Modal Analysis of Typical Missile Configuration

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***Abstract* - Missile's which cruise in air are susceptible to gust loading which leads to fatigue failure, if the missile operates at its own natural frequency. Geometrical model of the typical missile is developed and computational modal analysis is performed. The geometrical model is fabricated and Experimental Modal analysis is performed on it with Free-Free boundary conditions. The obtained natural frequencies are compared with the computational results and the mode shapes are identified.**

General Terms - Computational Modal analysis, experimental modal analysis i.e. impact hammer test.

Keywords - Natural frequencies, mode shapes, Frequency response Function.

1. INTRODUCTION

Missiles are one of the developing technologies these days and are more prone to wind induced vibrations during their cruise. If these vibrations are at a frequency equal to the Natural frequency of the missile then it leads to the resonance, which is the most undesirable situation.

This Resonant vibration is caused by the interaction between elastic and inertial properties of the materials within a structure. Resonance leads to the vibration of the system at high amplitude in a cyclic manner. This cyclic application of the loads leads to the fatigue failure.

In addition to other mechanical tests Ground Vibration tests have become must these days. With these tests the natural frequencies and their corresponding mode shapes are obtained and the missiles are restricted to operate at these frequencies with an operating tolerance of ±5%.

So we first develop the geometrical model of the typical missile in CATIA V5-R21 then perform FEM analysis to obtain natural frequencies and their corresponding mode shapes computationally with the major assumption that damping is zero. Once the computational results are obtained we proceed towards the fabrication of the geometrical model. Geometrical model is fabricated with aluminum alloy of grade 2 and Impact Hammer Test is carried out with SO analyzer base platform software with free-free boundary condition. Frequency Response Plots are generated using a vibration pilot device.

Experimental and Computational frequencies are compared and the mode shapes are identified.

2. MATHEMATICAL TREATMENT

The first step in performing a dynamic analysis is determining the natural frequencies and mode shapes of the structure with damping neglected. The deformed shape of the structure at a specific natural frequency of vibration is termed its normal mode of vibration. Each mode is associated with a specific natural frequency.

The solution of the equation of motion for natural frequencies and normal modes requires a special reduced form of the equation of motion

$$[M]\{\ddot{U}\} + [K]\{U\} = 0$$

Where

[M] = mass matrix

[K] = stiffness matrix

This is the equation of motion for the undamped free vibration. Let us assume the solution to be

$$\{U\} = \{\Phi\} \sin \omega t$$

Where
{Φ} = eigenvector or mode shape
ω = circular natural frequency (rad/sec)
The harmonic form of the solution means that all the degrees of freedom of the vibrating structure move in synchronous manner. The structural configuration doesn't change its basic shape during motion; only its amplitude changes.
Substituting the desired harmonic solution in the fundamental equation we have after simplifying

$$([K] - \omega^2[M])\{\Phi\} = 0$$

The above equation is an Eigen value analysis problem which has two cases one leading to trivial solution and another to the non-trivial solution and we are interested in non-trivial solution only.
Mode shape it is the shape that the structure oscillates within at frequency. Said in less technical terms: If we deform the structure statically into the mode-shape, then set it free, it will oscillate between the initial deformed shape and the negative of the initial deformed shape at a frequency. Over time it will dampen out, but for low amounts of damping it will slowly decay in amplitude.
Each mode shape occurs at a very specific frequency called the natural frequency of the mode. It is entirely possible for a structure to have multiple modes at the same frequency. An example is a beam with a symmetrical cross-section, clamped at one end: The first two bending mode shapes will be at the same frequency. However, the mode-shape will be in different planes.
That's the reason there is a requirement to identify the mode shape experimentally.

