

Assignment 1

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1302416 – Assignment 1

Assignment 1

University of Wales Trinity Saint David

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Assessment of a Helicopter Tail Rotor

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Date: 15/11/2019

Advanced Computational Methods M6X00408

Kelvin Lake



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Abstract

The purpose of this report is to analyse how calculated forces will affect the tail rotor blade made from the chosen material of titanium, on an Apache helicopter. For the purpose of this report the Apache AH-64A is being studied. It highlights assumptions and weaknesses in the analysis and concludes that the report does not fully consider all the potential forces that would be applied to a tail rotor blade. Therefore, there is potential for further analysis to be made however, due to limitations of the author it is not possible for these to be undertaken for this report. Priority analysis has been done on stress, displacement, strain and frequency.

1 Introduction

The Apache helicopter was first designed in 1972 by Hughes Aircraft Toolco Aircraft Division with its delivery to the US army in January 1984 (Newkirk, 2007). The final design is considered revolutionary due to its advanced weaponry and flying ability (Harris, 2002) because of this the Apache is used in warfare by countries all over the world including the USA, Great Britain and United Arab Emirates (Boeing.com, 2019). The Apache AH-64A shown below, is suited for two-man operation, typically one to operate the helicopter controls and the other to operate the weaponry.



Figure 1: Apache Helicopter (Army Technology, 2019)

A simple breakdown of the Apache AH-64A is shown in Figure 2. Analysis will be undertaken on the forces and stresses that will be experienced on the tail rotor blade.

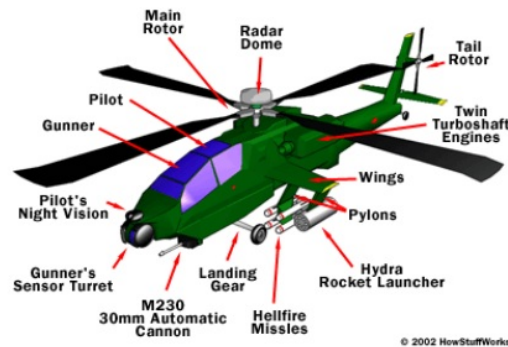


Figure 2: Simplistic Breakdown of an Apache (Harris, 2002)

1.1 Forces Acting on a Helicopter

There are four main forces acting on a helicopter when it is taking flight as illustrated below,

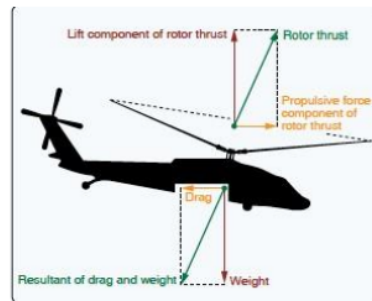


Figure 3: Forces Acting on a Helicopter in Flight (FAA.gov, 2019)

When studying the forces experienced on the tail rotor of an Apache helicopter the reactionary force to the main rotor torque, called tail rotor thrust, must be considered. This is calculated by calculating the main rotor power and torque. To understand the forces acting on the blade in the simulation, we need to calculate the power to weight ratio. This is calculated by dividing the power of the engine by the weight of the helicopter, both these figures are from Table 1. This gives us an answer of 0.20627KW/Kg, this can be used to calculate the power to weight ratio, and therefore the torque experienced on each blade;

$$\text{Power/ Weight ratio} = 0.20627\text{kW/KG}$$

$$\text{therefore Power} = 6.1314\text{kW}$$

$$\text{Power} = \text{Torque} \times \text{Speed} / 9.5488$$

$$6.1314 = (? \times 289) / 9.5488$$

$$\text{Torque} = 202.59\text{Nm}$$

This needs to be divided by 4 for the torque experienced on each blade;

$$= 50.6475 \text{ Nm}$$

There are four forces acting on a helicopter; thrust, drag, lift and weight. Lift opposes the downward force of weight, this acts perpendicular to the flight path through the centre of lift. Weight is the combined load of the aircraft and gravity. It opposes lift and acts vertically downward through the aircraft's centre of gravity. Thrust is the force produced by the rotor, it opposes the drag force. Drag is a rearward force caused by the disruption of airflow. Drag opposes thrust and acts rearward parallel to the relative wind (FAA.gov, 2019) the analysis conducted was on the forces acting on the rotor blade which are demonstrated in Figure 4.

