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Design and Analysis of Black Hawk UH-60 Rotor Blade Using Composite Materials

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ABSTRACT

In depth literature survey on the main rotor blade of helicopters was carried out, and Black Hawk UH-60 has chosen for design, development and analysis. The blade configuration details including the plan form, taper, root joint and profiles was studied. The various load cases were analyzed.

The main scope of this project is to Design a hollow composite rotor blade using Carbon Fibre Reinforced Plastic (CFRP) with different stacking sequences. The required thicknesses at various span wise locations to compensate the developed loads were calculated using strength of material approach. Finally the model is analyzed using ANSYS software to know the resulting displacements, stresses and mode shapes.

INTRODUCTION

Rotor blade

The rotor blades of a helicopter are airfoils that provide aerodynamic forces when exposed to a relative motion of air across their surface. The rotational motion of the rotor hub initiated by the helicopter engine develops this relative motion, as well as forward, sideward and backward flight. While developing aerodynamics lift and drag forces, structural loads occur on the blades along their span and across their chord. A helicopter's rotor is generally made of two or more **rotor blades**. . Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail rotor, which connects through a combination of drive shaft(s) and gearboxes along the tail boom.

LITERATURE SURVEY

Specifications of Black Hawk UH-60

Crew: 2 pilots (flight crew) with 2 crew chiefs/gunners
Length: 64 ft 10 in (19.76 m)
Fuselage width: 7 ft 9 in (2.36 m))
Rotor diameter: 53 ft 8 in (16.36 m)
Height: 16 ft 10 in (5.13 m)
Disc area: 2,260 ft² (210 m²)
Empty weight: 10,624 lb (4,819 kg)
Loaded weight: 22,000 lb (9,980 kg)
Max. Takeoff weight: 23,500 lb (10,660 kg)
Power plant: 2 × General Electric T700-GE-701C turbo shaft, 1,890 hp (1,410kW) each

Performance:

Never exceed speed: 193 knots (222 mph; 357 km/h)
Maximum speed: 159 KN (183 mph; 295 km/h)
Cruise speed: 150KN (173 mph; 278 km/h)
Combat radius: 368 mi (320 nautical miles; 590 km)

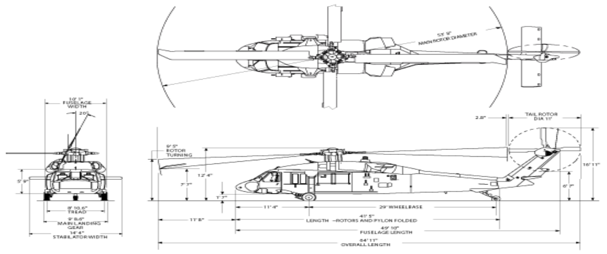

Fig 2.1 Orientation of Black Hawk UH-60

Like airplane wings, early rotor blades had a main spar, ribs and a covering of fabric. The blades were symmetrical because this shape offered a good lift-to-drag ratio and a stable center of pressure, and they were easy to build. This was to be the design and shape of rotor blades for many years. The early blades

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were a blend of several types of wood, each adding properties the other materials lacked.

Material properties
Selection of material: Carbon Fiber

Material Description

Material:	T700S 12k/3900-2
Form:	Plain weave fabric prepreg, 3 tows per inch, fiber areal weight of 193 g/m^2, typical cured resin content of 35%-36%, typical cured ply thickness of 0.0073-0.0079 inches.
Processing:	Autoclave cure, 350°F, 85 psi, 3°F/minute ramp rate, 2 hours

General Supplier Information

Fiber:	T700 fibers are continuous, standard modulus, no twist carbon filaments made from a PAN precursor, surface treated to improve handling characteristics and structural properties. Filament count is 12,000filaments/tow. Typical tensile modulus is 34 x 10^6 psi. Typical tensile strength is 700,000psi 3900-2 is an toughened epoxy resign

DESIGN OF ROTOR BLADE
Blade Configuration

Overall configuration and key data which is required to replicate a blade are collected. Literature survey has been carried out on the configuration and load cases.

