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DESIGN OPTIMIZATION FOR IMPROVING THE FREE VIBRATION CHARACTERISTICS OF HELICOPTER MAIN ROTOR BLADES

Hariramakrishnan.L

Lecturer, Department of Aeronautics, St. Theresa International College, Thailand

Abstract

Helicopter rotor blade design is one of the most complex tasks in the aviation industry. During the design, the designer needs to concentrate on the vibration because excessive vibration may lead to affect the performance, design and stability of the helicopter. In this research, carry out the vibration analysis of the helicopter rotor blades in order to determine the vibration-natural frequency with respect to using the different lengths of the blades, based on the number of blades, speeds and different materials. so, this research helps identify the suitable rotor blade for the BELL 403 helicopter. In addition, designers can improve the strength and stability of the rotor blades and it could be helpful for further improvement with dynamic analysis. The rotor blade model is designed by the CATIA V5 design software and ANSYS – Finite Element Analysis (Vibration Analysis) is used to analyse the designed rotor blades.

Keywords: Rotor blades, Vibration- Natural Frequency, ANSYS – Finite Element Analysis.

INTRODUCTION

The dynamic characteristics analysis of the rotor blade is mainly involved in the calculation of natural frequency and modal shape. The objective is to calculate the natural frequency and modal shape of the rotor blade to control those frequencies and avoid resonance at rotational speed, thus the vibration level of the helicopter may reduce. There are many methods to compute the natural frequency of the rotor blade, but a 'non-uniform' beam is the best to calculate the vibration characters for the complex structures, three-dimension elasticity with minus twist angle.

MODELLING

AIRFOIL SELECTION

BELL 403 Helicopter rotor blade design is taken to improve the performance by reducing the natural frequency over the blades and using appropriate material. In this helicopter main rotor is designed with the NACA0012 series. This aerofoil can create more lift force and stability of its symmetric aerofoil characteristics.

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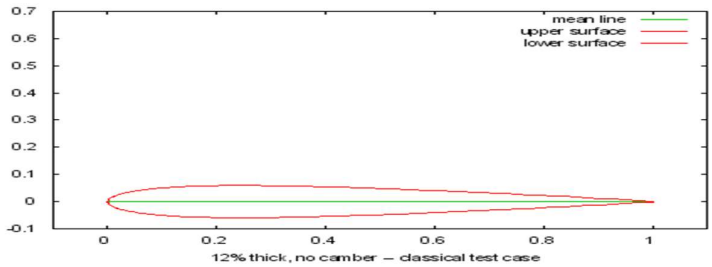

NACA0012 AIRFOIL

MODEL DESCRIPTION

The modal test data record is used to draw the NACA0012 aerofoil by the designing software. The computer-aided designing software CATIA software is preferable to design dimensional drawing models. The research concept is to minimize the natural frequency vibration to give a better performance during flight operation. The model has been developed by CATIA with various dimensions for different sizes with different shapes, like 3,4 blades, with one hub. The length of the helicopter's main rotor blade is specified through the standards like 5.433m, 6.400m, and 7.010m in a specified unit. And the rotor blades are rotating at different speeds of 1000RPM and 1500RPM. The volume of the three blades for the first length the volume 6400mm (1.1122676E9mm3), and for the second length of the rotor blade is 7010mm (1.883457E9mm3). Normally, the hub diameter for all blades is 600mm, the shaft diameter is 200mm and the angle between the 3blade is 120° and for the 4-blade angle is 90°.

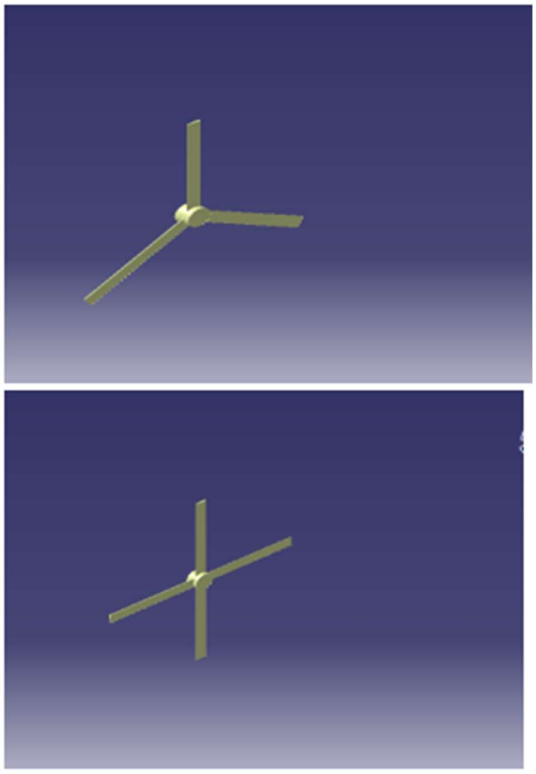

Fig. - CATIA Model Of 3 and 4 Blades

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MATERIAL SELECTION AND PROSPERITIES

The helicopter rotor blade is one of the primary parts which is a high-speed rotational component. The high rotational speed produces the vibration force to the rotor and the hub. Thus, vibration plays a hazardous role in the rotor blade design. So, the rotor blade material should withstand that vibration during the high rotation and the same time need to consider the weight and the cost. In this research, Aluminium and Carbon-fiber-reinforced polymer (CFRP). The material properties are the following:

S.No.	Properties	Materials	Values	
1.	Young's Modulus	Al	73.1Gpa	
		CFRP	E_1 = 14.7Gpa E_2 = 10.3Gpa E_3 = 10.3Gpa	G_{12} = 7Gpa G_{23} = 3.7Gpa G_{31} = 7Gpa
2.	Poisson Ratio	Al	0.334	
		CFRP	$1/m_1 = 0.27$, $1/m_2 = 0.54$, $1/m_3 = 0.27$	
		Ti	0.30	
3.	Density	Al	2768Kg/m^3	
		CFRP	1600Kg/m^3	

Vibration Analysis

Vibration analysis is helpful to identify the mechanical components issues by the vibration frequency. Through this analysis, we can determine the material behaviour like stress, strain and deformation at a different rotational speed. This research focused on the static analysis of the rotor blades under different conditions. The ANSYS analysis software is used for this research.

Aluminium Blades

Aluminium is one of the suitable materials for rotor blades which has good thermal conductivity and corrosion resistance and low density. So, the chosen aluminium blades are analysed in different conditions

Three blades speed of 1000 RPM with 5.433m

The Deformation and von-mises stress are Shown in figure. The Deformation value is 0.030143m, von-mises stress value is 6.1228E^8 N/m^2 For Speed in 1000RPM, Length5.433m.

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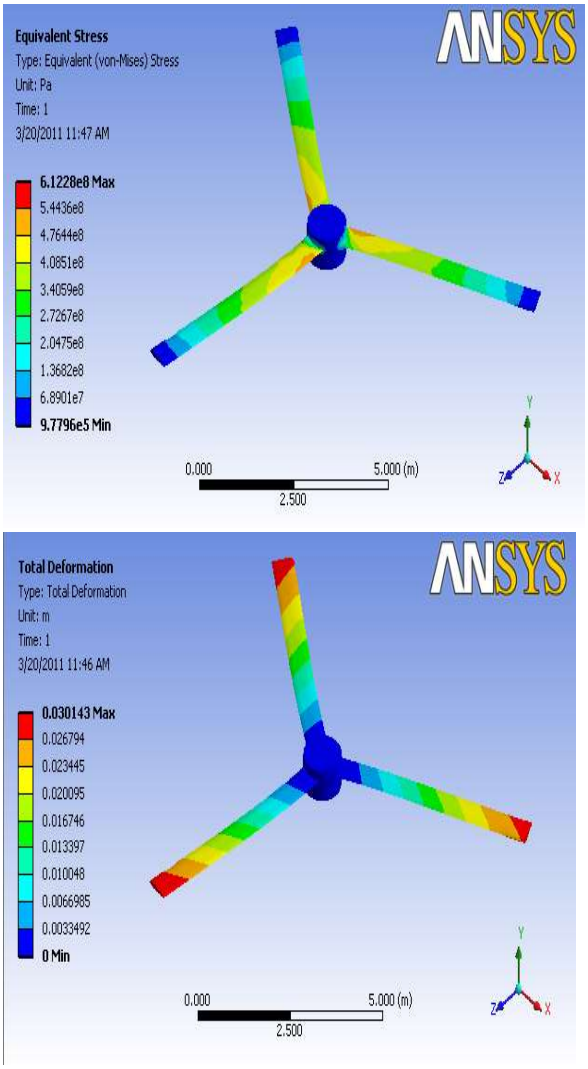

