

Assessment of a helicopter tail rotor

by Matthew Parry

Submission date: 17-Nov-2019 02:22PM (UTC+0000)

Submission ID: 113600154

File name: 1386_Matthew_Parry_Assessment_of_a_helicopter_tail_rotor_216460_1333457470.docx (5M)

Word count: 4284

Character count: 23151

Advanced
Computational
Methods

Assessment of a Helicopter tail rotor

Matthew Parry (P151377)

P151377



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Contents

Abstract.....	3
Introduction	4
AH-64 Apache Model	5
AH-64 Apache rotor blade material	7
Forces applied to tail rotor	8
Torque Force Calculation	8
Drag Force Calculation	9
Centrifugal force Calculation	10
Evaluate tail rotor component.....	12
Finite Element Analysis	13
Mesh Geometry	13
Analysis	14
17mm Mesh	15
19mm Mesh	16
21mm Mesh	17
15mm Mesh	18
13mm Mesh	19
2mm Mesh	20
h-Adaptive mesh convergence at 10mm	21
Results.....	23
Stress Analysis.....	23
Displacement	25
Mesh Convergence	25
Frequency	27
Fatigue Study	27
Conclusion.....	29
References	31
Table of Figures.....	33

Abstract

This report looks at Finite element Analysis and investigates how an Ah-64 Apache helicopter tail rotor is loaded. The Apache model used has been taken from GragCAD.com. The model is not of the same size as the Apache. For ease of analysis the model scale has been increased to an Apache's true representation. As there is no assigned material to this model, and as the true properties of an AH-64 Apache tail rotor blade are most likely top secret, the material has been selected based on current aerospace applications. Therefore, as titanium is highly used in this sector for this analysis the tail rotor will be a solid rigid body of titanium. The analysis will focus on von Mises, displacement, frequency, fatigue findings.

Introduction

The AH-64 Apache is a helicopter designed and manufactured by Boeing. It is an attack helicopter that has an incredible capability in terms of aerobatics and its potential arsenal. The helicopter consists of a main rotor which has four blades and is powered by two engines. The main rotor spins which generates enough lift to counter act the mass of the helicopter and generates lift. To stop the helicopter body from spinning a tail rotor is utilised which generates thrust which counter acts the torque from the main rotor (Boeing, 2019).

FEA (Finite element analysis) is a computer based method of analysing materials and components on how they could cope under their specified application (Hussain, 2019). Almost all new aerospace applications would have first been researched using some form of FEA analysis. (Wichita, 2017)

This report will focus on the tail rotor and using FEA to look at how much force is acting on the blade.



AH-64 Apache Model

The model of the AH-64 Apache is not of the same scale as the physical aircraft. This can cause issues when applying analysis on Solidworks. Also, there would be far too many assumptions which would make this study pointless and of no meaning to the result discovered.

The Apache has a rotor span of 14.640m. The model has a rotor span of 3.830m.

$$\frac{14640}{3830} = 3.822454309$$

5. Narrative(-)

By dividing the two values we can use this quantity to scale the Solidworks model to suit the physical properties of an Apache which should make the analysis result more accurate.

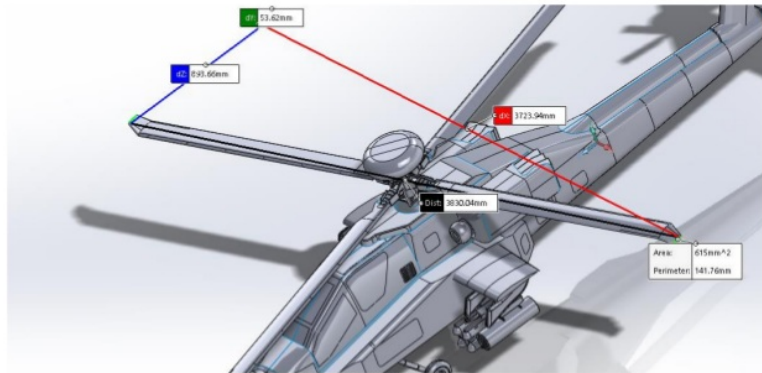


Figure 1. Measurement of Solidworks model main rotor distance (Solidworks, 2019)

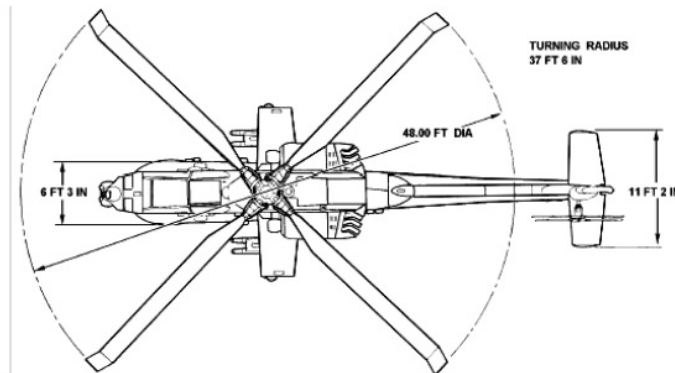


Figure 2. Overview of an AH-64 Apache dimensions (Cooke, 2001)

Assessment of a Helicopter tail rotor

By using insert, features, scale, and highlight the entire model so that each element is included in the rescaling. Scale about the origin using uniform scaling and use the value calculated  7
3.822454308 (Onwubolu, 2013).



Figure 3. Scale feature on Solidworks (Solidworks, 2019)

By using this method, the model scale has been increased to that on an actual Apache helicopter.

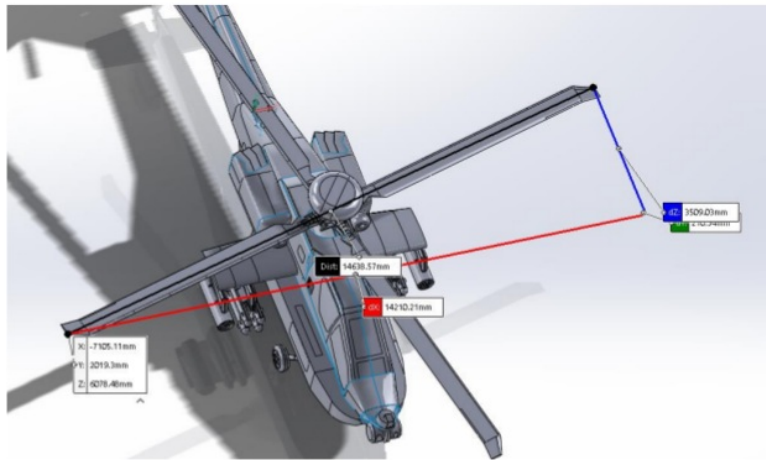


Figure 4. Updated model scale (Solidworks, 2019).

AH-64 Apache rotor blade material

The Apache rotor blade comprises of five stainless steel arms called spars. The spars are encased by a fiberglass skeleton. The trailing edge of each blade is protected with a durable graphite composite material. The leading edge of the blade is made from titanium. The titanium must be strong enough to endure skirmishes with trees and other minor obstructions. The Apache requires this strength in materials to be able to sneak up on its enemies and attack by surprise (Harris, 2019).  8

For this analysis the tail rotor will be a solid body material. The material will be titanium. This has been selected because of its high strength to weight ratio, resistance to corrosion and its high temperature characteristics (TMS Titanium , 2013).  9

Property	Value	Units
Elastic Modulus	1.1e+11	N/m ²
Poisson's Ratio	0.3	N/A
Shear Modulus	4.3e+10	N/m ²
Mass Density	4600	kg/m ³
Tensile Strength	235000000	N/m ²
Compressive Strength		N/m ²
Yield Strength	140000000	N/m ²

Figure 5. Material properties (Solidworks, 2019).

Forces applied to tail rotor

For this analysis there will be three force applied to the rotor blade. These are force generated from the torque from the main rotor, centrifugal and drag. Helicopters are subject to four general forces during flight. These are thrust, weight, drag, and lift. The lift force is generated by the main rotor blades which are driven by the engine. When lift is created the helicopter's, body is spun in the opposite direction to the rotor blades. This is described in Newtons third law which states that for every action there is an equal and opposite reaction. To counter this the tail rotor is used to create enough torque to stop the main rotor spinning the body (Harris, 2019).

Torque Force Calculation

The Apache has two T700 engines that deliver 1491Kw of power (General Electrics , 2019).

