

Nathan Jones - ACM

by Nathan Jones

Submission date: 16-Nov-2019 06:56PM (UTC+0000)

Submission ID: 113579687

File name: 2841_Nathan_Jones_Nathan_Jones_-_ACM_216460_528139845.docx (9.49M)

Word count: 3940

Character count: 20239



ADVANCED COMPUTATIONAL METHODS

Assessment of a Helicopter Tail Rotor Blade

Nathan Jones (P151484)

1. EXECUTIVE SUMMARY



This report is going to look at establishing knowledge and understanding of the use and purpose of a tail rotor blade upon an Apache helicopter, this knowledge will then be used to carry out appropriate FE studies.

In order to carry out the FE studies, a number of assumptions such as materials, mesh's, and forces will need to be established and justified in order to complete the static simulation, based on these assumptions SolidWorks will then be used to simulate the Stress, Displacement and Strain which will be present on the tail rotor blade.

Once a static study has been completed a frequency study will then be carried out within SolidWorks in order to check that the natural vibration of the component is safe for use and won't be within the range of any of the other frequencies in which the component is likely to see.

A review of the suitability of the FE study will then be analysed in order to understand if the results obtained from the studies are suitable and if or why they should be questioned.

Finally a conclusion will be drawn up to justify all reasoning as to why assumptions and choices were made and what recommendations could be useful for future studies.



1 TABLE OF CONTENTS

1. Executive Summary.....	1
2. Introduction	4
3. Findings.....	5
3.1 Background Knowledge and Understanding	5
3.2 Helicopter Tail Rotor – Anti Torque System	5
3.3 Assumptions for FE Study	7
3.3.1 Material Selection	7
3.3.2 Fixtures.....	8
3.3.3 Mesh Parameters	10
3.3.4 Forces Required	11
3.4 FE Study.....	15
3.4.1 Stress	15
3.4.2 Displacement	17
3.4.3 Strain	18
3.4.4 Natural Frequency.....	20
3.5 Problems with FE Study	21
4. Conclusion and Recommendations	22
5. Works Cited.....	23

Figure 1 - Tail Rotor Compensation (FEDERAL AVIATION ADMINISTRATION, 2019).....	6
Figure 2 - Tail Rotor Blade.....	7
Figure 3- Fixture Options	8
Figure 4- Fixed Geometry of blade	8
Figure 5- Tail Rotor Assembly	9
Figure 6 - Centre of Mass from assembly	11
Figure 7- Centre of Mass for blade.....	11
Figure 8- Centrifugal Forces (SolidWorks, 2019)	12
Figure 9- Centre of Mass position	12
Figure 10 - Drag affected area 1 (Jones, 2019)	13
Figure 11- Drag affected area 2 (Jones, 2019)	13
Figure 12- Lift area of blade (Jones, 2019).....	14
Figure 13- Applied Forces (Jones, 2019)	15
Figure 14- von Mises' Scale (SolidWorks, 2019)	15
Figure 15- Stress on blade (Jones, 2019)	16
Figure 16- Underside of blade (Jones, 2019)	16
Figure 17- Displacement Scale (Jones, 2019).....	17
Figure 18- Side view of displacement (Jones, 2019).....	17
Figure 19- Stress/Strain Graph (SolidWorks, 2019)	18

5. Formatting

Figure 20- Strain Scale (Jones, 2019)	18
Figure 21- Side view of strain on blade (Jones, 2019)	19
Figure 22- Underside of strain on blade (Jones, 2019)	19
Figure 23- Stress/Strain Non-linear graph (Wikipedia, 2019)	21

Table 1- Ti-6Al-4V Material Properties	7
Table 2 - Centrifugal Forces	11
Table 3- Drag Force Equation.....	13
Table 4 - Lift Force Equation	14
Table 5- Natural Frequency Studies (Jones, 2019).....	20

2. INTRODUCTION

The aim of this report is to carry out appropriate FE studies upon a Apache tail rotor blade.

Once an understanding of how an Apache helicopter tail rotor blade operates, the assumptions which will be used in the FE studies will then established.

The first assumptions for the FE study is going to be the material choice, this is going to be established and the reasoning behind the choice justified.

The next assumption will be how to fix the component in position in order to carry out the FE study, this will then be identified and the reasoning for this shall be noted.

5. Proof Read

The other assumptions such as mesh parameters and forces will then be calculated in order to establish the best suited properties for the study. This will involve hand calculations which will be completed and proven to show why and where they will be used within the study.

