Dynamic Analysis of Horizontal Stabilizer and Vertical Fin Of Light Utility Helicopter

Submitted by

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Industrial Training – I (**ME1047**) carried out at

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I also express my gratitude to my family and friends for their support and encouragement which helped in the completion of the project.

DECLARATION

I hereby declare that the entire work embodied in this dissertation has been carried out by me and no part of it has been submitted for any degree or diploma in any institution.

DHRUV HALDAR | 7th July, 2016

ME1047-INDUSTRIAL TRAINING - I | RWR&DC, HAL, Bangalore

DEPARTMENT OF MECHANICAL ENGINEERING,

SRM UNIVERSITY, GHAZIABAD

HAL/DC/RC/HR/201(12)/2016

07th July 2016

CERTIFICATE

This is to certify that Shri. Dhruv Haldar, student of B.Tech (Mechanical Engineering), SRM University, Ghaziabad has carried out Internship on "Acquaintance of Dynamic Analysis Procedure for Helicopter Design" on No-pay-No-fee basis from 14.06.2016 to 07.07.2016 at Dynamics Group, Design & Drawing Department, Rotary Wing Research & Design Centre, Hindustan Aeronautics Limited, Bangalore.

His Punctuality, Conduct, Behavior and Progress in Training was Excellent as rated by the Department Head during his stay with us.

(SATISH BABU KATA)
MANAGER (HR)

Shri. Dhruv Haldar,
B.Tech(Mechanical Engineering),
SRM University, Ghaziabad.

HINDUSTAN AERONAUTICS LIMITED, DESIGN COMPLEX, BANGALORE
RWR&DC
HR Department

CONTENTS

Company Background

- Hindustan Aeronautics Limited is an Indian state-owned aerospace and defence company based in Bangalore, Karnataka. It is governed under the management of the Indian Ministry of Defence.

- The government-owned corporation is primarily involved in the operations of the aerospace industry. These include **<u>manufacturing and assembly of aircraft, navigation and related communication equipment and airports operation</u>**.

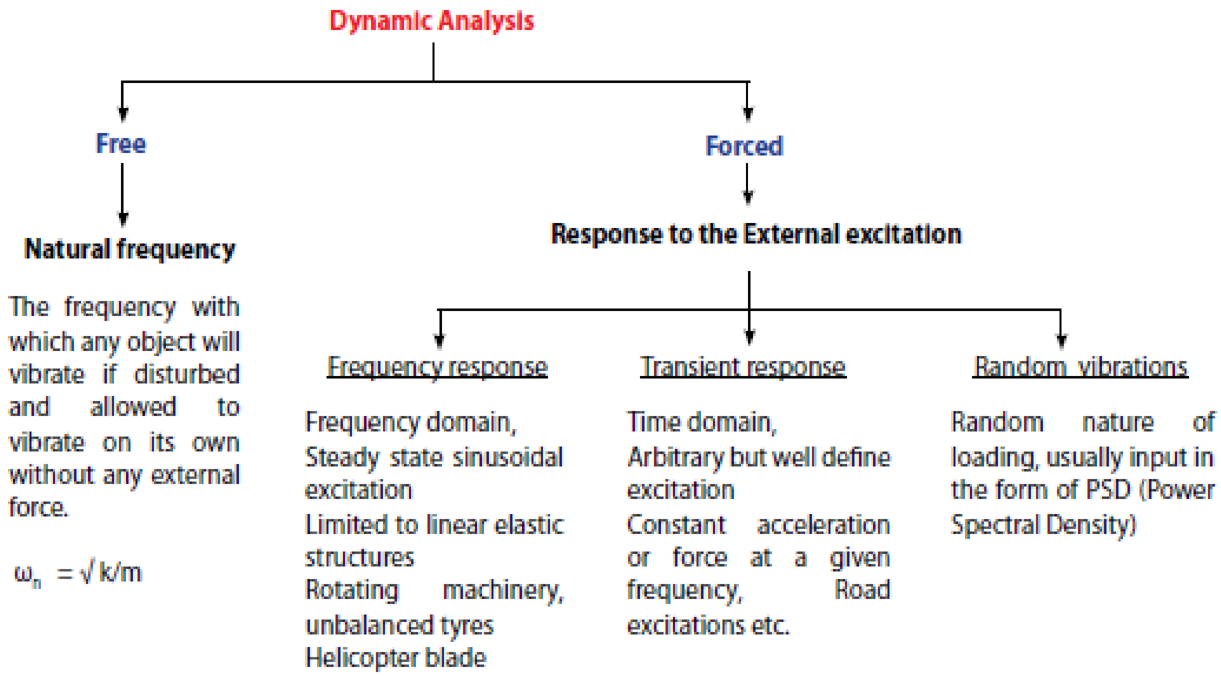
- HAL built the first military aircraft in South Asia. It is currently involved in the design, fabrication and assembly of aircraft, jet engines, helicopters and their spare parts. It has several facilities spread across India. The locations where the manufacturing plants are operated by HAL include Nasik, Korwa, Kanpur, Koraput, Lucknow, Bangalore and Hyderabad.

- Hindustan Aeronautics has a long history of collaboration with several other international and domestic aerospace agencies such as Airbus, Boeing, Lockheed Martin, Sukhoi Aviation Corporation, Elbit Systems, Israel Aircraft Industries, RSK MiG, BAE Systems, Rolls-Royce plc, Dassault Aviation, MBDA, EADS, Tupolev, Ilyushin Design Bureau, Dornier Flugzeugwerke, the Indian Aeronautical Development Agency and the Indian Space Research Organisation.

- In-house developed products include – HA 31 Basant Agro Aircraft, Light Combat Aircraft (LCA) Tejas and helicopters like ALH Dhruv, Light Combat Helicopter (LCH) , Light utility helicopter (LUH),Cheetah and Chetak (trainer helicopters) and ALH Rudra (Attack Helicopter)
- HAL Aerospace Museum is <u>India's first aerospace museum</u> located at Hindustan Aeronautics Limited premises, in Bangalore. Established in 2001, the Museum is part of the HAL Heritage Centre and Aero Space Museum, and showcases the growth of the Indian aviation industry and HAL for six decades.

Topic: Dynamic Analysis of various components Light Utility Helicopter (LUH)

Introduction

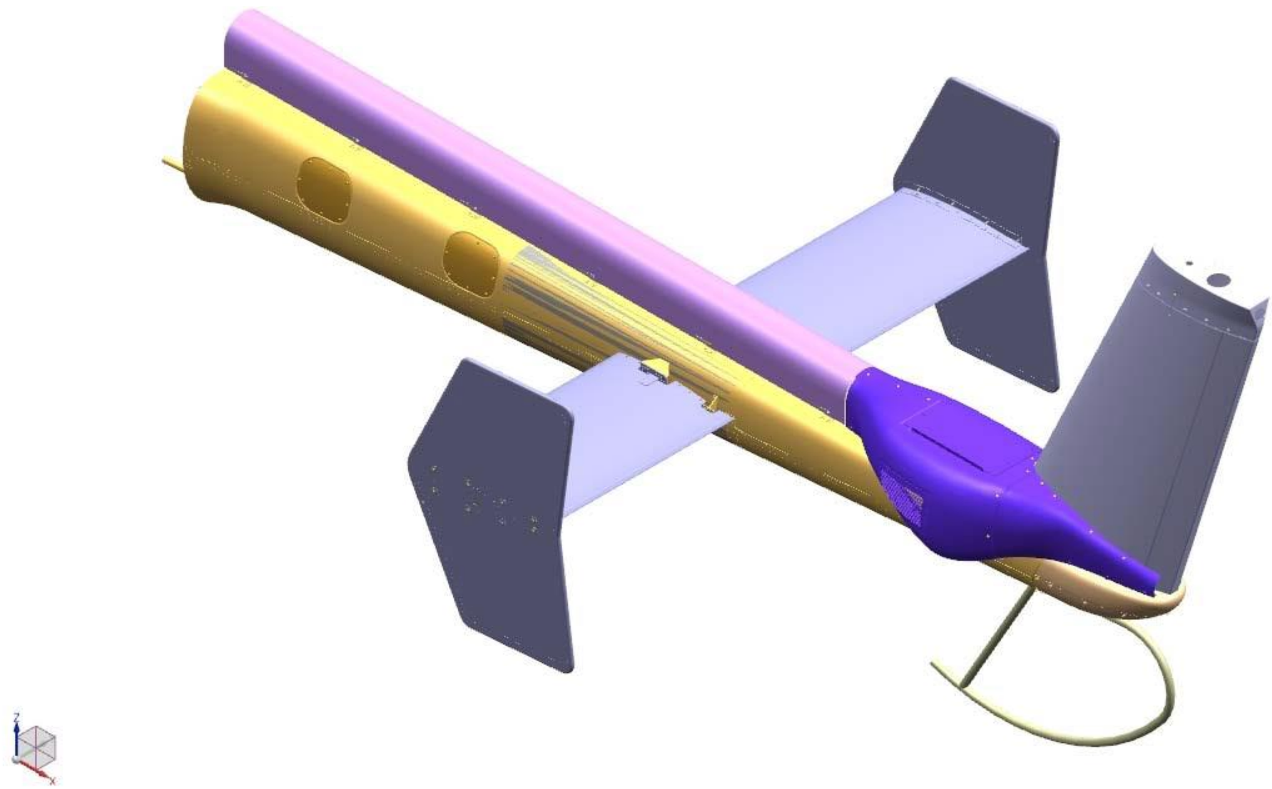


The aim of Dynamic analysis of a helicopter component is to find the values of natural frequencies using Finite Element Analysis of model.