Fig: . Deformation and Von mises stress Aluminium at 1000RPM

Three blades speed of 1000RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.056889m von-mises stress value is $7.1611E^{8}N/m^{2}$ For Speed in 1000RPM, Length6.40m

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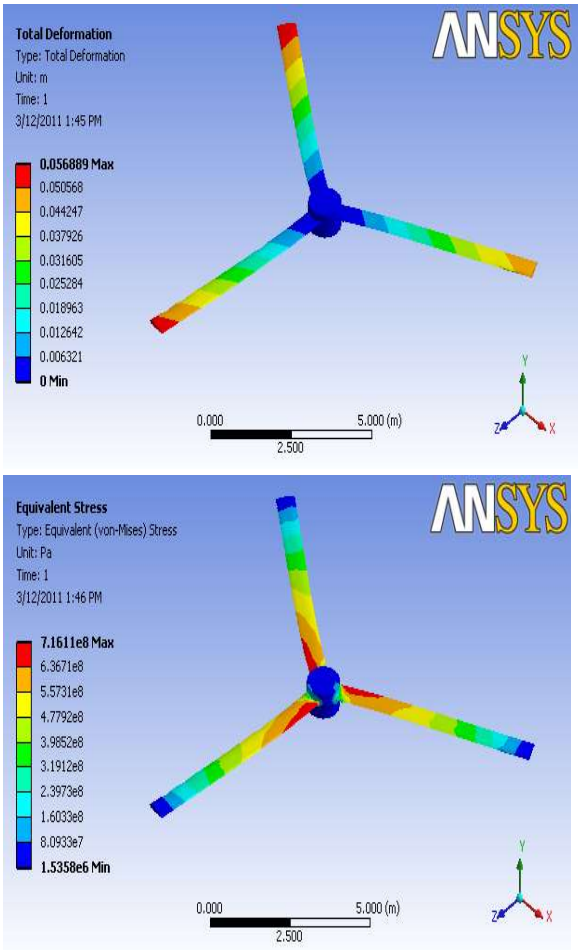

Fig: 4. Deformation and Von mises stress Aluminium at 1000RPM

Three blades speed of 1000RPM with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.08631m von-mises stress value is $8.7402E^{8}N/m^{2}$ For Speed in 1000RPM, Length7.01m

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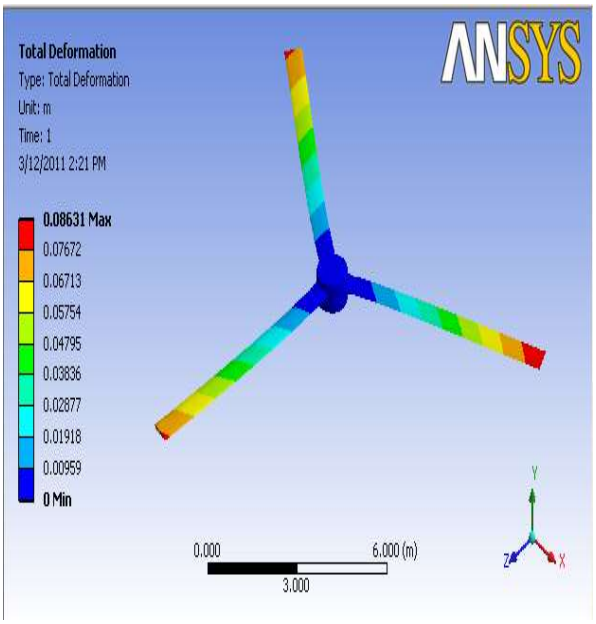

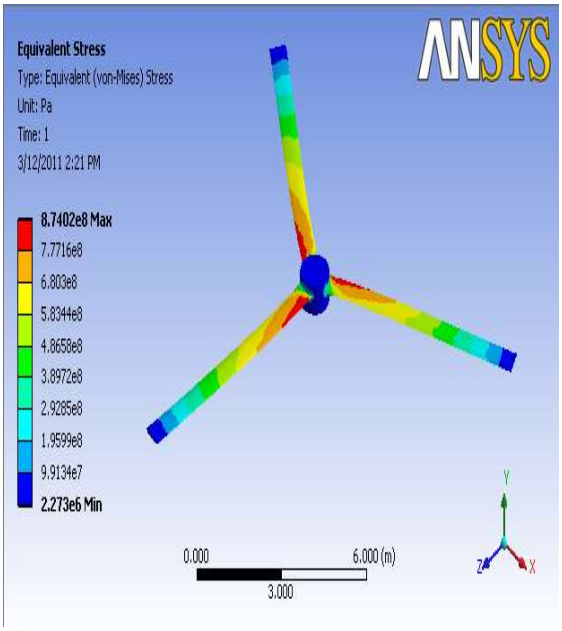

Fig: . Deformation and Von mises stress Aluminium at 1000RPM

Three blades speed of 1500 rpm with 5.433m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.067392m von-mises stress value is $1.3689E^{9}N/m^{2}$ For Speed in 1500RPM, Length5.433m.

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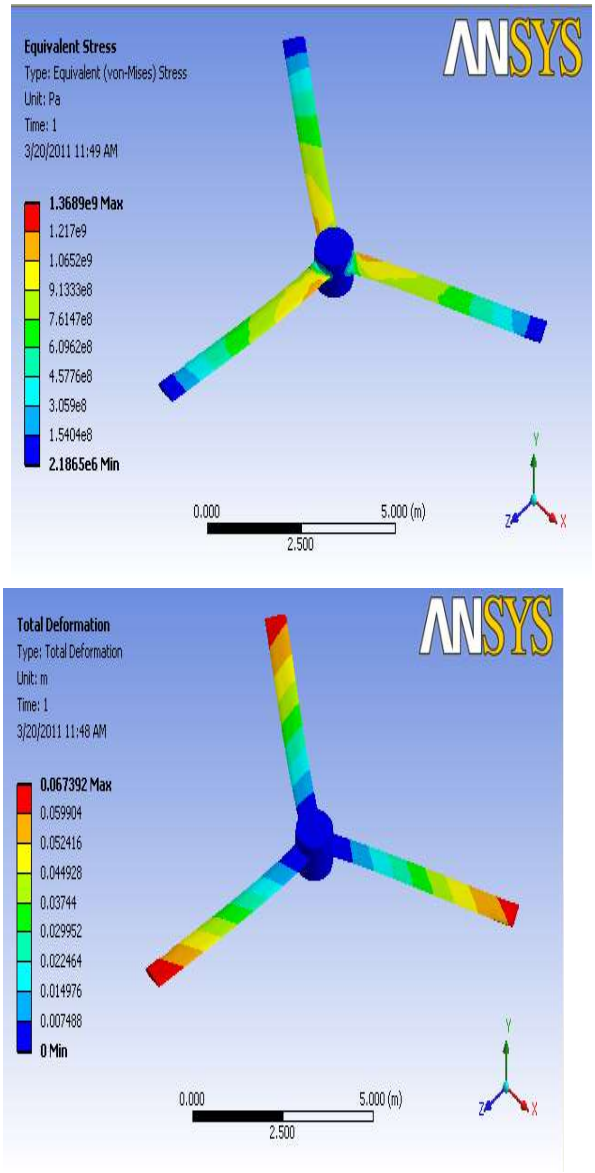

Fig: . Deformation and Von mises stress Aluminium at 1500RPM

Three blades speed of 1500 RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.12719m, von-mises stress value is $1.601E^{9}N/m^{2}$ For Speed in 1500RPM, Length6.40m

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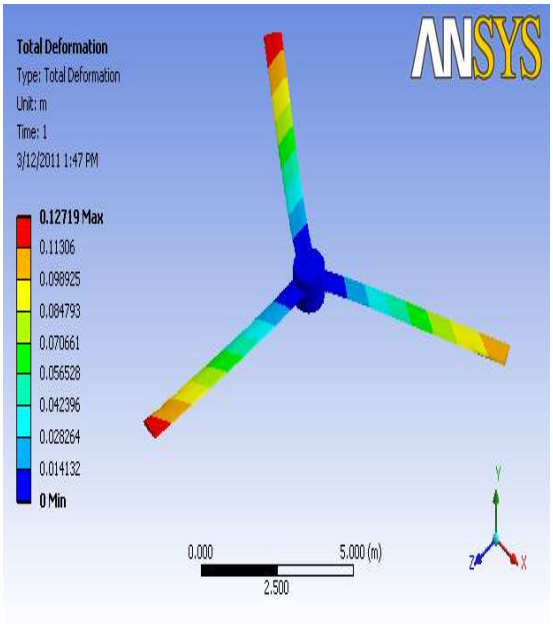

