DESIGN AND ANALYSIS OF HELICOPTER MAIN ROTOR HEAD

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Abstract - *The rotating component of a helicopter that produces lift is called the rotor system. The hub, rotor blades, and mast make up this rotor. A mast is a hollow, cylindrical metal shaft that stretches upward and is propelled. It is occasionally additionally supported by a transmission. In this scenario, a rotor hub must support the weight of the blades as well as aerodynamic forces. The strength of the helicopter blades and rotor hub will be determined. The rotor blades' attachment point to a top is a mast (hub).The helicopter main rotor head consist of rotor hub, mash, rotor blade and a swash plate. The Helicopter Rotor Head Model and Assemble will be completed, along with theoretical calculations, a Structural Analysis & Modal Analysis on two different materials for the Helicopter Rotor Head, and analysis in ANSYS. In order to calculate displacements and stresses under static conditions, structural analysis is used. A three component system's vibration characteristics (natural frequencies & mode shapes) are determined via modal analysis.*

The main focus of this study was the modeling and analysis of the helicopter rotor head. SOLIDWORKS, a cutting-edge modeling programme, was used to model and assemble the components . In ANSYS 2022 R2, an analysis is performed.

Key Words: Analysis, Optimization, Solid works (Modelling), ANSYS (Static structural analysis, Fatigue analysis, modal analysis).

1. INTRODUCTION

Although helicopters exist in a wide range of sizes and designs, the most of them have similar main parts. A chapter introduces the main portions and components of a helicopter as well as the systems that go along with it. Knowing how a helicopter's parts and systems function helps a pilot see problems and potential emergency situations more quickly. A revolving component of a helicopter that produces lift is the rotor system. A mast, hub, and rotor blades make up a rotor. A mast is an upward-extending hollow cylindrical metal shaft that is powered by and occasionally supported by a transmission. A hub, which serves as a rotor blade's connection point, is located at the top of a mast. There are several different ways to attach rotor blades to a hub. The way a main rotor blade is attached to and moves in relation to a main rotor hub determines what type of main rotor system it is. Semirigid, rigid, or completely articulated are the three fundamental categories. An designed combination of ase types is used in several contemporary rotor systems, such as bearingless rotor systems.

2. LITERATURE REVIEW

Richard L. Rotelli, Jr. did a three-dimensional stress analysis of a new main rotor hub design for an SH-2F helicopter using a cycle symmetry feature of MSC/NASTAN. The investigation used cyclic symmetry. A one-eighth symmetry finite element model was made using the FEMGEN interaction graphics mesh generator. A graphic representation of the structural reaction of a rotor hub to various loading situations, as predicted by MSC/NASTAN, was provided using an interactive results viewing tool developed by FEMGEN. A novel design for a primary rotor hub benefited from the NASTRAN analysis results when they were presented in this manner.

Modes form and harmonic analysis of various helicopter blade architectures by Yon CHEVALIER, Abd-el-Kader NOUR, and Mohamed Tahar GHERBI. This research focuses on the helicopter blade's dynamic behaviour. A goal is to mimic the behaviour of a blade made of various materials under an aerodynamic force using the finite elements approach. This study was carried out to compute the stresses operating on a structure for various modes and to analyse the aerodynamic loads imposed and evaluated using a numerical simulation of frequencies and Eigen modes. The determination of vibration responses resulting from unbalance and other stimulation modes has been made possible through the study of transient behaviour.

Moritz Grawunder, Roman Reß, Victor Stein, Christian Breitsamter, and Nikolaus A. Adams, "Flow Characteristics of a Five-Bladed Rotor Head," This paper gives an examination of the flow properties, including cyclic pitch, of a spinning five-bladed rotor head. Finding opportunities for efficiency gains is a key goal. Through numerical simulations based on incompressible unstable Reynolds average Navier Stokes equations, findings are produced. Mesh deformation is used to simulate cyclic pitch motion. It is demonstrated that a pitch control system significantly increases parasite drag. Thus, there is potential for reducing drag by increasing the aerodynamic fairing of ase components. Additionally, it is demonstrated that the aerodynamic properties are significantly impacted by the cyclic pitch motion of a blade cuff.

3. METHODOLOGY

For improved performance, the design and material of the helicopter's main rotor head have been adjusted. The main rotor head of the helicopter should be optimised for durability, toughness, high dimension stability, wear resistance, strength, and cost of materials as well as economic considerations.

- Perform Helicopter Main Rotor Head design in Solidworks based on design calculation and design model dimension.

- Make design calculations for various types of Helicopter Main Rotor Head.

- To create a solid works model of the helicopter's main rotor head's structural integrity Analytical calculations were utilised to calculate a part's dimensions, which were then applied to modelling. A base of the main rotor head of the helicopter was an extruded object. On a top, extruded cut profiles were used. An ANSYS workbench model was imported after being saved.

- To create and store static, modal, and fatigue analyses for a helicopter main rotor head's structural study in ANSYS

- Following the completion of a finite element analysis, data collection, and comparison of the designs for helicopter main rotor heads, By experimenting with several materials, choose the optimum material that will work for the helicopter's main rotor head (steel or alluminium)

- Perform static analysis where force, displacement, total deformation, and equivalent stress are determined.

- Perform a fatigue analysis, which determines a fatigue life and a fatigue safety factor.

- determine the natural frequency and perform modal analysis at various frequencies.

- Perform a modal analysis, which identifies various modes at various frequencies.

- Helicopter design Various materials are analysed for the Main Rotor Head, and data is gathered to determine whether the design is safe or not.

