Department of Aerospace Engineering

JGI Global Campus, Jakkasandra Post, Kanakapura Taluk, Ramanagara District, Pin Code: 562 112

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A Fundamentals of Innovation and Venture Development in Entrepreneurship

Report on

HELICOPTER VIBRATION DIAGNOSTIC FOR MAINTENANCE

Submitted in partial fulfilment for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

AEROSPACE/AERONAUTICAL ENGINEERING

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CERTIFICATE

This is to certify that the project work titled **"HELICOPTER VIBRATION DIAGNOSTIC FOR MAINTENANCE"** is carried out by Name: IBRAHIM HAMED KASSIM (20BTRAN047), Name: SAMUEL MWESIGWA EDSON (20BTRAN041), Name: PANTALEO PROSPER KIRUWA (20BTRAS057), Name: THEOPHOR LWEMBU HENJEWELE (20BTRAS067), a bonafide students of Bachelor of Technology at the Faculty of Engineering & Technology, Jain (Deemed-to-be) University, Bangalore in partial fulfilment for the award of degree in Bachelor of Technology in Aerospace/Aeronautical Engineering, during the year 2023-2024.

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DECLARATION

We, Name: IBRAHIM HAMED KASSIM (20BTRAN047), Name: SAMUEL MWESIGWA EDSON (20BTRAN041), Name: PANTALEO PROSPER KIRUWA (20BTRAS057), Name: THEOPHOR LWEMBU HENJEWELE (20BTRAS067) are students of 8th semester B. Tech in Aerospace/Aeronautical Engineering, at Faculty of Engineering & Technology, JAIN (Deemed-to-be University), hereby declare that the project titled "**HELICOPTER VIBRATION DIAGNOSTIC FOR MAINTENANCE"** has been carried out by us and submitted in partial fulfilment for the award of degree in Bachelor of Technology in Aerospace/Aeronautical Engineering during the academic year 2023-2024. Further, the matter presented in the project has not been submitted previously by anybody for the award of any degree or any diploma to any other University, to the best of our knowledge and faith.

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Keywords: helicopter maintenance, Helicopter Vibration Diagnostic system, sensors, algorithms, vibrations, real-time monitoring, predictive maintenance.

ABSTRACT.

The goal of this project is to study and improve helicopter maintenance using the Helicopter Vibration Diagnostic technology. Helicopters are essential tools in a wide range of industries, from emergency services to defence, but they require rigorous maintenance due to their mechanical designs.

The Helicopter Vibration Diagnostic systems use modern sensors and complex algorithms to continuously detect and assess vibrations in helicopters. It provides predictive capabilities in addition to real-time monitoring, enabling proactive maintenance. This project enables operators to recognize and fix mechanical defects before they become serious, decreasing downtime, lowering maintenance costs, and improving safety by building a comprehensive database of vibration signatures across diverse helicopter models and Operational situations.

Additionally, broader use of the knowledge and technology created for knowledge and technology this research includes structural health monitoring, and industrial gear maintenance. The Helicopter Vibration Diagnostic system represents a paradigm-shifting advancement in maintenance techniques, guaranteeing the dependability and airworthiness of helicopters throughout essential missions while also delivering significant advantages across numerous industries.

1. INTRODUCTION AND OBJECTIVE.

1.1 Introduction.

The rotor system, tail rotor, engine, and transmission are the main causes of vibrations in helicopters. These vibrations can cause fatigue damage to structural elements, discomfort for people, difficulty reading instruments, and reduced efficacy of armament systems. Vibration analysis and measurement is becoming a standard procedure in the helicopter industry and is a powerful condition monitoring tool. Helicopters rarely suffer from unannounced or unexpected malfunctions, which are typically signalled by elevated vibration levels. The increasing vibration signature in a helicopter provides various insights into the state of numerous structural elements and parts.

An effective method for identifying possible structural deterioration or approaching component failure is vibration measuring at different structural locations. Helicopters are subjected to constant exposure to cyclic loads and vibration conditions, which can cause fatigue damage in multiple components. Helicopter maintenance is now performed by monitoring and changing many parts at predetermined intervals. This is an expensive technique that drives up maintenance expenses considerably. To tackle this challenge, Helicopter Vibration Diagnostic systems will be developed with the objective of identifying early signs of damage in helicopter components, estimating their remaining life, and facilitating the switch from scheduled-based maintenance to condition-based maintenance.