The calculations used for this are shown in the reference tables. The results were then used for the simulation. The forces used and how these were applied to the blade are illustrated below;

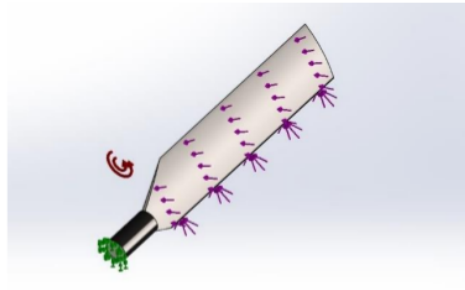


Figure 4: Forces Applied to Blade (Gore, 2019)

3. BCs (-)

The rotor blade has a fixed geometry at the end of the cylindrical root, which would be attached to the helicopter. The first force applied is the tail rotor thrust, in this case the calculated force, 50.6475Nm, has been divided by the radius of the blade and the result, 39.8956N used as a force on the face that would be counter acting the main rotor thrust. Secondly lift is applied to the blade, which would occur on the bottom of the blade. For the purpose of this analysis only the blades angled at 55° have been simulated, a force of 10172N has been applied. Accurate lift applied in simulation would be taken on the main rotor, however for analysis purposes it has been applied to the tail rotor. Finally, a centrifugal force has been added to the blade of 147.7596rad/s and 27717 rad/s². The results are limited as the tail rotor thrust force has been calculated for the model, whereas centrifugal and lift forces have been calculated for the blade sizes in the reference tables.

1.2 Helicopter specifications

All the design specifications used in the simulation are taken from Reference Tables.

1.3 Tail Rotor Blade

According to Newkirk (2007) each tail rotor blade has one stainless steel spar and two aluminium spars. However, for the purpose of this simulation the tail rotor blade is made out of Titanium, Commercially Pure CP-Ti UNS R50400 (SS) (SolidWorks, 2019). Titanium was chosen as it is a material that is currently used on the leading edge of rotor blades (Harris, 2002). Current Apache production uses a variety of materials for rotor blade manufacture. A helicopter blade is exposed to many elements and forces. The tail rotor blade in an Apache AH-64 flies through vegetation, close to the ground and can experience heavy fire, so the material chosen must be resilient and strong yet lightweight (Kelley, 1990). Before commissioning a blade, a series of stress tests will need to be undertaken, as well as the simple analysis in this report, these include; application of accurate service stresses, expected service exposure, NDT and destructive testing (Wanhill, 2003). The Apache was the first helicopter to set its tail rotor hubs at 55° instead of the conventional 90° (Newkirk,

2007), this was used in the simulation to calculate the lift coefficient experienced on the blade. From the design, it can be assumed there will be natural weaknesses in the design of the blade especially on the connection between the root and the fin. This area will experience a high level of stress and the design will need to take this into consideration. It will also need to be considered how the components are to be attached and manufactured as certain procedures can lead to material and part weaknesses.

2 Analysis

The dimensions of the part are important in this analysis as it helps to define where forces will be placed on the surfaces and how these will affect the part and results. It was decided to keep the current design of the part as the dimensions and geometric entities are simple and any further simplification would limit the effectiveness of the analysis results. There is no symmetry noted in the design of the blade, however there is symmetry noted in the complete tail rotor blade and therefore, any analysis conducted on the rotor as a whole component could be assumed that both sides would experience the same forces and stresses. Assumptions are made towards the accuracy of the simulation programme to analyse the part under the stresses as well as assumptions made within the simulation programme relating to material strength.