4. HELICOPTER MAIN ROTOR HEAD DIMENSIONS

For improved performance, the design and material of the helicopter's main rotor head have been adjusted. The main rotor head of the helicopter should be optimised for durability, toughness, high dimension stability, wear

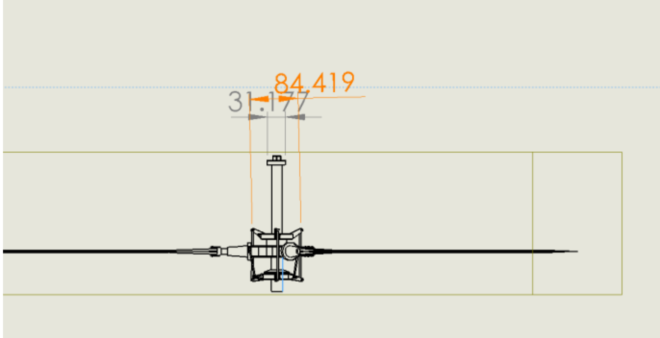

Figure 1: side view 1

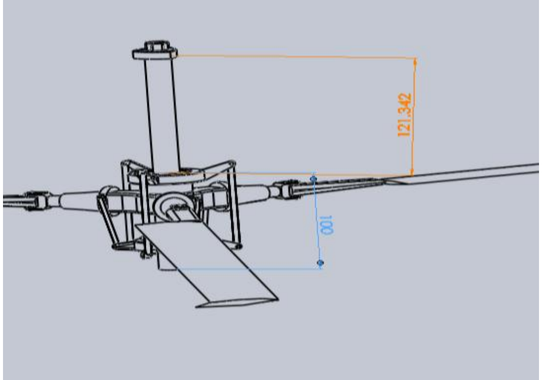

Figure 2: side view 2

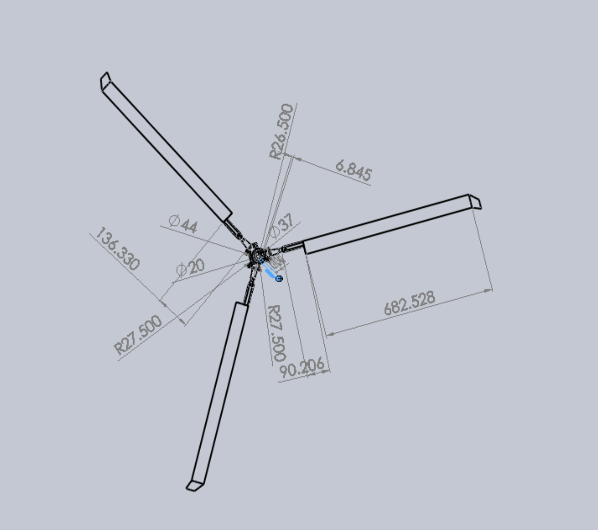

Figure 3: dimension of Helicopter rotor head top view

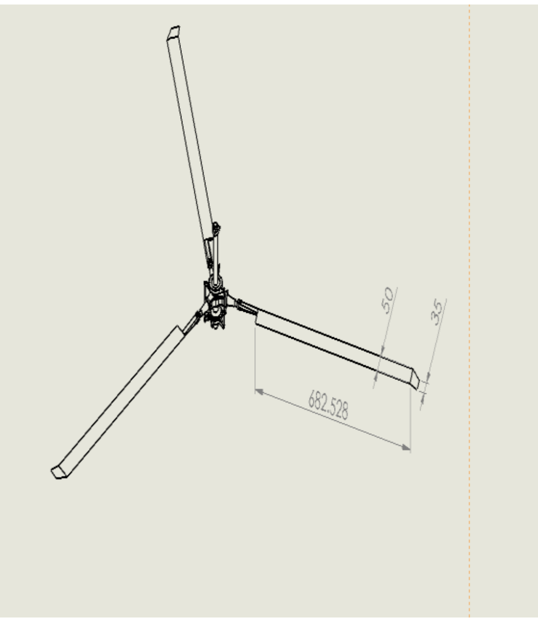

Figure 4: isometric view

5. ANALYTICAL DESIGN OF HELICOPTER MAIN ROTOR HEAD

5.1 Design Specifications conditions

Analyzing the benefits and drawbacks of various rotor head designs was the first step in the rotor head selection process. The following criteria for a design were decided upon:

1. diameter of a rotor would be approximately one meter
2. rotor head should be fully articulated and Coaxial
3. blades must be easily interchangeable to test different designs
4. number of blades should be variable

parameters were met by a final design, which was built based on a Coaxial system. Changing a total number of blades can be accomplished by removing a blade grip assemblies and reattaching am to a different hub built for a appropriate number of blades. Individual blades are changed by disconnecting am from a blade grip and attaching a new blade.

5.2 Design Specifications

We are going to design a helicopter main rotor head using analytical method of calculation for that taking some standard specification are given on following Table

5.2.1 Specification of Coaxial helicopters

Length:	16 m (52 ft 6 in)
Height:	4.93 m (16 ft 2 in)
Empty weight:	7,700 kg (16,976 lb)
Gross weight:	9,800 kg (21,605 lb)
Max takeoff weight:	10,800 kg (23,810 lb)
Powerplant:	2 × Klimov VK-2500 turboshaft engines, 1,800 kW (2,400 shp) each
Main rotor diameter:	2 × 14.5 m (47 ft 7 in)
Main rotor area:	330.3 m2 (3,555 sq ft) contra-rotating 3-bladed main rotors

Table 1: Specification of Coaxial helicopters

Kind of load	
Value Unit Aerodynamic lift force	1500 N
Centrifugal force of a blade	6156 N
Aerodynamic drag force of a blade	40 N
Torque	160 Nm
Rotational speed	180 rad/s

Table 2: Loads in Coaxial helicopters

5.3 Design Calculations

5.3.1 Blade sizing

A very first step of our design is to determine a dimension of a rotor blade of a rotor mechanism. This part is done by following various design approach of RC helicopter blades.