Fig 3.1 Blade Configuration

Configuration	Actual
Length	5 m
Root Chord	298.28 mm
Tip Chord	238.04 mm
Surface Area Blade	1.4 sq.mts
Surface Area Disc	210 sq.mts
Sweep Angle L.E	20 deg

Table 3.1 Configuration of Blade

Various points on the Blade are located by station numbers

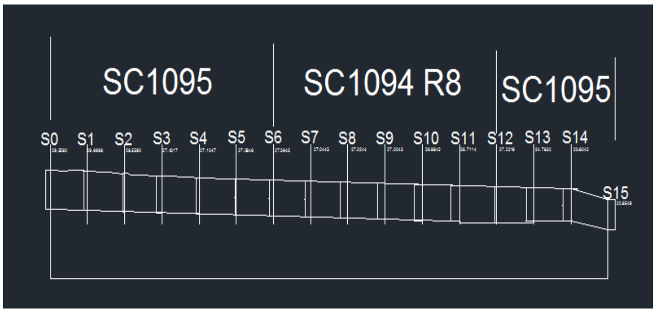

Fig 3.2 Blade span-wise stations

Chord line and maximum thickness.

The airfoil chosen was a SC1094R8 and SC1095, which is one of the more favorable of an extended series of related airfoils developed. The SC1095 airfoil and the SC1094 R8 airfoil, modified from the SC1095 by adding droop at the leading edge. The effect of the nose droop was to extend the SC1095 chord from 20.76 in. to20.965 in., thereby reducing the airfoil thickness from 9.5 percent to 9.4 percent (hence the change in the section nomenclature). The addition of nose droop also rotated the mean chord line by –1 deg, the two airfoil sections are compared on a non-dimensional basis

There is a linear transition between the SC1094 R8 and SC1095airfoil sections. The SC1095 section is then used to the blade tip.

The root airfoil measured 295.28mm chord length while the wing tip airfoil measured 238.04 mm chord length.

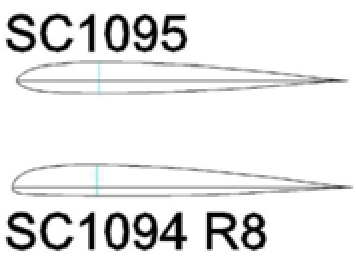

Fig 3.3 Chord length and Maximum thickness of airfoils at each stations are noted.

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Station	Chord	Maximum
0	295.28	27.25
1	296.998	27.408
2	285.59	26.356
3	274.017	25.288
4	271.047	25.013
5	270.846	24.995
6	270.645	24.976
7	270.445	24.719
8	270.244	24.701
9	270.043	24.683
10	269.842	24.664
11	267.114	24.415
12	272.216	24.881
13	247.832	22.871
14	238.042	21.968
15	228.549	21.092

Table 3.2 Chord and Thickness (at C/4) at each station

Chord-wise and Span-wise thickness calculation

S.no	Station	Chord Length	55% of Chord	Flexural Strength	Bending Moment (N-mm)	M/F
1	0	295.28	162.404	466.6666667	1059600	2270.571429
2	1	296.998	163.3489	466.6666667	908630	1947.064286
3	2	285.59	157.0745	466.6666667	685330	1468.564286
4	3	274.017	150.70935	466.6666667	609420	1305.9
5	4	271.047	149.07585	466.6666667	583031	1249.352143
6	5	270.846	148.9653	466.6666667	572433	1226.642143
7	6	270.645	148.85475	466.6666667	551030	1180.778571
8	7	270.445	148.74475	466.6666667	540830	1158.921429
9	8	270.244	148.6342	466.6666667	532731	1141.566429
10	9	270.043	148.52365	466.6666667	432741	927.3021429
11	10	269.842	148.4131	466.6666667	413372	885.7971429
12	11	267.114	146.9127	466.6666667	399945	857.025
13	12	272.216	149.7188	466.6666667	384066	822.9985714
14	13	247.832	136.3076	466.6666667	362725	777.2678571
15	14	238.042	130.9231	466.6666667	350730	751.5642857
16	15	228.549	125.70195	466.6666667	348712	747.24

Table 3.3 Chord-wise and Span-wise thickness calculation

Station	t
0	1.0675
1	0.899
2	0.7292
3	0.7043
4	0.689
5	0.677
6	0.652
7	0.647
8	0.638
9	0.517
10	0.4935
11	0.488
12	0.4495
13	0.51
14	0.5352
15	0.58