The tail rotor spins at a speed of 300 RPM (Newkirk, 2007) (khanacademy, 2019).

$$Torque = \frac{Power}{Speed}$$

$$Torque = \frac{9.5488 \times 1491 \times 2}{300} = 94915.07 \text{ NM}$$

To calculate the force applied to the tail rotor we must use $F = \frac{\tau}{r}$

Where

τ = Torque applied from the two engines in NM

r = length of the moment arm in M

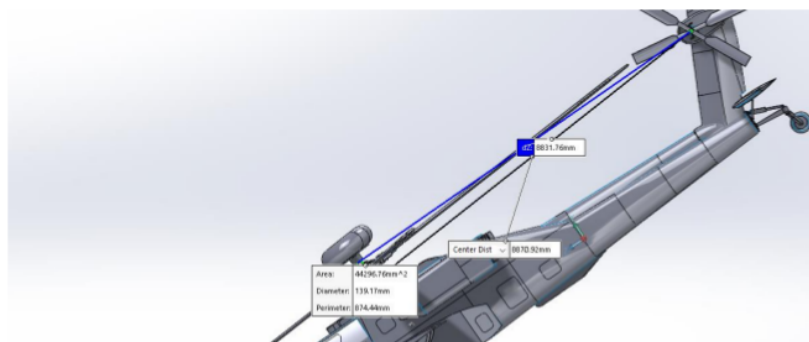


Figure 6. length of the moment arm (Solidworks, 2019)

Assessment of a Helicopter tail rotor

Please note that because the main rotor is constantly spinning for this analysis the angle will be assumed as 90° therefore the $\sin 90^\circ = 1$

Therefore

$$F = \frac{94915.07}{8.870} = 10700 \text{ NM} \quad \text{10}$$

There are four blades on the tail rotor so the force acting on one is

$$\frac{10700}{4} = 2675 \text{ NM}$$

Drag Force Calculation

Drag force is a force that opposes the movement of a helicopter through the air and is created when lift is generated. Drag must be overcome by the engines that turn the main and tail rotors. Drag always acts parallel to the relative wind (FAA, 2019) (khanacademy, 2019).

$$\text{Drag Force} = C_d \times A \times \frac{\rho V^2}{2}$$

Where

$C_d = 0.04$ is the coefficient of drag 11

$A = 0.02942114$ is the surface area in m^2

$\rho = 1.225$ is the density of air in kg/m^3

$V = 57$ rads/sec is the tangential velocity of the blade in m/s

$$F_d = 0.04 \times 0.02942114 \times \frac{1.225 \times 57^2}{2}$$

$$F_d = 2.342 \text{ N}$$

Centrifugal force Calculation

To calculate the centrifugal force, we must first convert the speed of the tail blade from RPM to angular velocity measured in rads/sec (khanacademy, 2019).

$$\text{Angular velocity} = \frac{\text{RPM}}{60} \times 2\pi$$
$$\frac{1500}{60} \times 2\pi = 157.08 \text{ rads/sec}$$

$$\text{Centrifugal Force} = M \times V^2 \times r$$

Where

M = 22.13332 is the mass of the rotor blade in kg

V = 157.08 is the angular velocity of the rotor in rads/sec

R = 0.701155 is the radius of the blade m

$$\text{Centrifugal Force} = 22.13332 \times 157.08^2 \times 0.701155$$

$$\text{Centrifugal Force} = 382830.3551 \text{ N}$$

$$\text{Centrifugal Force} = 382.83 \text{ KN}$$

We must now resolve the forces in both the y and z axis to find the resultant force. The angle of the rotor blade can be found by drawing a simple rectangle and measuring from the blade to the rectangle from the horizontal.

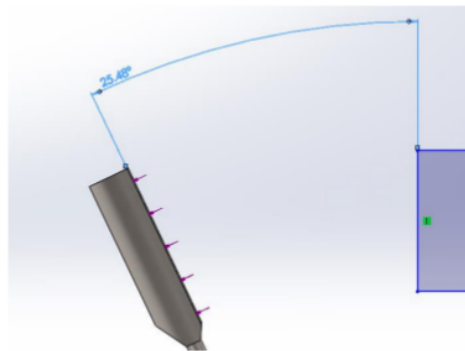


Figure 7 Angle of blade (Solidworks, 2019)

Assessment of a Helicopter tail rotor

$$Y \text{ axis} = 382830.3551 \times \cos 25.04 = 346849.1N$$

$$Z \text{ axis} = 382830.3551 \times \sin 25.04 = 162033.3N$$

Using solid works, we can use mass properties to the centre of mass in each axis.

$$x = 533.70mm$$

$$y = 3012.01mm$$

$$z = -4212.55mm$$

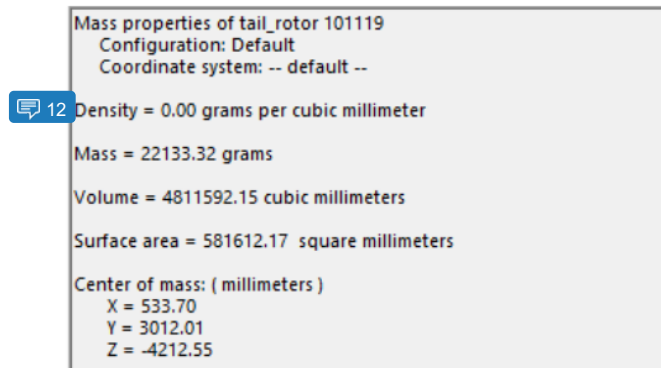


Figure 8 Mass properties of tail blade (Solidworks, 2019)

Evaluate tail rotor component

The area of contact which the drag force will be applied has been calculated using the measuring tool on Solidworks.

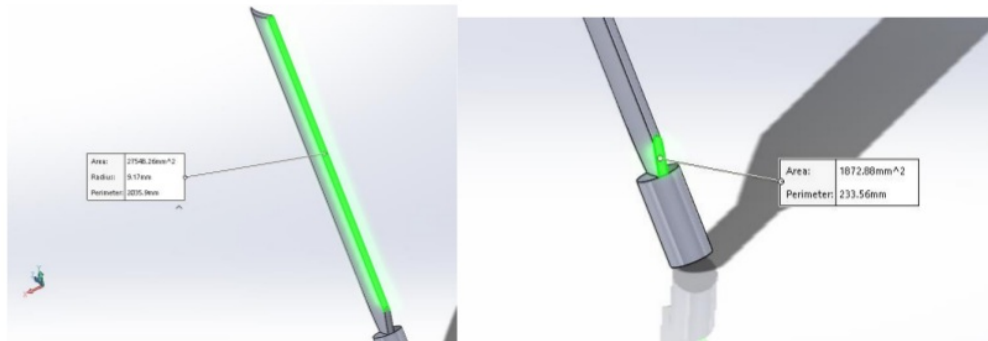


Figure 9 Area calculation of rotor blade in contact with drag force (Solidworks, 2019)

The tail blade has been measured using a measuring tool on Solidworks. The length from the tip of the blade to the centre point of the tail blade assembly is 1402.31mm

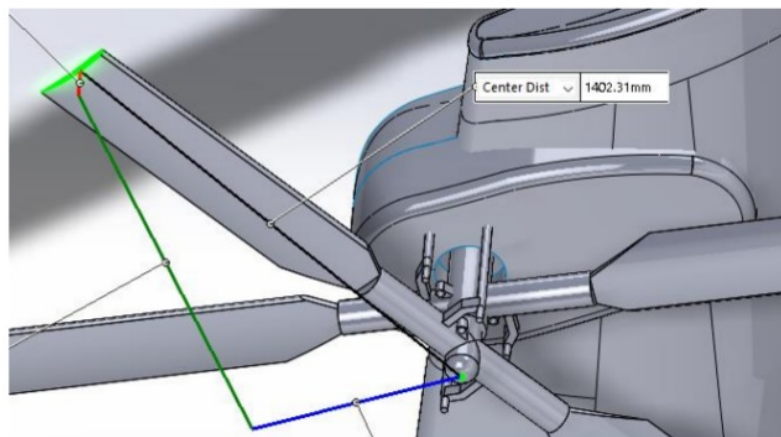


Figure 10 Measurement of tail rotor (Solidworks, 2019)

Finite Element Analysis

FEA is a numerical method that is modelled by a computer that is used to analysis stresses in materials and components. It is extremely useful on otherwise difficult geometries that would be difficult to calculate. By analysing a computer aided design FEA can predict the failure of the material or component and present unknown stresses by displaying areas under theoretical stress (Onwubolu, 2013).

Mesh Geometry

Materials and components that are analysed using FEA are based on a solid geometry which are used to define the boundary condition of the material or component. They are of tetrahedral geometry and are either first order which has four nodes and second order which consists of ten nodes (Onwubolu, 2013).