A primary assumption of a dimension for a blade is, Disc radius = Blade span = R = 0.5m , Blade Chord = C = 0.1m , N = Number of blades

From Blade elementary aory,

Solidity Factor, Solidity Factor,

$\sigma = \text{(Blade Area)}/\text{(Disc Area)} = ((N \times C))/(\pi \times R)$

Now, For 3 Blade, N = 3, Solidity Factor,

$\sigma = ((3\times0.1))/((\pi\times0.5)) = 0.191$

Again, For 2 Blade, N = 2, Solidity Factor,

$\sigma = ((2\times0.1))/((\pi\times0.5)) = 0.127$

Lift curve slope,

$$a = \frac{a_0}{1+(\frac{a_0}{\pi\times e\times AR})}$$

Here, a_0= First term in Fourier series = 2 π/ rad E = Oswald Efficiency Factor = 0.9 AR = aspect ratio = R/C = 0.5/0.1 = 5 So, Lift Curve slope,

$$a = \frac{\frac{2\pi}{rad}}{1+(\frac{\frac{2\pi}{rad}}{\pi\times0.9\times5})} = 4.34/rad$$

Now, Flapping Frequency,

$$\lambda = \frac{\sigma\times a}{16}\left[\sqrt{\left(\frac{64\times\theta}{3\times\sigma\times a}\right)+1}-1\right]$$

$$\lambda = \frac{0.191\times4.34}{16}\left[\sqrt{\left(\frac{64\times5}{3\times0.191\times4.34}\right)+1}-1\right]=0.5381$$

Here, θ = Pitch angle of a blade varies from $0\text{-}12^0$

Angular velocity for a rotor blade,

$\omega = 2\times(\pi/60)\times N = 2\times(\pi/60)\times 3 = 0.3151$

And blade tip velocity,

$V_T = 0.5\times\omega = 0.5\times 0.3141 = 0.1570$

coefficient of thrust

$C_T = 4\lambda^2 = 4\times 0.5381^2 = 2.1524$

Thrust,

$T = 0.5\times1.225\times0.1570^2\times0.7853\times2.1524 = 0.02551$

Here,

Density of Air, $\rho=1.225$ kg/m^3 Area = 0.7853981634 m^2

Coefficient of power,

$C_P = 4\lambda^3 = 4\times 0.5381^3 = 0.6232$

Power,

$P = 0.5\times\rho\times V_T^3\times A\times C_P = 0.5\times1.225\times0.1570^3\times0.7853\times0.6232 = 1.1600\times10^{-3}$

Here,

Density of Air, $\rho=1.225$ kg/m^3

Area = 0.7853981634 m^2

In order to determine if a rotor head design will withstand a forces it will be subjected to during normal operations, a maximum forces and moments were calculated. A forces were needed to calculate a stresses on individual components while a moments were used to calculate a coning angle. By calculating a coning angle it was possible to evaluation of a various force components. A two most significant forces and moments on a components are those generated by a centrifugal force and a lift force

A rotor head is designed to operate between 1000 to 1350 rpms with a maximum radius of 0.6 meters based on this a forces and moments are calculated using 1500rpms. By using 1500rpm a margin of safety was built directly into a calculations. When a moment generated by centrifugal force and moment generated by lift are equal a coning angle can be calculated.