Once all the assumptions have been identified the FE study will then be completed to gather the information for the stress, displacement and strain of the component under the set parameters.

These studies will then be reviewed to identify what the studies prove and why they prove this, the accuracy and reliability will also be questioned.

Additionally a natural frequency study will be carried out to ensure that the natural vibrations of the component don't meet the vibrations which the component will see whilst being used.

Finally a conclusion and justification will be drawn up to summarise all the assumptions and results which are provided within this report, and to explain the reasonings for the software choices for future studies.

3. FINDINGS

3.1 BACKGROUND KNOWLEDGE AND UNDERSTANDING

Prior to commencing any FE studies, it is important to understand how the tail rotor of an Apache helicopter operates to make sure that the loading conditions are suitable, ensuring that it will be fit for purpose.

(Swopes, 2016) states that the design of the tail rotor system on the Apache is unique due to the blades being spaced at 55° and 125° angles as oppose to being evenly spaced at 90°, (Irvine, 2003) says this is “because the two sets of blades use a "Delta-Hinge" which allows the blades to simultaneously flap and feather. The purpose of this design is to render the blades more efficient and to reduce noise”



The tail rotor blade is also said to have a diameter of 8.33 feet, and rotate at a speed of 1,411rpm (Swopes, 2016), (Irvine, 2003) also states the ratio between the tail rotor and main rotor at 4.86:1. With the main rotor spinning rate of 5.25 Hz and the tail rotor spinning at a rate of 25.5 Hz.

3.2 HELICOPTER TAIL ROTOR – ANTI TORQUE SYSTEM

Helicopters which use a single main rotor are required to have an antitorque system, this antitorque system is primarily in the form of a tail rotor. This tail rotor is used to compensate for the torque generated by the main rotor blades, this can be seen in (Figure 1.), showing the torque generated by the main rotor being in the opposite direction of the compensated torque of the tail rotor.

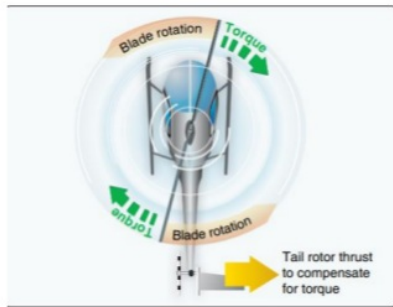


Figure 1 - Tail Rotor Compensation (FEDERAL AVIATION ADMINISTRATION, 2019)

Knowing the fixed ratio between the main and tail rotor, pilots can “vary the thrust of the antitorque system to maintain directional control whenever the main rotor torque changes” (FEDERAL AVIATION ADMINISTRATION, 2019), ensuring the fuselage stays within the direction of travel.

3.3 ASSUMPTIONS FOR FE STUDY

3.3.1 Material Selection

Although composite materials can be manufactured to fulfil the requirements of the conditions in which a tail rotor commonly sees such as velocities, temperatures and humidity's (Williams, 2019).

To carry out the simulation for the tail rotor blade as seen in (Figure 2.), a titanium alloy will be used as simulation couldn't be carried out with a composite material, because of this the appropriate material which should be used is a titanium alloy (Ti-6Al-4V) the reason for this is "the aerospace industry is one of the largest users of titanium, where titanium alloys are used as material in compressor discs and blades" the primary alloys are "Ti-6Al-4V and Ti-6Al-2Sn-4Zr-6Mo" (Pederson, 2004).

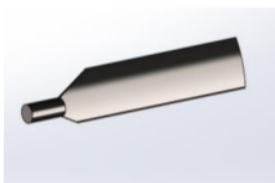


Figure 2 - Tail Rotor Blade

When looking at (Table 1.) all the material properties for the chosen titanium alloy can be seen, when this material is added to the blade, properties such as mass will then be used for all calculations, and assumptions for assessing the model.

Property	Value	Units
Elastic Modulus	1.0480031e+11	N/m ²
Poisson's Ratio	0.31	N/A
Shear Modulus	4.1023807e+10	N/m ²
Mass Density	4428.784	kg/m ³
Tensile Strength	1050000000	N/m ²
Compressive Strength		N/m ²
Yield Strength	827370880	N/m ²
Thermal Expansion Coefficient	9e-06	/K

Table 1- Ti-6Al-4V Material Properties

3.3.2 Fixtures

When completing simulation within SolidWorks there is a number of criteria which must be met in order for the software to portray what would be happening to the model. One of the criteria which is required is 'fixtures', looking at (Figure. 3) it can be seen that the software offers multiple options for choosing the fixture which best suits the need for the simulation.