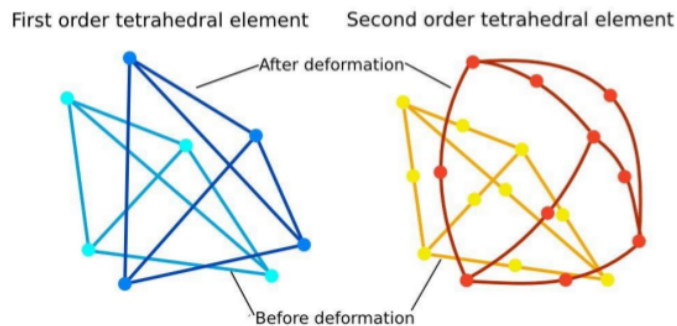


Figure 11. First and second order element (Hussain, 2019)

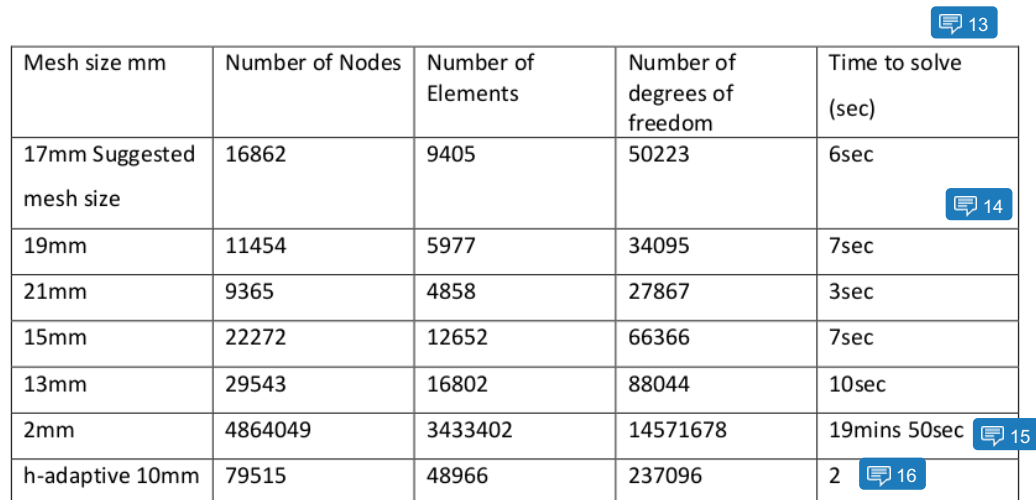
The distance between meshing and the number of nodes dictate the amount of calculation that are required to complete the analysis. As a result, the time taken to complete the analysis can be too long so designers balance between time to solve and how much information is required to complete the study (Onwubolu, 2013).

Analysis

For this analysis the initial meshing size will be used from the suggested size given by Solidworks and round up to the nearest number. Then from this number the meshing will increase and decrease in increments 2mm by two values either side of the recommended mesh size from Solidworks.

For a greater understanding of how the complex calculations are completed using this system on Solidworks the blade will also run analysis using a 2mm mesh. This will be used to determine the time taken and the difference in results against the other mesh sizes.

Mesh refinement can play an important part of successfully using SolidWorks simulation. Selective mesh refinement can help the user obtain highly accurate results without consuming large quantities of time waiting for calculations to be resolved. Adaptive meshing is a feature used to iteratively vary the mesh size automatically for your model. SolidWorks simulation uses two different methods to achieve this. These are called h-adaptive and p-adaptive meshing. H-adaptive meshing physically modifies the size of the mesh node in areas of the model where smaller mesh is required. Whereas p-adaptive meshing adjusts the polynomial order of the mesh to enhance accuracy of the analysis (Hawk Ridge Systems, 2013).



Mesh size mm	Number of Nodes	Number of Elements	Number of degrees of freedom	Time to solve (sec)
17mm Suggested mesh size	16862	9405	50223	6sec
19mm	11454	5977	34095	7sec
21mm	9365	4858	27867	3sec
15mm	22272	12652	66366	7sec
13mm	29543	16802	88044	10sec
2mm	4864049	3433402	14571678	19mins 50sec
h-adaptive 10mm	79515	48966	237096	2

Figure 12. Table of results of FEA analysis (Solidworks, 2019)

Assessment of a Helicopter tail rotor

17mm Mesh

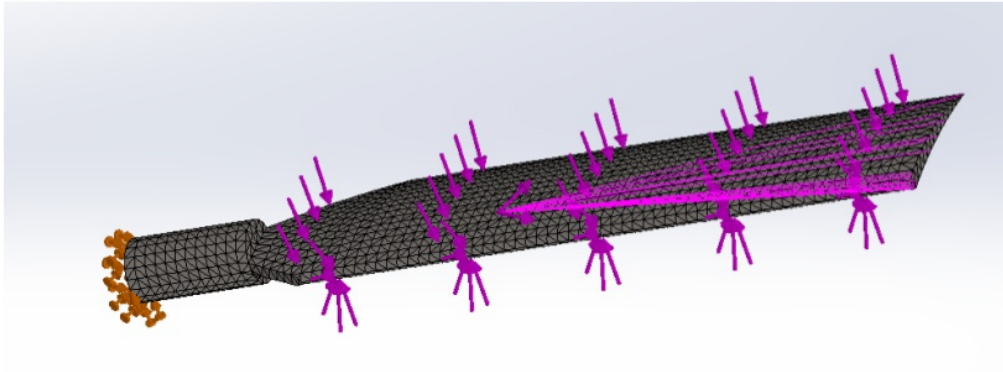


Figure 13. 17mm mesh (Solidworks, 2019).

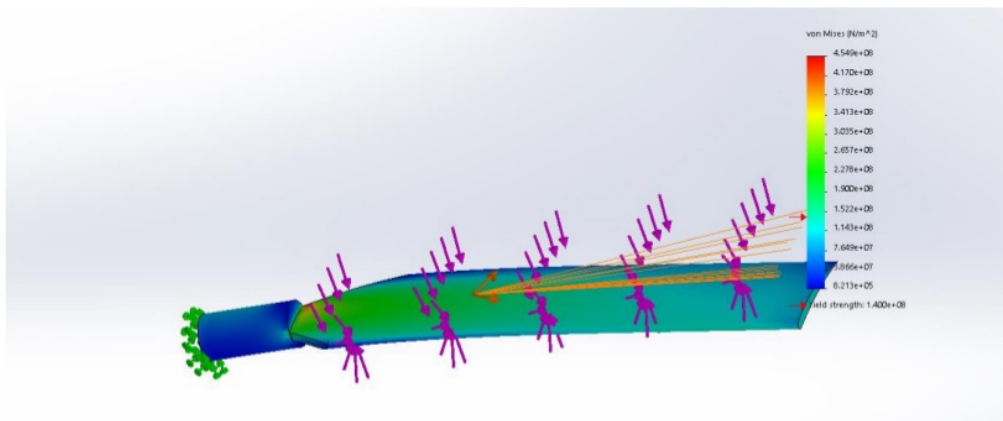


Figure 14. 17mm mesh von Mises results (Solidworks, 2019)

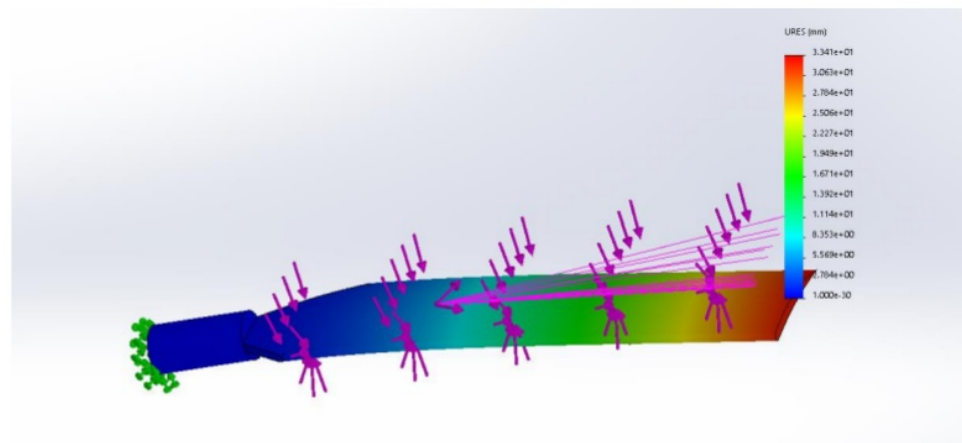


Figure 15. 17mm mesh displacement results (Solidworks, 2019).

19mm Mesh

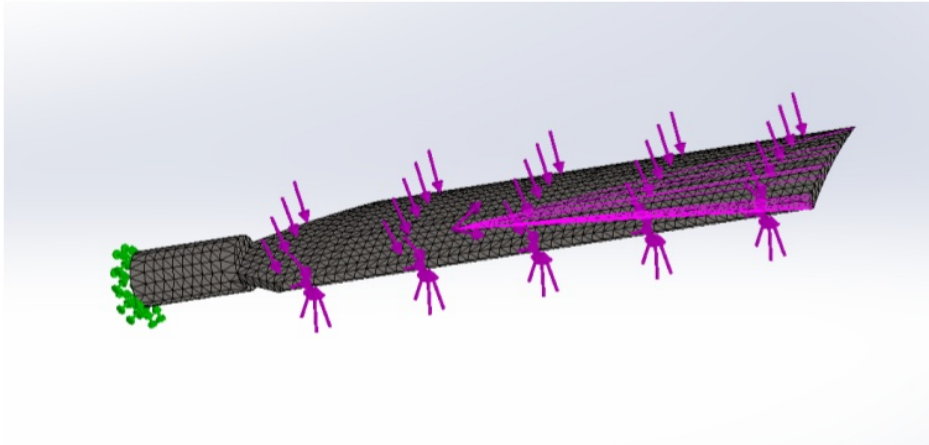


Figure 16. 19mm mesh (Solidworks, 2019).