6. RESULT AND DISCUSSION

6.1 3D Model in Solidworks

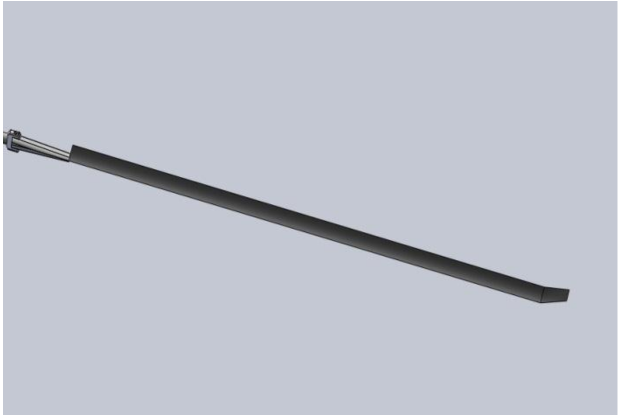

Figure 5: Part Design of Blade

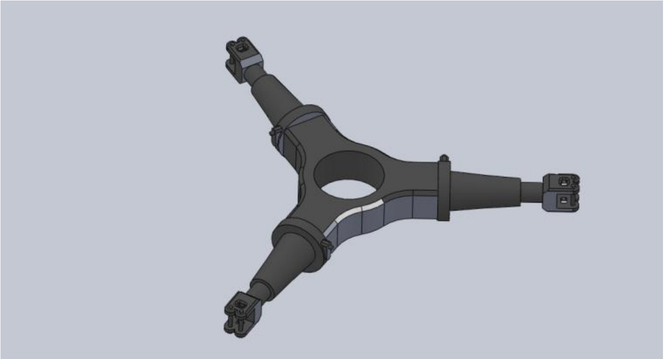

Figure 6: Part Design of Helicopter main rotor Hub

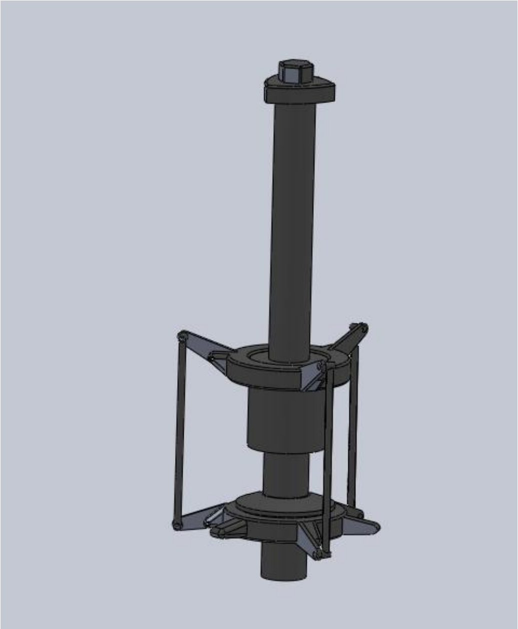

Figure 7: Part Design of Helicopter swash plate

6.2 3D MODEL of Helicopter Main Rotor Head Assembly

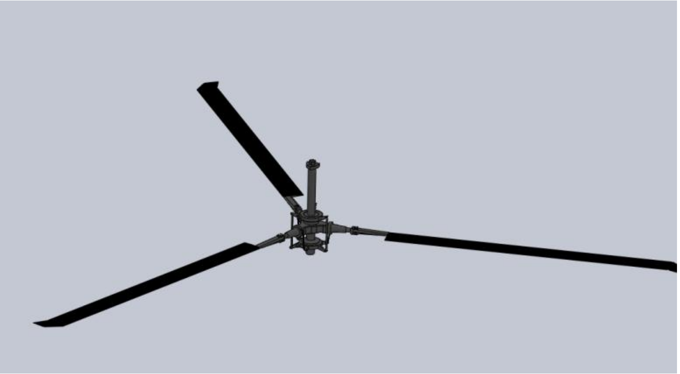

Figure 8 : 3D MODEL Assembly of Helicopter Main Rotor Head

6.3 Helicopter Main Rotor Head Model in Ansys

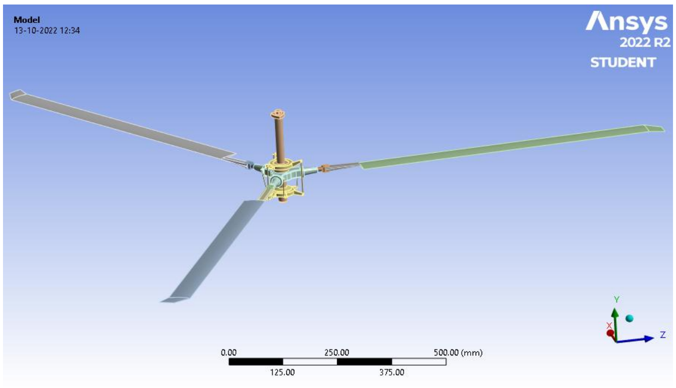

Figure 9: Helicopter main rotor head in Ansys

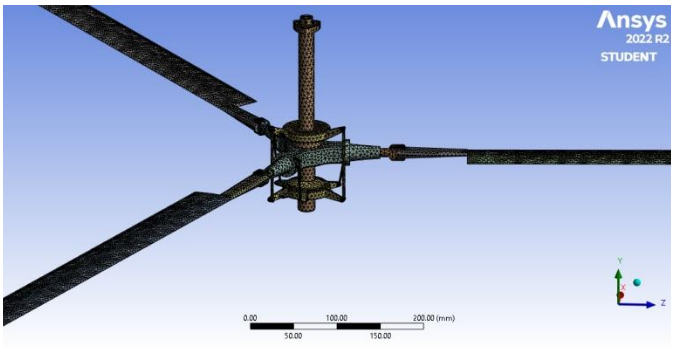

Figure 10: mesh