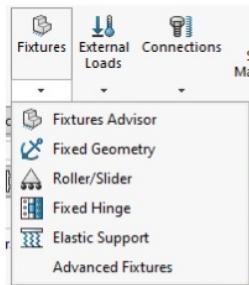


Figure 3- Fixture Options

Based on the fixtures listed in (Figure 3.) a 'Fixed Geometry' has been used to allow simulation of the model seen in (Figure 4.)

3. BCs (-)

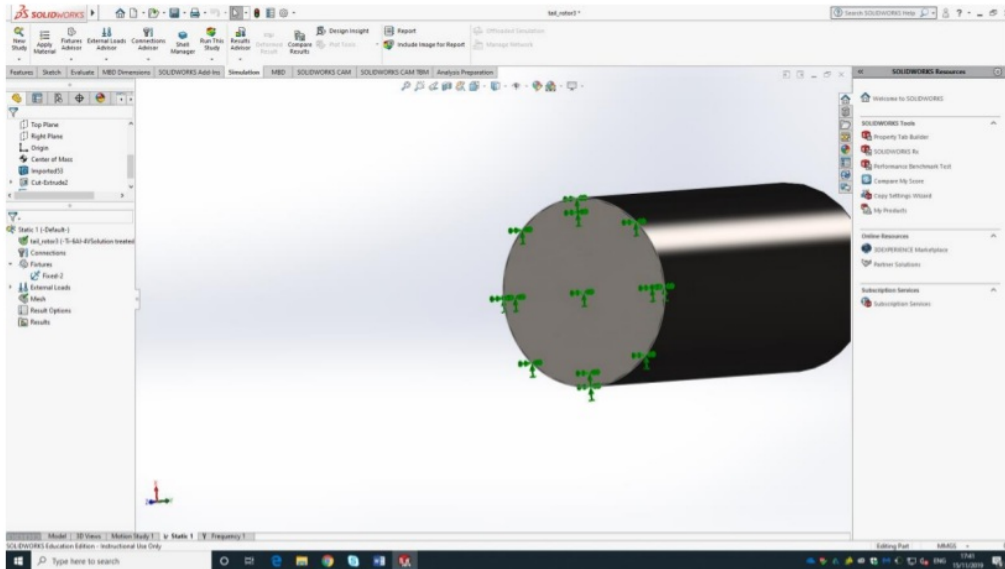


Figure 4- Fixed Geometry of blade

The reason this fixture was used, is down to the way in which the blade is mounted once within the full assembly and the parameters stated by (Dassault Systemes, 2019), (Figure 5.) shows how the blade is fixed at the one end within the assembly, which is the fixture which has been replicated through the use of a 'Fixed Geometry' as seen in (Figure 4.).

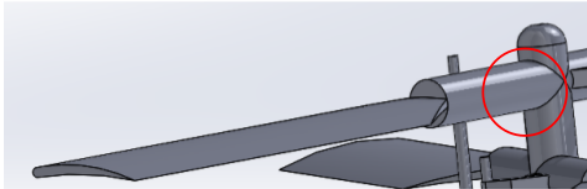


Figure 5- Tail Rotor Assembly

3.3.3 Mesh Parameters

In order to run the simulation a mesh is required, this is to allow SolidWorks to “predicts the behaviour of the model by combining the information obtained from all elements making up the model.” (Dassault Systemes , 2017) When a mesh is applied to a surface which has volume, the software applies a “3D tetrahedral solid element”, where SolidWorks then allows element sizes to be chosen for the given component. The mesh will then divide the “model into small pieces of simple shapes (elements) connected at common points (nodes). “ (Dassault Systemes , 2017)



Mesh Parameters	No. of nodes	No. of elements	No. of DOF	Total Solution Time
2mm	121,362	75,687	362,538	16 seconds
4mm	19,172	10,493	57,066	5 seconds

(Jones, 2019)

Looking at the data gathered by (Jones, 2019), it can be seen that for a 2mm mesh although the solve time took over 3 times longer it can be believed that the results will be more accurate due to the number of nodes, elements and degrees of freedom, (Dassault Systemes, 2017) states “a smaller element size in a region improves the accuracy of results in that region.”

As stated by (Lake, 2019) it is believed that the optimum mesh size should be $1/3^{\text{rd}}$ of the minimum material thickness, given the thickness of the tail rotor blade going to 0, a mesh of 2mm is being used to as accuracy will be adequate and the solve time won't be excessive, although the finer the mesh the better the accuracy of the simulation.