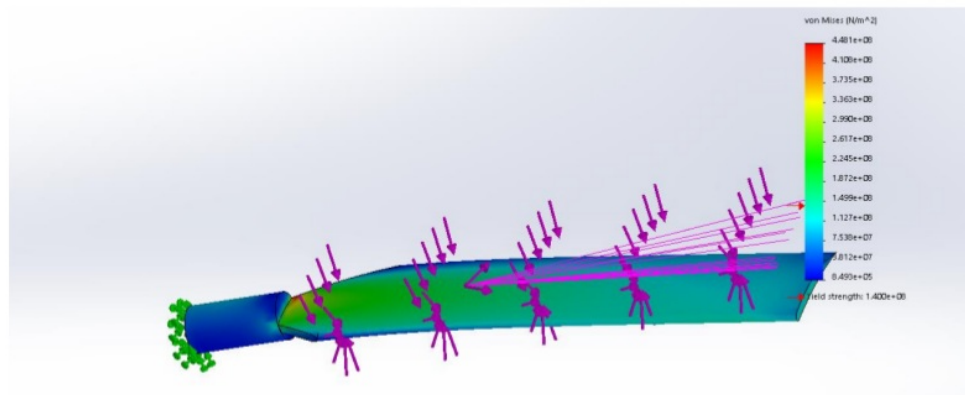


Figure 17. 19mm mesh von Mises results (Solidworks, 2019).

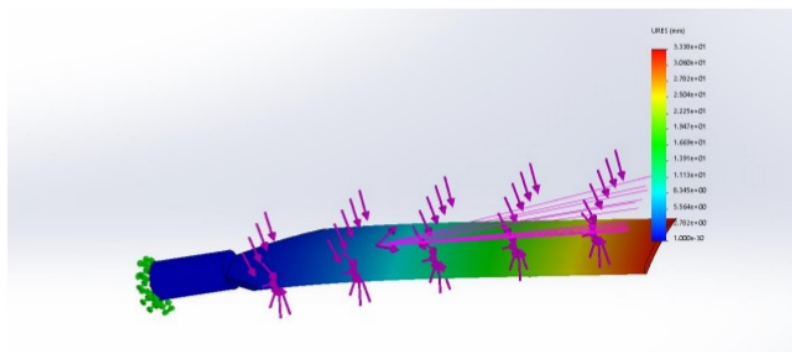


Figure 18. 19mm mesh displacement results (Solidworks, 2019).

Assessment of a Helicopter tail rotor

21mm Mesh

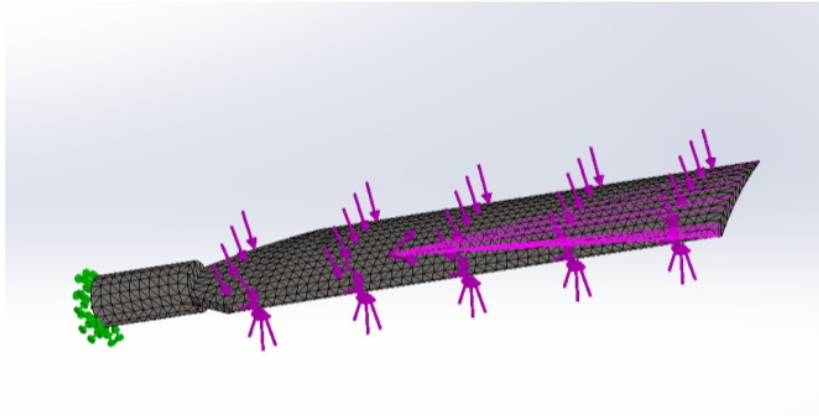


Figure 19. 21mm mesh (Solidworks, 2019).

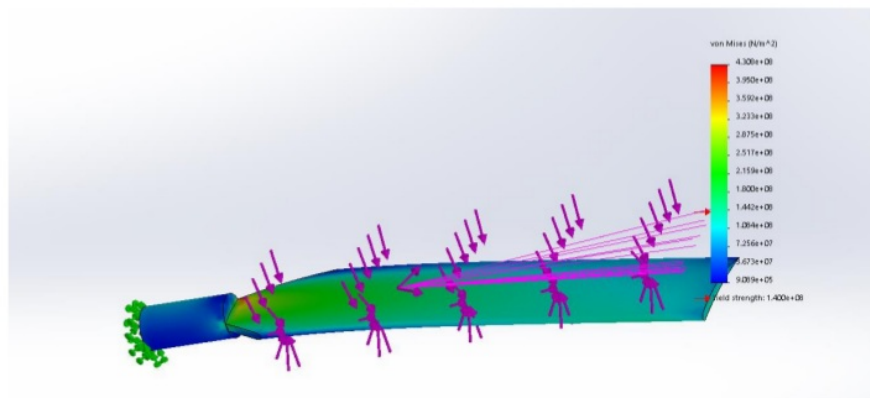


Figure 20. 21mm mesh von Mises results (Solidworks, 2019).

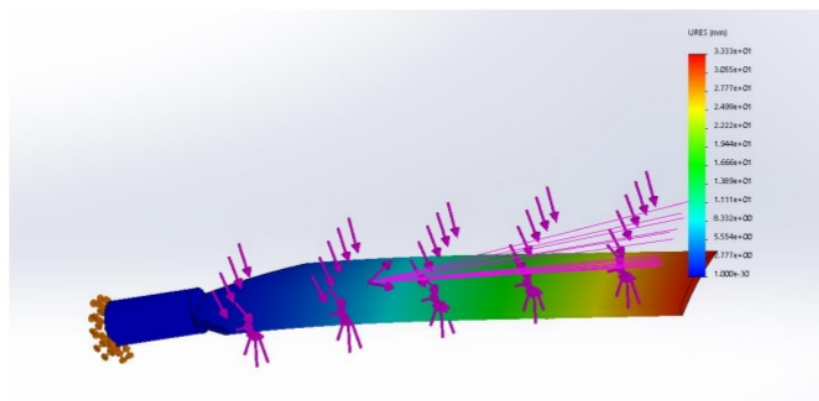


Figure 21. 21mm mesh displacement results (Solidworks, 2019).

Assessment of a Helicopter tail rotor

15mm Mesh

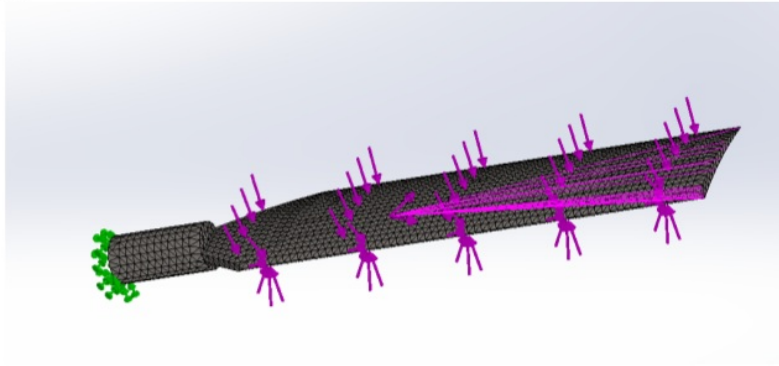


Figure 22. 15mm mesh (Solidworks, 2019).

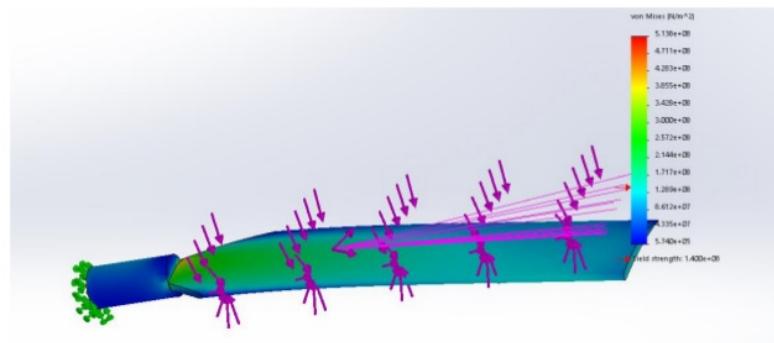


Figure 23. 15mm mesh von Mises results (Solidworks, 2019).