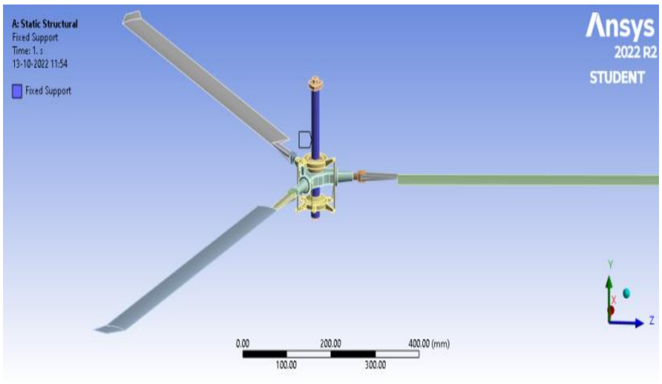

Figure 11: cylindrical support

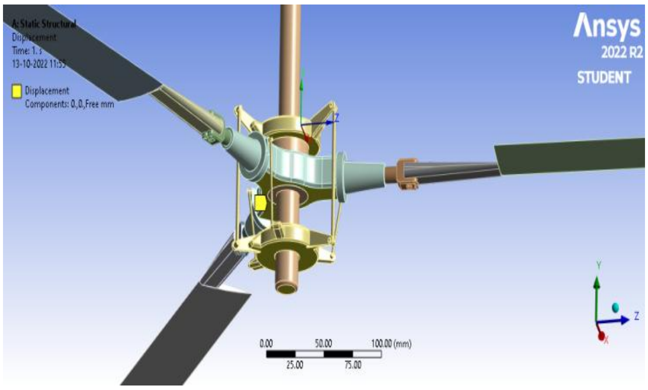

Figure 12: displacement

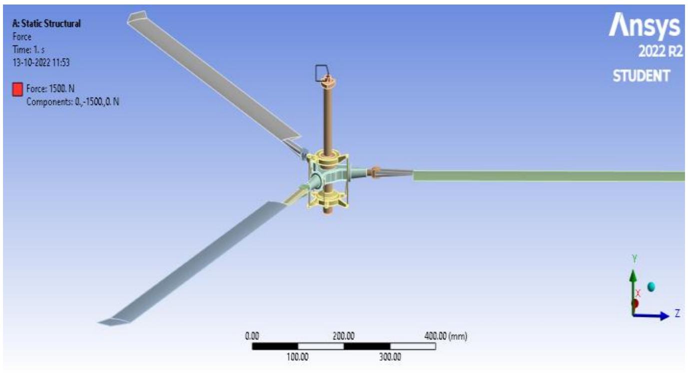

Figure 13: force 1

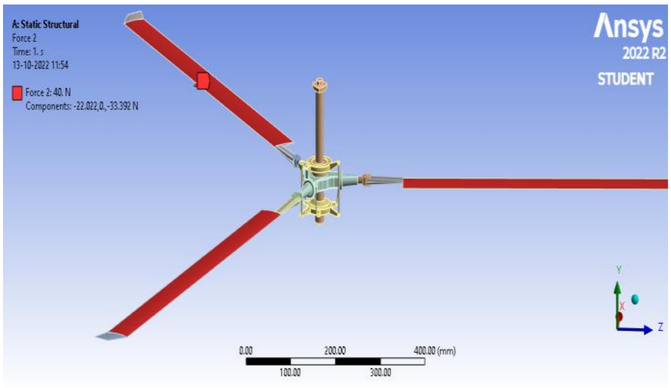

Figure 14: force 2

6.4 Helicopter Main Rotor Head of steel

6.4.1 Static analysis

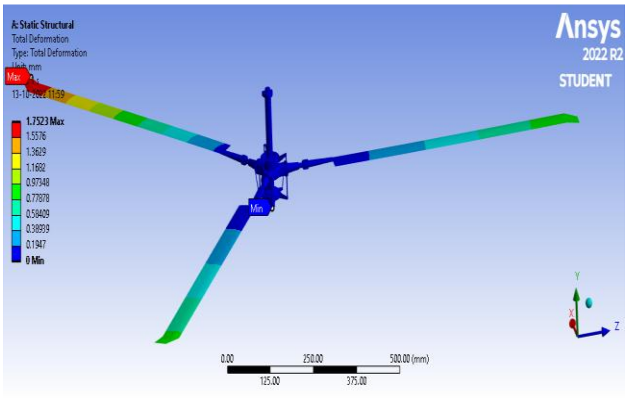

Figure 15: total deformation- steel material

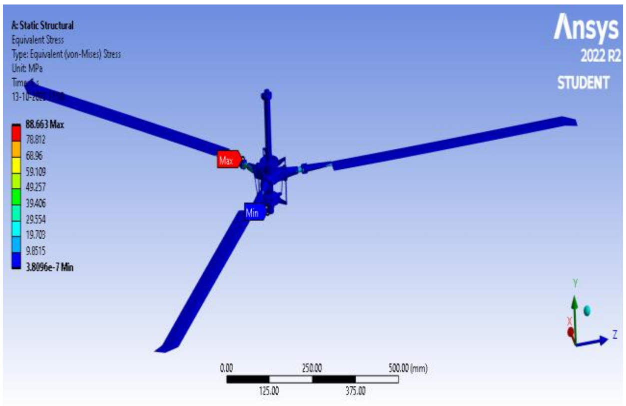

Figure 16: equivalent stress - steel material

Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	0.	1.7523	0.32282

Table 3: total deformation

Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1.	3.8096e-007	88.663	1.1991