To identify and specify the minimal amount of information required for the identification of probable failure aspects of systems in operational service, our study focuses on measuring vibrations on a Light Utility helicopter and Bo-105.

Fig 1. HAL Light Utility Helicopter

1.2 Objective.

The goal of the project is to develop and implement the Helicopter Vibration Diagnostic (HVD) technology, which uses structural health monitoring (SHM) techniques, cutting-edge sensors, and complex algorithms to continuously detect and measure vibrations in helicopters. It is used to calculate normal operating conditions of an engineering system using models that determine the current state of the system, projecting the future loading environments for that system, and then forecasting through simulation and previous records the remaining useful life of the system. This estimate is then used as a reference to identify the presence and quantify the extent of damage in a system based on the output from the measured system response.

Predictive maintenance features built into the HVD system enable operators to foresee and proactively fix mechanical issues before they worsen. The system offers instantaneous response during helicopter operations because to its real-time monitoring features. The main objective is to reduce maintenance expenses by using proactive maintenance techniques to avert significant mechanical problems. In addition, by identifying and fixing mechanical flaws early on, the research hopes to improve safety and lower the likelihood of mishaps and incidents during flight.

2. LITERATURE REVIEW.

Structural health monitoring (SHM) and Helicopter Vibration Diagnostic (HVD) technology in particular, has been a subject of extensive research in the helicopter industry, and aerospace engineering in general. Numerous studies have focused on identifying the causes of damage in engineering systems, and extensive analysis of the dynamics of the helicopter reveal that rotor blades, tail rotor, engines and other rotating systems such as hydraulic pumps and air forces acting on the fuselage are the main sources of vibrations and have been found to be the cause of fatigue damage to structural elements, which causes discomfort to people, makes it difficult to read instruments, and reduces the effectiveness of weapon systems.

It has also been observed by studies that before suffering significant malfunctions, helicopters usually vibrate excessively. An important signal that offers comprehensive information on the state of different structural parts and components is the increase in the vibration signature. Vibration measurements at various structural locations are recognised as useful instruments for identifying possible failures in parts or structural damage.

The literature also explores the difficulties with standard helicopter maintenance procedures, which involve costly operational costs due to the high number of parts that must be replaced and checked at predetermined intervals. Helicopter vibration diagnostic systems were created and put into service because of the increasing agreement that novel solutions are required. These devices, which use HVD technology, are designed to identify early signs of degradation in helicopter parts, estimate their remaining life, and help with the transition from scheduled to condition-based maintenance.

3. METHODOLOGY.

The analysis involved distributing structural and non-structural weight to the appropriate areas of the finite element model. In the case of rotorcraft, most weight is of a structural nature. The mass model was generated by listing the weight and inertia properties of several components. The analysis also involved developing an analytical damping model for the global finite element model based upon the realistic dynamic behavior of the rotorcraft fuselage. Using MSC Nastran, the suggested methodology performs finite element analysis of a planned helicopter model with an emphasis on dynamic behaviour and precise structural component representation. MSC Nastran will simulate and assess vibrations coming from important components using vibration analysis, this leads to the extraction of free-response quantities such as resonant shapes/frequencies, damping levels, and frequency/time domain response function. The findings of the vibration analysis in a measured engineering system will be compared with the MSC Nastran simulations while mathematical models based on theoretical concepts are generated concurrently. To improve both the mathematical and numerical models, the work employs sensitivity analysis, experimental data validation, and an iterative optimization procedure. Enhancing helicopter vibration modelling approaches is the goal of the thorough documentation and reporting, which aims to offer insights into the advantages and disadvantages of each strategy.

4. ANALYSIS PROCESS.

The following steps were taken during the whole analysis process;

4.1 Definition of Helicopter Model:

The conducted methodology commenced with the development of a detailed 3D model of the helicopter using CAD software, ensuring a precise representation of structural components, including the rotor system, tail rotor, engine, and transmission.

Specifications of our model helicopter were derived from Bo-105 helicopter model, which is a lightweight, dual-engine, multifunctional helicopter created by West German Bölkow.