Blade Design

The drawing of SC-1094R8 and SC-1095 airfoil is produced using AutoCAD by plotting the coordinates. The airfoils at each station are designed in such a way that, the rib is at the required pitch angle

Fig 3.8 Blade designed using Composite Thickness

ANALYSIS OF ROTOR BLADE

Finite Element Analysis

For the sake of validating results ANSYS software has chosen. The material properties of each resin system is obtained based on their data sheets and tested results of neat resin casting (provided by CPDC) and using rule of mixtures the required properties (E_1,E_2,υ_{12},υ_{23}, G_{12},G_{23}) are calculated. These values are given as inputs to the software and various tests are carried out according to the actually tested specimens.

Material Properties of Carbon fiber

Carbon T700S properties

E_{11} = 139.27 GPA
E_{22} = 7.843 GPA
E33 = 7.843
υ_{12} = 0.255
υ_{23} = 0.38
υ_{31} = 0.255
G_{12} = 3.802 GPA
G_{23} = 2.951GPa
G_{31} = 3.802GPa
Density = 1565kg/m^3

Results

The imported model from AUTOCAD into ANSYS was meshed using mesh tool command resulting in fine mesh which is shown in the following figures.

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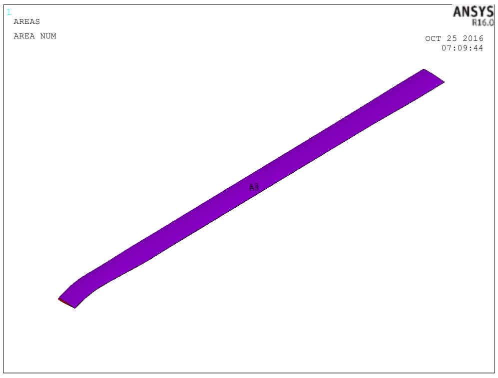

Fig 4.1: Imported model from AUTOCAD

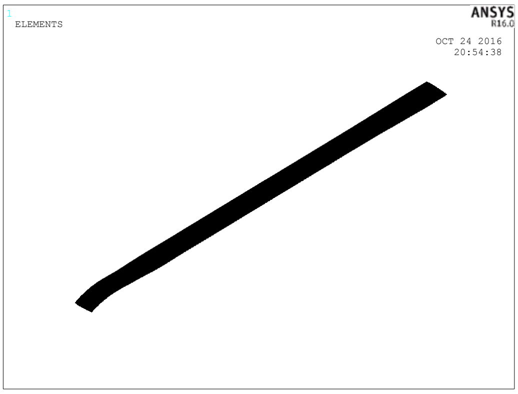

Fig4.2: Total meshed body

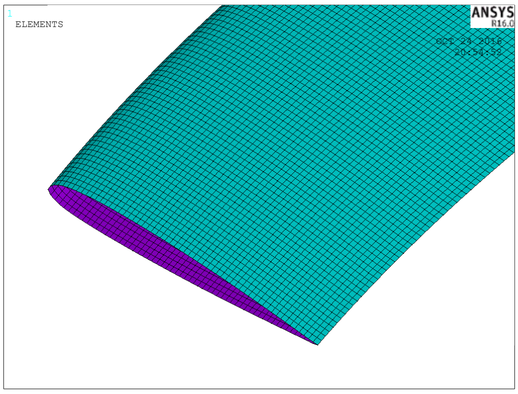

Fig 4.3: Zoomed out mesh

Case I

In the first case the considered stacking sequence is [90/0/90/0/90/0/90/0/90/0/90] which is a symmetrical stacking sequence.