The first step in simulation analysis is to decide the mesh size required for sufficient data collection and accurate analysis. The sampled mesh sizes are in Table 6. Mesh size of 4mm was decided upon due to the length of time the smaller mesh sizes were taking to simulate. The time taken to simulate the forces and stresses applied to the part was lengthy due to the amount of stress applied; this is because they were calculated for a life scale model not the blade used. A smaller mesh size would provide a more detailed analysis, however, it was decided that 4mm was adequate for the purpose. An image of the part when 4mm mesh is shown below;



Figure 5: Mesh Represented on Part (Gore, 2019).

The first analysis conducted was a static study with tail rotor thrust, lift and centrifugal forces applied.

From the above calculations the applied forces were as follows:

$$\begin{aligned}\text{Tail Rotor Force} &= 50.6475/1.2695 \\ &= 39.8956\text{N}\end{aligned}$$

$$\begin{aligned}\text{Lift experienced on each blade at } 55^\circ & \\ &= 10.172\text{KN}\end{aligned}$$

$$\begin{aligned}\text{Centrifugal Force} & \\ &= 147.7596 \text{ rad/s} \\ &= 27717 \text{ rad/s}^2\end{aligned}$$

When the forces are applied to the rotor blade the static study result is shown below,

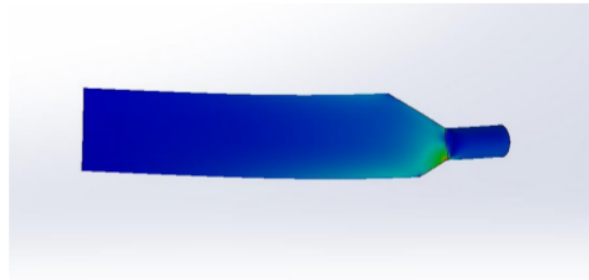


Figure 6: Forces Applied to Blade 1 (Gore, 2019)

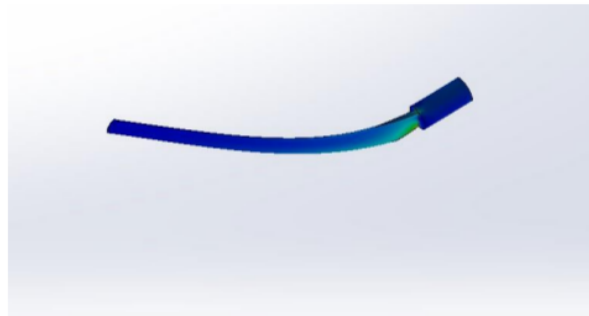


Figure 7: Forces Applied to Blade 2 (Gore, 2019)

2.1 Stress

Figures 6 and 7 show the stresses that the blade will experience when exposed to the calculated forces. It also highlights a weakness in the material where the cylindrical root attaches to the fin of the blade.

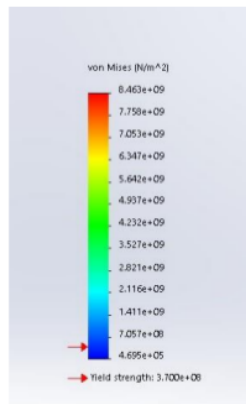


Figure 8: Von Mises Chart (Gore, 2019)

From the Von Mises chart in Figure 8, the yield strength of the chosen material is 3.700e08N/m². Unfortunately, the chosen material and design will fail if the calculated forces are applied as the area around the connection of the fin and the root exceed this. There are methods that could be taken which would minimise this failure or eradicate it completely. A simple first option would be to change the material to something that is less likely to experience high levels of stress, or is more flexible without compromising safety or strength. Another option is to strengthen the blade in this area by adding extra material or supports.