The helicopter specifications are given below;

Country of Origin:	**West Germany**	
Aircraft Crew:	One or two pilots	
Transport Capacity:	Four passengers or 2 stretchers and 2 attendants	
Aircraft Dimensions:		
	Length:	38 ft 11 in (11.8 m)
	Rotor Size:	32 ft 3 in (9.8 m)
	Height:	9 ft 10 in (3 m) Low Skids
Aircraft Weights:		
	Max T/O:	5,500 lb (2,500 kg)
	Fuel quantity:	160 Gal (570 l)
	Fuel types:	Jet A, JP4, JP5, JP8
Aircraft Performance:		
	Max Speed (VNE):	145 Kt (268 km/h)
	Range (no reserve):	361 nm (670 km);425 nm (784 km) AUX
	HIGE (max gross):	6,000 ft.
	Ceiling:	17,000 ft. (10,000 ft. above 2400kg gross weight)
	Powerplant:	2X Allison (Rolls-Royce) 250-C20B

	Power:	420 shp

Fig 2. Bo-105 specifications.

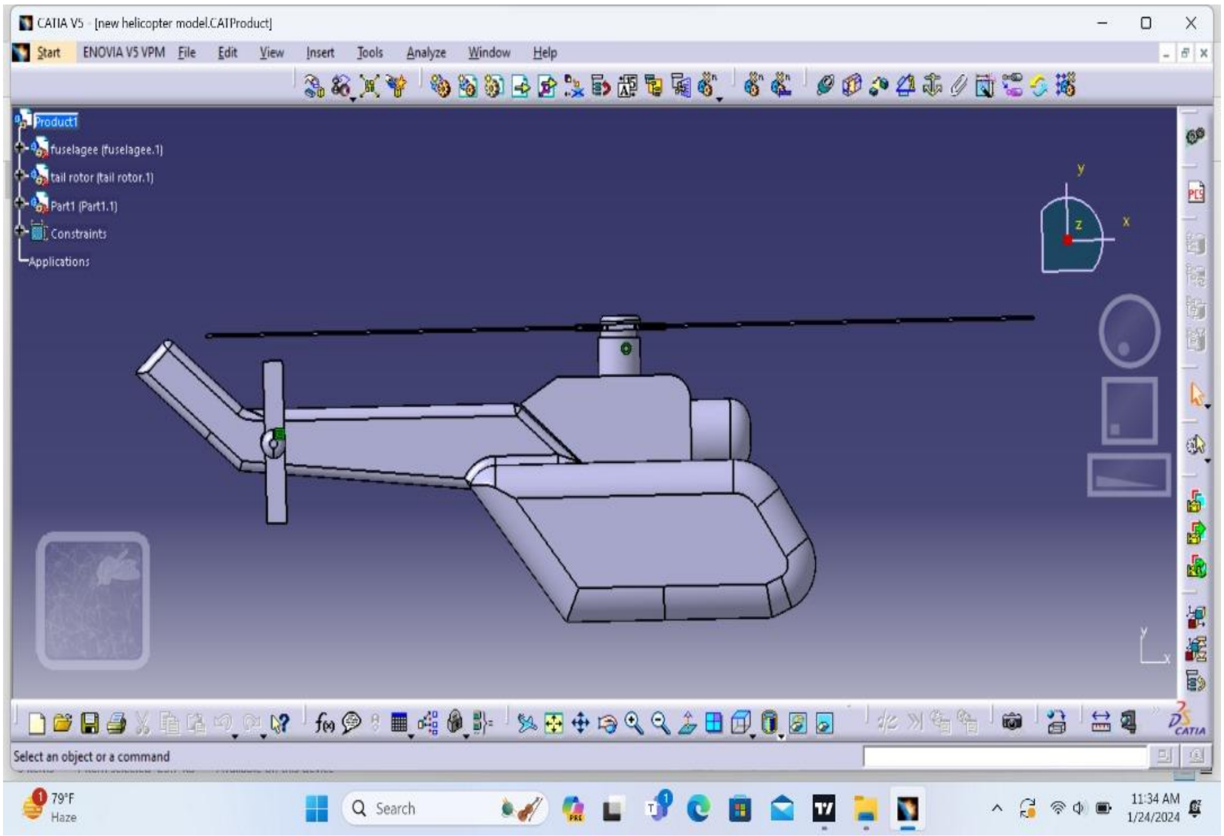

Fig 3. 3D model by CATIA v5.