3.3.4 Forces Required

There are three primary forces which act upon a tail rotor blade at any time. These forces are “centrifugal force, drag and lift”, all these forces will be applied to simulate how the blade behaves under these given forces, and standard operating conditions (Rutherford, 1996).

In order to gain an accurate representation of the model under the given loads, the load values need to be calculated so they can be applied to the appropriate positions upon the tail rotor blade, (Table 2.), (Table 3.) and (Table 4.) show all the calculations which were made to gather the forces required for the simulation.

3.3.4.1 Centrifugal Force

Equation	Definition	Value	Si Units
$F_c = m \times \omega^2 \times r$	Centrifugal Force Equation	1551.45	<i>N</i>
F_c	Centripetal force	1551.45	<i>N</i>
m	Mass	0.38	<i>KG</i>
ω^2	Angular Velocity	147.76	<i>Rad/s</i>
r	Radius	0.187	<i>M</i>

Table 2 - Centrifugal Forces

It can be seen that the force which needs to be applied to the blade to model centrifugal force is 1551.45N, this is based on the mass results from SolidWorks for material based on the blade size and geometry, the angular velocity is based on 1,411rpm (Swopes, 2016), and the radius is based around the centre of mass which has been calculated using SolidWorks which can be seen within (Figure 6.) and (Figure 7.). (SolidWorks, 2019)

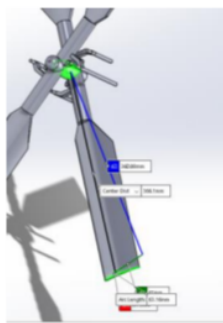


Figure 6 - Centre of Mass from assembly

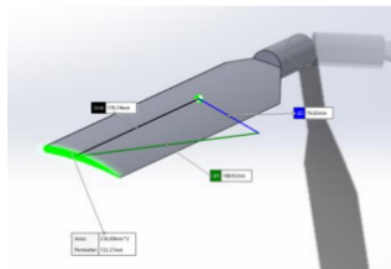


Figure 7- Centre of Mass for blade

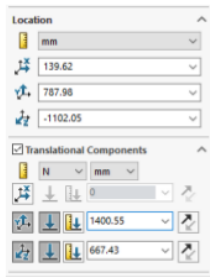


Figure 8- Centrifugal Forces (SolidWorks, 2019)

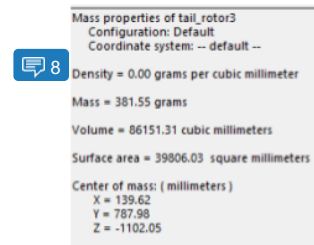


Figure 9- Centre of Mass position

Looking at (Figure 8.) and (Figure 9.) it can be seen that the locations within each coordinate system has been specified, this was found within SolidWorks, but the forces acting in each direction was found using trigonometry (SolidWorks, 2019).

$$F_Y = 1551.45 \times \cos(25.48)$$

$$F_Y = 1400.55N$$

$$F_Z = 1551.45 \times \sin(25.48)$$

$$F_Z = 667.43N$$



3.3.4.2 Drag

Equation	Definition	Value	Si Units
$F_D = C_D \times A \times \rho \times \frac{V^2}{2}$	Drag Force Equation	0.1433	<i>N</i>
F_D	Drag force	0.1433	<i>N</i>
C_D	Drag Coefficient	0.04	
A	Area	0.002	m^2
ρ	Air Density	1.225	$\frac{kg}{m^3}$
$\frac{V^2}{2}$	Tip Velocity	$\frac{54.08^2}{2}$	m/s^2

Table 3- Drag Force Equation

It can be seen in (Table 3.) that the drag force which is present on the blade is 0.1433N, although this is a minor force due to the drag coefficient of the air foil shape (NASA, 2014), and the small area in which the drag affects, the affected area can be seen within (Figure 10.) and (Figure 11.)



Figure 10 - Drag affected area 1 (Jones, 2019)

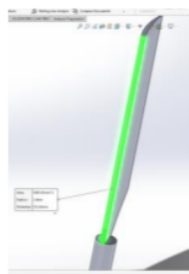


Figure 11- Drag affected area 2 (Jones, 2019)

When carrying out the simulation the force of 0.1433N will be applied to the highlighted areas to model the effects of drag upon the rotor blade.