LUH is studied for free dynamic analysis since the control surfaces like horizontal stabilizer and vertical fin is a complex physical problem when solved mathematically. LUH is modeled with low weight fiber composite for horizontal stabilizer and vertical fin. The Horizontal stabilizer is positioned on the tail boom ahead of the tail rotor and the vertical fin is positioned vertically at the end of tail boom to off load the tail rotor and for yaw control.

Q. Why to find out natural frequency?

A. Natural frequencies or resonant frequencies of helicopter components are found out in order to see if they match with the values of natural frequencies of rotor. Because if they match, the *structure of helicopter would be unstable and unsafe for flight*.



Location of Horizontal Stabilizer and Vertical Fin in Helicopter (Isometric View)

HAL LIGHT UTILITY HELICOPTER (HAL-LUH)

- The HAL Light Utility Helicopter (LUH) and its derivative HAL Light Observation Helicopter (LOH) is a single-engine light helicopter under development by Hindustan Aeronautics Limited of India.
- **First LUH GTV ground run is due July 2016**
- Production is planned to begin in 2018 at 10 per year, later on going up to 36 per year and delivery of 187 HAL's LUHs is to be completed by 2022

- Specifications

1. General characteristics
2. Crew: 2
3. Capacity: up to 6 passengers
4. Empty weight: 1,675 kg (3,693 lb)
5. Max takeoff weight: 2,700 kg (5,952 lb)
6. Powerplant: 1 × HAL/Turbomeca Shakti 1U turboshaft engine, 1,272 kW (1,706 hp)

- Performance

1. Cruising speed: 220 km/h (137 mph; 119 kn)
2. Never exceed speed: 250 km/h (155 mph; 135 kn)
3. 10.Range: 350 km (217 mi; 189 nmi)
4. 11.Service ceiling: 6,500 m (21,325 ft)
5. Rate of climb: 7.5 m/s (1,480 ft/min)
6. Fuel consumption: 0.69 kg/km (2.4 lb/mi)
7. Thrust/weight: 5.6

LIST OF ABBREVIATIONS

HT - Horizontal Stabilizer

VT - Vertical Fin

DOF - Degree of Freedom

LUH - Light Utility Helicopter

CG - CENTER OF GRAVITY

NASTRAN - NASA Structural Analysis

MATLAB - Matrix Laboratory

SCHUB - SHEAR (German)

FE - Finite Element

FAR - Federal Aviation Regulation

VF - Flutter Speed

VNE - Never exceed speed

b - Semi chord/Semi span (HT/VT)

ET- Equipment Panel

GTV- Ground Testing Vehicle

DYNAMIC ANALYSIS: LUH HORIZONTAL STABILIZER (HT)

Method Used: Finite element method

The FE method was used to model the HT using HYPERMESH and the natural frequencies were obtained through modal analysis using NASTRAN.

The Horizontal stabilizer has a uniform airfoil GAW2 (inverted) profile which is rigidly fixed to the helicopter tail boom with end plates and a sectional view with geometric construction is shown in Fig-1 and the FE model of airfoil in Fig-2. The sectional details of GAW2 airfoil is given in Table 1. In addition to torsional motion, bending motion is included in the model and there is a phase shift between torsion and bending motion due to aerodynamic loads.

The first bending mode and the first torsion mode of LUH HT are given below.

The HT 1st Flap bending mode frequency = 23.61Hz

The HT 1st Torsional mode frequency = 55.74Hz

Since the classical bending-torsion theory is used, the bending and torsion frequencies are obtained from NASTRAN.

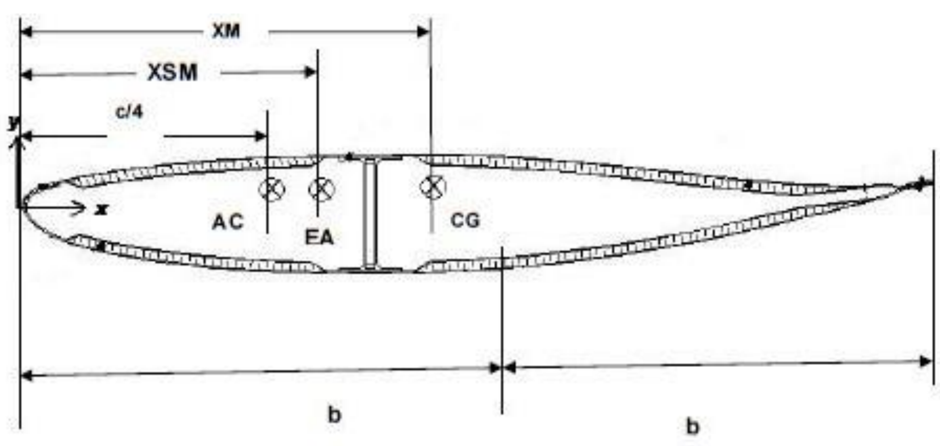
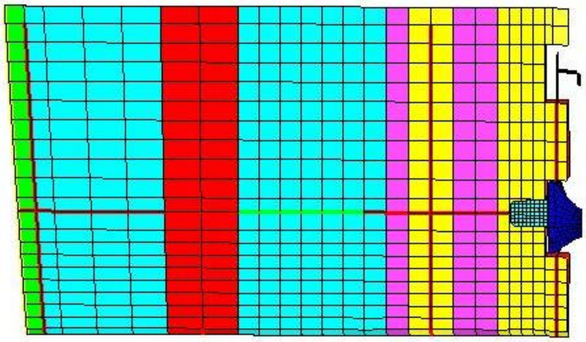
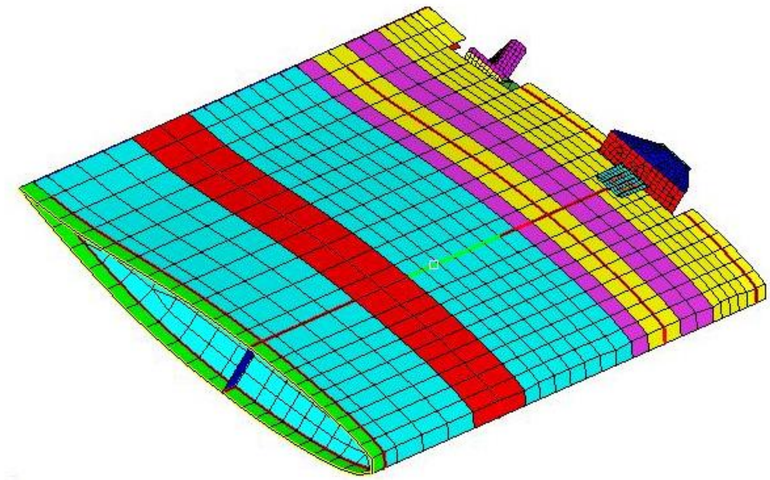


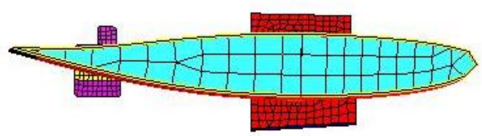
Fig 1. Cross section of horizontal stabilizer



TOP VIEW



ISOMETRIC VIEW



SIDE VIEW

Fig 2. FEM Model of LUH Horizontal Stabilizer

Table -1: Sectional properties for GAW2 (Inverted) Aerofoil Section for Horizontal stabilizer

Parameter	Description	Unit	Value
MPL	Mass per unit length	Kg/mm	2.292
MJxx	Out of plane Mass moment of inertia about mass centre	Kg.mm	1.482E-03
MJyy	In-plane Mass moment of inertia about mass centre	Kg.mm	3.810E-02
XM	Mass centre	mm	259.30
YM		mm	8.393
XSM	Shear centre	mm	200.6
YSM		mm	0.648