The obtained results from static analysis are shown in the following figures

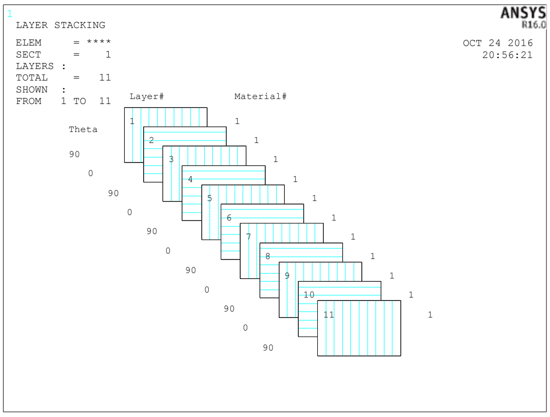

Fig 4.4: Selected stacking sequence for the first case

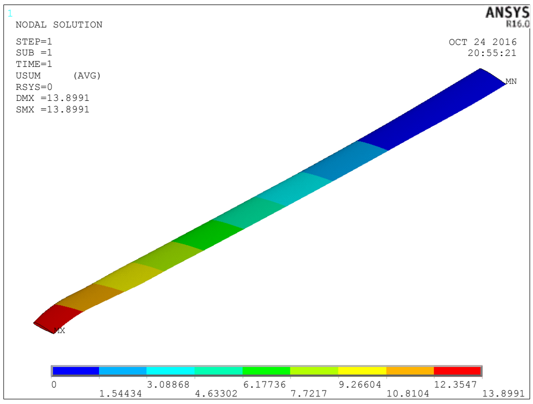

Fig 4.5: Displacement plot for the first case

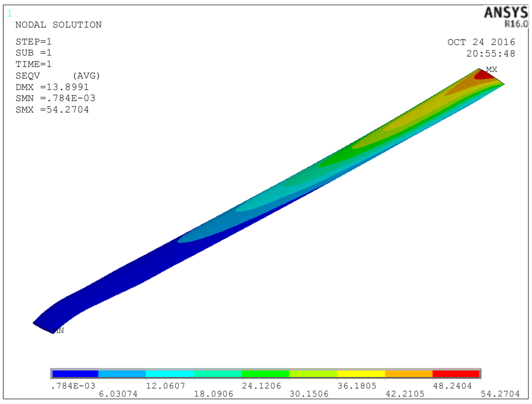

Fig 4.6: Von Misses stress plot for the first case

The modal analysis has resulted in the following mode shapes

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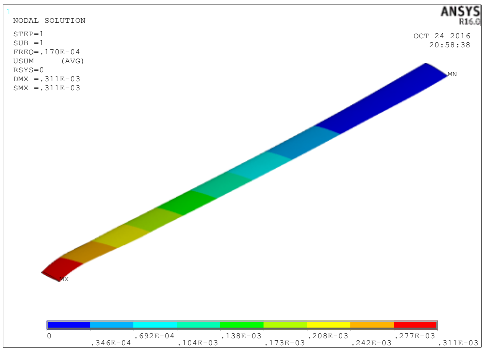