Table 4: equivalent stress

6.4.2 Fatigue analysis

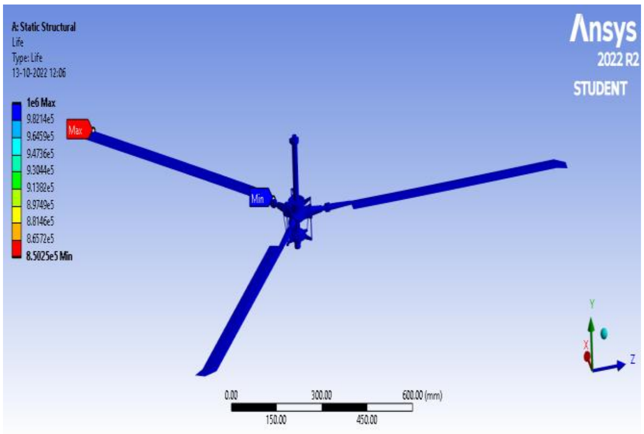

Figure 17: life- steel material

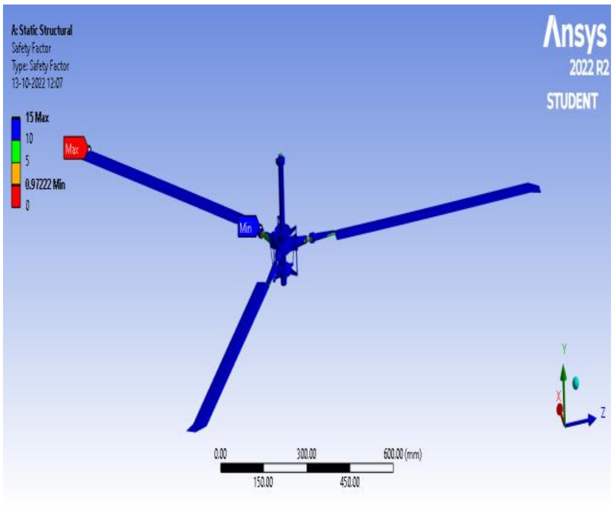

Figure 18: safety factor- steel material

Time [s]	Minimum	Maximum	Average
1.	8.5025e+005	1.e+006	1.e+006

Table 5: life

Time [s]	Minimum	Maximum	Average
1.	8.5025e+005	1.e+006	1.e+006

Table 6: safety factor

Figure 19: Fatigue Sensitivity

6.4.3 Modal analysis

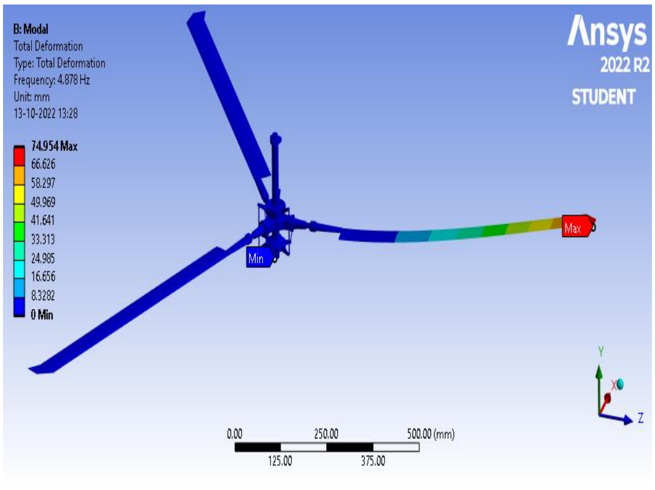

Figure 20: Total deformation 1- steel material

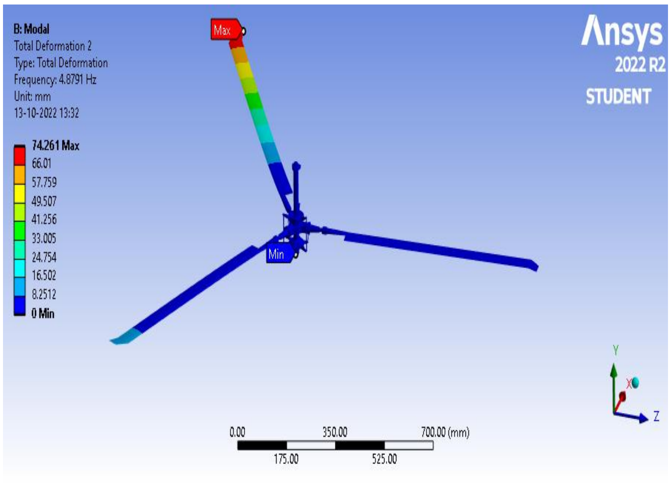

Figure 21: Total deformation 2- steel material

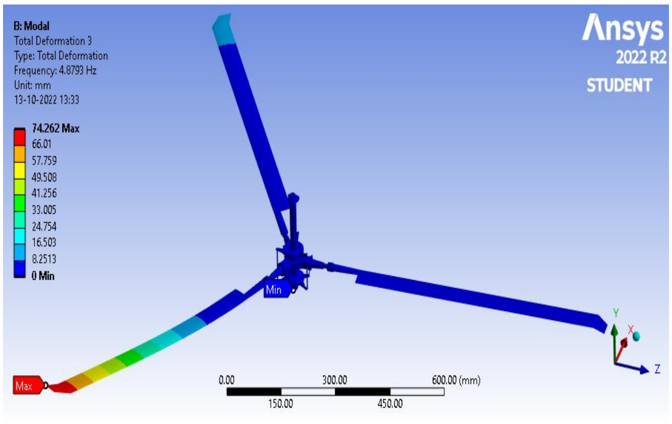

Figure 22: Total deformation 3- steel material

Mode	Frequency [Hz]	Maximum [mm]
1.	4.878	74.95
2.	4.8791	74.26
3.	4.8793	74.26

Table 7 : Frequency

6.5 Helicopter Main Rotor Head of Aluminum

6.5.1 Static analysis

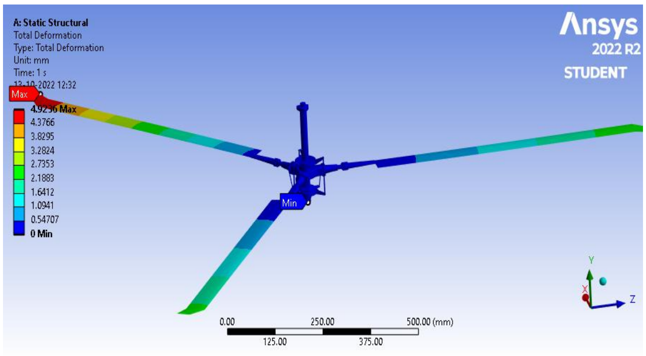

Figure 23: total deformation- Aluminium material

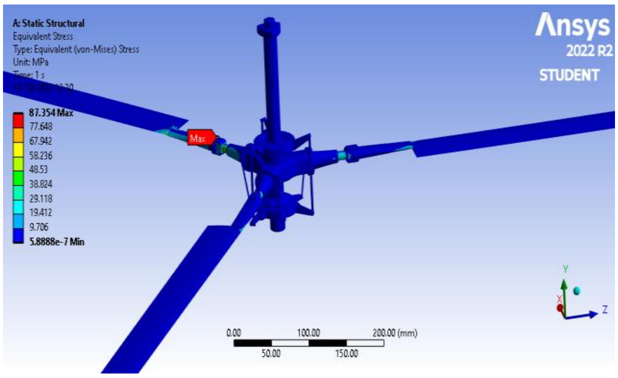

Figure 24: equivalent stress- Aluminium material

Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	0.	4.9236	0.90716

Table 8: total defornation

Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1.	5.8888e-007	87.354	1.2

Table 9: equivalent stress

6.5.2 Fatigue analysis

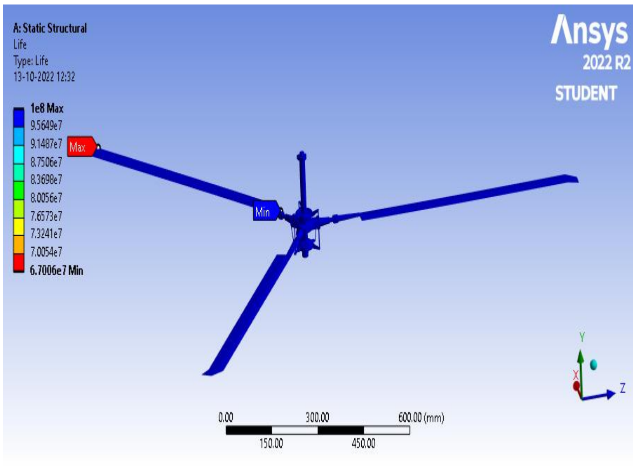