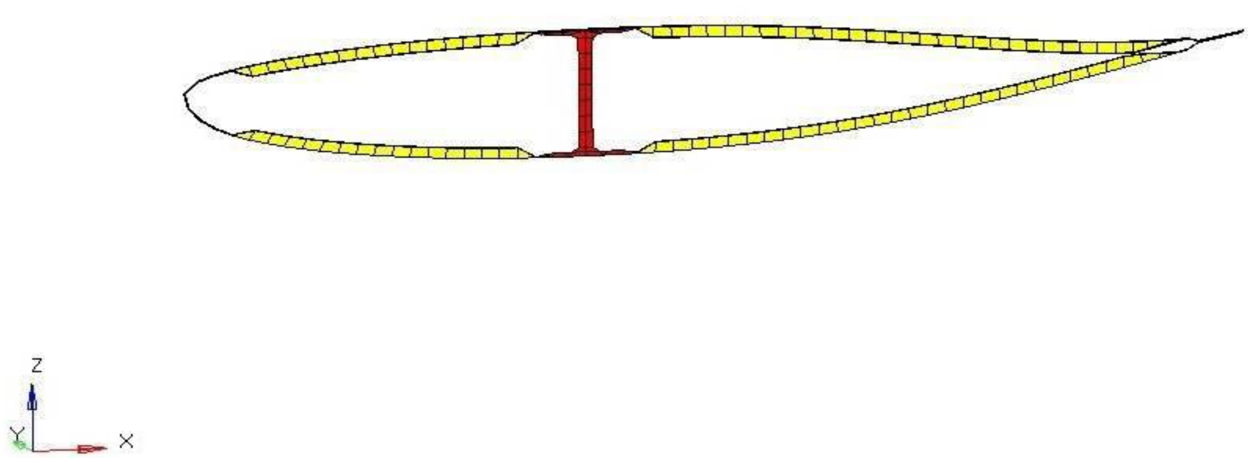


Fig 3. SCHUB FE Model of Horizontal Stabilizer uniform airfoil (GAW2) section

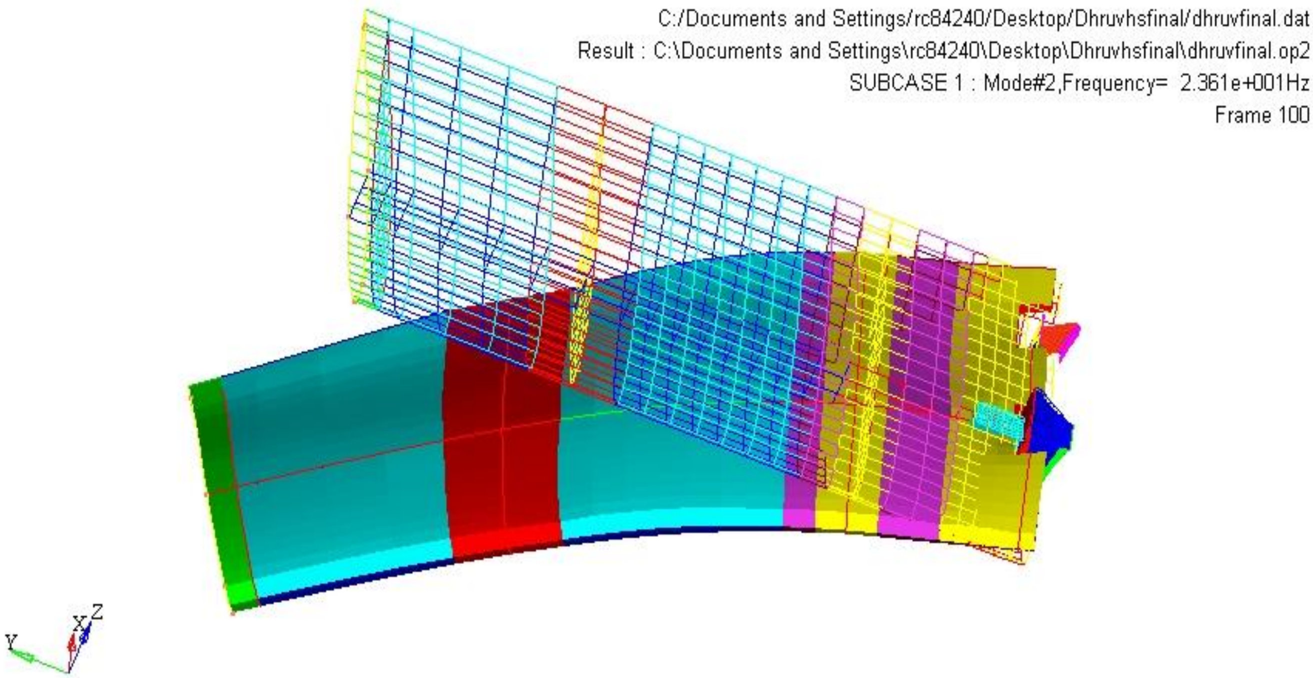


Fig 4. Fundamental bending mode.

Frequency=23.61 Hz

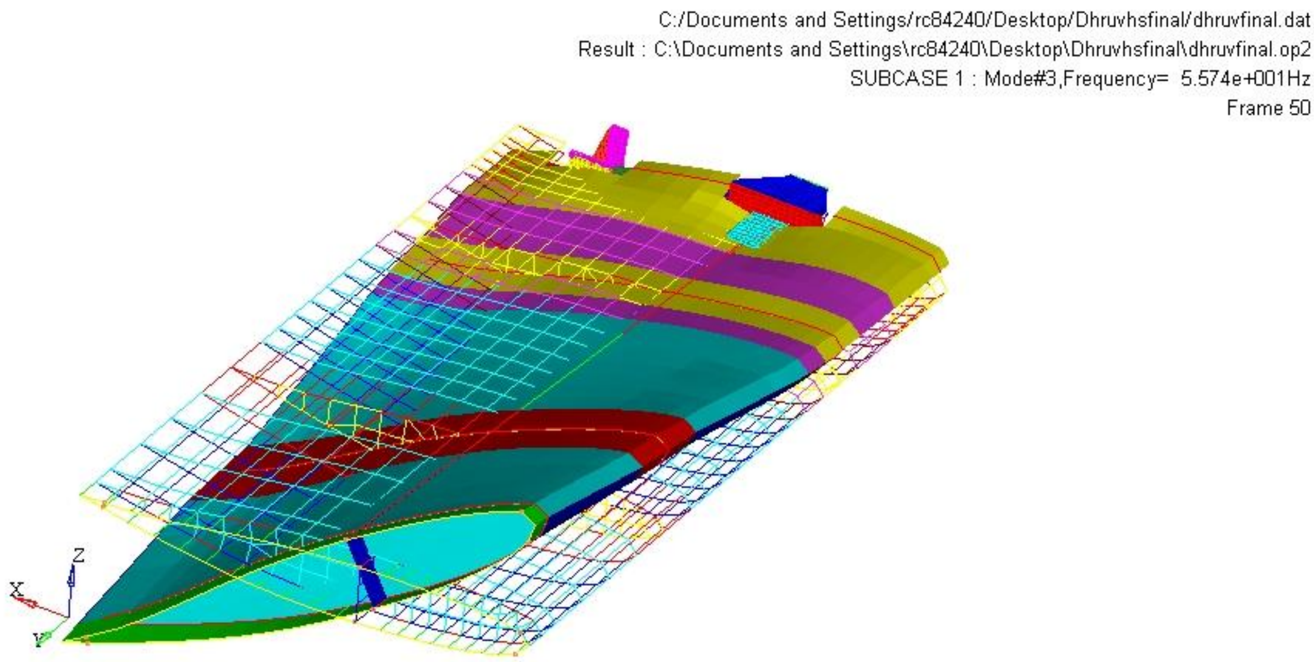


Fig 5. Fundamental torsion mode

Frequency=55.74 Hz

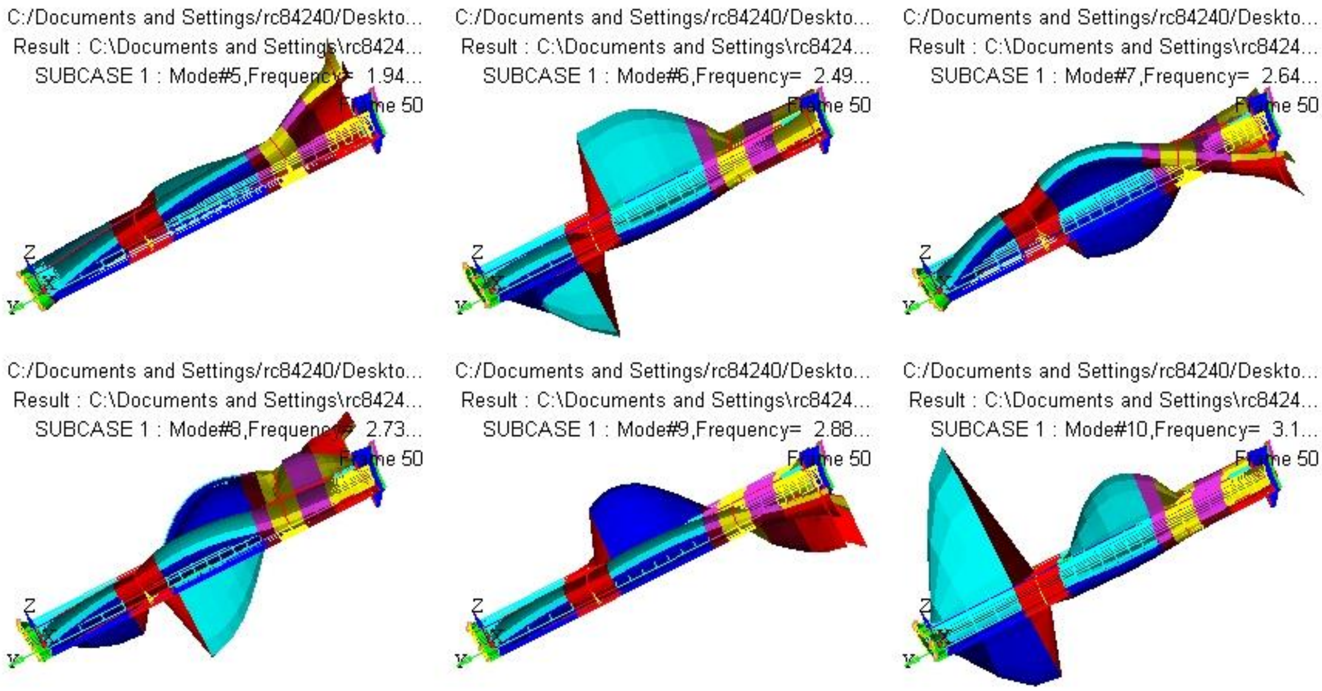


Fig 6. Other modes (5 to 10)