3.3.4.3 Lift

Equation	Definition	Value	Si Units
$F_L = C_L \times A \times \rho \times \frac{V^2}{2}$	Lift Force Equation	41.55	<i>N</i>
F_L	Lift force	41.55	<i>N</i>
C_L	Lift Coefficient	1.45 (Sciencing, 2019)	
A	Area	0.016	m^2
ρ	Air Density	1.225	$\frac{kg}{m^3}$
$\frac{V^2}{2}$	Tip Velocity	$\frac{54.08^2}{2}$	m/s^2

Table 4 - Lift Force Equation

(Table 4.) shows how the calculations for identifying the lift force required has been calculated, it can be seen that the lift force present on the blade is 41.55N, (Figure 12.) shows the area in which the lift force is present. Similarly, to the drag equation, air density of 1.225kg/m³ has been used which is the density of air at 15°C (Cavcar, 2018), and the tip velocity has been calculated which is 147.76 rad/s X 0.366m which is the length of the blade.



Figure 12- Lift area of blade (Jones, 2019)

3.4 FE STUDY

In order to run the simulation of the tail rotor blade it is important that the forces discussed in (Section 3.3.4) are applied to the model, this can be seen in (Figure 13.), it can be seen that the blade has the 'Fixed Geometry' fixture at the end, the drag force being applied along the side of the blade, lift force under the blade and centrifugal force spreading across the blade from the centre of mass point.

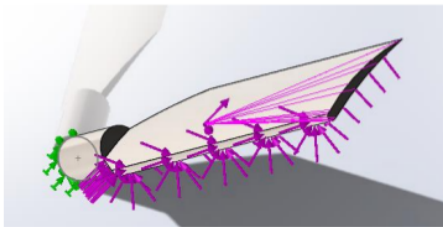


Figure 13- Applied Forces (Jones, 2019)

3.4.1 Stress

When using SolidWorks for stress simulation the given result uses von Mises' theory, this is appropriate for this study as von Mises' is most suited to "ductile materials", the scale used by SolidWorks can be seen in (Figure 14.). (Harish, 2019)



Figure 14- von Mises' Scale (SolidWorks, 2019)

Looking below the scale in (Figure 14.) it shows the 'Yield Strength of 827MN/m^2 ' when comparing this value to the maximum stress generated in the simulation which is ' 118MN/m^2 ' it can be

understood that this is well within the acceptable limits proving this material is suitable for the purpose.

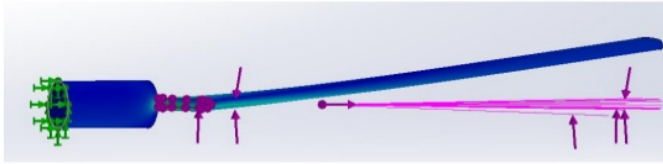


Figure 15- Stress on blade (Jones, 2019)

(Figure 15.) shows the side view of the blade under load, it can be seen from this view that the forces exerted on the blade are towards the lower end of the von Mises scale. When looking at (Figure 16.) it can be seen that under the blade is where the highest stress concentration occurs, and this is between the cylindrical surface of the blade and the air foil shape, this is what would typically be expected due to it being a straight join with no fillets/radii (Thomas, 2019).

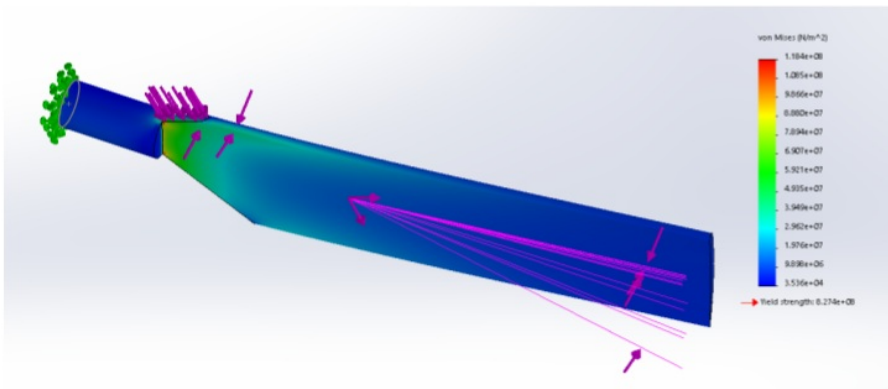


Figure 16- Underside of blade (Jones, 2019)

In order to clarify the accuracy of the results obtained by SolidWorks additional hand calculations should be carried out to ensure that the stress on the blade is as displayed in (Figure 16.).