2.2 Displacement

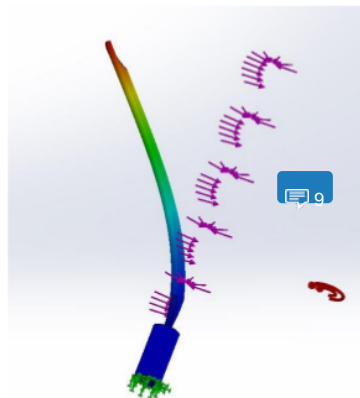


Figure 9: Displacement of Blade (Gore, 2019)

Figure 9 shows the displacement that the blade would experience under the calculated forces. A static displacement plot is represented in Figure 10 and represents the factor of displacement that the blade has experienced. It is exaggerated in this simulation, but as expected, the tip of the blade would experience the most displacement under the calculated forces. Although a small displacement, it would need to be further analysed as to how this would affect the flight of the helicopter and whether this movement would interact with any

other parts. Methods to reduce this would need to be evaluated, by again choosing a different material or changing the design of the part. A possible solution is to add extra supports along the back of the blade which would reduce the amount of movement seen in the analysis, however it would add weight to the part, which is critical in this application. Therefore careful consideration and evaluation needs to be undertaken when looking at redesign options.

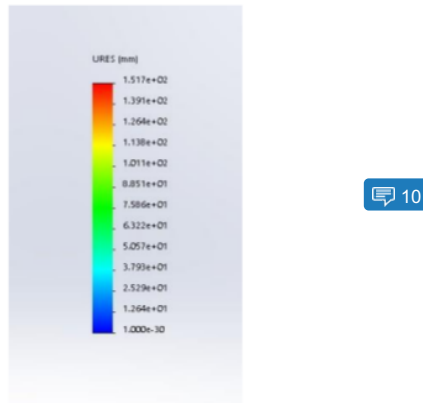


Figure 10: URES Chart (Gore, 2019)

2.3 Strain

The final evaluation in the static analysis is the measure of strain that the blade will experience, shown in Figure 11 below,

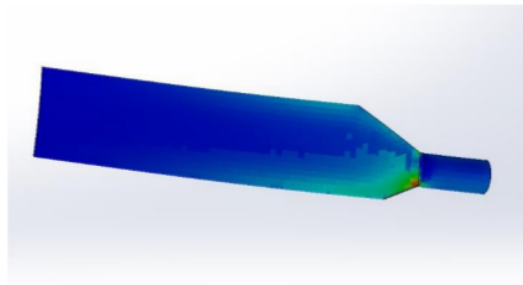


Figure 11: Strain placed on blade (Gore, 2019)

The strain placed on the blade is highlighted to be where the root of the blade connects with the fin and maximum strain is experienced. It is vital to understand the repercussions of the maximum strain and how that will affect the blade. The strain experienced could cause the material to flex and snap or distort which will affect the efficiency of the blade and potentially cause catastrophic issues when used in flight.

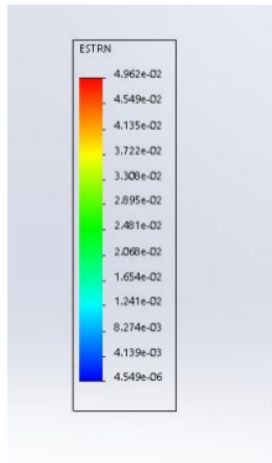
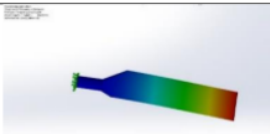
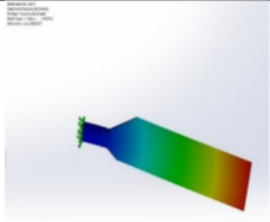


Figure 12: ESTRN Chart (Gore, 2019)

Figure 12 shows the equivalent strain that is experienced by the blade and is calculated by measuring normal strain, shear strain and in the first, second and third principal direction (SolidWorks Help, 2019),

2.4 Frequency

A frequency study was conducted next. This is used to analyse how the material and structure of the part can cause vibrations and any issues that are caused due to this. As a standard SolidWorks will apply 5 frequency modes, this was increased to 10 to enable analysis of the modes that are a combination of principle directions, these modes are shown below;