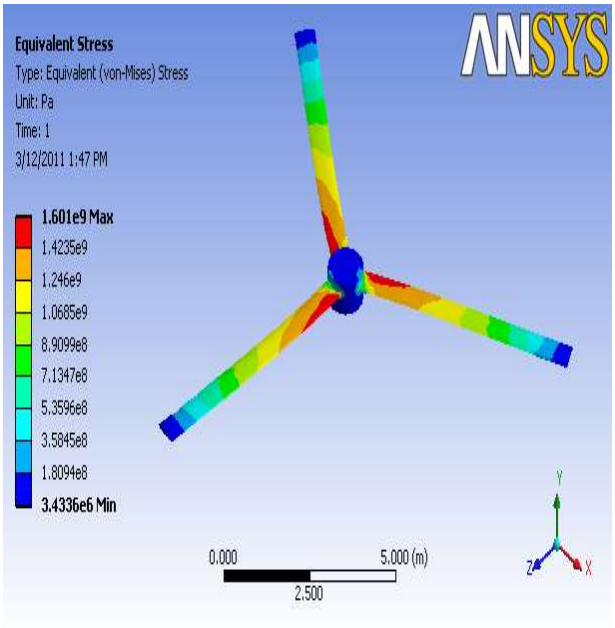

Fig: . Deformation and Von miss stress Aluminium at 1500RPM

Three blades 1500 rpm with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.19297m von-mises stress value is 1.95419E^9 N/m^2 For Speed in 1500RPM, Length7.01m

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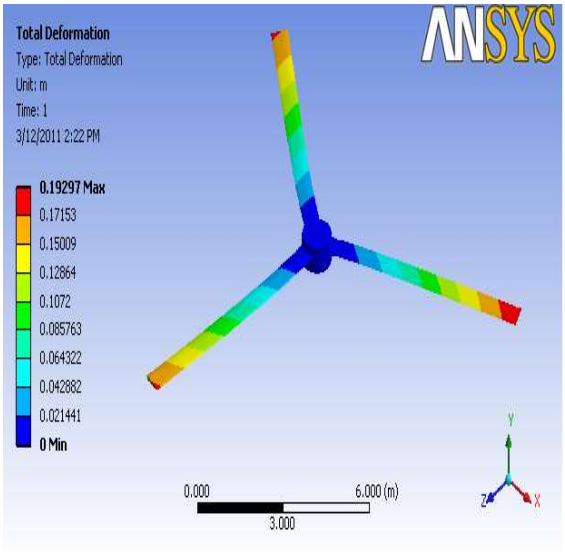

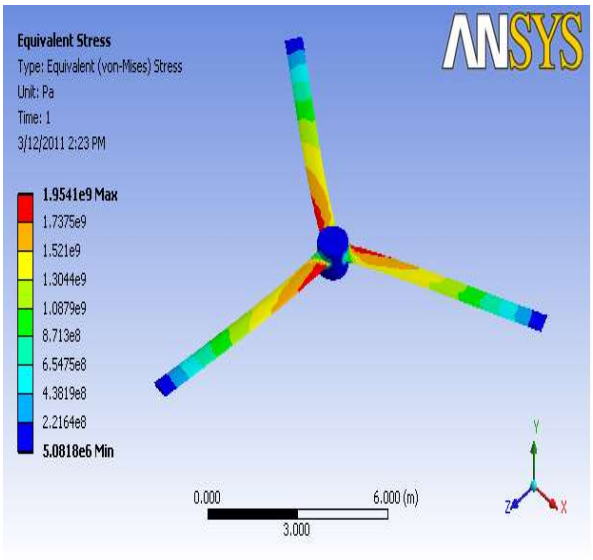

Fig: . Deformation and Von mises stress Aluminium at 1500RPM

Four blades speed of 1000RPM with 5.433m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.030582m von-mises stress value is $5.219E^{8}N/m^{2}$ For Speed in 1000RPM, Length5.433m

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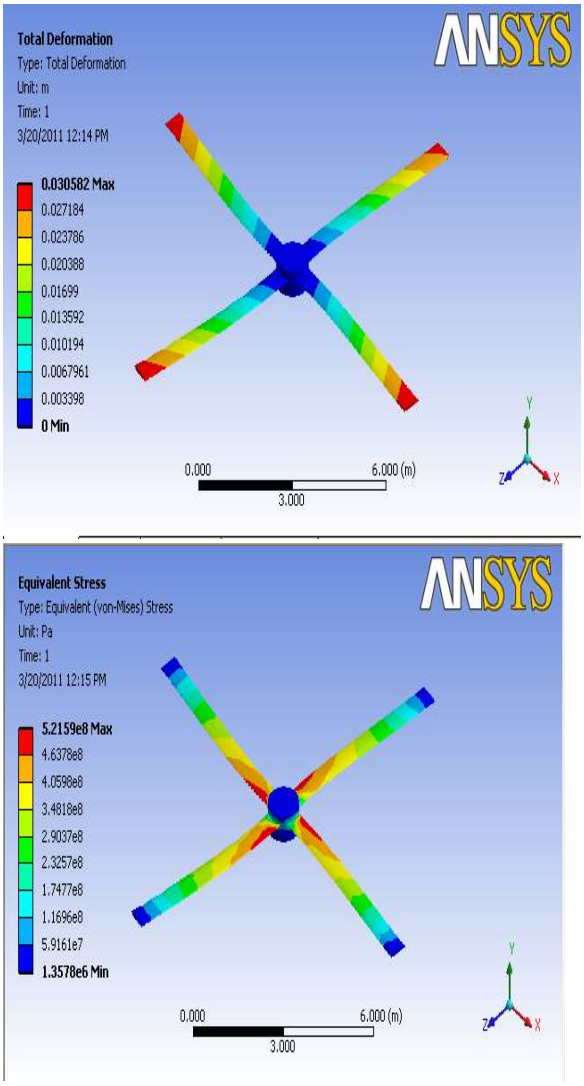

Fig: . Deformation and Vonmises stress Aluminium at 1000RPM

Four blades speed of 1000RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.058517m, von-mises stress value is $7.7832E^{8}$ N/m^{2} For Speed in 1000RPM, Length6.40m.

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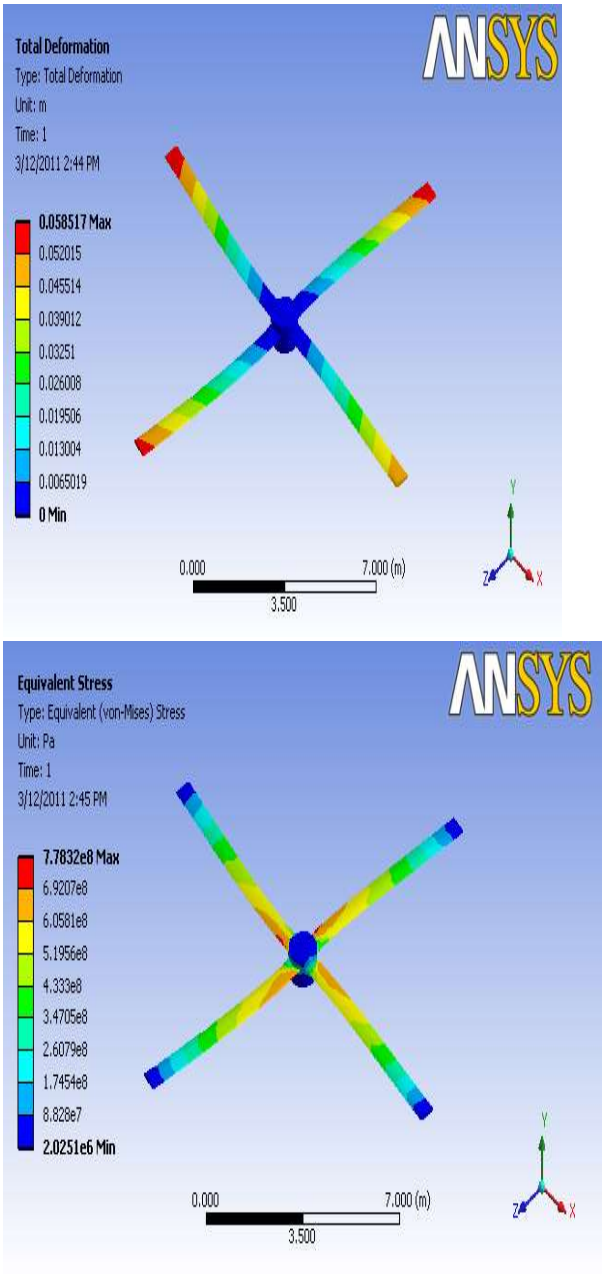

Fig: . Deformation and Von mises stress Aluminium at 1000RPM

Four blades speed of 1000RPM with 7.01m

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The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.087613m von-mises stress value is 8.7782E^{8} N/m^{2} For Speed in 1000RPM, Length7.01m.