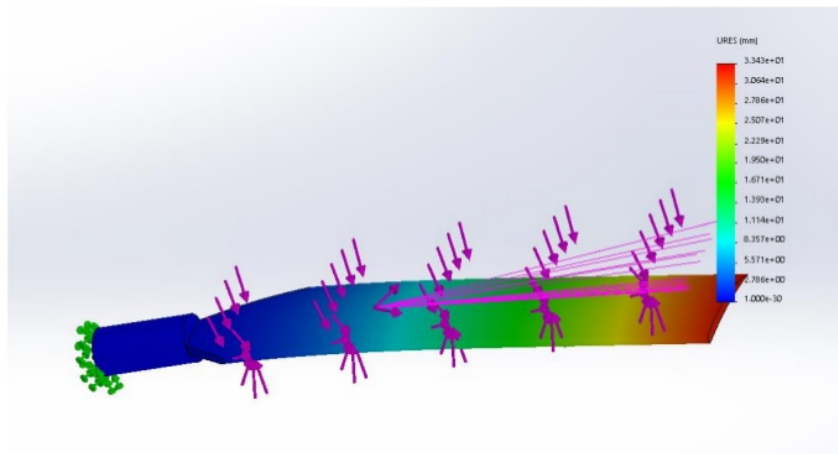


Figure 24. 15mm mesh displacement results (Solidworks, 2019).

Assessment of a Helicopter tail rotor

13mm Mesh

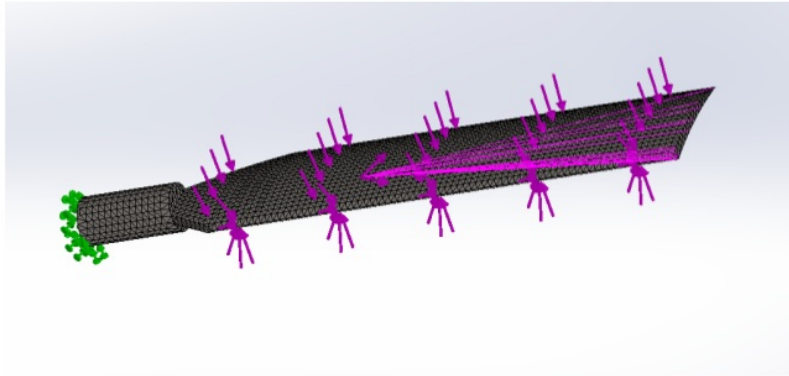


Figure 25. 13mm mesh (Solidworks, 2019).

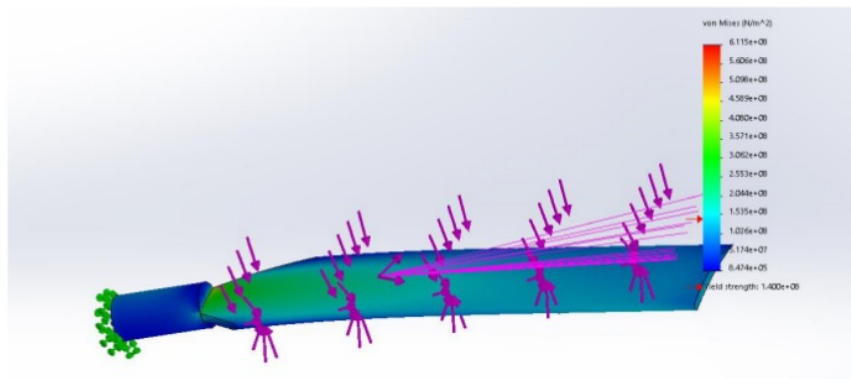


Figure 26. 13mm mesh von Mises results (Solidworks, 2019).

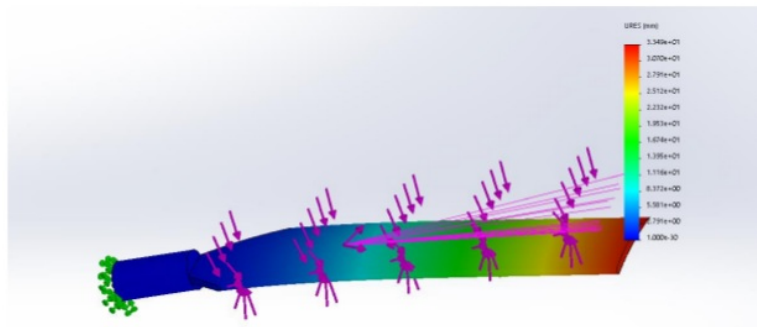


Figure 27. 13mm mesh displacement results (Solidworks, 2019).

Assessment of a Helicopter tail rotor

2mm Mesh

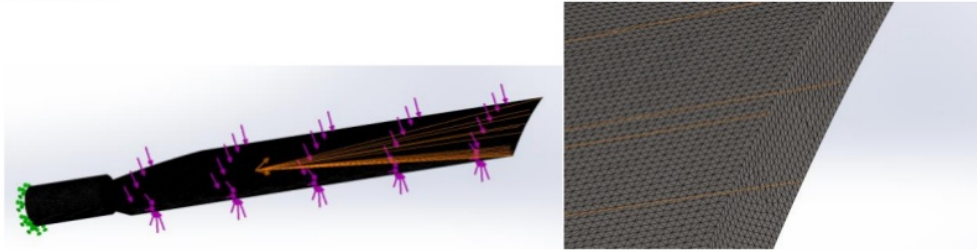


Figure 28. 2mm mesh (Solidworks, 2019)

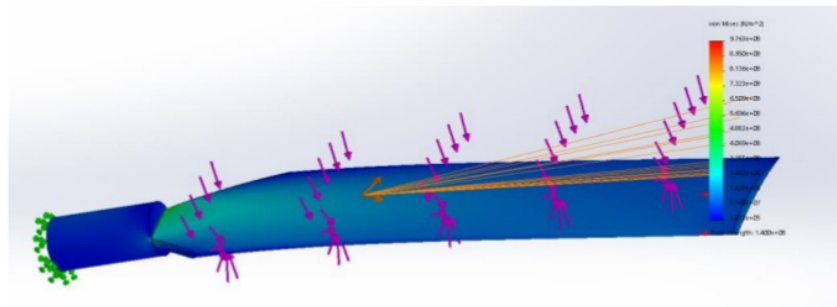


Figure 29. 2mm mesh von Mises results (Solidworks, 2019).

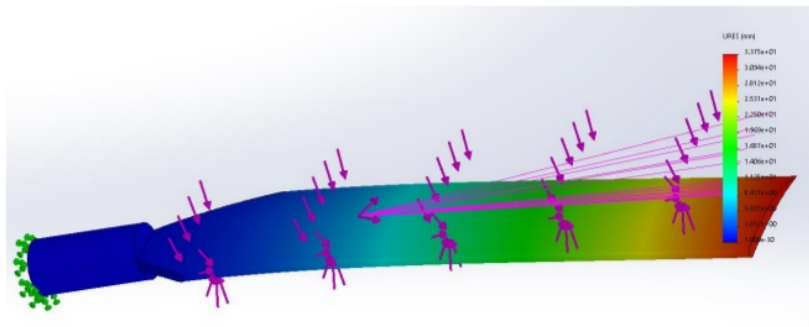


Figure 30. 2mm mesh displacement results (Solidworks, 2019).

h-Adaptive mesh convergence at 10mm

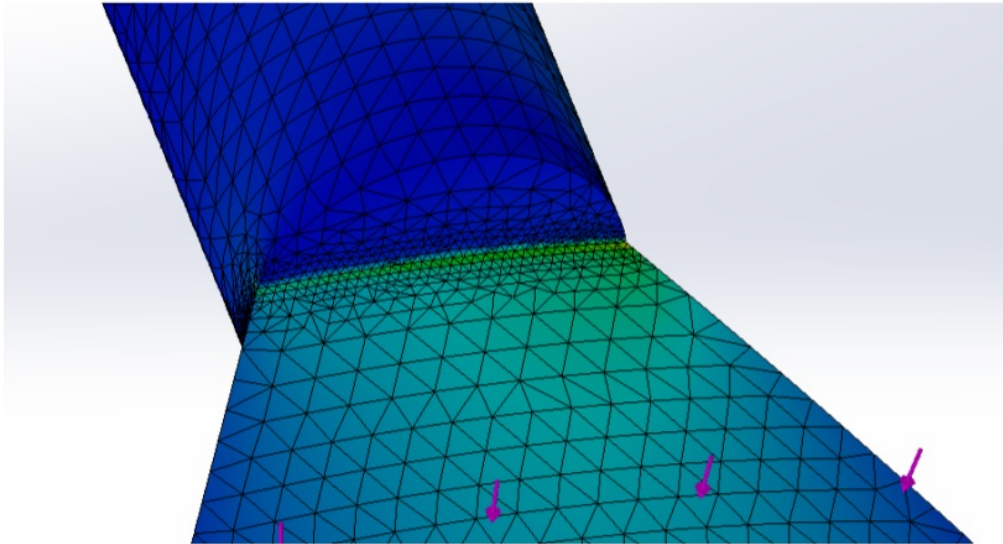


Figure 31. h-Adaptive mesh results showing how mesh size has decreased around high stress area (Solidworks, 2019).

