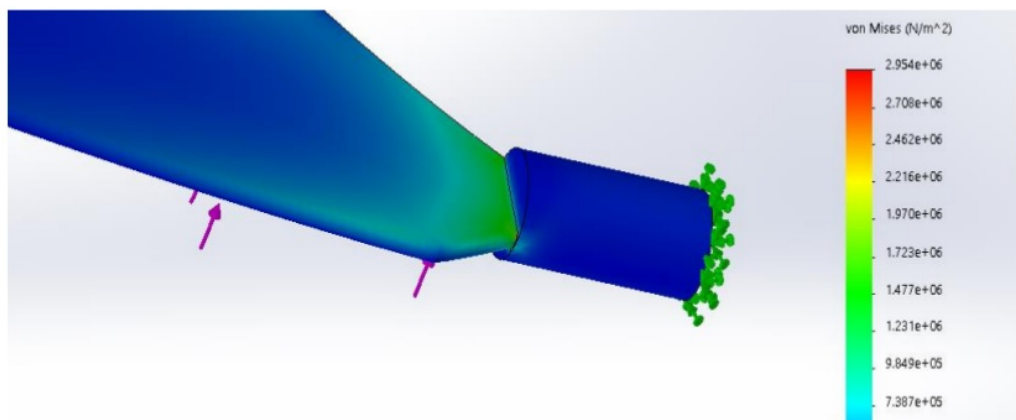


Fig. 16. FEA stress reduction after fillet (Doyle, 2019).

13

For the purpose of this study, the velocity of the blade has been taken as an average and this has been applied to all areas of the blade. In reality however, there is significant velocity variation along the entire blade. According to Leishman, (2016) the variation in velocity on the blade is radially linear, with the rotating axis being zero and the end tip of the blade reaching a maximum known as V_{tip} . This is highlighted in figure 17, with arrows signalling the velocity of the blade at different distances from the centre. A recommendation in future reports is to use solidworks to create a bearing load on the blade so that force is relative to the distance from the centre.

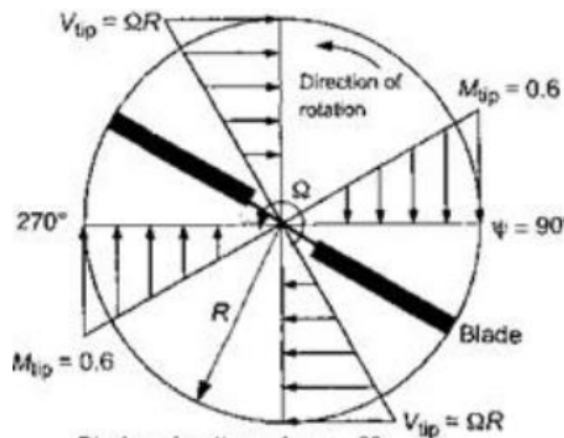


Fig. 17. Velocity variation across the blade (Leishman, 2016).

5. Resolution(-)

Good

For the report, the lift force generated has been applied to the one blade, however in reality this should have been divided by the four blades on the apache. Factors not considered in this report that are very important on helicopter blades are the lag, pitch and flap. Also not analysed, is the type of weather that may be experienced which could increase or influence vibration in many components. It is recommended that further research be conducted on the blade that incorporates all features and weather systems in the FEA analysis.