3. DESIGN AND COMPUTATIONAL ANALYSIS

3.1 Development of Geometrical model

The Geometric model of the missile is developed in CATIA V5-R21 platform. Since a typical Missile configuration contains Wings, Fins and a nozzle assembly we Design individual components in part design and finally assemble them to obtain the complete missile assembly. The various Part Designs and the Final assembly is shown below

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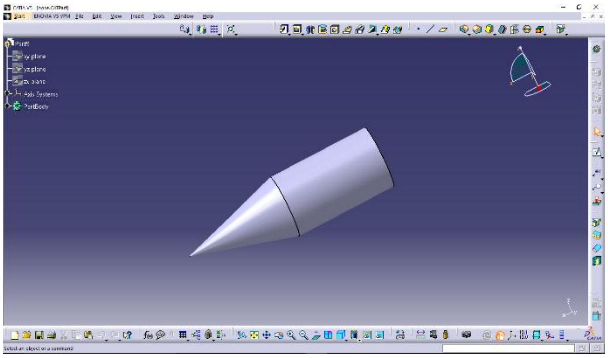

Fig 1: Nose Cone

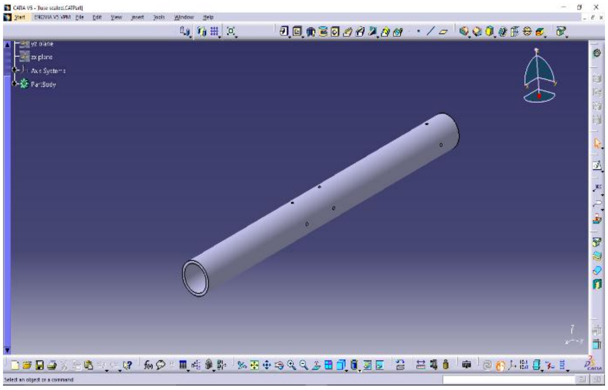

Fig 2: Missile Fuselage Section

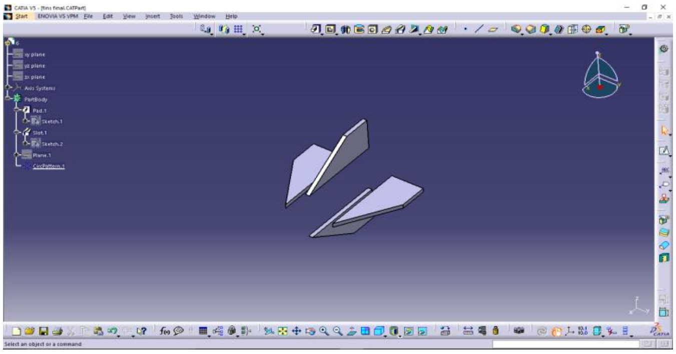

Fig 3: Fins Part Design

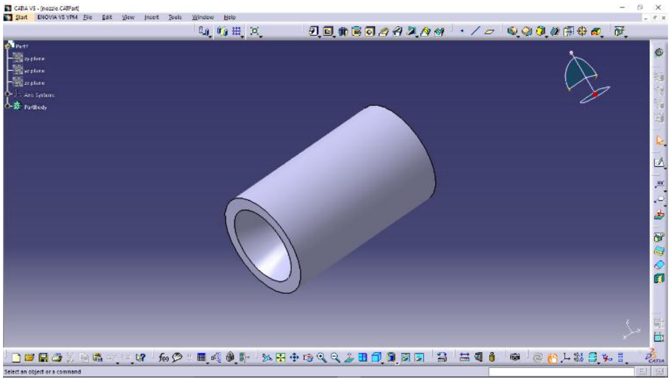

Fig 4: Nozzle Part Design

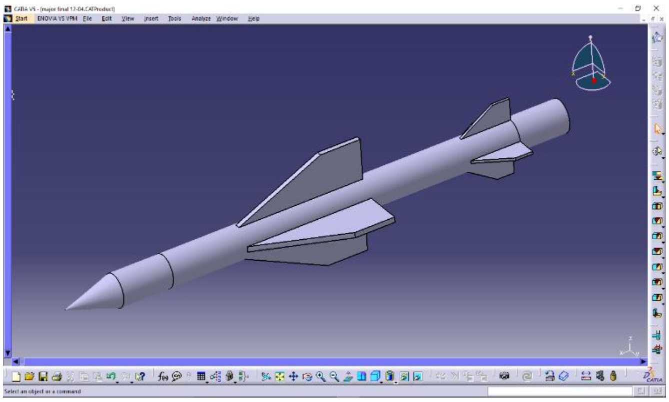

Fig 5: Final Assembly of the Missile

3.2 Dimensions of the Missile

The dimensions of the various components shown above are listed below in table 1

Table 1. Dimensions of the Missile

Total length	1m
Diameter	0.06m
Wing Dimensions	0.25m×0.08m×0.005m
Fin Dimensions	0.1m×0.04m×0.005m
Nozzle Type	C-D Nozzle
Nose cone Length	0.1m

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3.3 Finite element analysis