3.4.2 Displacement

The next result which is generated by SolidWorks is the displacement of the blade under the specified loading conditions, it can be seen by the scale in (Figure 17.) that the maximum displacement of the blade is 3mm.



Figure 17- Displacement Scale (Jones, 2019)

When using the scale from (Figure 17.) and comparing that to the image portrayed in (Figure 18.) it can be seen that the maximum displacement is produced at the end of the blade, this is what would be expected as it is the furthest point from where it is fixed. This displacement isn't surprising due to the value of the forces being applied, in order to reduce the displacement a thicker air foil section and fillets could be applied to the join point, as the join point is a sharp geometry which could potentially be reduced (Thomas, 2019).

11

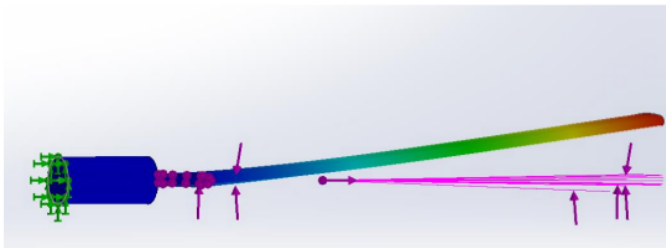


Figure 18- Side view of displacement (Jones, 2019)

3.4.3 Strain

As SolidWorks is a linear solver it uses the generated stress value to give reference for what the strain value should be, this relationship between stress and strain can be seen in (Figure 19.), the slope of the line is the “elastic modulus of the material (E).” (Dassault Systemes, 2015).

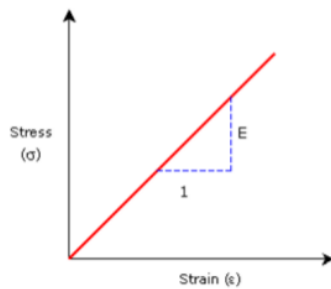


Figure 19- Stress/Strain Graph (SolidWorks, 2019)

Based on the data in (Section 3.4.1) the maximum stress of 118 Mn/m^2 gives a maximum strain of 8.806×10^{-4} given the linear relationship between the pair. The maximum strain can be seen in (Figure 20.)

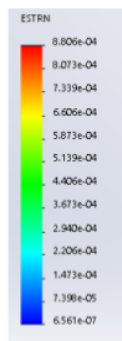


Figure 20- Strain Scale (Jones, 2019)

When using (Figure 20.) to cross reference against (Figure 21.) and (Figure 22.) it can be seen that the maximum strain upon the blade is around the same position where the maximum stress occurs, this is expected because in order to have strain in a component there has to be stress (Ormand, 2018), this agrees with (The Engineering ToolBox, 2019) who states “strain is defined as deformation of a solid due to stress”.

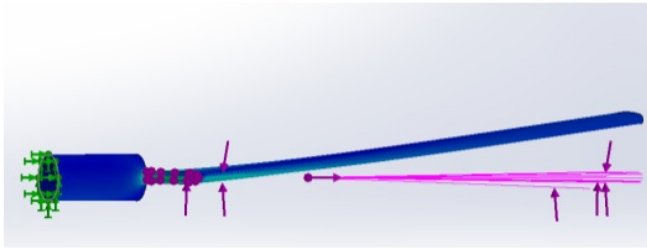


Figure 21- Side view of strain on blade (Jones, 2019)

Looking at (Figure 22.) it can be seen that the strain occurs between the cylindrical and air foil shapes of the design, which could mean that a potential redesign will reduce unneeded strain within the component.

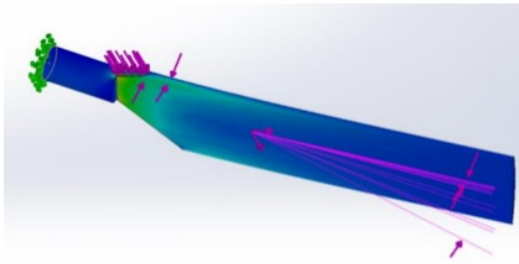


Figure 22- Underside of strain on blade (Jones, 2019)

3.4.4 Natural Frequency

Image	Mode Shape	Frequency
	1	45.996Hz
	2	220Hz
	3	300.63Hz

Table 5- Natural Frequency Studies (Jones, 2019)

When reviewing (Table 5.) it can be seen that for the 1st mode shape of the natural frequency study that the frequency in which the material naturally resonates at is 45.996Hz, this is totally expected as the actual frequency of the tail rotor blade is 25.5Hz meaning that this is safe due to the fact they vibrate at different rates (Irvine, 2003). In order to clarify the suitability of the part it would be important to carry out natural frequency studies of the surrounding parts to ensure that nothing else vibrates within the same frequency. (Reuss, 2015) States that by carrying out natural frequency studies it “helps us ensure that the natural modes of vibration are well away from environmental forcing frequencies that a design might encounter during service”, this proves that the tail rotor blade is safe for use.