Natural Frequencies

5. 20.27 Hz

6. 26.27 Hz

7. 27.69 Hz

8. 28.67 Hz

9. 30.84 Hz

10. 32.07 Hz

DYNAMIC ANALYSIS: LUH VERTICAL FIN (VT)

Method Used: Finite element method

The Finite element method was used to model the VT using HYPERMESH and the natural frequencies were obtained through modal analysis using NASTRAN.

The NACA0017 truncated airfoil is used and the geometric detail of vertical fin is shown in Fig. The study is limited to fins of simple geometry and construction**.**

Some assumptions made are

1. Homogeneous construction of surface
2. Plate thickness to chord ratio between 0.04 and 0.09
3. Zero sweep of mid chord line.

The first bending mode and the first torsion mode of LUH VT are given below.

The VT 1st Flap bending mode frequency = 39.32 Hz

The VT 1st Torsional mode frequency = 60.15 Hz

Procedure for creation of FE Model:

1. Obtained Original Geometry (CAD Parasolid File of extension .x_t)

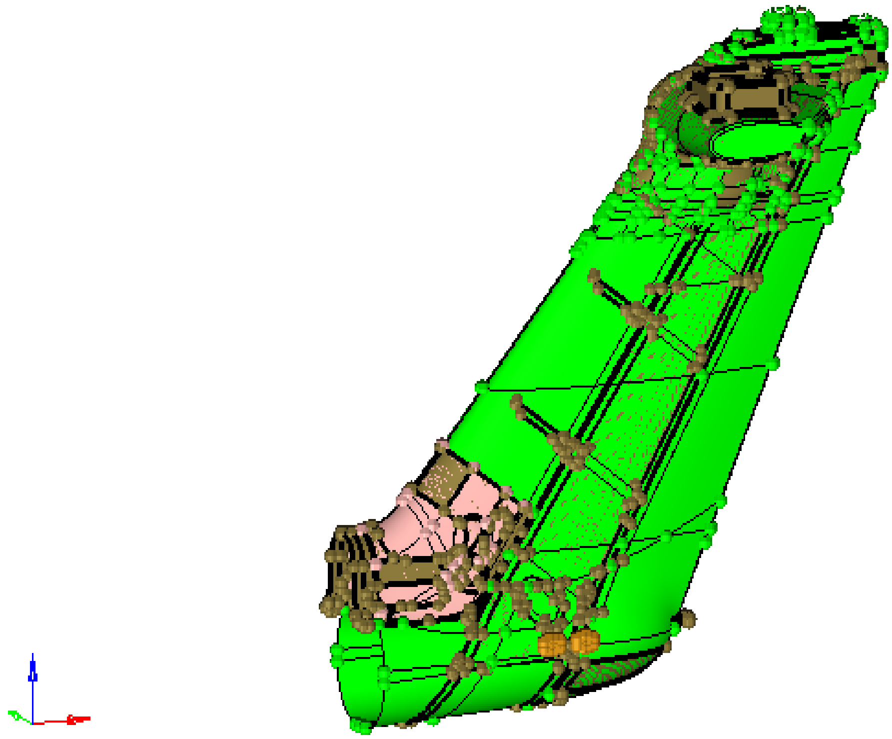
2. Geometry Cleanup: Removal of Red Lines- Free edges (only corrected where required)

Removal of Yellow Lines-Surfaces which are shared by 3 or more surfaces

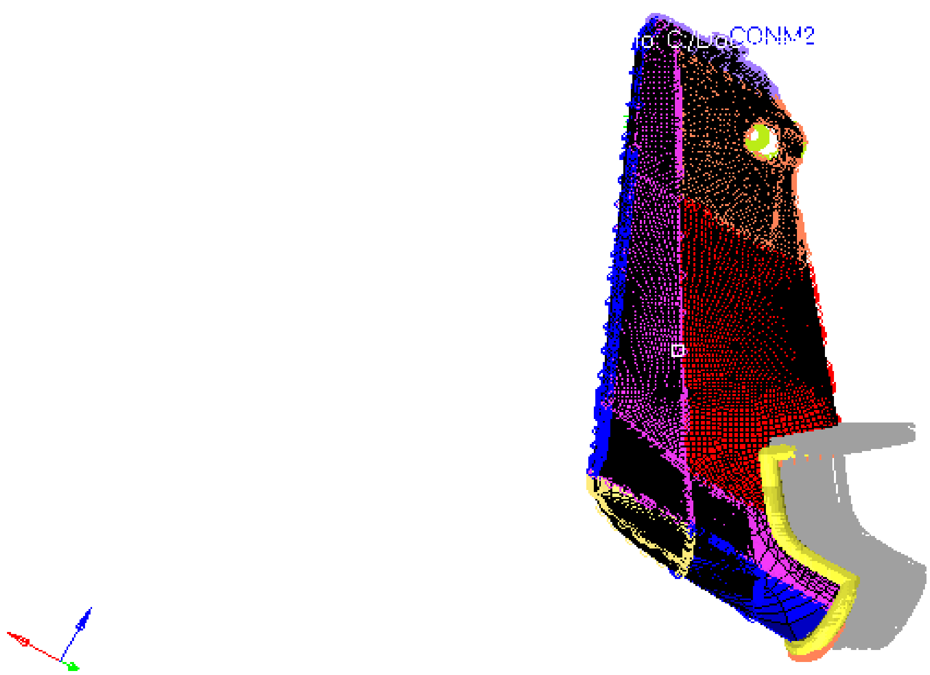
Green Lines –Required lines /Shared edges

3. Creation of nodes at the area which is to be attached to the Tail Boom

4. Meshing: Command AUTOMESH used surface-by-surface



ORIGINAL GEOMETRY



CORRECTED AND MESHED GEOMETRY WITH ASSIGNED MASS (CONM2)

Table -2: Sectional properties for NACA0017 Aerofoil Section for Vertical Fin

Parameter	Description	Unit	Value
b	Semi span	mm	1450
C_t	Chord At Root	mm	550
C_f	Chord At Tip	mm	780