Mode	Image	Frequency Hz
1		46.038
2		219.02

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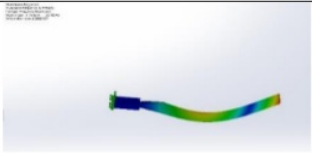
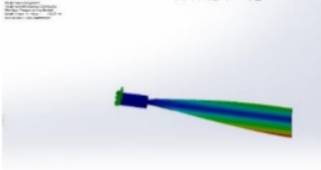
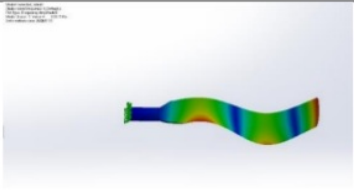
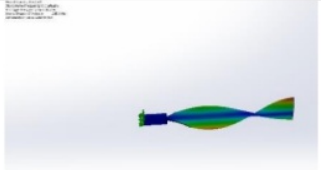
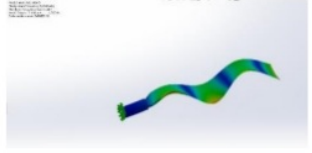
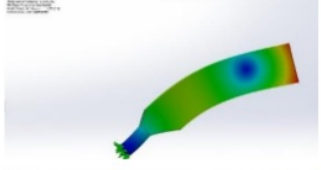
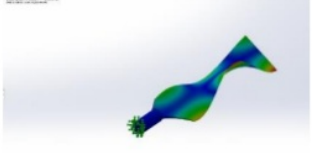
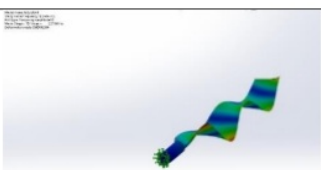
3		299.92
4		412.03
5		836.15
6		1245.1
7		1592
8		1973.3
9		2124.3
10		2519.8

TABLE 1: FREQUENCY MODES. ALL IMAGES (GORE, 2019)

The images in Table 1 represent how the material choice, fixed geometry and shape of the blade affects the natural frequency of the part. The natural frequency of the blade is 46.038Hz, however, when excited can reach ranges up to 2519.8Hz. This is a large range and as such would have implications on the design of the tail rotor and how it is attached to the helicopter and possibly even the design of the helicopter. For effective analysis it needs to be understood how this would affect operations and the flight of the helicopter. Possible ways to reduce or change the frequency are by fixing the part differently or by using a different material. These options would have to be investigated in order to produce the most efficient option for the blade material. Again, the distortion is exaggerated in the images however, they represent how the blade will vibrate when in use, this knowledge can help the author to understand how to potentially minimise the vibration and where the worst occurrences will be. To enable full comprehension of the effects of natural frequency on the blade, analysis will need to be undertaken on the model of the Apache, this information can then be used to determine whether any of the frequencies highlighted via this analysis will cause an issue when the helicopter is manufactured. If there is potential for the model to vibrate at the same frequency as the blade, this could cause issues when trying to operate and would have to be eliminated or minimised to reduce the affect on the operation of the helicopter.

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3 Recommendations

To enable the author and designer of the Apache to gain a full understanding of how forces will affect the blade and the helicopter it is recommended for fatigue analysis to be undertaken. This will outline how many operating cycles the blade will be able to endure before failure and any damage due to fatigue will be witnessed. It is also recommended to conduct the analysis on the model as a whole component as any issues the blade might experience due to frequency or static analysis will be highlighted. Another recommendation is to understand the potential forces experienced on the tail rotor and blade to ensure that the forces applied are in the correct plane. The designer must understand any significant environmental factors that will affect the part as the analysis is assuming there are no external forces being applied or environmental factors, like wind or debris affecting the blade in simulation.

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4 Conclusion

From the static analysis it can be concluded that the material chosen for the part is not suitable for the forces applied as it causes failure. However, it must be remembered that the forces applied to the part in this simulation are not accurate as there are limitations to the author's application of forces in SolidWorks; it is a very crude representation of the potential forces that could be applied on a tail rotor blade during flight. It is also difficult to represent the forces and how they change during take-off, flight, hovering and landing. The tail rotor blade experiences varying forces during its life span and due to the limitations of the simulation and the author's knowledge this was not applied and so not analysed. It is also not considered realistic analysis as it makes assumptions to the direction and what forces there will be. The static analysis highlights the need for extra strengthening to the part to eliminate, as far as possible, the movement in the blade as well as increasing the strength of the fin to the cylindrical root as this was a highlighted weakness.