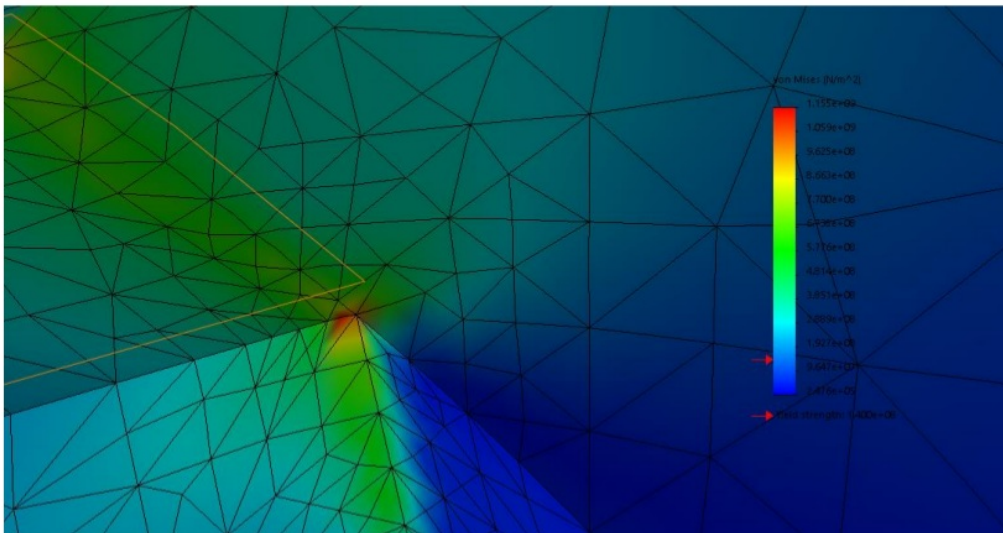


Figure 32. h-Adaptive mesh showing high stress area (Solidworks, 2019).

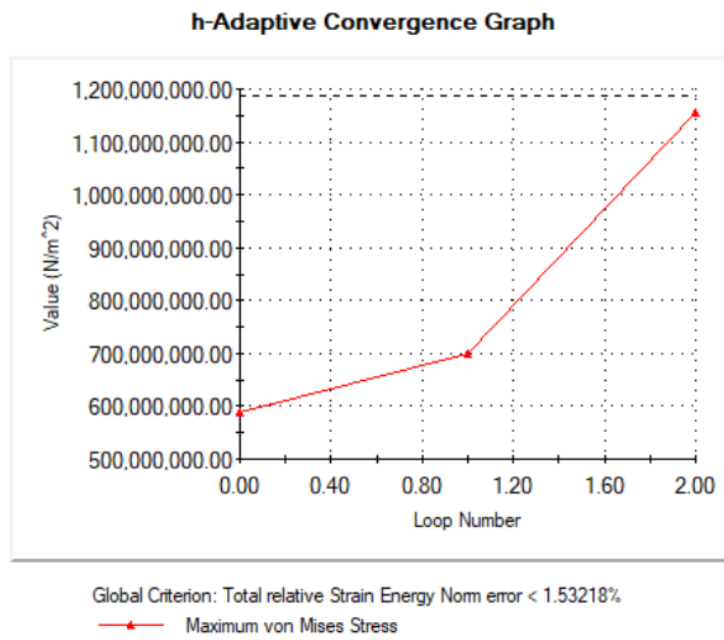


Figure 33. h-Adaptive convergence graph (Solidworks, 2019).

18

Results

Stress Analysis

From the results of the FEA analysis it is clear to see that the tail rotor blade has failed and could not endure the three  19 that were applied during the simulation. The Yield strength of the material (Titanium) is 140 Mpa (Solidworks, 2019). However, during all studies that were run the yield strength was exceeded through out most of the material.

On each study there appears to be high stress point located on the same area of the tail rotor blade. As the mesh size decreases and the number of nodes increase the yield value amplifies. This can be seen in Fig 14, 17, 20, 23, 26, and 29. The results also show that there is a high stress area in the centre of the blade which does not spread through to the outer area. The force generated from the torque of the main rotor is acting on the whole of the blade. However, as discussed this does not seem to be the case based on the results. This could be in view of the fact that the rotor is spinning so the force is not acting on the whole surface area. Additionally, the stress appears to be less concentrated towards the end of the tail rotor. This may possibly be due to the centrifugal force that is acting on the end of the blade.

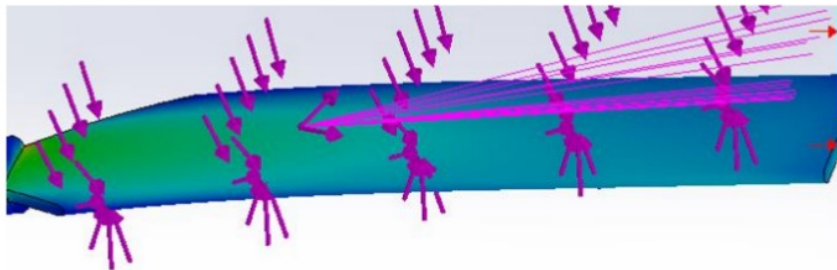


Figure 34. Stress concentration acting through rotor blade (Solidworks, 2019)

The tail rotor spinning at 1500 RPM must overcome drag. For this analysis drag was calculated at 2.342N and from the study it would give the impression that even at this low value the blade has exceeded its yield strength. In spite of this, the thrust force acting on the blade could be increasing the stress on the blade and may give the impression of the drag force causing the stress.

Assessment of a Helicopter tail rotor

There appears to be a consistent display of stress on each of the analysis run with all mesh sizes. As the tail rotor shaft finishes and extends out to the main blade there is a congregation of stress on the narrow part of the material. This stress is in the region of the max stress calculated from the study and can be seen in all mesh sizes. This suggests a weakness on this part of the rotor blade which can be described as a stress concentration.

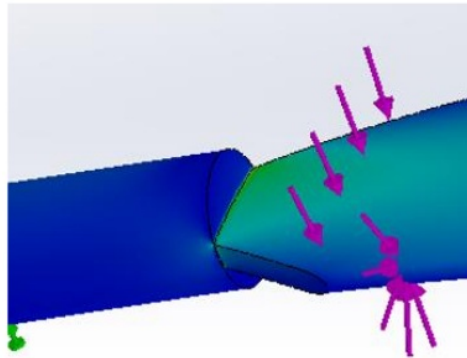


Figure 35. Material weakness showing the highest concentration of stress (Solidworks, 2019).

Stress concentration is a contained concentration of stress that is significantly higher than normal and is due to sudden changes in a materials geometry (Engineers Edge, 2019).

The geometry of the tail rotor has sudden changes in the shape of the blade. As the shaft ends and the blade starts to fan out the material changes abruptly.

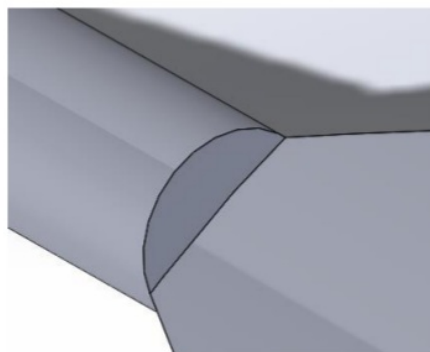


Figure 36. Tail rotor blade (Solidworks, 2019).

Assessment of a Helicopter tail rotor

From the analysis this could suggest that the materials geometry could be a cause of the rotor blade failing. As this is the weak area this allows the stress applied by the three forces to be exacerbated and increased through the material.

Mesh size mm	Material Yield Strength	Max Stress	Max Displacement
17mm	140 Mpa	454.9 Mpa	3.34mm
19mm	140 Mpa	448.1 Mpa	3.338mm
21mm	140 Mpa	430.8 Mpa	3.33mm
15mm	140 Mpa	513.8 Mpa	3.343mm
13mm	140 Mpa	611.5 Mpa	3.349mm
2mm	140 Mpa	976.3 Mpa	3.375mm
h-adaptive Convergence with 10mm mesh	140 Mpa	1155 Mpa	3.372mm

20

Figure 37. Table of results of FEA analysis

Displacement

From the analysis the displacement results are roughly of the same magnitude. As the max stress increases the displacement also increases. However, with the mesh at 21mm and 2mm there is a difference of max stress 545.5 Mpa but the max displacement has a difference of 0.045mm. The max stress difference is more than double that of the 21mm mesh result so the displacement result does seem to be not accurate.