Figure 25 : life- Aluminium material

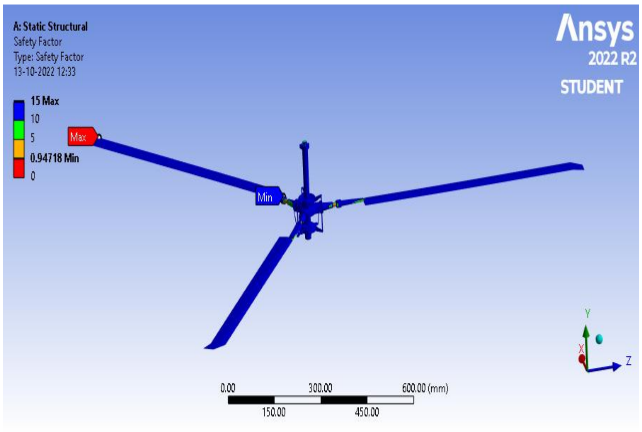

Figure 26: safety factor- Aluminium material

Time [s]	Minimum	Maximum	Average
1.	6.7006e+007	1.e+008	1.e+008

Table 10 : life

Time [s]	Minimum	Maximum	Average
1.	0.94718	15.	14.763

Table 11 : safety factor

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Figure 31: Fatigue Sensitivity

6.5.3 Modal analysis

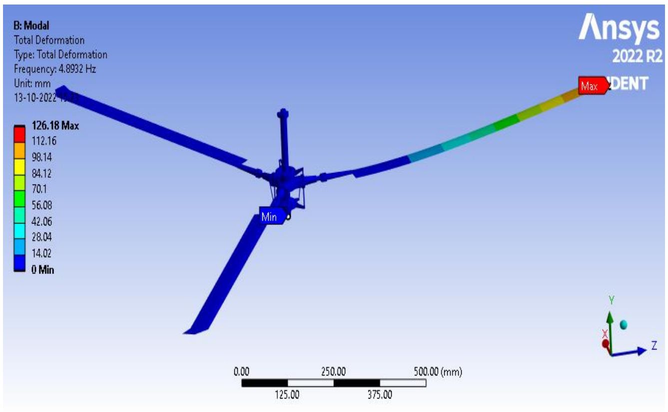

Figure 27: total deformation 1- Aluminium material

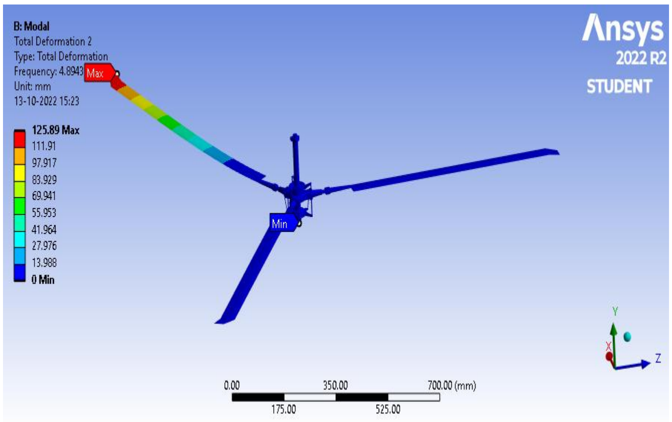

Figure 28: total deformation 2- Aluminium material

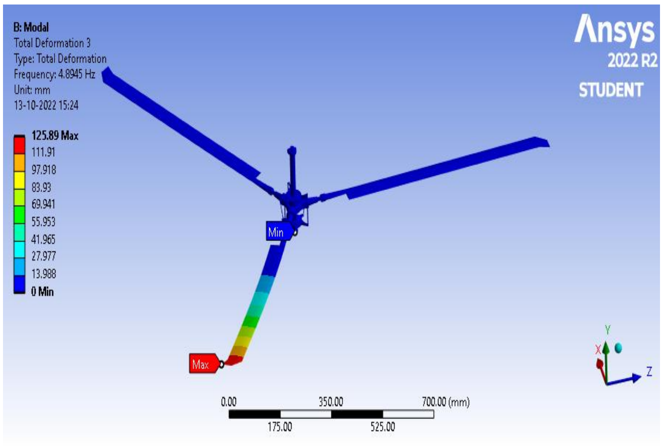

Figure 29: total deformation 3- Aluminium material

Mode	Frequency [Hz]	Maximum[mm]
1.	4.8932	126.18
2.	4.8943	125.89
3.	4.8945	125.89

Table 12 : Frequency

Compressive Ultimate Strength MPa	Compressive Yield Strength MPa	Tensile Yield Strength MPa	Tensile Ultimate Strength MPa
0	250	250	460

Table 13: Structural steel parameter

Alternating Stress MPa	Cycles	Mean Stress MPa
3999	10	0
2827	20	0
1896	50	0
1413	100	0
1069	200	0
441	2000	0
262	10000	0
214	20000	0
138	1.e+005	0
114	2.e+005	0
86.2	1.e+006	0

Table 14: S-N Curve of Structural steel

Strength Coefficient z (MPa)	Strength Exponen-t	Ductility Coefficien-t	Cyclic Strength Coefficient (MPa}	Cyclic Strain Hardening Exponent
920	0.106	0.213	1000	0.2