Fig 4.7: Mode - 1 for the first case

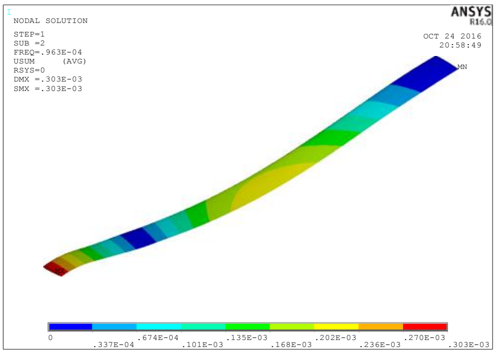

Fig 4.8: Mode - 2 for the first case

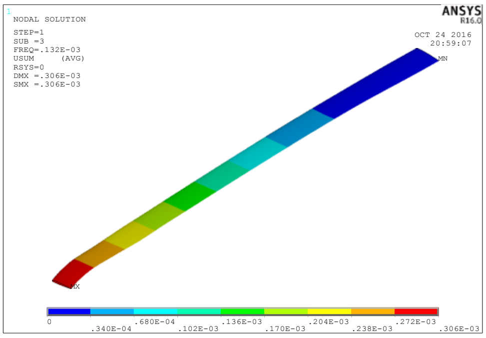

Fig 4.9: Mode - 3 for the first case

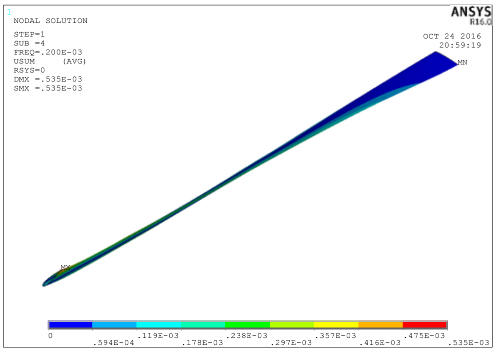

Fig 4.10: Mode - 4 for the first case

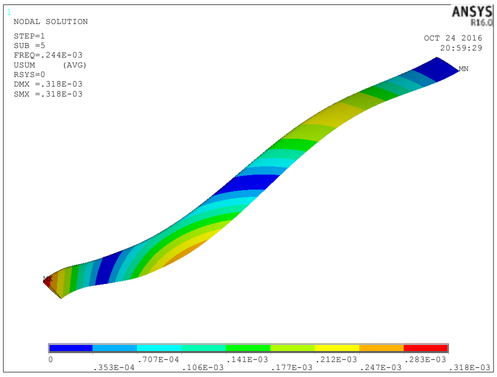

Fig 4.11: Mode - 5 for the first case

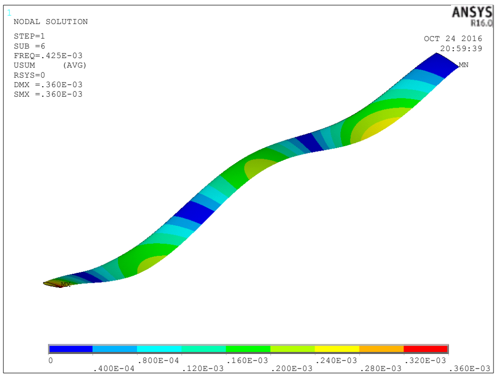

Fig 4.12: Mode - 6 for the first case

Case II

In the second case the considered stacking sequence is [45/-45/45/-45/45/0/45/-45/45/-45/45] which is a symmetrical stacking sequence

The obtained results from static analysis are shown in the following figures

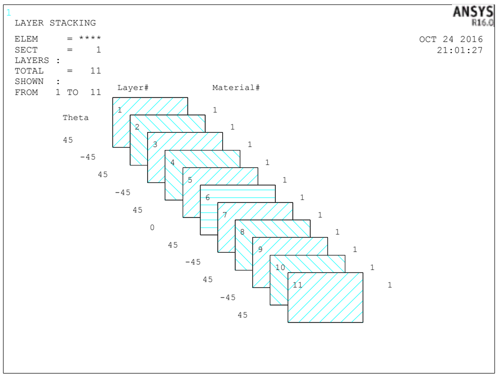

Fig 4.13: Stacking sequence for Second case

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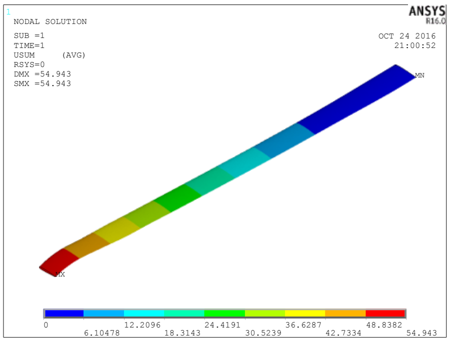