3.5 PROBLEMS WITH FE STUDY

Due to SolidWorks being a linear solver the strain figure of 8.806×10^{-4} has estimated based on the  13 118 Mn/m^2 of stress which the software has generated, based on these figures the Young's Modulus equals 133.9 Mn/m^2 , where as the Young's Modulus of the material given in (Table 1.) is 104.8 Mn/m^2 , had a finer mesh been applied to the model the figure differences could potentially be a lot more substantial.

Based on the properties in (Table 1.), this shows that SolidWorks isn't the appropriate software to be using in order to carry out this simulation as in (Section 3.4.1) and (Section 3.4.3) it shows that the stress and strain figures are well within the appropriate limits, where as the strain value would actually be significantly different due to it being in the plastic deformation region meaning a non-linear solver would be required to run this simulation study. Looking at (Figure 23.) a graph showing stress against strain in a non-linear relationship shows that once the yield strength of the material is overcome the material will then act significantly different before fracturing.

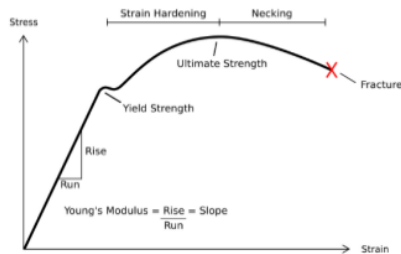


Figure 23- Stress/Strain Non-linear graph (Wikipedia, 2019)

Based on the figures obtained from SolidWorks and the hand calculations which have been carried out to establish the fact that the software which has been used is unsuitable resulting in inaccurate and questionable results.

4. CONCLUSION AND RECOMMENDATIONS

It was understood that the material which was chosen in (Section 3.3.1) was most suitable for use within the simulation based on the information gathered which justified the choice for the material, although future studies could use a composite material to generate alternative results.

The mesh parameters which were chosen were based upon running tests to understand how the mesh size effects the results and using the standard 1/3rd thickness approach, when the requirements for improved accuracy are required a finer mesh size could be applied although this could heavily increase the run time.

The forces which were calculated could be slightly inaccurate as the coefficient for lift and drag were assumed based upon the shape in which the air effects, and the air density was assumed to be at 15°C.

Based on the results obtained from the FE studies in (Section 3.4) it can be seen that SolidWorks shows that the stress and strain values obtained are safe for use and proving that the component would be suitable for use. When carrying out hand calculations this conflicts with what SolidWorks states and this is due to SolidWorks being a linear solver and in order to obtain more realistic, accurate results a non-linear solver should be used.

It can be seen within (Section 3.4.4) that the natural frequency within the first 3 modes are completely distant from what the component is likely to see once in use, meaning that the component is safe for use, although this should also be retested as the accuracy of SolidWorks has become questionable based upon the results of the FE static studies.

5. WORKS CITED

Cavcar, M., 2018. *The International Standard Atmosphere (ISA)*, Eskisehir: Anadolu University .

Chen, R., 1992. *An Exploratory Investigation of the Flight Dynamics Effects of Rotor RPM Variations and Rotor State Feedback in Hover*, California : NASA .

Dassault Systemes , 2017. *Meshing*. [Online]

Available at:

https://help.solidworks.com/2017/english/SolidWorks/cworks/c_Background_on_Meshing.htm

[Accessed 14th November 2019].

Dassault Systemes, 2015. *Stress-Strain Relation for Linear Material*. [Online]

Available at: http://help.solidworks.com/2015/English/SolidWorks/cosmosxpresshelp/c_Stress-Strain_Relation_for_Linear_Material.htm?id=750a1787e091436e8a32621569ceae92

[Accessed 16 November 2019].

Dassault Systemes, 2017. [Online]

[Accessed 14 November 2019].

Dassault Systemes, 2019. *Immovable*. [Online]

Available at:

https://help.solidworks.com/2019/english/SolidWorks/cworks/c_Immovable.htm?verRedirect=1

[Accessed 15 November 2019].