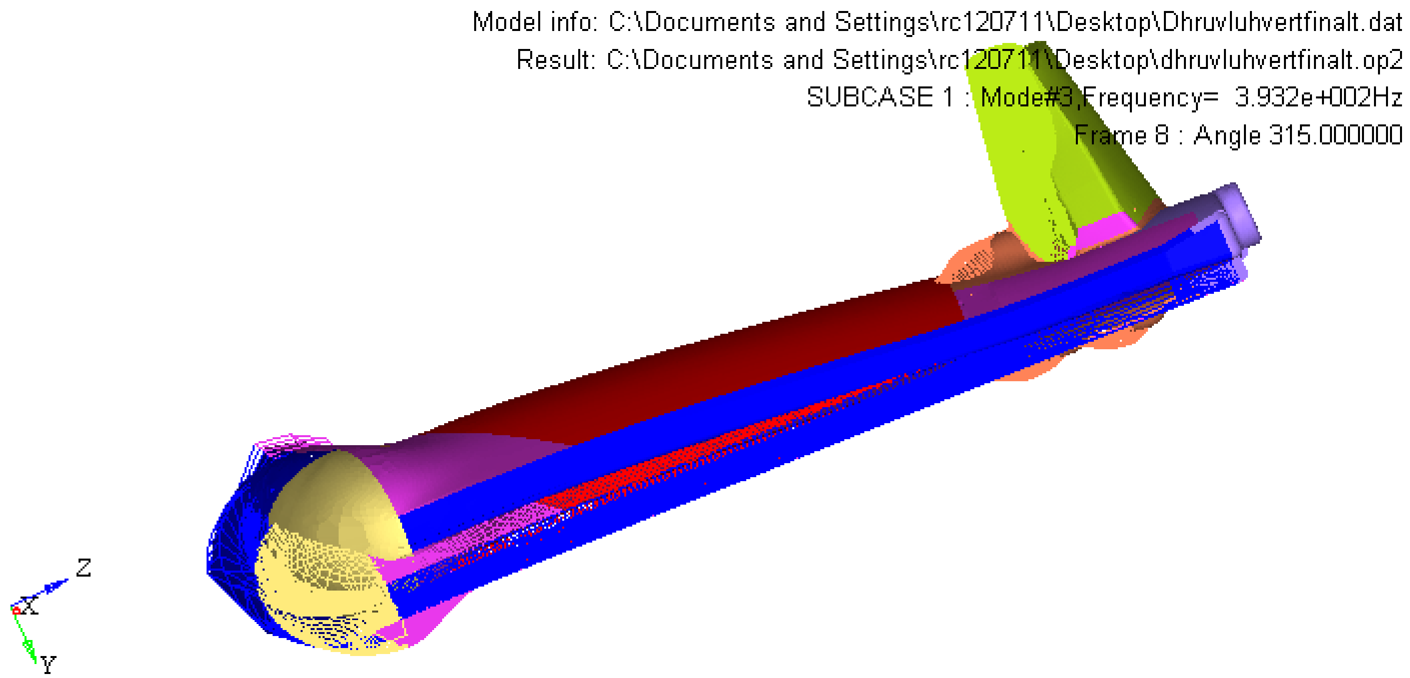


Fig 7. Fundamental bending mode.

Frequency= 39.32 Hz

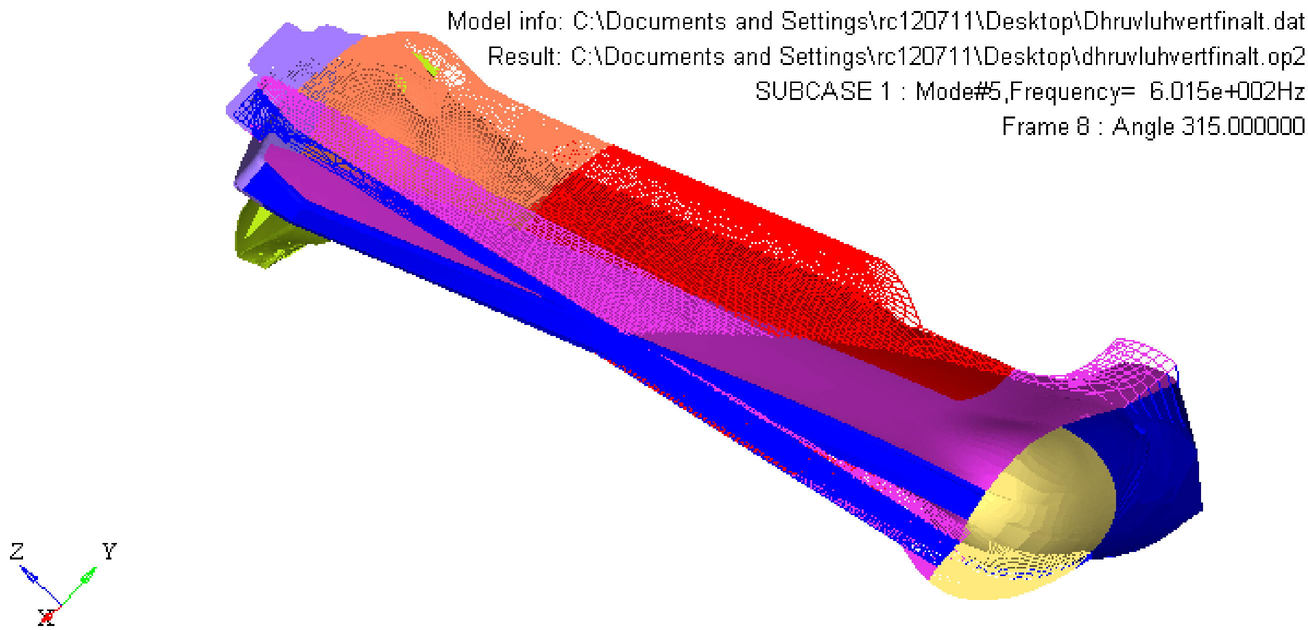


Fig 8. Fundamental torsion mode

Frequency=60.15 Hz

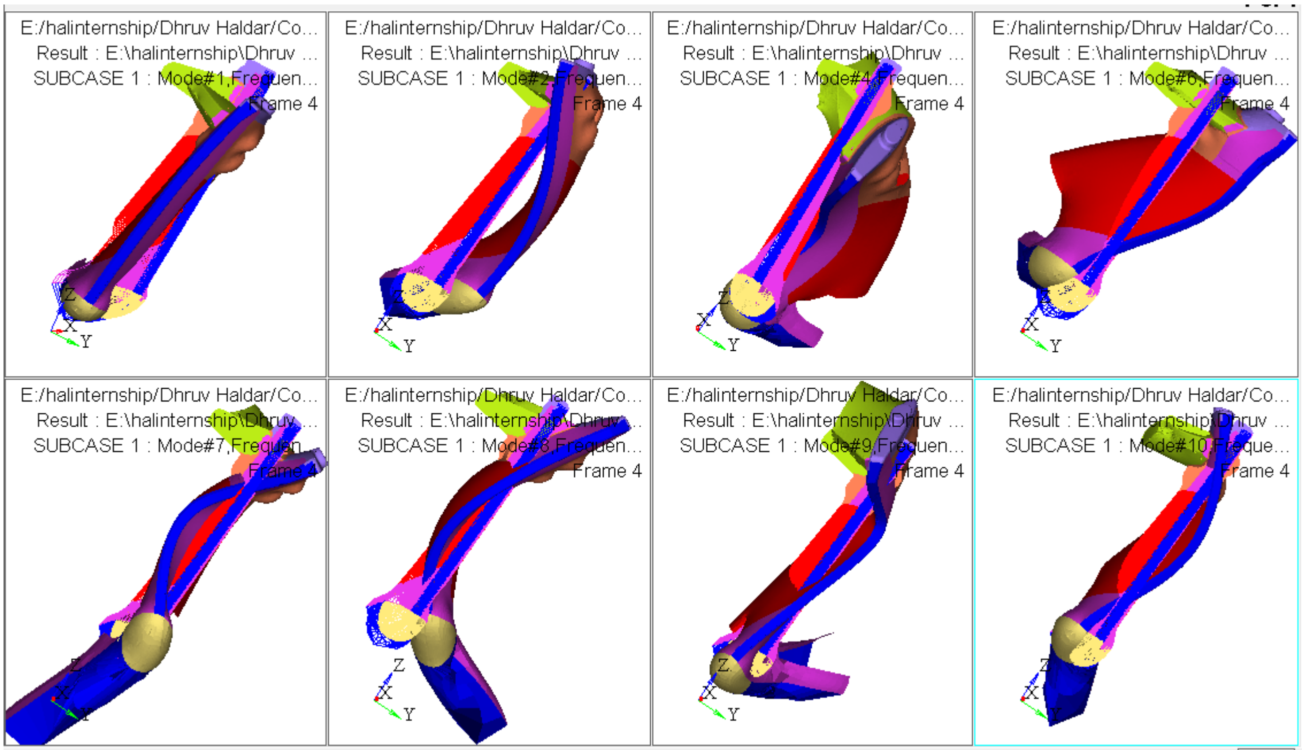


Fig 9. Other modes (1, 2, 4, 6, 7, 8, 9, 10)

Natural Frequencies

5. 19.14 Hz

6. 33.89 Hz

7. 50.79 Hz

8. 87.19 Hz

9. 98.02 Hz

10. 101.36 Hz

DYNAMIC ANALYSIS: LUH EQUIPMENT PANEL (LUH ET)

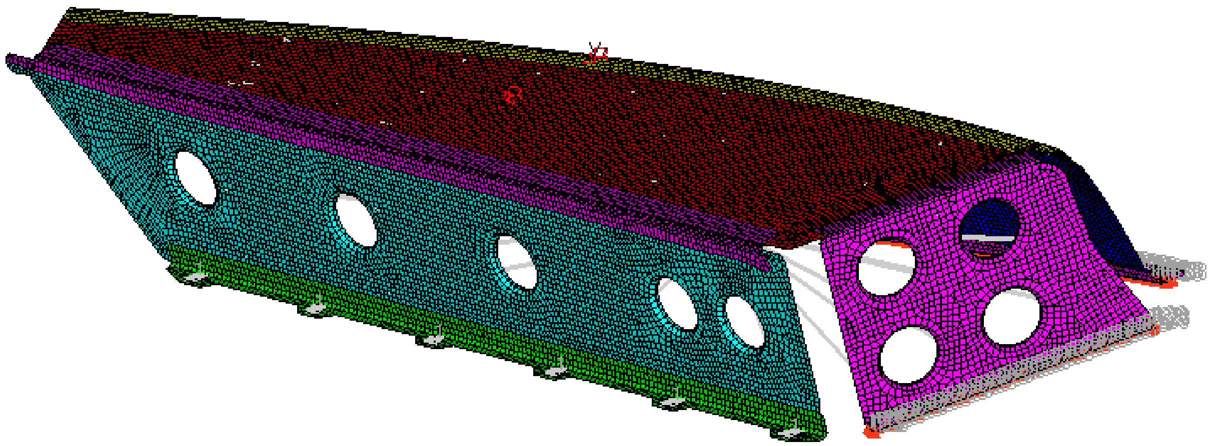
Method Used: Finite element method

The Finite element method was used to model the ET using HYPERMESH and the natural frequencies were obtained through modal analysis using NASTRAN.