Fig 4.14: Displacement plot for the second case

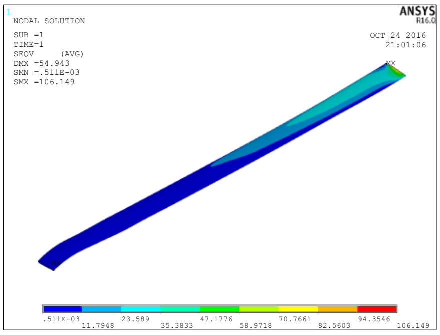

Fig 4.15: Von Misses stress plot for the second case

The modal analysis has resulted in the following mode shapes

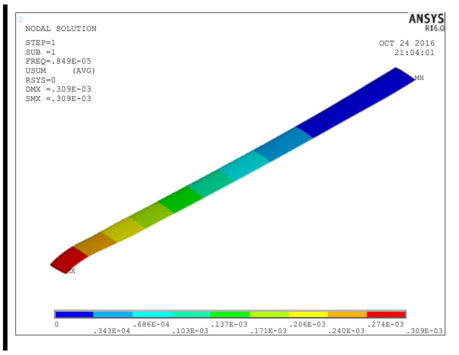

Fig 4.16: Mode - 1 for the second case

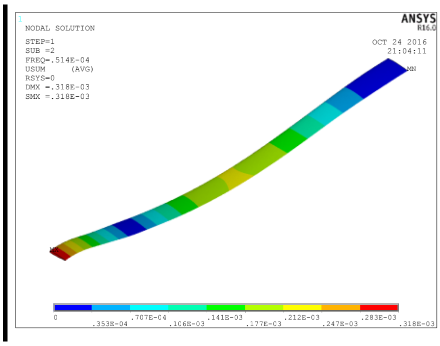

Fig 4.17: Mode - 2 for the second case

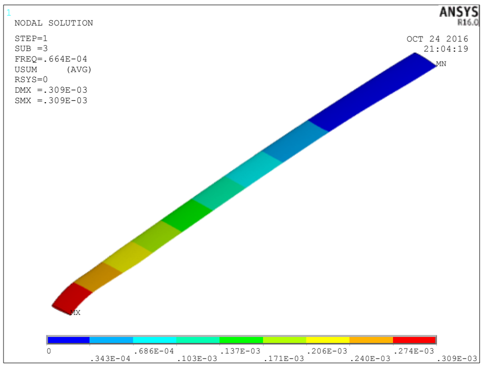

Fig 4.18: Mode - 3 for the second case

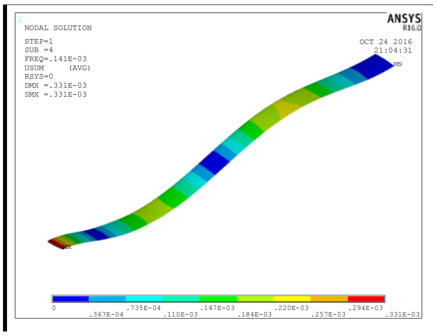

Fig 4.19: Mode - 4 for the second case

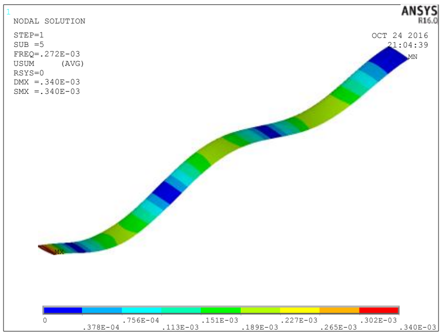

Fig 4.20: Mode - 5 for the second case

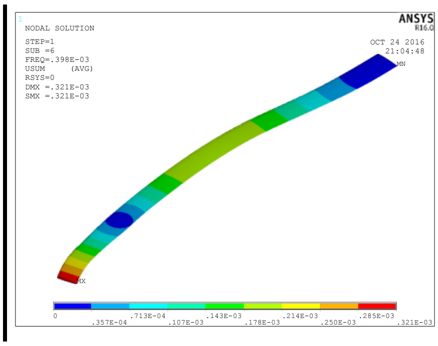

Fig 4.21: Mode - 6 for the second case

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Case III

In the third case the considered stacking sequence is [-45/45/90/0/90/0/90/0/90/45/-45] which is a symmetrical stacking sequence.