The Geometrical model developed above is exported to Ansys Workbench and the Computational Modal analysis is Performed with Zero Damping and Free-Free Boundary condition. Meshing or finite element modelling of the geometric model was done with a minimum element size of 1.76e-004m and edge length of 1.74e-005m. With a medium relevance center and relevance of 80 using the on curvature advanced sizing function and medium smoothening

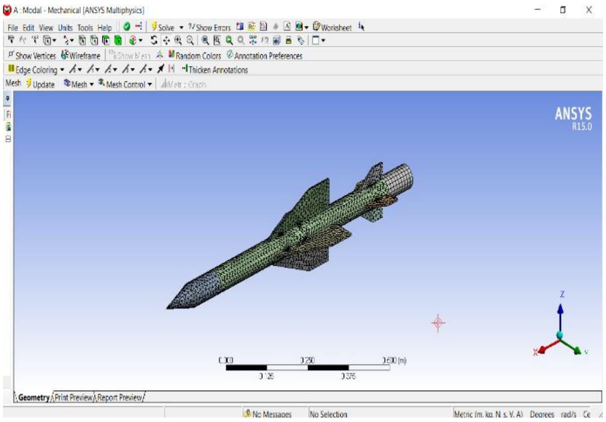

Fig 6: FEM Model of the missile

25072 number of nodes were created are and 12531 number of elements are generated

The material used was aluminum alloy with elastic modulus of 69GPa, Poisson ratio of 0.3, Density of 2770 kg m^{-3} the mode shapes and frequencies obtained are shown below

Table 2. Computational Natural Frequencies

S. No	Frequency (Hz)	Remarks
1	0	Rigid body translation X-axis
2	8.7311e-003	Rigid body translation Z-axis
3	1.5396e-002	Rigid body translation Y-axis
4	5.1687	Rotation about Y-axis
5	5.7348	Rotation about Z-axis
6	76.624	Rotation about X-axis
7	337.16	First elastic Bending
8	338.67	Second elastic Bending
9	802.89	Wing Body Bending
10	811.63	Wing Body Bending