3.3 Centrifugal Force

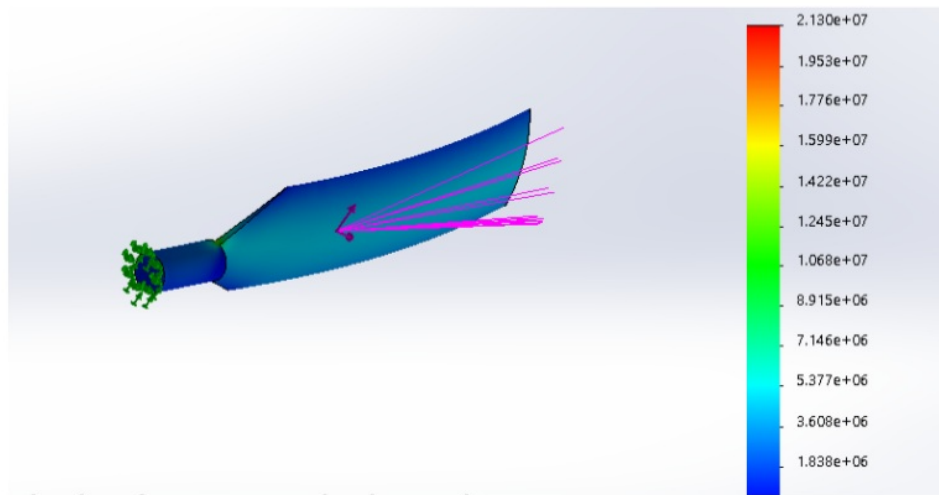


Fig. 18. FEA of centrifugal force (Doyle, 2019).

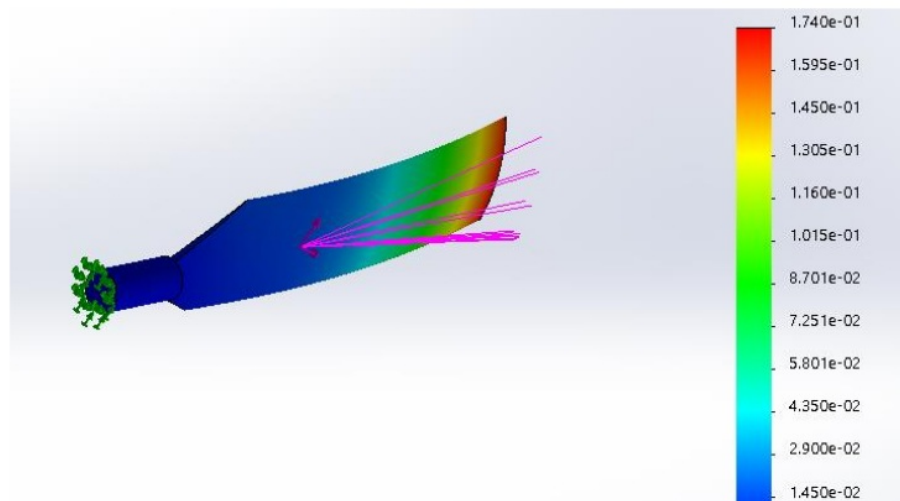


Fig. 19. FEA showing displacement (Doyle, 2019).

Figures 18 and 19 illustrate the effect that centrifugal force has on the blade in terms of stress and deformation. From the study it can be observed that the centrifugal forces do not exceed the material yield strength, however this analysis does not factor in the fatigue generate from the constant displacement of the blade tip by 0.174m . For a future report, a full fatigue analysis could be attempted

to view an S-N curve of the component . This can predict the lifetime of the blade in terms of the number of cycles before failure.

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3.4 Material

The report uses an aluminium alloy known as 2014 alloy in the FEA analysis, however, according to Shanyavskiy & Tousehntsov, (2016) the helicopter blades are composed of a variety of materials, that increase their stiffness and strength. These materials include a mixture of carbon fibre composites with an inner foam core . Compared to aluminium alloys, these are very aerodynamic and increase the blades efficiency. Glukhikh, et al., (2008) agree that composite materials such as glass reinforced plastics, are usually preferred as they are capable of high performance under the heavy vibration from the aircraft, however, they can be more expensive than aluminium and can take longer to manufacturer. Figure 20 shows the layers within a helicopter blade.

16

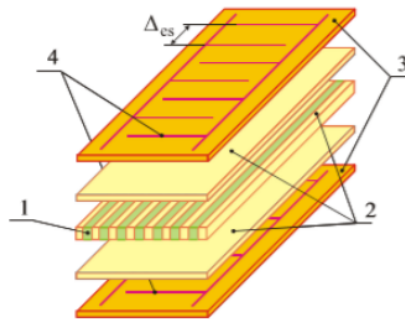


FIG. 20. Layers within a helicopter blade (Glukhikh, et al., 2008).