The obtained results from static analysis are shown in the following figures

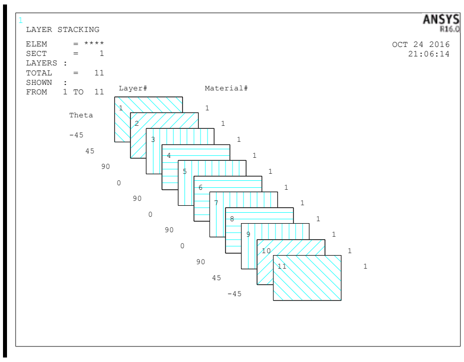

Fig 4.22: Stacking sequence for third case

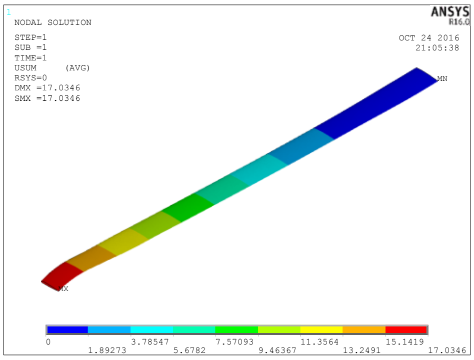

Fig 4.23: Displacement plot for the third case

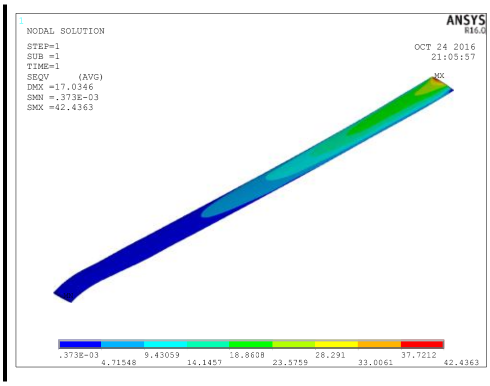

Fig 4.24: Von Misses stress plot for the third case

The modal analysis has resulted in the following mode shapes

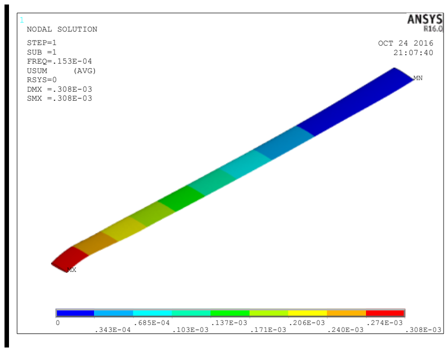

Fig 4.25: Mode - 1 for the third case

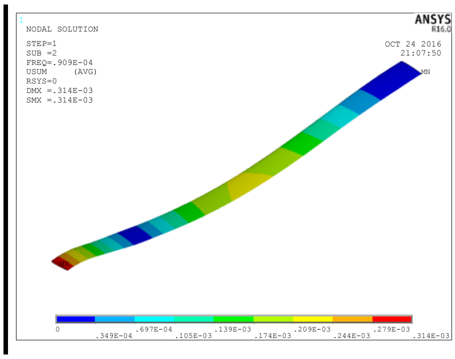

Fig 4.26: Mode - 2 for the third case

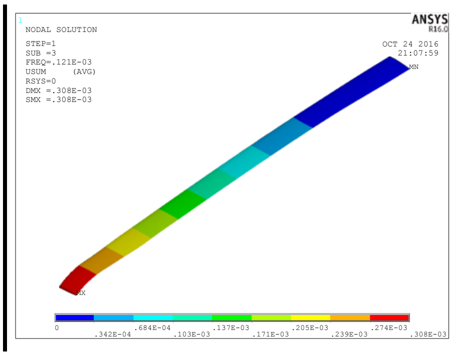

Fig 4.27: Mode - 3 for the third case

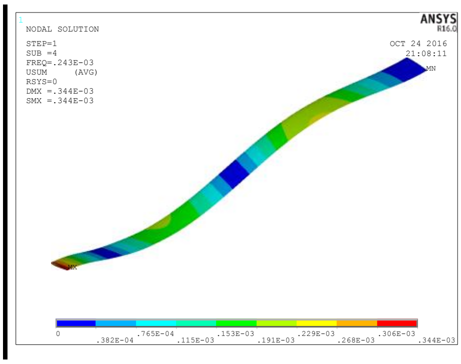

Fig 4.28: Mode - 4 for the third case

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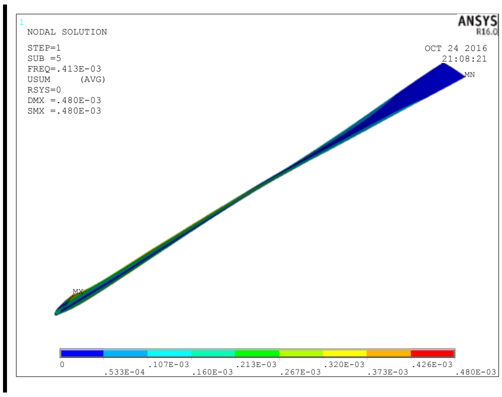