The first bending mode and the first torsion mode of LUH ET are given below.

The ET 1st bending mode frequency = 13.35 Hz

The ET 1st Torsional mode frequency = 17.32 Hz



FE Model of LUH ET

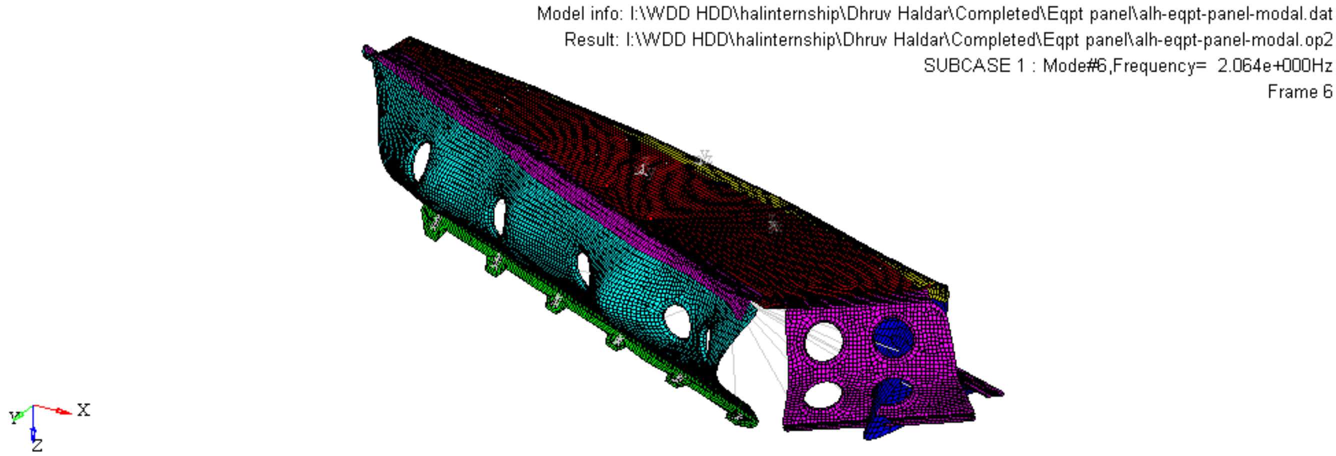


Fig 10. Fundamental bending mode.

Frequency= 13.35 Hz

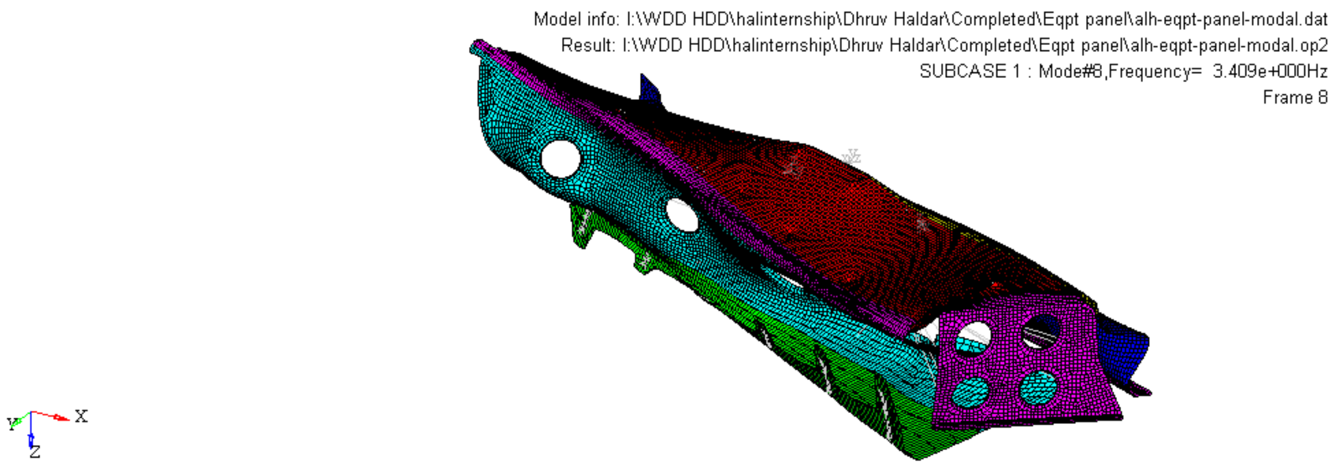


Fig 11. Fundamental torsion mode

Frequency=17.32 Hz

MATLAB code for finding out Natural Frequency

Natural Frequency as obtained by Free Dynamic Analysis is given by:

$$\omega_n = \sqrt{\frac{k}{m}}$$

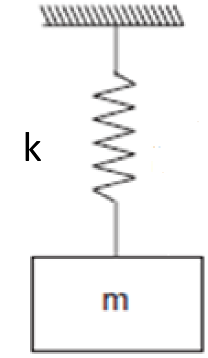
Where k = Stiffness (in N/m)
m = Mass of Material (in kg)

Created two files natfreq.m and matlist.m.natfreq.m file contains the MATLAB code and matlist.m contains the function matlist() which consists of the values of Young's Modulus of different types of Materials.

```
%File name: natfreq.m

%Calculation of Natural Frequency


disp('*** Finding out the Natural Frequency ***');

fprintf('\n All parameters should be entered in SI units');

l=input('\nEnter length (in m)= ');

p=input('\nEnter Force (in N)= ');


%Calling function matlist
matlist();


E=input('\nEnter E of material ');

I=input('\nEnter Moment of Inertia= ');

%Displacement value for cantilever beam
%Horizontal Stabilizer acts as Cantilever beam

displacement=(p*(l^3))/(3*E*I);


%Stiffness
stiffness=p/displacement;
fprintf('\nStiffness  ');
disp(stiffness);

%Natural Frequency
natfreq=sqrt(stiffness/mass);
fprintf('\nNatural Frequency');
disp(natfreq);
```

```
%File name: matlist.m

function matlist()

disp('Material List');
disp('For Aluminium E=72*10^9');
disp('For Glass-Polyester E=38*10^9');
disp('For Carbon-Epoxy E=220*10^9');
disp('For Steel E=200*10^9');
disp('For Boron-Epoxy E=200*10^9');



end
```

MATLAB code for generating Time Response Curve



Given a mass m which is attached rigidly to a surface with a spring of stiffness k.

According to General Vibration Equation Free Body Diagram of DOF=1

- $m\ddot{x} + kx = 0$

The above equation can be written as:

- $\ddot{x} + \omega^2 x = 0$
- $x = A\cos\omega t + B\sin\omega t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (1)$

Initial Condition

At t=0

$x = 0; \dot{x} = x_0\omega$

Putting x=0 in equation (1)

- $0 = A\cos 0 + B\sin 0 = A$

$$\therefore A = 0$$

Putting $x = x_0\omega in equation$ (1)