Table 15: Strain-Life Parameters of Structural steel

Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa	Relative Permeability
2.e+005	0.3	1.6667e+005	76923	10000

Table 16: Isotropic Elasticity of Structural steel

Compressive Ultimate Strength MPa	Compressive Yield Strength MPa	Tensile Yield Strength MPa	Tensile Ultimate Strength MPa
0	280	280	310

Table 17 : alluminium alloy properties

Alternating Stress MPa	Cycles	R-Ratio
275.8	1700	-1
241.3	5000	-1
206.8	34000	-1
172.4	1.4e+005	-1
137.9	8.e+005	-1
117.2	2.4e+006	-1
89.63	5.5e+007	-1
82.74	1.e+008	-1
170.6	50000	-0.5
139.6	3.5e+005	-0.5
108.6	3.7e+006	-0.5
87.91	1.4e+007	-0.5
77.57	5.e+007	-0.5
72.39	1.e+008	-0.5
144.8	50000	0

120.7	1.9e+005	0
103.4	1.3e+006	0
93.08	4.4e+006	0
86.18	1.2e+007	0
72.39	1.e+008	0
74.12	3.e+005	0.5
70.67	1.5e+006	0.5
66.36	1.2e+007	0.5
62.05	1.e+008	0.5

Table 18 : S-N Curve of alluminium alloy

Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa	Relative Permeability
71000	0.33	69608	26692	1

Table 19 : Aluminum alloy property

[1] Manually calculated permissible stress of modified design= 11.43 N/mm2

Analytically calculated equivalent stress of modified design for steel = 89.445 Mpa

Analytically calculated equivalent stress of modified design for aluminum = 88.131 Mpa

Fatigue life of steel = 1×106

Fatigue life of aluminum = 1×108

Fatigue Safety factor of steel and aluminum = 15

[2] Equivalent von-Mises stresses of our helicopter's main rotor head design are less than a yield strength. These results have been compared with current results of a similar model under the same loading conditions to validate FEA results. The yield stress, which is 250 MPa for steel and 280 MPa for aluminium, is far below the stress value. Analysis revealed that the von-Mises stresses for the two materials were nearly identical.

Tensile yield strength of steel = 250 MPa

Tensile yield strength of aluminum = 280 MPa

Endurance limit of steel = 230 MPa

Endurance limit of aluminum = 310 MPa

The structural behaviour of the main rotor head of a helicopter was investigated for various materials. A blade weight and aerodynamic forces are carried by the main rotor head of the helicopter in this illustration. In that situation, the strength of the helicopter's main rotor head will be determined. Therefore, a static analysis, fatigue analysis, and modal analysis are carried out on the main rotor head of the helicopter for various materials, such as steel and aluminium alloy.

Equivalent von-Mises stress is lower than yield strength and fatigue limit, thus steel has a lower fatigue life and endurance limit than aluminium. Since steel is lighter than aluminium and can handle enormous loads or weight, it is a more ideal material for the main rotor head of a helicopter. We discovered a distortion in modal analysis at various frequencies.

7. CONCLUSION

Extensive historical research makes it evident that the issue has not yet been fully resolved, and designers are still having many difficulties, particularly with stress concentration and the impact of loading other oar variables. The most well-liked strategy for analysing fracture mechanics issues is the finite element approach. Some helicopter main rotor heads made of steel are almost as light as those made of aluminium. However, steel's key benefit is that it is more rigid and has higher fatigue strength than aluminium. We can therefore conclude that aluminium is good for producing inexpensive helicopter main rotor heads whereas steel is a better material in terms of strength. SOLIDWORKS was used to successfully complete a project's design. Using SOLIDWORKS, issues that arose during the design of a machine were successfully resolved.

The majority of the key components of SOLIDWORKS, a flexible and all-inclusive programme for three-dimensional solid modelling, were used in the project design.

The primary features used to develop components are protrusion and cut. Using SOLIDWORKS, a component is drawn very precisely. Hence, When compared to the existing design of the helicopter's main rotor head at the same applied force, the modified design for the variable valve actuation system carries less stress. It demonstrates that a modified helicopter main rotor head is more durable than an existing one over a lengthy period of time, and according to a design assessment, the new design is simpler than the existing one and exhibits less deformation. Equivalent von-Misses stress is smaller than yield strength and fatigue limit. A steel's endurance limit is lower than an aluminium's in terms of fatigue life. Since steel is lighter than aluminium and can handle enormous loads or weight, it is a more ideal material for the main rotor head of a helicopter. We discovered a distortion in modal analysis at various frequencies. Each blade of a rotor responds to inputs from a control system as it rotates, enabling helicopter control. A centre of lift affects pitch, roll, and upward motion on a full rotor system in response to inputs. The structural behaviour of the main rotor head of a helicopter was investigated for various materials. Here, a helicopter rotor hub must support the weight of the blades and aerodynamic forces as they rotate. In that situation, the strength of the helicopter's main rotor head will be determined.

In this project, a 3D model of the helicopter's main rotor head was created in SOLIDWORKS and imported into the ANSYS software for static, fatigue, and modal analyses to examine its strength and dynamic properties. The model was then optimised using various materials, such as steel and aluminium alloy.

The main rotor head of a helicopter has stresses and deflections within the design parameters of the materials employed, according to the structural analysis discussed above. We can infer from the data that a steel material model for the helicopter main rotor hub had better FOS and weight reduction than an oar material model.

By altering the way a stress in a helicopter's main rotor head varied under heavy load conditions, we were able to make this observation. We have suggested the optimum material for a helicopter's main rotor head under conditions of heavy stress. The effects of loading and oar variables, as well as stress concentration, are major issues for designers. A steel helicopter's main rotor head is almost as light as an aluminium one, and steel has higher stiffness and fatigue strength than aluminium.

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