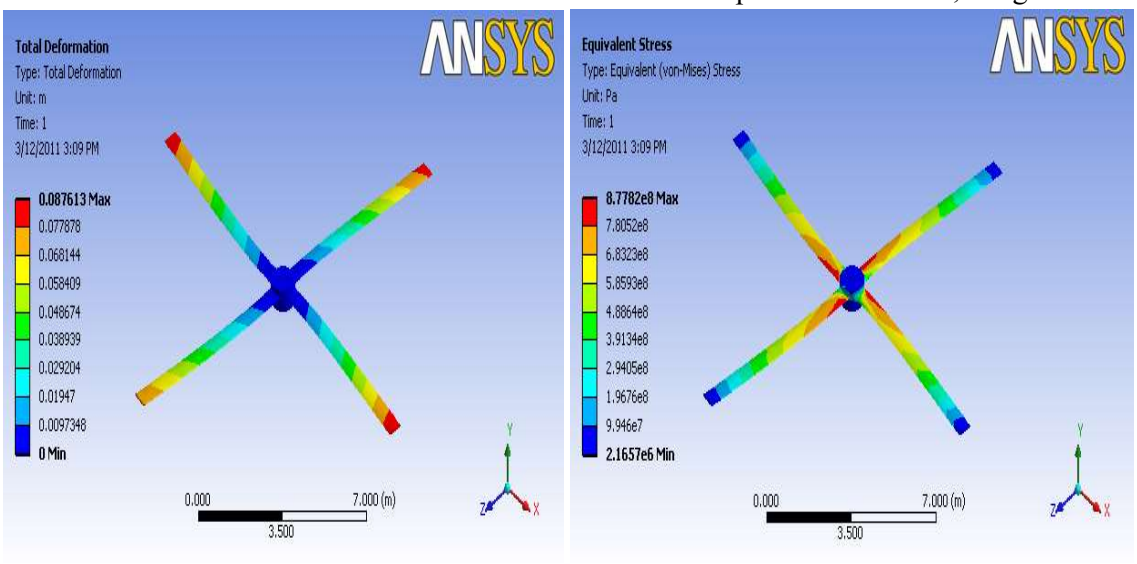
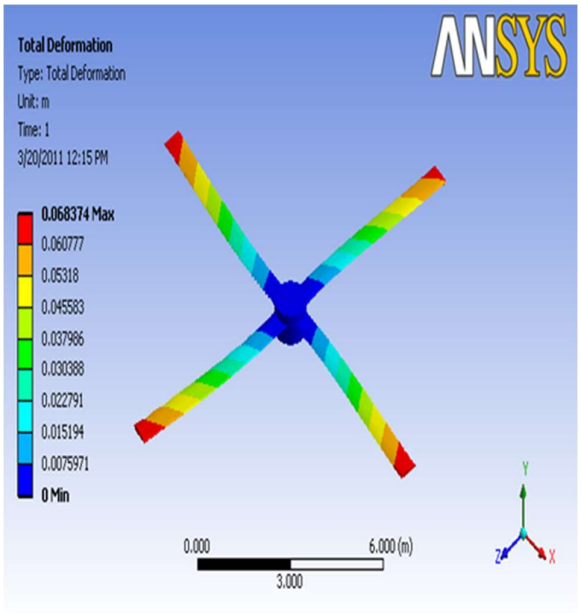


Fig: 4.34. Deformation and Von mises stress Aluminium at 1000RPM

Four blades speed of 1500RPM with 5.433m

The Deformation and von-mises stress are Shown in figure. The Deformation value is 0.068374m,von-mises stress value is 1.1661E^{9} N/m^{2} For Speed in 1500RPM, Length5.433m



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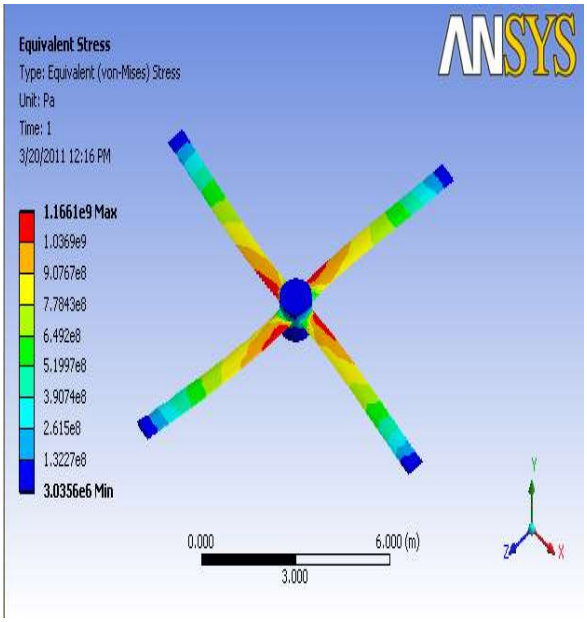
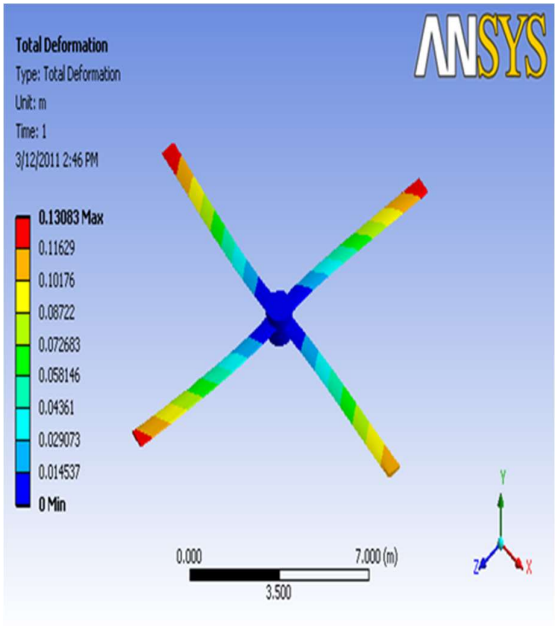


Fig: 4.28. Deformation and Von mises stress Aluminium at 1500RPM

Four blades speed of 1500RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.13083m von-mises stress value is $1.7401E^{9}N/m^{2}$ For Speed in 1500RPM, Length6.40m.



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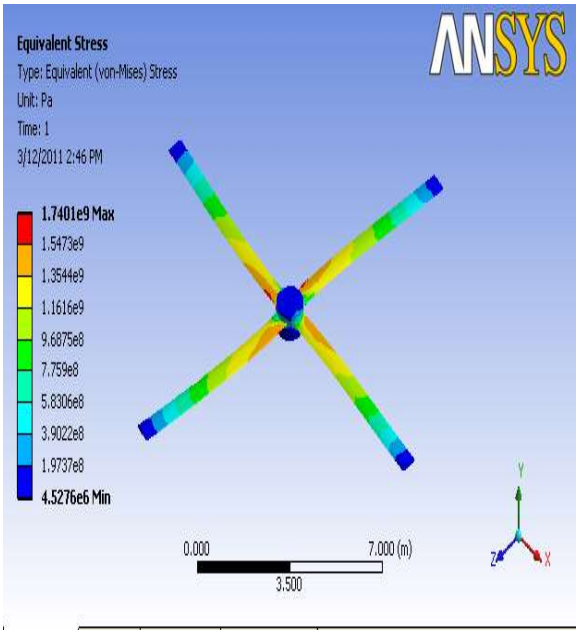
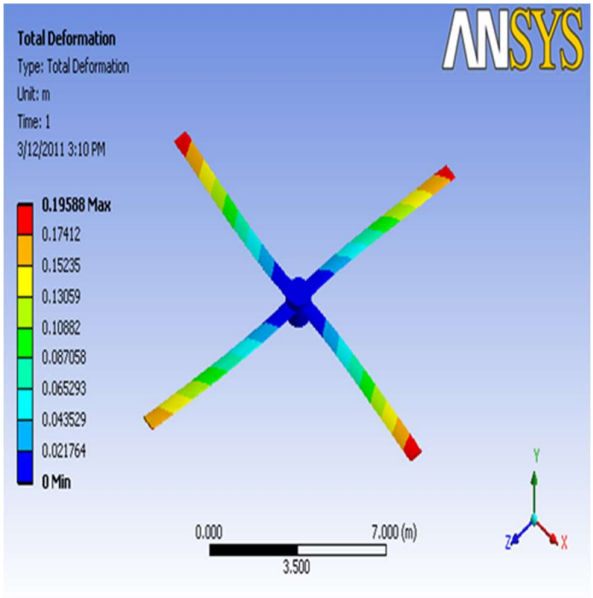


Fig: 4.32. Deformation and Von mises stress Aluminium at 1500RPM

Four blades speed of 1500RPM with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.19588m von-mises stress value is $1.9626E^9$ N/m^2 For Speed in 1500RPM, Length7.01m.