- $\dot{x} = A\sin\omega t + B\cos\omega t$
- $B\omega = \dot{x} = x_0\omega$

$\therefore B = x_0$

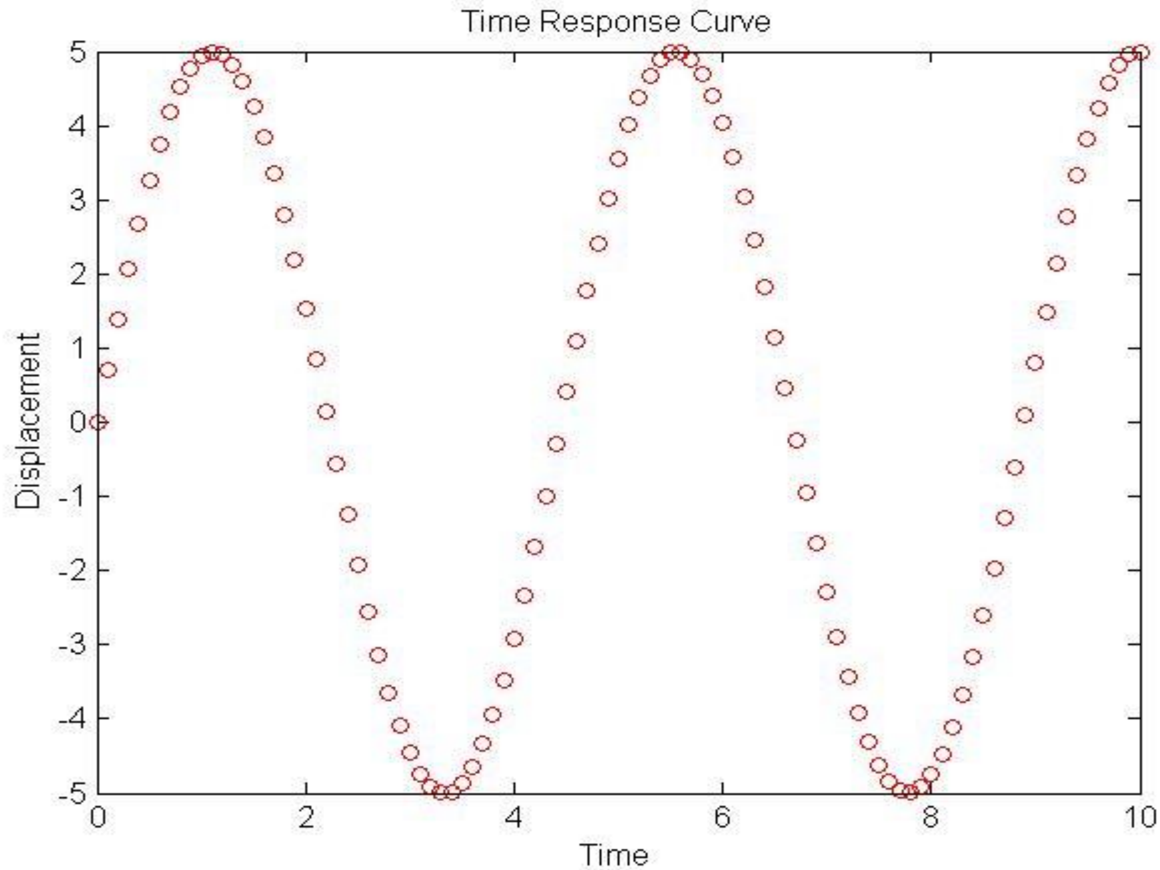
Now , putting value of A and B in equation (1)

$\therefore x = x_0 \sin\omega t$ (Final Solution)

Plotting displacement as a function of time

```
%File name: timeresponsecurve.m
%Time Response curve


clear all;close all;clc;
disp('  Time response curve ');

mass=input('\nEnter mass (Default 5 kg) =  ');
if isempty(mass)
          mass = 5;
end

k=input('\nEnter Stiffness (Default 10 N/m)= ');
if isempty(k)
          k = 10;
end

x0=input('\nEnter Initial Displacement (Default 5 m) = ');
if isempty(x0)
          x0 = 5;
end

w=sqrt(k/mass); %Natural Frequency

i=1;

%Loop for response at each time from t=0 to t=10
for t=0:0.1:10
y(i)=x0*sin(w*t);
i=i+1;
end

t=linspace(0,10,101);

%Graph
disp('Time Response Curve');
plot(t,y,'or');
% Create xlabel
xlabel({'Time'});
% Create ylabel
ylabel({'Displacement'});
% Create title
title({'Time Response Curve'});
```

```
Output
Time response curve

Enter mass (Default 5 kg) =

Enter Stiffness (Default 10 N/m)=

Enter Initial Displacement (Default 5 m) =
Time Response Curve
```



Time Response Curve: Graph generated by Displacement vs Time

CHEETAH/CHEETAL

Cheetal helicopter is a single-engine multi mission helicopter in 2-tonne class with a modern fuel efficient high performance engine TM 333 2M2 fully controlled by Full Authority Digital Electronic Control (FADEC) System in place of ARTOUSTE IIIB engine. Cheetal is manufactured by Helicopter Division of the Hindustan Aeronautics Limited (HAL). This is also called as HAL SA216 Alouette III.

Some of the salient features of Cheetal are:

- Elimination of clutch due to free turbine engine.
- Introduction of Inversion Gear Box
- Modified electrical system/instrument panels by adding DC master box, new engine instruments with modular warning lights.
- Introduction of Master warning flasher light in the cockpit, which flashes in the event of any warn, comes ON in cockpit.
- Automatic takeover of engine control by Electronic Backup Control Box system (EBCB) in the event of FADEC failure.

The Cheetal helicopter is modified for a wide range of missions like

- Personnel transport (4 persons plus the pilot)
- Casualty evacuation
- Reconnaissance
- Logistic Air support
- Rescue operations
- Under slung loads

The advantages of Cheetal helicopter over its predecessor as follows:

- Modern state of the art fuel efficient engine and hence higher reliability.
- Better power margin at high altitude resulting in increased rate of climb.
- Lower specific fuel consumption resulting in higher payload capability, increased range and endurance.
- Simpler and faster starting procedure.
- Improved right rudder margins resulting in easier takeoff and landing at high altitude helipads.
- Lower noise level.

Cheetal helicopter landed at 23220 ft (7070 m) pressure altitude equivalent to 25150 ft (7670 m) density altitude at 'Saser Kangri' of Ladakh region in Himalayas setting a world record of high altitude landing.

BASIC DATA

Particulars	Cheetal	Cheetah
Empty Weight (kg)	1140	1140
Maximum Permissible weight (kg)		
-with internal	1950	1950
-with external	2300	2300
Overall Length (m)	12.92	12.92
Overall Height (m)	3.09	3.09
Main Rotor diameter (m)	11.02	11.02
Maximum Fuel Capacity (l)	575	575

PERFORMANCE DATA [SL,ISA +15°C]		
Particulars	**Cheetal**	**Cheetah**
Cruising Speed (kmph)	1140	1140
Velocity Not To Exceed (VNE) (kmph)	210	210
Max Operating Altitude (m)	7000	7000
Max Altitude for Starting (m)	6000	5800
Range (km) **(with Max Take Off Weight & at Sea Level)**	640	500
Endurance (Hrs)(Full Fuel & No Reserve)	3.80	3.10
Best Endurance Speed (kmph)	80-90	80-90
Specific Fuel Consumption (kg/kwhr)	0.38	0.47

CHETAK

The Chetak helicopter is a two ton class helicopter operated by several military and civil operators all over the world. Chetak is manufactured by Helicopter Division of the Hindustan Aeronautics Limited (HAL).It is a versatile multi-role, multi-purpose helicopter that is spacious. This elegantly designed seven seater (two pilots and five passengers) is also cleared for single pilot flying and thus can carry 6 passengers. This is also called as HAL SA315B Lamas

The Chetak helicopter is powered by a single Turbomeca ARTOUSTE IIIB turbo shaft engine manufactured by engine division of HAL. The engine is provided with a governor, a starter-generator, a tachometer generator and with fuel and oil pumps. The engine produces a maximum power of 563 SHP. The governor maintains a constant engine rpm of 33,500.

The Chetak helicopter is utilized for the following roles:

- Communication Duties (Passenger transport)
- Cargo/ Material Transport
- Casualty Evacuation (CASEVAC)
- Search and Rescue (SAR)
- Aerial Survey and Patrolling
- Emergency Medical Service (EMS)
- Electronic News Gathering
- Anti- Hijacking
- Off shore Operations

- **Went to Cheetah and Chetak hangar and got acquainted with the working of ALOUETTE III transmission system**

BASIC DATA	
Particulars	**Chetak**
Empty Weight (kg)	1200
Maximum Permissible Takeoff Weight (MTOW)(kg)	2200
Overall Length (m)	12.82
Overall Height (m)	2.97
Main Rotor diameter (m)	11.02
Maximum Fuel Capacity (l)	575
Particulars	**Cheetah**
Cruising Speed (kmph)	185
Velocity Not To Exceed (VNE) (kmph)	210
Max Operating Altitude (m)	6500
Max Altitude for Starting (m)	5800
Range (km) **(with Max Take Off Weight & at Sea Level)**	500
Endurance (Hrs)(Full Fuel & No Reserve)	3.00
Best Endurance Speed (kmph)	80-90
Specific Fuel Consumption (kg/kwhr)	0.47

ALOUETTE III TRANSMISSION SYSTEM

Q. Why use a transmission system in helicopter?

A. The angular velocity (in rpm) generated from the engine is very high and therefore it needs to be reduced by a significant margin, so transmission system is used in helicopter.