4.2 Simplified model creation in MSC Nastran:

Given their complex mechanical architecture of a helicopter, a simplified model was required and necessary to conduct vibration analysis. This involved placement and orientation of Vibration prone points, considering that vibrations in helicopters are mostly caused by the rotor system, tail rotor, engine, and gearbox.

To obtain a statement of minimum loading, excitation levels and their corresponding frequency ranges used, selection of specific correlation points and the coincidence of accelerometer measurement locations with NASTRAN model grid points were considered.

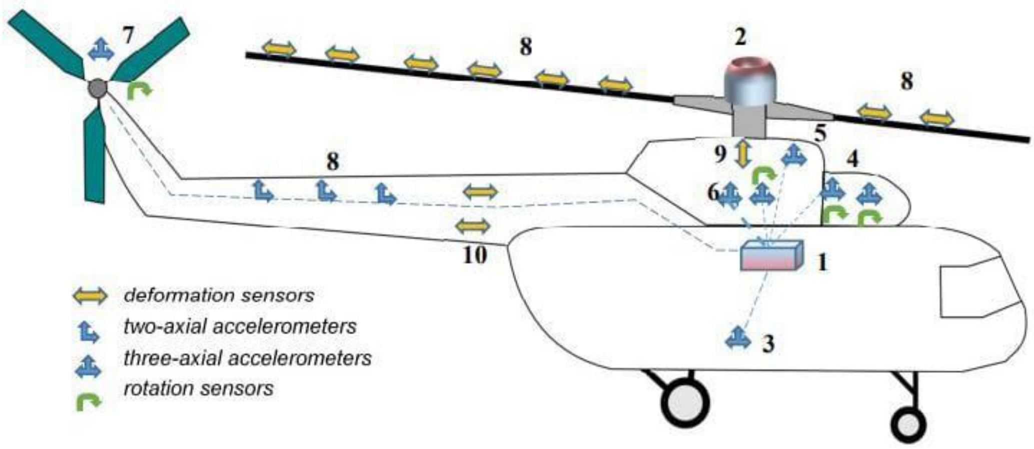

Fig 4. Vibration prone points (ref. 8)

To accurately mimic real-world settings, material parameters, boundary conditions, and loading scenarios were carefully determined. Consider,

Material	***Elastic modulus (N/m²)***	***Poisson's Ratio***	***Density (Kg/m³)***
Aluminium	7.0 x 10^{10}	0.33	2710.0
Steel	20.0 x 10^{10}	0.28	8000
Carbon Fiber Reinforced Polymer	7.0 x 10^{10}	0.28	1500

Fig 5. Materials assigned and properties.

A simplified 2D model below, consists of main parts of the helicopter that are prone to vibration and were assigned properties, dimensions, area moments of inertia, loading conditions and constraints at specific points to set a range for a steady vibration, from which component deterioration or damage can be observed via changes in the measured value.