The frequency analysis has shown that the blade has a wide range of frequency that will occur when in operation. This is not ideal as it has potential to interact and affect frequencies that might occur when the blade is attached to the main body of the helicopter. As outlined in the analysis, there is potential to reduce this by fixing the blade differently to the main body or changing the design of the blade.

The material chosen is not the most suitable as titanium is an expensive option to make a helicopter blade, generally a blade is made from a composite of materials utilising carbon fibres and metals. This is done as the stronger metals can be used as leading edges and for the main body structures to add strength and ensure that the blade is able to withstand the forces applied when in flight, leaving the remaining parts of the blade to be made out of lighter carbon fibres. This not only helps reduce the weight of the part, but ensures it is a
 13 ring as possible with the lowest natural frequency available.

There are many weaknesses in this analysis and as such it should not be considered adequate testing for a tail rotor blade.

Reference Tables

Main Rotor	Tail Rotor	Engine	Weight
4 Blades	4 blades spaced at 55Deg and 125Deg	General Electric YT700 – GE – 700 turboshaft engine	Empty – 4760kg
48ft Diameter/ 14.630m	8.33ft Diameter/ 2.539m	1536 Horsepower	Loaded – 5553 kg
289 rpm	1411 rpm	20000 rpm	Gross weight – 8119 kg

TABLE 2: FIGURES USED FOR HELICOPTER ANALYSIS (SWOPES, 2016)

Mass of Part	388.54g	0.38854kg
Surface Area of Part	39806.03mm ²	0.03981m ²
Speed of Tail Rotor	1411 rpm	147.7596 rad/sec
Diameter of Tail Rotor	8.33ft	2.359m
Radius of Tail Rotor	4.165ft	1.2695m
Speed of Main Rotor	289rpm	30.264 rad/sec

TABLE 3: FIGURES USED FOR CALCULATIONS (FIGURES FROM LAKE, 2019 AND SWOPES, 2016)

TABLE 4: FIGURES USED FOR CALCULATIONS PT 2.

Name	Value	Source
Coefficient of Drag	0.04	(Engineeringtoolbox.com, 2019)
Density of Air	1.204kg/m ³	(Engineeringtoolbox.com, 2019)
Cross Sectional Area of Blade	0.00023669m ²	(Lake, 2019)
Area of Blade	0.03981m ²	(Lake, 2019)
Mass of Blade	0.38854 Kg	(Gore, 2019)
Velocity	187.58m/s	Velocity (m/s) = Angular Velocity (rad/sec) X Radius (m) = 187.58

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Force	Calculation	Result
Drag Force on Tail Rotor Blade (Calculated for each blade)	$\frac{1}{2} \times (\text{Coefficient of Drag} \times \text{Density of Air} \times \text{Cross-Sectional Area of Blade} \times \text{Velocity}^2)$	$= \frac{1}{2} \times (0.04 \times 1.204 \times 0.00023669 \times 18.58^2)$ $= 0.2005 \text{ N}$
Weight (Loaded weight used)	Weight = Mass * Gravity	$= 5553 \times 9.81$ $= 54474 \text{ KN}$
Thrust (power needed to overcome drag on each blade)	Power = Force of Drag * Velocity	$= 0.2005 \times 187.58$ $= 37.60979 \text{ W}$
Lift (Calculated for each blade)	Force of Lift = Coefficient of Lift * $\frac{1}{2} \times \text{Density of Air} \times \text{Velocity}^2 \times \text{Area of Blade}$	For Blades at 55° $= 6.03141 \times \frac{1}{2} \times 1.204 \times 187.58^2 \times 0.03981$ $= 5086.0495 \text{ N}$ For Blades at 125° $= 13.703 \times \frac{1}{2} \times 1.204 \times 187.58^2 \times 0.03981$ $= 11555.1980 \text{ N}$ For all Blades: $= (2 \times 5086.0495) + (2 \times 11555.1980)$ $= 33282 \text{ N}$
Coefficient of Lift	$= 2 \times 3.14 \times \text{Angle (in rad/sec)}$	For Blades angled 55° $= 2 \times 3.14 \times 0.95993$ $= 6.03141$ For Blades angled 125° $= 2 \times 3.14 \times 2.18166$ $= 13.703$
Centrifugal Force	Centrifugal Force = Mass * Angular Velocity ² * Radius	$= 0.38854 \times 1411^2 \times 1.2695$ $= 27717 \text{ m/s}^2$