Features of the ALLOUETTE III Transmission system

1) Used in both Cheetah and Chetak helicopters
2) Consists of the following components:
   i. Turbine
   ii. Main Gear Box (MGB)
   iii. Tail Gear Box (TGB)
   iv. Main Rotor Head (MRH)
   v. Vent Gear Shaft (VGS)
   vi. Tail Rotor Head
   vii. Clutch Unit
   viii. Free wheel (similar to Flywheel)
   ix. Inclined Drive Shaft
   x. Coupling Shaft
   xi. Tail Drive Shaft
3) The rpm of blades in a helicopter should be constant
4) Angular Velocities of the transmission components are as follows :

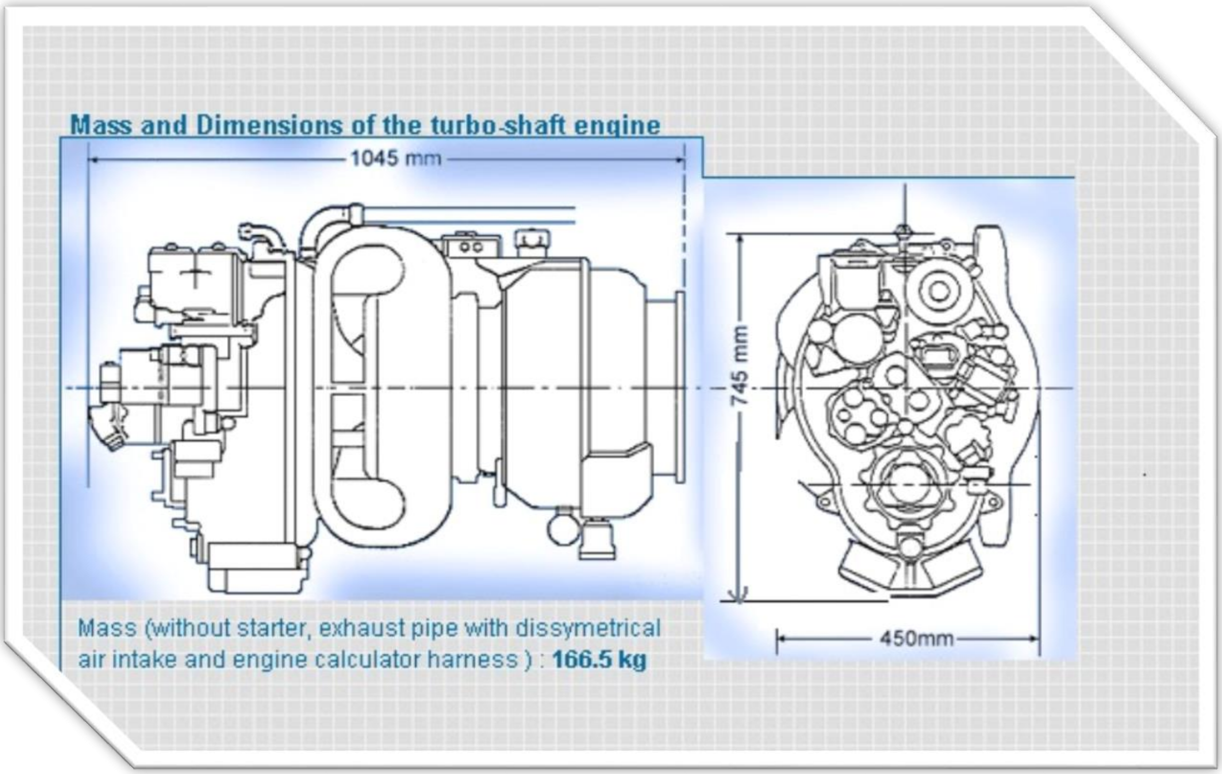
Components	Angular Velocity (in rpm)
Engine (Turbine)	33500
Main Gear box (MGB)	5770
Vent Gear Shaft (VGS)	2820
First Stage Planetary Gear	999
Main Rotor Head (MRH)	353
Tail Rotor Head (TRH)	1940
MGB Reduction Ratio	16.253:1

GENERAL HELICOPTER CONTROLS

1. Helicopter is controlled by <u>controlling the angle of attack of the rotor blade</u>.
2. It consists of the following controls:
   I. Rudder: Helps in controlling the movement of the tail rotor
   II. Cyclic: Helps control the swashplate, whatever direction the swashplate tilts in, that is the direction the helicopter will move in.
   III. Collective: Helps change the pitch angle of all the main rotor blades collectively (i.e., all at the same time) and independent of their position

TM 333 -2B2 ENGINE

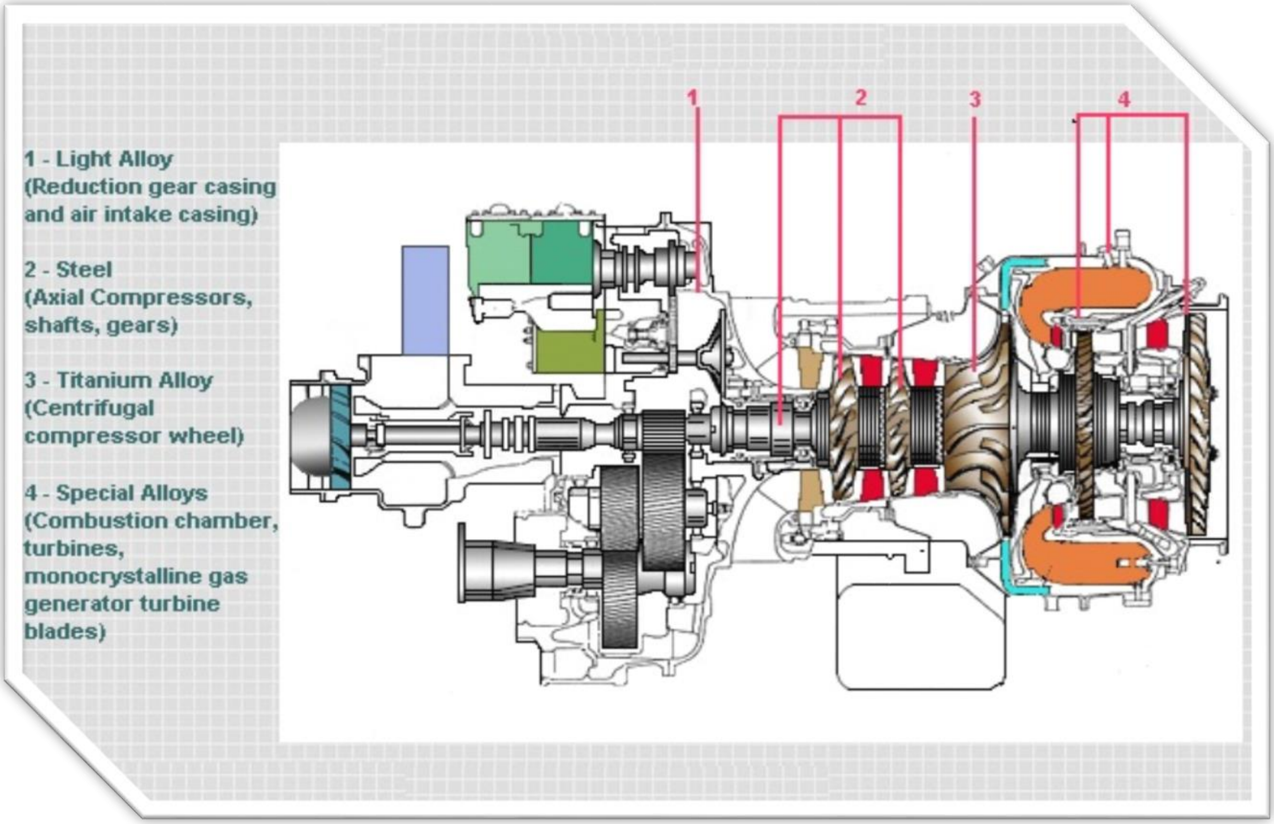
- The TM 333-2B2 Engine is manufactured by Turbomeca Inc for use in ALH DHRUV.
- **A**dvanced **L**ight **H**elicopter (**ALH**) is powered by two **TM 333-2B2** Engines. The TM- 333-2B2, is a free turbine, turbo-shaft engine of the **801kW (1073 shp)** class, intended to power medium class twin-engine Advanced Light Helicopter. The power turbine is independently connected to the main gearbox. The engines are of modular construction and modules can be replaced in unit level, without sending engine back to the manufacturer.



- Fig. shows the mass and dimensions of the TM 333-2B2 engine.

- This engine has a Three stage compression-2 Axial and 1 Centrifugal.
- This engine has High Pressure (HP) and Low Pressure (LP) Gas Power Turbine.
- The engine works on the principle of Brayton cycle.
- The turbine rotation which is generated by the engine is 6000 rpm.
- Since ALH runs on 330 rpm, the output generated by turbine is reduced to 4000 due to gear reduction mechanism.

- Now, the output generated by turbine goes to transmission where it is further reduced.
- Final rotor rotation speed is 330rpm.



6. Conclusion

The dynamic analysis of the horizontal stabilizer and vertical fin of the LUH helicopter is determined. The helicopter is expected to have a maximum speed of 280 Km/h. Since the natural frequencies do not match the frequencies of rotor (40.75 & 62.86 for LUH Rotor Bending and Torsion), the helicopter is stable and safe for flight.

REFERENCES

1. Horizontal stabilizer assembly LHS No. 205P 551H 1000 001

2. Vertical Fin Assembly No. 205P 553H 2000 001

3. Report on "Structural dynamic analysis for LUH", No.RC-LUH-DYN-TR-018, dated 21.1.2012

4. Report on Aerodynamics (Design Freeze) No.RC/LUH/DF/001, dated 06.08.10