FEDERAL AVIATION ADMINISTRATION, 2019. *Helicopter Flying Handbook*. Oklahoma City: U.S. Department of Transportation FAA.

Harish, A., 2019. *What Is the Meaning of the Von Mises Stress and the Yield Criterion?*, Boston: SimScale.

Irvine, T., 2003. Apache Helicopter Noise. *Vibration Data*, 4(1), pp. 3-11.

Jones, N., 2019. *Advanced Computational Methods*. [Art] (UWTSD).

Lake, K., 2019. *Advanced Computational Methods*. Swansea: UWTSD.

NASA, 2014. *Shape Effects on Drag*. [Online]

Available at: <https://wright.nasa.gov/airplane/shaped.html>

[Accessed 15 November 2019].

Ormand, C., 2018. *Stress and Strain*. [Online]

Available at: <https://serc.carleton.edu/quantskills/methods/quantlit/stressandstrain.html>

[Accessed 16 November 2019].

Pederson, R., 2004. *The Microstructures of Ti-6Al-4V and Ti-6Al-2Sn-4Zr-6Mo and their Relationship to Processing and Properties*, Lulea: Luleå University of Technology.

Reuss, B., 2015. *Natural Frequency Analysis*, Kansas: INFLOW.

Rutherford, S., 1996. *Helicopter Inverse Simulation Incorporating An Individual Blade Rotor Model*, Sorrento: University of Glasgow.

Sciencing, 2019. *How to Calculate Lift Coefficient*. [Online]
Available at: <https://sciencing.com/calculate-lift-coefficient-7463249.html>
[Accessed 11 November 2019].

SolidWorks, 2019. *SolidWorks*, s.l.: Dassault Systemes.

Swopes, B., 2016. *30 September 1975*, California : This Day in Aviation .

The Engineering ToolBox, 2019. *Stress, Strain and Young's Modulus*. [Online]
Available at: https://www.engineeringtoolbox.com/stress-strain-d_950.html
[Accessed 16 November 2019].

Thomas, S., 2019. *Stress Concentrations: How to Identify and Reduce Them in Your Designs*. [Online]
Available at: <https://www.fictiv.com/hwg/design/stress-concentrations-how-to-identify-and-reduce-them-in-your-designs>
[Accessed 15 November 2019].

Wikipedia, 2019. *Deformation*. [Online]
Available at: [https://en.wikipedia.org/wiki/Deformation_\(engineering\)](https://en.wikipedia.org/wiki/Deformation_(engineering))  14
[Accessed 16 November 2019].

Williams, E., 2019. *Composite Materials and Helicopter Rotor Blades*, Liverpool: University of Liverpool .



FINAL GRADE

GENERAL COMMENTS

Instructor

61 /100

PAGE 1

PAGE 2



Comment 1

use past tense



Comment 2

Good executive summary

PAGE 3



5. Formatting

PAGE 4

PAGE 5



5. Proof Read

Proof read your work before you submit it.

PAGE 6



Comment 3

convert any imperial dimensions to SI units.



Comment 4

?



Comment 5

Reasonable assumption



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 6

Solution time to do what? How did the results differ?



Comment 7

This is confusing. 0/3 is 0.



Comment 8

Why is density 0?



Comment 9

where does this angle come from? Justify any figures that you use.



Comment 10

This assumes that the blade is in laminar air - do you think that this is realistic given that the blade is

This assumes that the blade is infinitesimal – do you think that this is realistic given that the blade is rotating and following another blade?

PAGE 15

QM

1. Primary(+)

Good Primary research

PAGE 16

PAGE 17

PAGE 18



Comment 11

Do you think that this is necessary? 3mm sounds reasonable.

PAGE 19

PAGE 20

PAGE 21



Comment 12

Do you think that quoting the frequency of this mode to such accuracy is appropriate give the number of assumptions that you have made?

PAGE 22



Comment 13

MN/m²

PAGE 23

PAGE 24

PAGE 25



Comment 14

consider the suitability of your sources



Comment 15

What element order have you used? Why?



Comment 16

Have you considered fatigue?

GRADING FORM: APACHE ACM

**NATHAN
JONES**

61

RESEARCH INFORMED LIT



12

KNOWLEDGE & UNDERSTANDING



12.6

ANALYSIS



17.1

PRACT APP & DEPLOYMENT



13

SKILLS FOR PROF PRAC



6.3