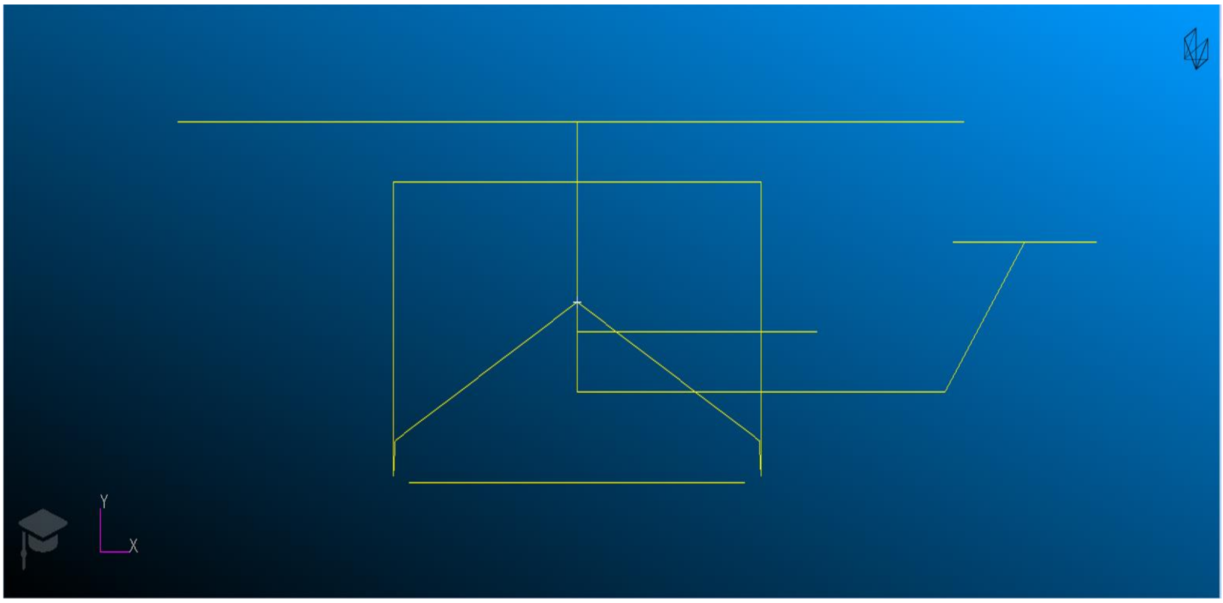

Fig 6. 2D model

For moment of inertia (I) calculations the helicopter has been broken down into the following segments:

1. Main rotor
2. Tail rotor
3. Engine
4. Fuselage and
5. Tail boom as shown in Fig7.

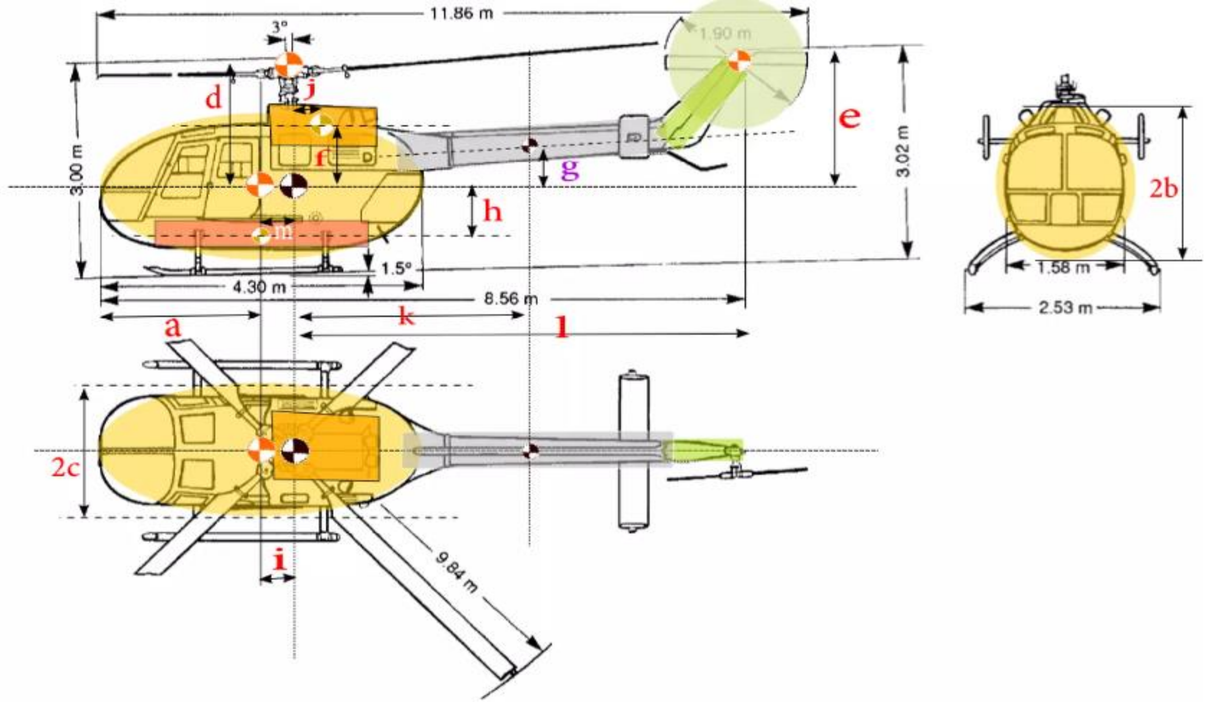

Fig 7. Bo-105 helicopter model.