Due to the limitation of being unable to use many composite materials on the helicopter blade, the FEA analysis was based on a blade made from an aluminium alloy. Future analysis needs to be taken to understand the stress concentration when using the different material as this make produce conflicting results.

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4. Conclusion

The report clearly demonstrates that there are a wide range of tests and techniques that can be applied to the analysis of the tail rotor of an apache helicopter. The key areas of analysis in the report include understanding natural frequency, applying the lift force and examining the centrifugal force on the blade. They have shown that there are many forces present on the blades in normal operation and these interact with the blades in a variety of ways. This includes, the decrease in stiffness by the addition of a central shaft, the high stress concentration and subsequent removal via a fillet, and the constant displacement by the centrifugal forces.

It must be remembered however, that there are many limitations to this report that may affect the results. As mentioned, the choice of material is important due to different properties and mass, and this is a limitation of the CAD software as only one choice of material could be implemented for use on the blade. Other recommendations have been as a result of limitations. These include further studies on fatigue analysis, research into the impact of weather systems on the blades and incorporating blades features such as lag pitch and feathering. Maybe one recommendation could be to trial a real life set up of the correct blade in a wind tunnel whereby all factors could be analysed and tested

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FINAL GRADE

GENERAL COMMENTS

Instructor

60/100

PAGE 1

PAGE 2



Comment 1

Apache



Comment 2

?

PAGE 3



5. Presentation(+)

Generally your presentation is good

PAGE 4

PAGE 5

PAGE 6



Comment 3

whose?



Comment 4

use past tense



Comment 5

adds?

QM

5. Resolution(-)

Make sure that any images that you take from other sources are of good enough resolution to be clear in your report



Comment 6

time taken to do what?



Comment 7

why?



Comment 8

where do these dimensions come from?

QM

5. Resolution(-)

Make sure that any images that you take from other sources are of good enough resolution to be clear in your report



Comment 9

Do you think that this is realistic?



Comment 10

why did you not consider drag? What about fatigue?



Good



3. BCs (-)

The components that the blade attaches to will obviously have some flexibility which will lower the stresses, increase the fatigue life, increase the displacements and lower the natural frequency of your results



Comment 11

N/m² - 59.6MPa



Comment 12

Good suggestion - this is what you would expect.



Comment 13

Images such as this should show the mesh so that the influence of the element size/shape can be understood.



5. Resolution(-)

Make sure that any images that you take from other sources are of good enough resolution to be clear in your report



Good



Comment 14

Have you assessed the lift and the centrifugal forces at the same time?

PAGE 24



Comment 15

Why did you not do this?



Comment 16

how can a material be aerodynamic? It may be to do with the manufacturing process that the material uses that allows aerodynamic SHAPES to be formed.



Comment 17

It is a reasonable assumption to use an Isotropic material for this analysis.

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PAGE 26

PAGE 27

GRADING FORM: APACHE ACM

**NATHAN LOUIS
DOYLE**

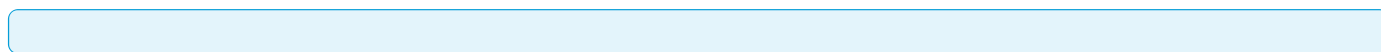
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RESEARCH INFORMED LIT



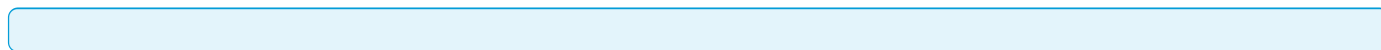
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KNOWLEDGE & UNDERSTANDING



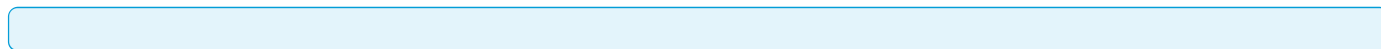
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ANALYSIS



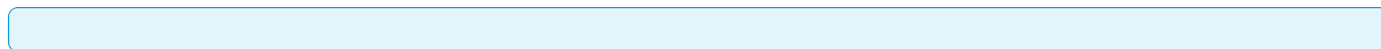
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PRACT APP & DEPLOYMENT



12

SKILLS FOR PROF PRAC



6.5