Mesh Convergence

As discussed earlier in the report h-adaptive feature in Solidworks focuses the mesh concentration around the highest stress area. This can be seen in the image below. As with the other analysis the results have indicated a high stress concentration around the abnormal geometry between the shaft and blade. Using this method, the max stress calculated was 1155 Mpa with a displacement of 3.372mm. The max stress is located in the stress concentration area which could suggest that the location of the nodes is over analysing the simulation and have returned inaccurate results.

Assessment of a Helicopter tail rotor

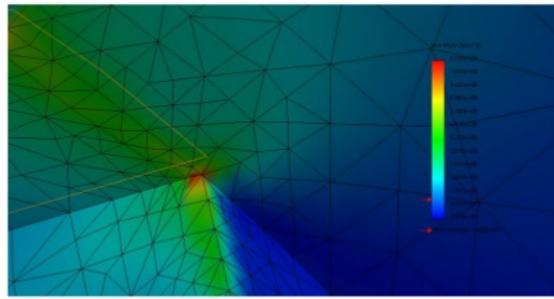


Figure 38. h-Adaptive mesh showing high stress area (Solidworks, 2019).

The high concentration area results from the h-adaptive can be seen throughout the abnormal geometry area and is roughly 576 Mpa. This result is close to that of the 15mm mesh. Though, this does not resemble any similarities in the two results.

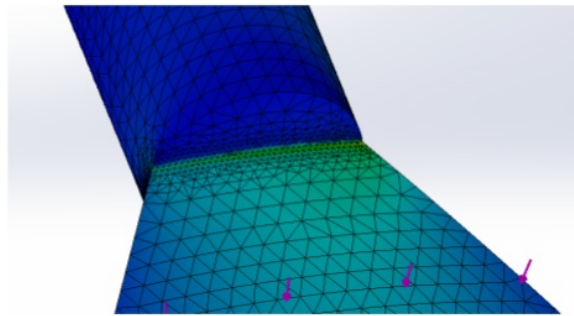
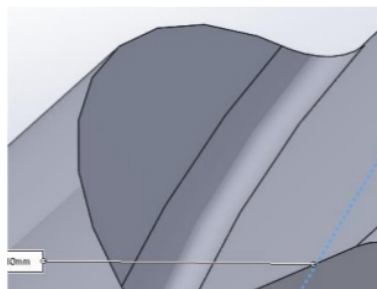


Figure 39. h-Adaptive mesh showing high stress area (Solidworks, 2019)

To reduce the stress concentration the rotor blade could be edited to remove sharp geometry change between the shaft and the rotor blade. Adding a fillet to the rotor blade could reduce or remove the stress concentration from this area of the blade. However, this may not guarantee a reduction in yield stress throughout the rotor blade.



Good

Figure 40. Fillet applied to rotor blade (Solidworks, 2019)

Frequency

The natural frequency of the Apache can be calculated using the RPM divided by 60 sec (Lewis, 2017). This gives a value of 25Hz. The results from the frequency study has revealed a natural frequency of 12.062Hz. By multiplying 12.062 by 60 sec this gives an RPM Of 732. This suggests that at that speed vibration will occur. As the speed increases the vibration may reduce. This could be due to the forces that are acting on it during flight.

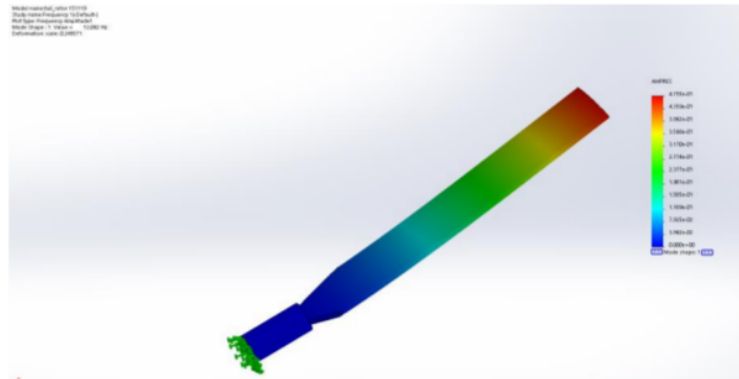


Figure 41. Natural frequency results (Solidworks, 2019).

Fatigue Study

The results from the fatigue study have calculated that the rotor will fail in two places. The fatigue study results can be analysed by using the key where red refers to a high life cycle and blue is the lowest life cycle. The blue areas on this analysis have given the rotor blade a life cycle of 100 cycles. Assuming that one cycle is one flight the results suggest that the rotor blade could fail at 100 flights which makes the blade unfit for this application.

Good

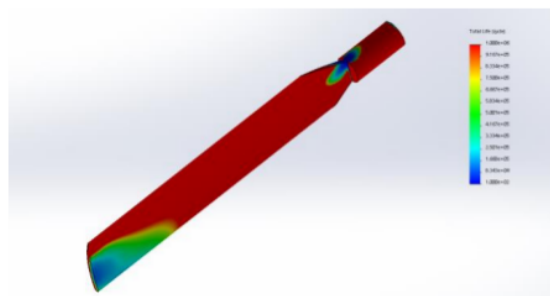


Figure 42. Total life cycle results (Solidworks, 2019).

Assessment of a Helicopter tail rotor

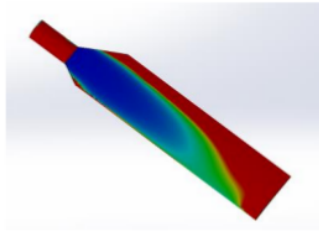


Figure 43. Total life cycle results (Solidworks, 2019).

Conclusion

The results from this FEA study are conclusive. The tail rotor blade failed to withstand the applied load, and as a result experienced stress greater than the materials yield strength. Additionally, according to the frequency analysis the tail rotor would fail at 100 cycles thus not making the blade fit for purpose. However, the results are by no means black and white. This whole analysis has been made and calculated on information that has been assumed and unsubstantiated. Engineers are required to assume some information in the design phase of a project. Never the less, the assumptions that are made must be backed up with their knowledge, experience, calculations or facts that help make their theories more realistic (Rogers, 2000).

The assumption made for this analysis that could suggest why the rotor failed initially focus on the selected material. As discussed earlier no material data sheet for the Apache was available so as an alternative titanium was selected due to its wide range of applications in aerospace industry. Despite this, the material did not withstand the loading that was applied to it and ultimately failed.

On the other hand, it is worth considering that the forces that were used may not be accurately representative of the loading on an actual Apache. Assumptions were made based on the properties and dimensions obtained from the CAD model. For the drag force the surface area was taken from the CAD model, and for centrifugal the mass of the material was taken from the CAD model. Therefore, these assumptions could explain that perhaps the material could withstand the actual forces that are applied to an Apache but in this analysis the forces applied are greater thus causing the tail to fail.

Conversely, the CAD model was scaled up to the true size of an Apache helicopter. This was achieved by taking the dimensions of the main rotor blade and upscaling the model so that the two dimensions were in the same order. Except, with further research, the size of the tail rotor did not match that of the scaled-up CAD model thus not giving the tail rotor the required properties and dimensions of that of an actual Apache.

For a factual FEA analysis of the Apache the following information would be required to gain a truer set of findings.

- Material properties.
- CAD model with an accurate description portrayal of the rotor blade properties and dimensions.
- An understanding of how and where the loads are directed at the rotor blade.

Matthew Parry
Advanced Stress Analysis & FEA
P151377

Assessment of a Helicopter tail rotor

- An understanding of when the highest force concentration is acting on the Apache. Such as during a combat situation.

With this information the FEA study would have a better chance of satisfying the critique for this report.

References

- Boeing, 2019. *AH-64 Apache Attack Helicopter*. [Online]
Available at: <https://www.boeing.com/history/products/ah-64-apache.page>
[Accessed 08 11 2019].
- Cooke, G. W., 2001. *AH-64 APACHE (McDONNELL DOUGLAS)*. [Online]
Available at: <https://www.inetres.com/gp/military/ar/rotor/AH-64.html>
[Accessed 14 11 2019].
- Engineers Edge, 2019. *Stress Concentration Fundamentals*. [Online]
Available at:
https://www.engineersedge.com/material_science/stress_concentration_fundamentals_9902.htm
[Accessed 16 11 2019].
- FAA, 2019. *Aerodynamics of Flight*. [Online]
Available at:
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/media/hfh_ch02.pdf
[Accessed 10 11 2019].
- Firdaus, J., Koto, M., Ishak, I. & Ammoo, M., 2014. *Aeronautical Engineering*. 1st ed. Pekanbaru: UTM.
- General Electrics , 2019. *T700-701D turboshaft engines*. [Online]
Available at: <https://www.geaviation.com/sites/default/files/datasheet-T700-701D.pdf>
[Accessed 10 11 2019].
- Gibbings, D. & Cox, T., 2019. *The Tail Rotor*. [Online]
Available at: <https://www.helis.com/howflies/tailrot.php>
[Accessed 10 11 2019].
- Han, D. & Barakos , G. N., 2016. Variable-speed tail rotors for helicopters with variable-speed main rotors. 1(1), pp. 443-448.
- Harris, T., 2019. *How Apache Helicopters Work*. [Online]
Available at: <https://science.howstuffworks.com/apache-helicopter.htm>
[Accessed 10 11 2019].
- Hawk Ridge Systems, 2013. *ADAPTIVE MESHING IN SOLIDWORKS SIMULATION*. [Online]
Available at: <https://hawkridgesys.com/blog/simulation-adaptive-meshing>
[Accessed 15 11 2019].
- HEADQUARTERS, DEPARTMENT OF THE ARMY, 1984. *TECHNICAL MANUAL, OPERATOR's MANUAL FOR HELICOPTER, ATTACK,AH-64A APACHE*. Washington: United States Army.
- Helicopters and Aircraft, 2016. *Rotor Solidity*. [Online]
Available at: <http://heli-air.net/2016/02/11/rotor-solidity/>
[Accessed 10 11 2019].