Fig 4.29: Mode - 5 for the third case

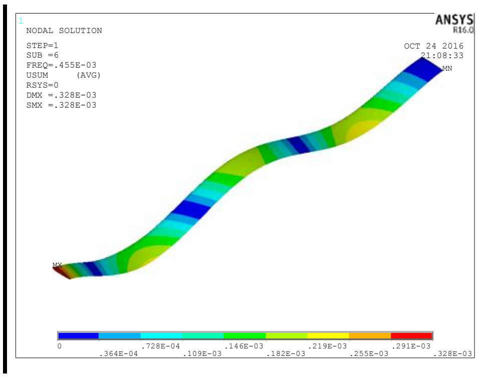


Fig 4.30: Mode - 6 for the third case

CONCLUSION AND FUTURE SCOPE

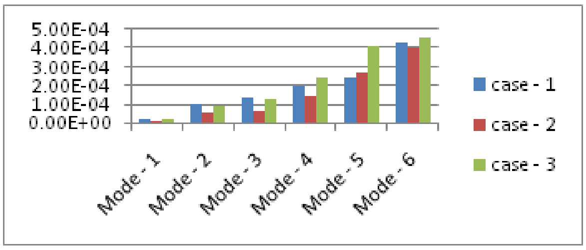
Conclusion

After observing the results from ANSYS the following conclusions are derived

1. The maximum displacement for case-1 stacking sequence is = 13.89 mm
2. The maximum stress for case-1 stacking sequence is = 54.27 MPA
3. The maximum displacement for case-2 stacking sequence is = 54.94 mm
4. The maximum stress for case-2 stacking sequence is = 106.149 MPA
5. The maximum displacement for case-3 stacking sequence is = 17mm
6. The maximum stress for case-3 stacking sequence is = 42 MPA

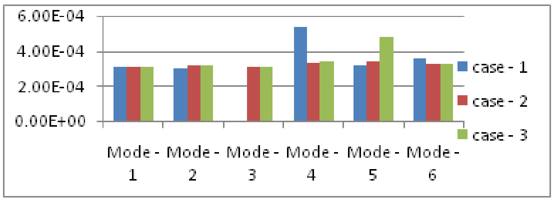
Comparing the modal analysis for all the cases, the obtained natural frequencies are

	case - 1	case - 2	case - 3
Mode - 1	1.70E-05	8.49E-06	1.53E-05
Mode - 2	9.63E-05	5.14E-05	9.09E-05
Mode - 3	1.32E-04	6.64E-05	1.21E-04
Mode - 4	2.00E-04	1.41E-04	2.43E-04
Mode - 5	2.44E-04	2.72E-04	4.13E-04
Mode - 6	4.25E-04	3.98E-04	4.55E-04



Comparing the modal analysis for all the cases, the obtained deflections for different modes are

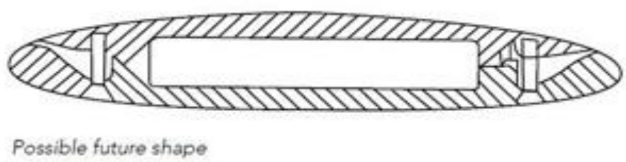
	case - 1	case - 2	case - 3
Mode - 1	3.11E-04	3.09E-04	3.08E-04
Mode - 2	3.03E-04	3.18E-04	3.14E-04
Mode - 3	0.306-3	3.09E-04	3.08E-04
Mode - 4	5.35E-04	3.31E-04	3.44E-04
Mode - 5	3.18E-04	3.40E-04	4.80E-04
Mode - 6	3.60E-04	3.21E-04	3.28E-04



After observing the results it is found that quasi isotropic stacking sequence is better for the manufacture of rotor blades which has resulted in less stresses i.e. compared to all other selected stacking sequences. It also resulted in reasonable minimum displacement i.e. 17mm compared to other stacking sequences.

Future scope.

A current goal of Defense is to use adaptive or “smart” materials that adjust the airfoil shape to reduce rotor vibration..



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In the current design, the number of layers of composites is fixed, and each layer has the same layer thickness. That is, the layer thickness is equal to the total thickness divides by the number of layers. However, because the feasible values of layer thickness are certain discrete numbers, this assumption possibly results in the infeasible layer thickness. A better way is to choose layer thickness and the number of layers as design variables. If the fiber orientations of all layers are 96 dependent design variables, the number of variables of the optimization problem is changeable. The applicable algorithm for such problem is very difficult to find in literature.

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