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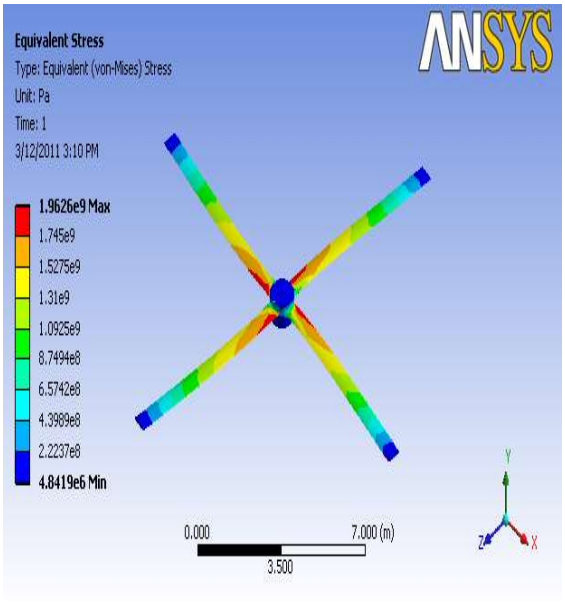


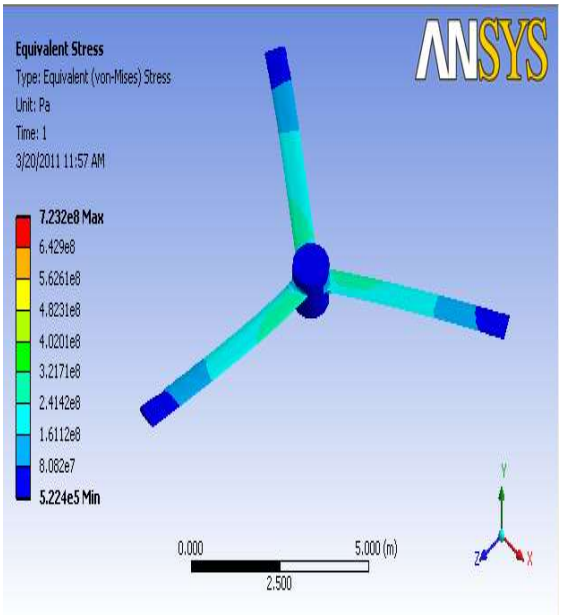
Fig: 4.36. Deformation and Von mises stress Aluminium at 1500RPM

CFRP Blades

Carbon fiber-reinforced polymer composites are frequently employed in the construction of airplane structures. It has a strong enough quality to withstand impact loads and vibration at the high rotational speed of the blades.

Three blades speed of 1000RPM 1000 RPM with 5.433m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.11682m, von-mises stress value is $7.232E^{8}N/m^{2}$ For Speed in 1000RPM, Length5.433m



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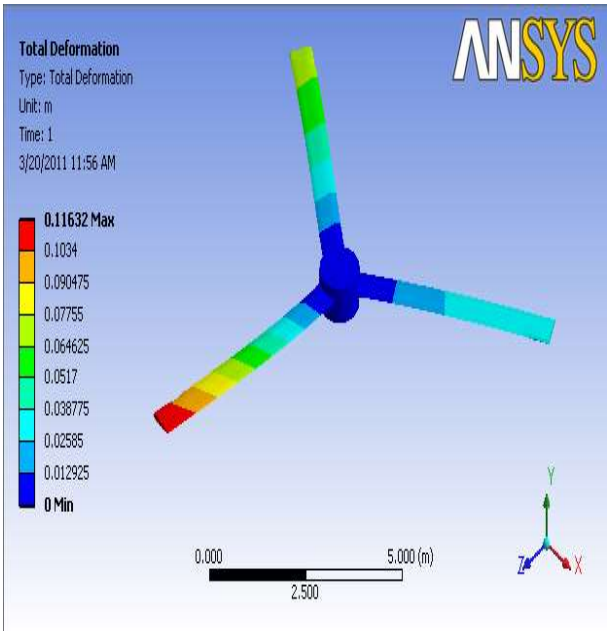
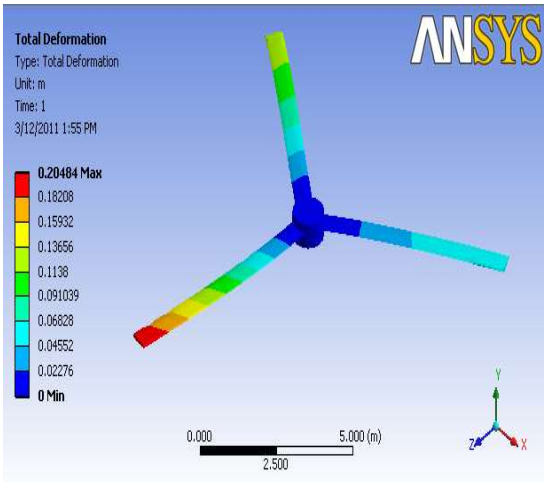


Fig: Deformation and Von mises stress CFRP at 1000RPM

Three blades speed of 1000RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.20484m, von-mises stress value is $4.785E^{8}N/m^{2}$ For Speed in 1000RPM, Length6.40m.



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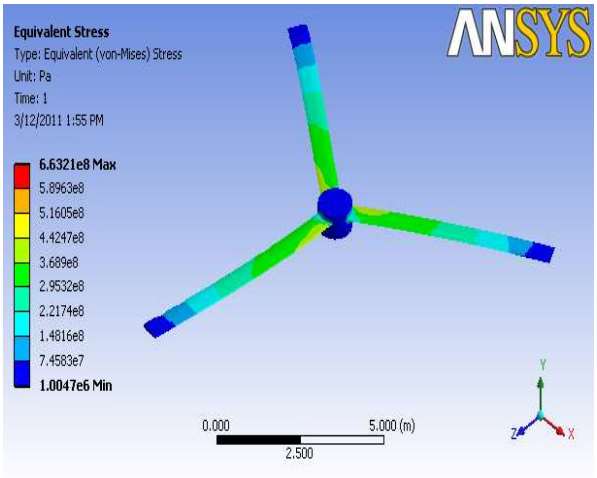
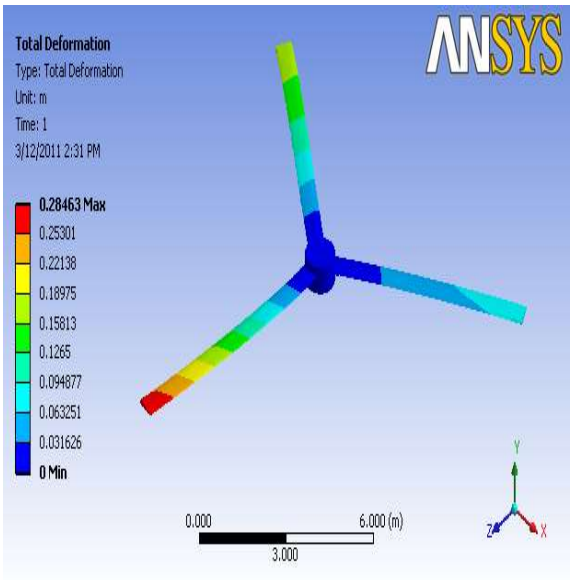


Fig: Deformation and Von mises stress CFRP at 1000RPM

Three blades speed of 1000RPM with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.28463m, von-mises stress value is $8.0947E^{8}N/m^{2}$ For Speed in 1000RPM, Length7.01m