TABLE 5: CALCULATIONS USED FOR ANALYSIS

TABLE 6: MESH SIZES

Mesh Size (mm)	Nodes	Elements	Time to complete (mins)
4.4179 (recommended)	16915	9431	0.9
2	121362	75687	0.17
1	766801	515318	1.23
4	19172	10493	0.10

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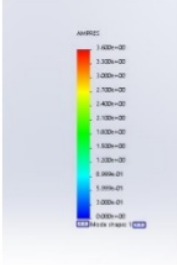
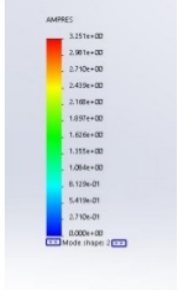
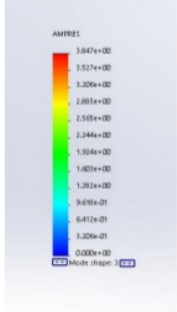
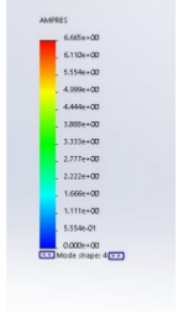
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Wanhill, R.J.H., (2003) Material-based Failure Analysis of a Helicopter Rotor Hub. Practical Failure Analysis April 2003 Volume 3 issue 2 pp 59-69

6 Appendix

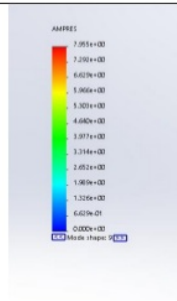
6.1 Ampres Charts for Modes 1-10. All images (Gore, 2019)

Mode	Chart
1	
2	
3	
4	

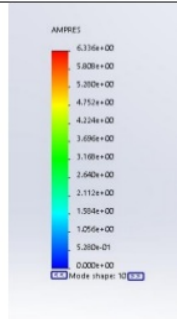
1302416 – Assignment 1



9



10



Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

59/100

PAGE 1



Comment 1

poorly presented title page.

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

QM

5. Narrative(-)

Your report should be written in third person narrative.

PAGE 7

QM

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 2

why? How have you calculated this?



Comment 3

Any numbers that you use must be explained and justified.



Comment 4

why is this in capitals?



Comment 5

Reasonable assumption



Comment 6

Why was this done? Will this have an effect. You lift/drag calculations assume laminar air, however the blade will be in turbulent air due to the fact that it is following another blade.

PAGE 8



Comment 7

Details?

PAGE 9

PAGE 10



Comment 8

370MPa



Good



Comment 9

Scale?

PAGE 11



Comment 10

Is this how much the blade deforms? 152mm seems excessive.

PAGE 12

PAGE 13



Comment 11

This is simply because you have shown the first 10 modes.



Comment 12

Why did you not do this?



Comment 13

?



Comment 14

Whilst you have carried out the above analysis, some of your conclusions based on this analysis are weak.

GRADING FORM: APACHE ACM

AIMEE DAVIES

58.90



12.4

KNOWLEDGE & UNDERSTANDING



11.6

ANALYSIS



17.1

PRACT APP & DEPLOYMENT



11

SKILLS FOR PROF PRAC



6.8