- Hussain, A., 2019. *When should I use a second order mesh*. [Online]
Available at: <https://www.simscale.com/forum/t/when-should-i-use-a-second-order-mesh/25899>
[Accessed 15 11 2019].
- khanacademy, 2019. *Khan Academy*. [Online]
Available at: <https://www.khanacademy.org/>
[Accessed 14 11 2019].
- Lewis, K., 2017. *How to Convert Hertz to Motor Rpm*. [Online]
Available at: <https://sciencing.com/convert-hertz-motor-rpm-5728009.html>
[Accessed 16 11 2019].
- Newkirk, M. C., 2007. *PROCESS IMPROVEMENTS FOR THE AH-64 TAIL ROTOR*, Ohio : AIR FORCE INSTITUTE OF TECHNOLOGY .
- Onwubolu, G., 2013. *Computer Aided Engineering Design with Solidworks*. 1st ed. London: Imperial College Press.
- Peeters, W., 1991. *AH-64A Apache Attack Helicopter*. 1st ed. O'Fallon: VLS Corporation .
- Penn Engineering , 2018. *AH-64 Apache Helicopter Analysis*. [Online]
Available at: <https://www.seas.upenn.edu/~dhawkes/ah-64-apache-helicopter-analysis/>
[Accessed 10 11 2019].
- Rogers, R. C., 2000. *Engineering Assumptions: Reasonable Diligence and Best Judgment at Issue*. [Online]
Available at: <https://trid.trb.org/view/670207>
[Accessed 16 11 2019].
- Solidworks, 2019. *Solidworks*, Vélizy-Villacoublay: Dassault Systèmes.
- Swopes, B. R., 2019. *This day in aviation*. [Online]
Available at: <https://www.thisdayinaviation.com/tag/ah-64-apache/>
[Accessed 10 Apache Ah-64 11 2019].
- The British Institute of Non-destructive Testing, 2015. *Non-Destructive Testing (NDT) –*. [Online]
Available at: <https://www.bindt.org/admin/Downloads/Apprenticeship-Guidance-Document.pdf>
[Accessed 2019 10 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 16 11 2019].
- TMS Titanium , 2013. *Titanium and the Aerospace Industry*. [Online]
Available at: <https://tms titanium.com/titanium-and-the-aerospace-industry/>
[Accessed 14 11 2019].
- Wen Technology, 2019. *Power calculation*. [Online]
Available at: [AH-64 Apache Helicopter Analysis](#)
[Accessed 10 11 2019].

Wichita, K. S., 2017. *Aerospace FEA Modeling Techniques*. [Online]
Available at: <https://www.nafems.org/events/nafeas/2017/aerospace-modeling-americas/>
[Accessed 16 11 2019].

Table of Figures

Figure 1. Measurement of Solidworks model main rotor distance (Solidworks, 2019)	5
Figure 2. Overview of an AH-64 Apache dimensions (Cooke, 2001)	5
Figure 3. Scale feature on Solidworks (Solidworks, 2019)	6
Figure 4. Updated model scale (Solidworks, 2019)	6
Figure 5. Material properties (Solidworks, 2019)	7
Figure 6. length of the moment arm (Solidworks, 2019)	8
Figure 7 Angle of blade (Solidworks, 2019)	10
Figure 8 Mass properties of tail blade (Solidworks, 2019)	11
Figure 9 Area calculation of rotor blade in contact with drag force (Solidworks, 2019)	12
Figure 10 Measurement of tail rotor (Solidworks, 2019)	12
Figure 11. First and second order element (Hussain, 2019)	13
Figure 12. Table of results of FEA analysis (Solidworks, 2019)	14
Figure 13. 17mm mesh (Solidworks, 2019)	15
Figure 14. 17mm mesh von Mises results (Solidworks, 2019)	15
Figure 15. 17mm mesh displacement results (Solidworks, 2019)	15
Figure 16. 19mm mesh (Solidworks, 2019)	16
Figure 17. 19mm mesh von Mises results (Solidworks, 2019)	16
Figure 18. 19mm mesh displacement results (Solidworks, 2019)	16
Figure 19. 21mm mesh (Solidworks, 2019)	17
Figure 20. 21mm mesh von Mises results (Solidworks, 2019)	17
Figure 21. 21mm mesh displacement results (Solidworks, 2019)	17
Figure 22. 15mm mesh (Solidworks, 2019)	18
Figure 23. 15mm mesh von Mises results (Solidworks, 2019)	18
Figure 24. 15mm mesh displacement results (Solidworks, 2019)	18
Figure 25. 13mm mesh (Solidworks, 2019)	19
Figure 26. 13mm mesh von Mises results (Solidworks, 2019)	19
Figure 27. 13mm mesh displacement results (Solidworks, 2019)	19
Figure 28. 2mm mesh (Solidworks, 2019)	20
Figure 29. 2mm mesh von Mises results (Solidworks, 2019)	20
Figure 30. 2mm mesh displacement results (Solidworks, 2019)	20
Figure 31. h-Adaptive mesh results showing how mesh size has decreased around high stress area (Solidworks, 2019)	21
Figure 32. h-Adaptive mesh showing high stress area (Solidworks, 2019)	21
Figure 33. h-Adaptive convergence graph (Solidworks, 2019)	22
Figure 34. Stress concentration acting through rotor blade (Solidworks, 2019)	23
Figure 35. Material weakness showing the highest concentration of stress (Solidworks, 2019)	24
Figure 36. Tail rotor blade (Solidworks, 2019)	24
Figure 37. Table of results of FEA analysis	25

Matthew Parry
Advanced Stress Analysis & FEA
P151377

Assessment of a Helicopter tail rotor

Figure 38. h-Adaptive mesh showing high stress area (Solidworks, 2019).....	26
Figure 39. h-Adaptive mesh showing high stress area (Solidworks, 2019).....	26
Figure 40. Fillet applied to rotor blade (Solidworks, 2019)	26
Figure 41. Natural frequency results (Solidworks, 2019).....	27
Figure 42. Total life cycle results (Solidworks, 2019).....	27
Figure 43. Total life cycle results (Solidworks, 2019).....	28

Assessment of a helicopter tail rotor

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

PAGE 1

PAGE 2

QM

5. Presentation(+)

Generally your presentation is good

PAGE 3



Comment 1

GrabCAD



Comment 2

Good explanation of how you have dealt with this issue



Comment 3

are they?



Comment 4

why Von mises?

PAGE 4



Comment 5

use past tense



5. Narrative(-)

Your report should be written in third person narrative.



Comment 6

convert imperial measurements to SI units



Comment 7

a step by step guide as to which buttons you pressed is not necessary.



Comment 8

You stated in your abstract that this was top secret!



Comment 9

This is a reasonable assumption for this analysis.



Comment 10

Nm



Comment 11

where have you got this coefficient from?



Comment 12

Why is your density zero?



Comment 13

Time to solve what? How did the results differ?



Comment 14

You have already stated that this is in seconds - there is no need to quote this again



Comment 15

You have stated in your table heading the the units are seconds, yet quoted the results here using minutes and seconds, this is confusing. 1190



Comment 16

2 what - you are not being consistent with your units.



Comment 17

When displaying images such as this, you should display the mesh so that the influence of the underlying elements on the results can be understood.



Comment 18

what is this graph showing me - comment on this in the text.

Comment 19



MPa

PAGE 24

PAGE 25



Comment 20

it would have been better to show this information graphically.

PAGE 26



Good

PAGE 27



Good

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33



Comment 21

be consistent - why do some of these figure numbers have . after them and some do not?

PAGE 34

GRADING FORM: APACHE ACM

MATTHEW
PARRY

69.70

RESEARCH INFORMED LIT



13.6

KNOWLEDGE & UNDERSTANDING



13.4

ANALYSIS



21.9

PRACT APP & DEPLOYMENT



13.8

SKILLS FOR PROF PRAC



7