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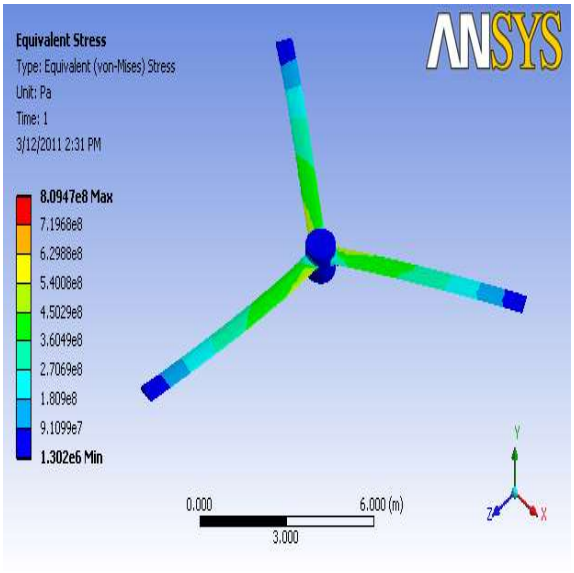
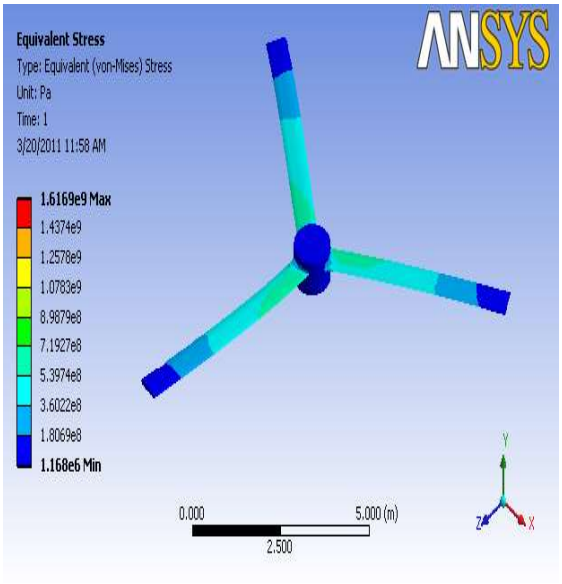


Fig: . Deformation and Von mises stress CFRP at 1000RPM

Three blades speed of 1500RPM with 5.433m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.26007m von-mises stress value is $1.6169E^{9}N/m^{2}$ For Speed in 1500RPM, Length5.433m.



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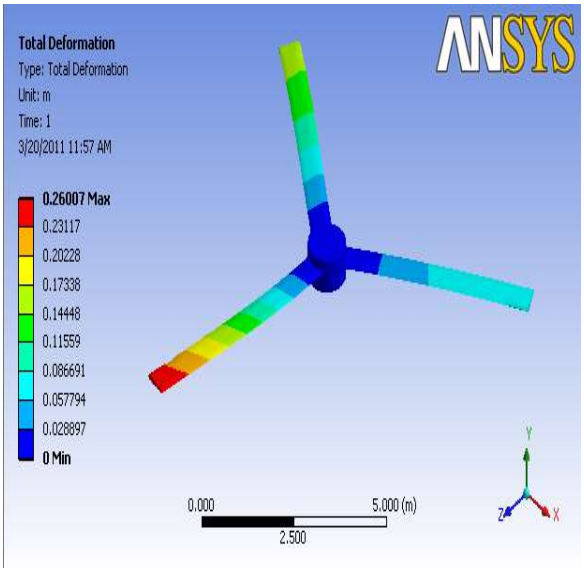
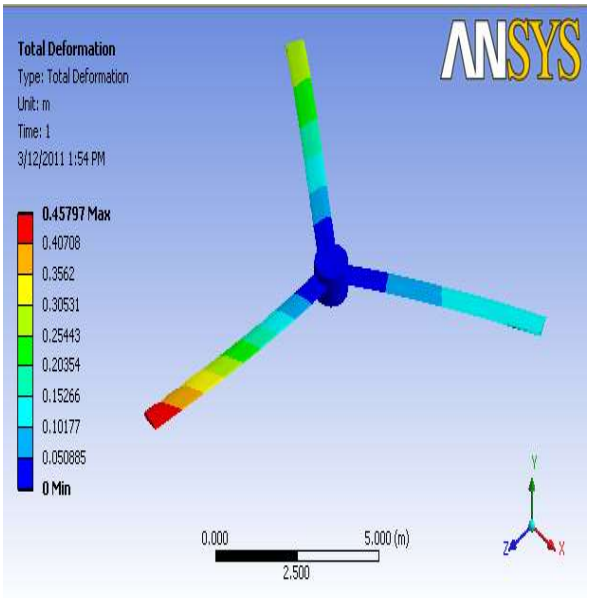


Fig: Deformation and Von mises stress CFRP at 1500RPM

Three blades speed of 1500RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.45797m, von-mises stress value is $1.4828E^{9}N/m^{2}$ For Speed in 1500RPM, Length6.40m.



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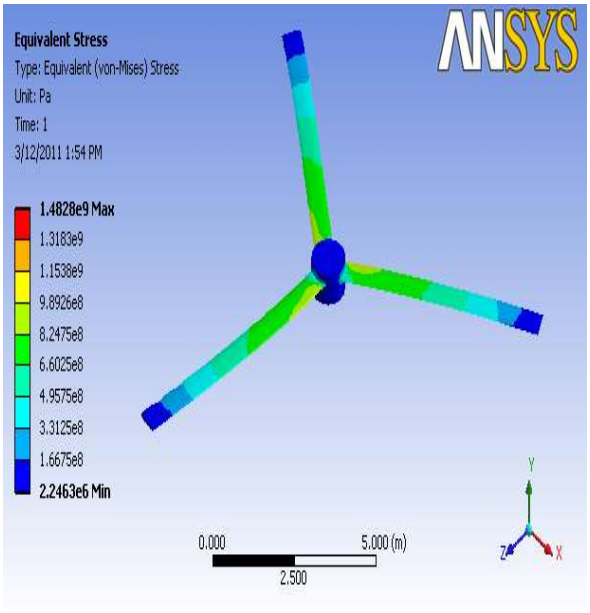
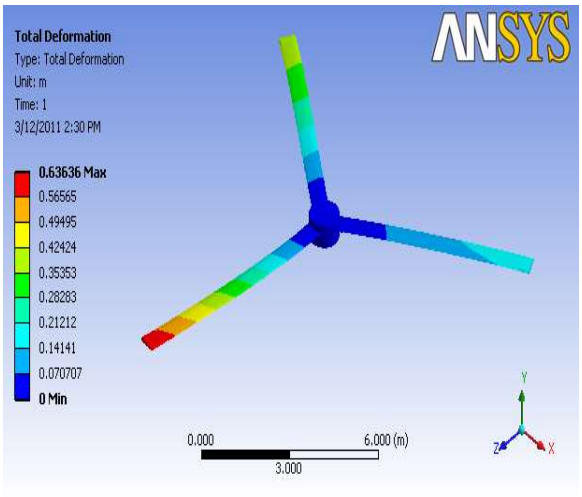


Fig: . Deformation and Von mises stress CFRP at 1500RPM

Three blades speed of 1500RPM with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.63636m, von-mises stress value is $1.8097E^{9}N/m^{2}$ For Speed in 1500RPM, Length7.01m



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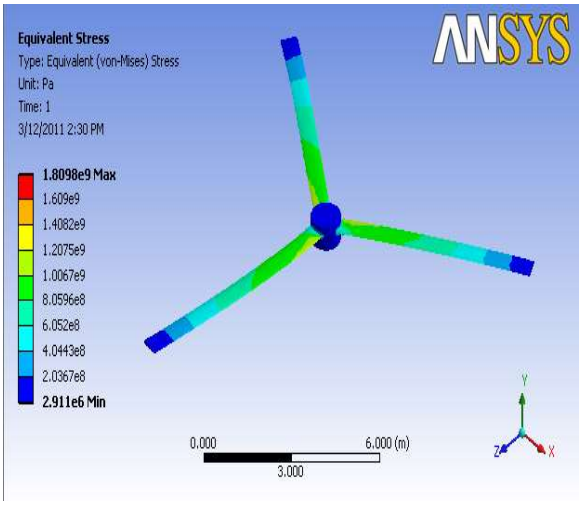
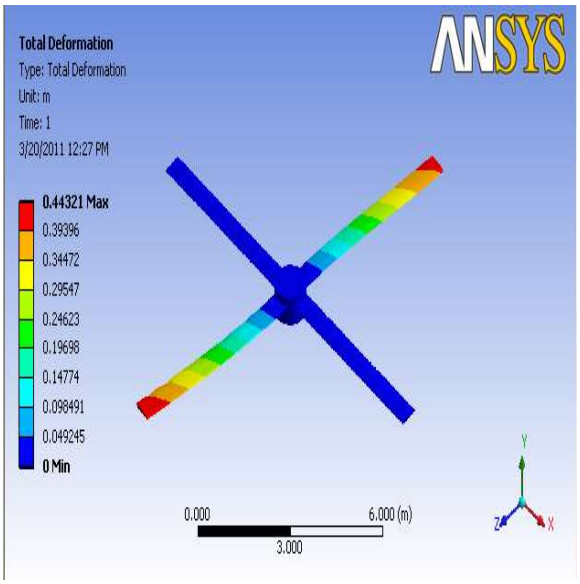


Fig: Deformation and Von mises stress CFRP at 1500RPM

Four blades speed of 1000RPM with 5.433m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.44321m von-mises stress value is $1.2809E^{9}N/m^{2}$ For Speed in 1000RPM, Length5.433m.