<u>Formulae used.</u>

For rectangular components.

Moment of inertia was calculated as,

$$I = \frac{1}{12} \times width \times (breath)^3$$

For cylindrical/rod components.

Moment of inertia was calculated as,

$$I = \frac{\pi}{64} \times (Diameter)^4$$

Torsional moment of Inertia was calculated as,

$$J = \frac{1}{2} \times (I_{xx} + I_{yy})$$

Individual contributions of different segments towards the Moments of Inertia are:

1. **Main rotor contribution:** main rotor is approximated by a disc. It is located vertically at a distance d (1.53 m), mass of the main rotor m = 75.85 kg, Radius R = 4.92 m.
   Moment of inertia about X axis of helicopter, $I_{xx} = 918\ m^4$
   Moment of inertia about X axis of helicopter, $I_{yy} = 459\ m^4$
   Torsional moment of Inertia = $688.5\ m^4$

2. **Tail rotor contribution:** tail rotor is approximated by a disc. It is located vertically at a distance e (1.74 m) and horizontally at distance l (6.023 m). Polar Moment of inertia $J=\frac{1}{2}mR^2=0.94\ kgm^2$. Radius R = 0.95 m. Using R and J, mass of the tail rotor, m = 2.08 kg.
   Using parallel Axis theorem $I_{yy} = J + m(l^2 + e^2) = 0.94 + 2.08 \times (6.023^2 + 1.742) = 82.7\ kgm^2$

3. **Engine:** MBB Bo105 helicopter uses Alison 250 model engine in two quantities. Dry weight of a single engine is 62 kg. it can be dimensionally approximated as a cylinder of length 1.029 m and diameter 0.572 m. It is located vertically at f (0.83 m) and horizontally at j (0.43 m).
   MoI of a single engine about its own principal axes (parallel to Y axis of mass 62 helicopter), $I_{yy} = \frac{mass}{12}(3 \times radius^2 + length^2) = \frac{mass}{12}(3 \times 0.286^2 + 1.029^2) = 6.74\ kgm^2$. For two engines, $I_{xx} = 2 \times 6.74 = 13.48\ kgm^2$. Using parallel Axis theorem
   $J = I_{yy} + 2\ mass \times (f^2 + j^2) = 13.48 + 2 \times 62 \times (0.83^2 + 0.43^2) = 117.72\ kgm^2$

4. **Fuselage:** fuselage is approximated by an ellipsoid of the dimensions: 2a (4.3 m) Length along longitudinal direction; 2b (2.13 m) height and 2c (1.8 m) along the width. Mass of the fuselage is approximated as 1500 kg. it is located horizontally at m (0.43 m). MoI of the fuselage about its own principal axes (parallel to Y axis of helicopter)
   $I_{xx} = \frac{mass}{5}(a^2 + b^2) = \frac{1500}{5}(2.15^2 + 1.065^2) = 1727\ kgm^2$.
   Using parallel Axis theorem $I_{yy} = I_{xx} + mass \times (m^2) = 1727 + 1500 \times (0.432) = 2000.5\ kgm^2$

5. **Tail boom:** Tail boom is approximated by a cylinder of length 3.6m (234 pixel) and diameter 0.30m. It weighs around 34 kg and is located vertically at g (35 pixel = 0.525 m) and horizontally at k (206 pixel = 3.14m). MoI of the tail boom about its own principal axes (parallel to Y axis of mass 34 helicopter)) $I_{yy} = \frac{mass}{12}(3 \text{ x radius}^2 + \text{length}^2) = \frac{mass}{12}(3 \text{ x } 0.15^2 + 3.6^2) = 36.8$ kgm². Using parallel Axis theorem, $I_{xx} = I_{yy} + \text{mass x } (g^2 + k^2) = 36.8 + 34 \text{ x } (0.525^2 + 3.14^2) = 381.4$ kgm².