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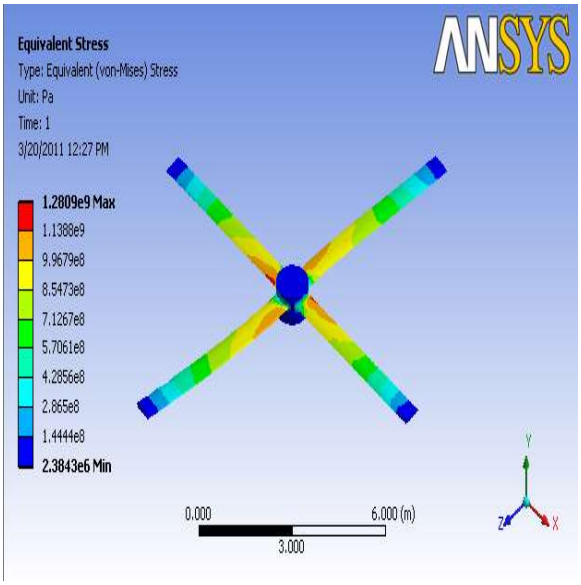
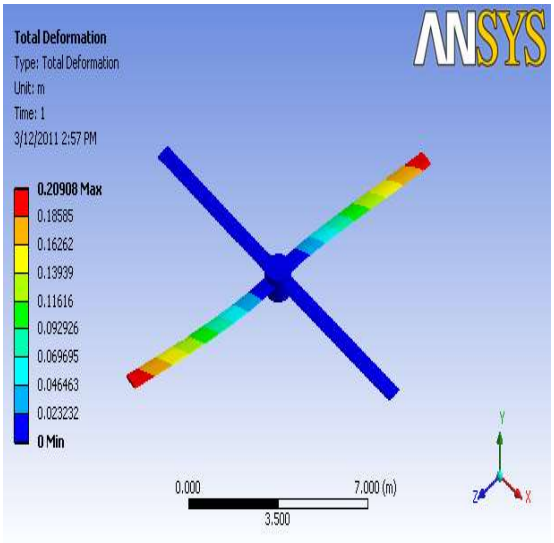


Fig: 4.27. Deformation and Von mises stress CFRP at 1000RPM

Four blades speed of 1000RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.20908m, von-mises stress value is $4.7851E^{8}N/m^{2}$ For Speed in 1000RPM, Length6.40m.



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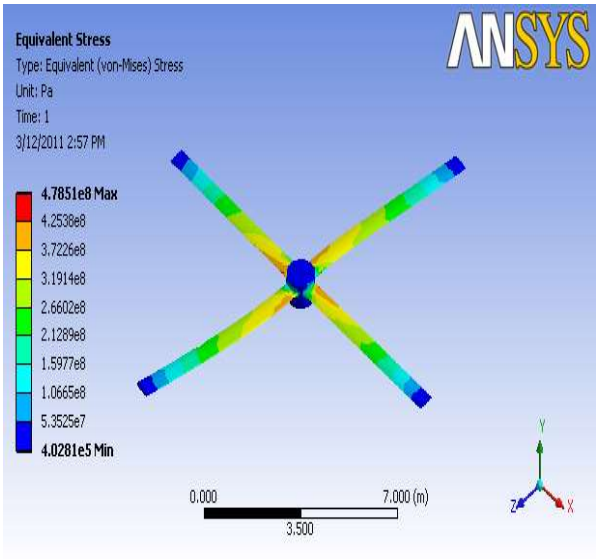

Fig: . Deformation and Von mises stress CFRP at 1000RPM

Four blades speed of 1000RPM with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.28949m von-mises stress value is 5.72818E^{8}N/m^2 For Speed in 1000RPM, Length7.01m

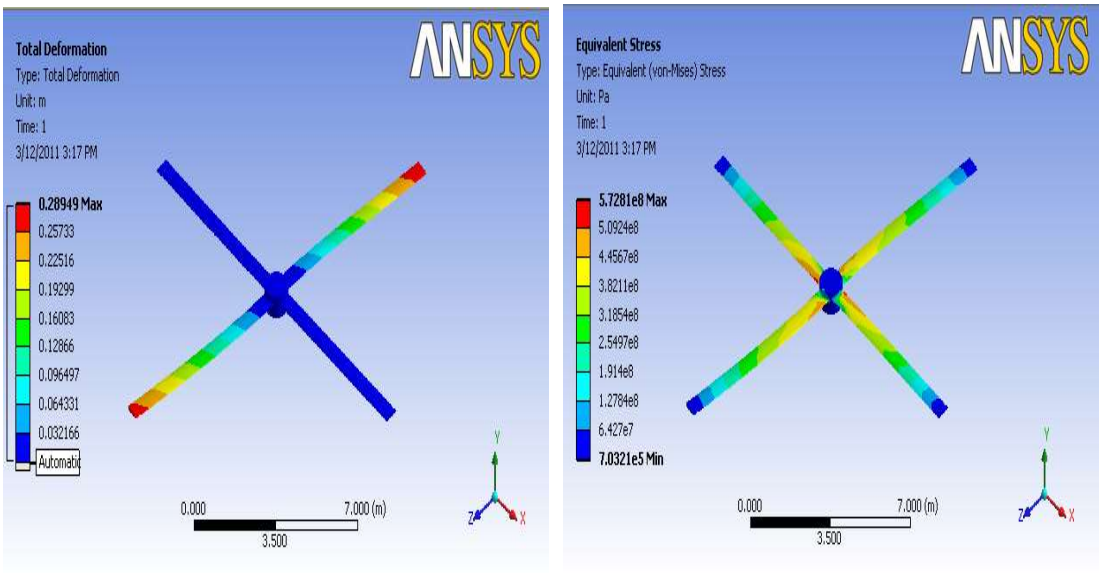

Fig: . Deformation and Von mises stress CFRP at 1000RPM

Four blades speed of 1500RPM with 5.433m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.25496m, von-mises stress value is 7.3684E^{8}N/m^2 For Speed in 1500RPM, Length5.433m.

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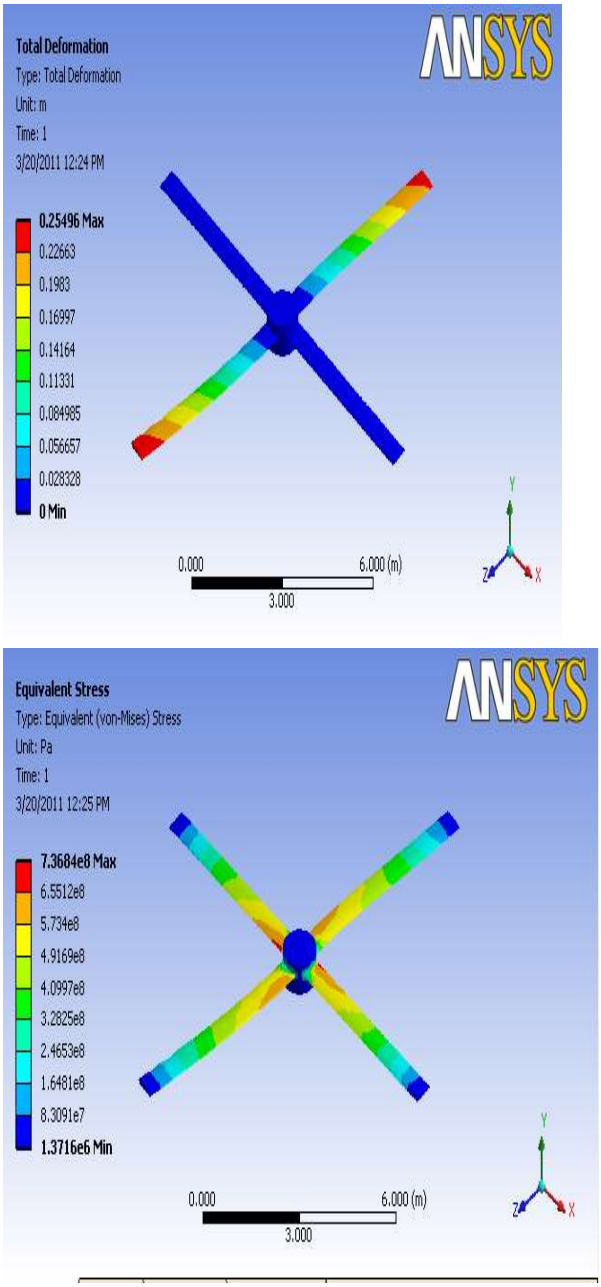

Fig Deformation and Von mises stress CFRP at 1500RPM

Four blades speed of 1500RPM with 6.40m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.46746m von-mises stress value is $1.0698E^{9}N/m^{2}$ For Speed in 1500RPM, the Length6.40m

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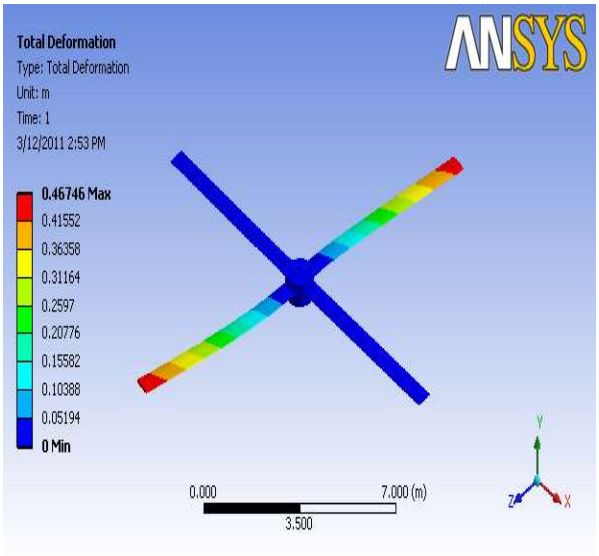

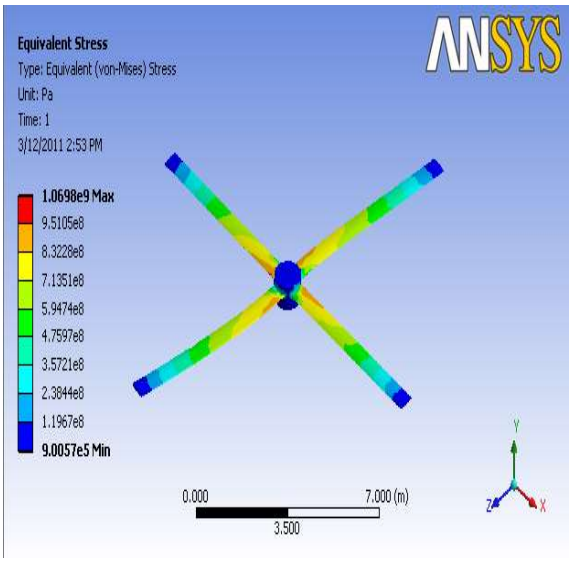

Fig: . Deformation and Vonmises stress CFRP at 1500RPM

Four blades speed of 1500RPM with 7.01m

The Deformation and von-mises stress are Shown in the figure. The Deformation value is 0.64723m,von-mises stress value is $1.2806E^{9}N/m^{2}$ For Speed in 1500RPM, Length7.01m.

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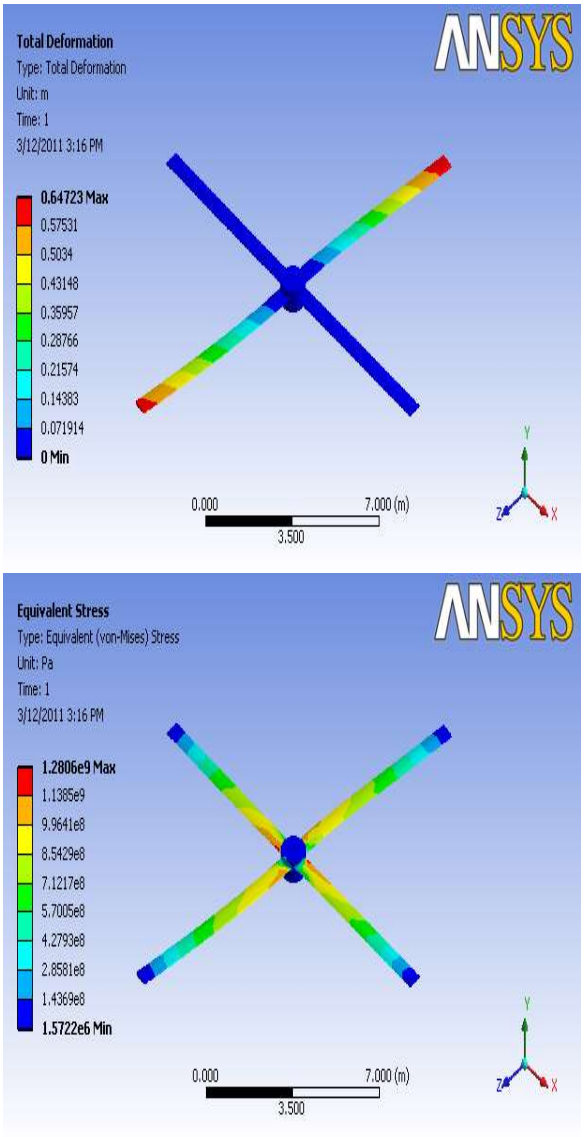

Fig:. Deformation and Von mises stress CFRP at 1500RPM

Blades	Length	Material	Mode1	Mode2	Mode3	Mode4	Mode5
3Blade	5.433	Aluminium	0.26564 E^{-02}	0.26636 E^{-02}	0.16698 E^{-01}	0.17030 E^{-01}	0.17353 E^{-01}
		CFRP	0.13031 E^{-02}	0.22241 E^{-02}	0.86218 E^{-02}	0.13862 E^{-01}	0.14435 E^{-01}
	6.400	Aluminium	0.16753 E^{-02}	0.16766 E^{-02}	0.10484 E^{-01}	0.11037 E^{-01}	0.29290 E^{-01}
		CFRP	0.2342 E^{-03}	0.13939 E^{-02}	0.84922 E^{-02}	0.8038 E^{-02}	0.8699 E^{-02}

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	7.010	Aluminium	0.13889 E^{-02}	0.13893 E^{-02}	038695 $2E^{-02}$	0.41850 E^{-02}	0.52139 E^{-02}
		CFRP	0.68249 E^{-03}	0.11523 E^{-02}	0.25658 E^{-02}	0.2002 E^{-02}	0.36917 E^{-02}

Modal results for three rotor blades with different lengths

Blades	Length	Material	Mode1	Mode2	Mode3	Mode4	Mode5
4 Blade	5.433	Aluminium	0.26526 E^{-02}	0.26526 E^{-02}	0.34830 E^{-02}	0.92638 E^{-02}	0.92655 E^{-02}
		CFRP	0.41782 E^{-07}	0.75903 E^{-07}	0.12812 E^{-06}	0.14629 E^{-02}	0.45724 E^{-02}
	6.400	Aluminium	0.16766 E^{-02}	0.16781 E^{-02}	0.10496 E^{-01}	0.10508 E^{-01}	0.11011 E^{-01}
		CFRP	0.82434 E^{-03}	0.30716 E^{-02}	0.51668 E^{-02}	0.54871 E^{-02}	0.10050 E^{-01}
	7.010	Aluminium	0.13904 E^{-02}	0.13912 E^{-02}	0.87076 E^{-02}	0.8711 $6E^{-02}$	0.91671 E^{-02}
		CFRP	0.68355 E^{-03}	0.25512 E^{-02}	0.42842 E^{-02}	0.45638 E^{-02}	0.11982 E^{-01}

Modal results for four rotor blades with different lengths

CONCLUSION

From the three, and four-blade main rotor blades it has been found that the four-blade main rotor is having low vibration due to its well-balanced condition than the three-rotor blade. From the length of the four blades, the blades in the rotor, 7010mm were found that best with low vibration than the other two lengths 6400mm, and 5433mm. Considering the material, it has been found that CFRP is the best one with low vibration for the four-blade main rotor than Aluminium. After the static analysis, it was confirmed that the stress and deformation acting in the CFRP main rotor four blades is less than when compared with the other.

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