4.3 Normal modes Analysis with MSC Nastran:

After that, normal modes analysis was done in MSC Nastran, with an emphasis on capturing dynamic behaviour and vibrations coming from vital parts including the engine, gearbox, rotor system, and tail rotor. The goal of the simulation is to produce extensive vibration response data that will enable a thorough comprehension of the vibrational modes of the helicopter.

A **mode shape** is the deformation that the component would show when vibrating at its natural frequency. Each part of helicopter has its unique natural frequency If any component is shaken near to its natural frequency it will respond, rattle, or bounce at higher amplitude

The output of the simulations is attached with this report for reference.

4.4 Mathematical Modeling of Vibrations:

Simultaneously, theoretical ideas are utilised to construct mathematical models for vibration analysis. The mathematical description of the vibrational modes of the helicopter is also achieved through the application of transfer matrix techniques and modal analysis.

The complete model's equations of motion are represented by a set of common first-order differential equations,

$$\dot{y} = f(y,u,t)$$

Where, t is time; u the control vector; the state vector y contains the fuselage states y_F, main rotor states y_R, inflow states y_I and unsteady aerodynamic states y_A. The fuselage states y_F include the translational and angular velocities of the rigid fuselage described by the nonlinear Euler equations, and three attitude angles governed by the kinematic equations. The main rotor states y_R are the generalized displacements and generalized velocities of the blade.

These models use analytical techniques to try and capture the dynamics that are intrinsic to the helicopter system.

4.5 Validation with Experimental Data:

Validation of the models are performed by comparing the simulation results with available experimental data, ensuring that the numerical and mathematical models accurately represent the helicopter's dynamic behavior.

Our project did not involve real-time monitoring of helicopter vibration to compare results, however, available data show a close correlation of the results with a normal helicopter, which provides confidence in this technique.

4.6 Optimization and Refinement:

An iterative optimization process was then followed, refining both models based on the comparison results and improving the overall accuracy of vibration predictions.

4.7 Results:

The following are the frequencies output from MSC Nastran simulation.

MODE No.	EXTRACTION MODE	EIGEN VALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	4.143640E+05	6.437111E+02	1.024498E+02	7.446407E+05	3.085523E+11
2	2	1.489397E+06	1.220409E+03	1.942341E+02	9.544014E+04	1.421483E+11
3	3	3.795294E+06	1.948151E+03	3.100579E+02	1.124458E+05	4.267648E+11
4	4	5.580095E+06	2.362223E+03	3.759594E+02	1.423415E+05	7.942792E+11
5	5	6.197046E+06	2.489387E+03	3.961982E+02	4.803680E+04	2.976862E+11
6	6	6.355278E+06	2.520968E+03	4.012245E+02	1.377876E+05	8.756782E+11
7	7	1.623278E+07	4.028993E+03	6.412342E+02	2.928189E+05	4.753267E+12
8	8	1.799379E+07	4.241908E+03	6.751207E+02	1.516270E+03	2.728343E+10
9	9	5.130683E+07	7.162879E+03	1.140008E+03	3.894129E+04	1.997954E+12
10	10	7.391534E+07	8.597403E+03	1.368319E+03	2.794381E+04	2.065476E+12

Fig 8. Results

5. CONCLUSION.

The potential of Helicopter Vibration Diagnostic (HVD) technology to transform helicopter maintenance procedures was thoroughly investigated in this paper, which concludes. The methodology comprised creating and implementing the HVD system with MSC Nastran for finite element analysis, as was explained in detail throughout the discussions. A sophisticated grasp of the dynamic behaviour of developed helicopter models are to be made possible by the comparisons between mathematical models and numerical simulations, highlighting the precision and predictive power made possible by cutting-edge technologies.

To emphasise the value of preventive maintenance and ongoing monitoring, this paper focuses on the causes of vibrations in helicopters and the consequences they have. Real-time monitoring and predictive maintenance are becoming more and more possible with the use of HVD technology, especially in the context of the MSC Nastran architecture. The wider ramifications of this initiative will be highlighted by the possible cost savings, safety improvements, and move to condition-based repair.

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