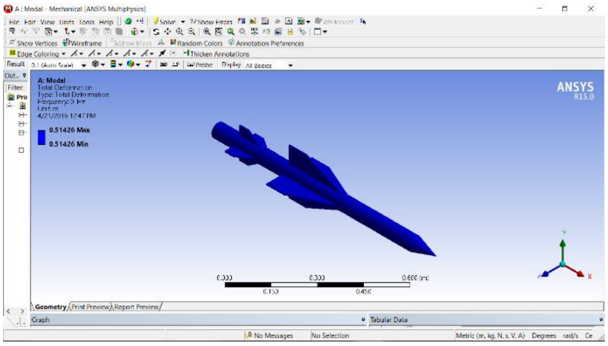

Fig 7: Mode 1- Rigid body translation X-axis

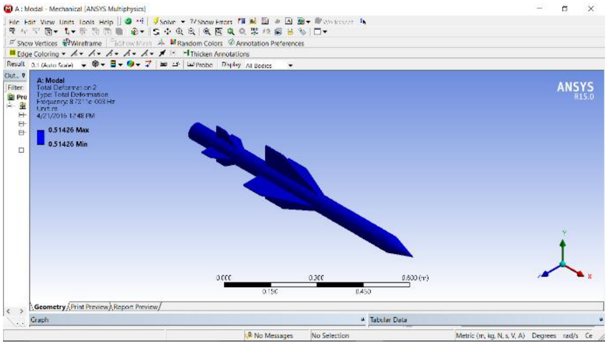

Fig 8: Mode 2- Rigid body translation Z-axis

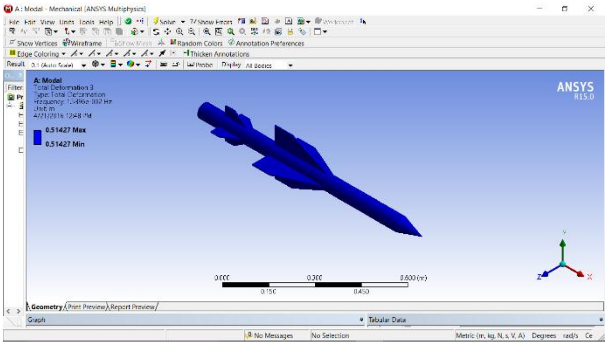

Fig 9: Mode 3- Rigid body translation y-axis

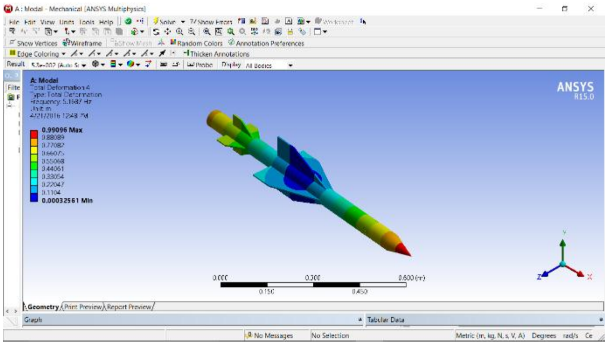

Fig 10: Mode 4- Rotation about Y-axis

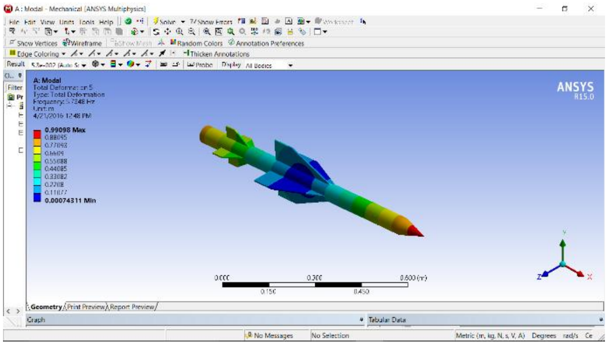

Fig 11: Mode 5- Rotation about Z-axis

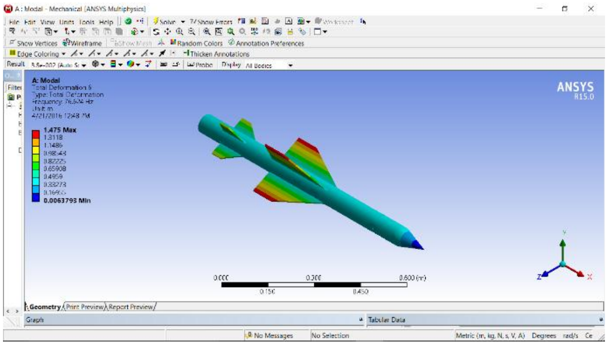

Fig 12: Mode 6- Rotation about X-axis

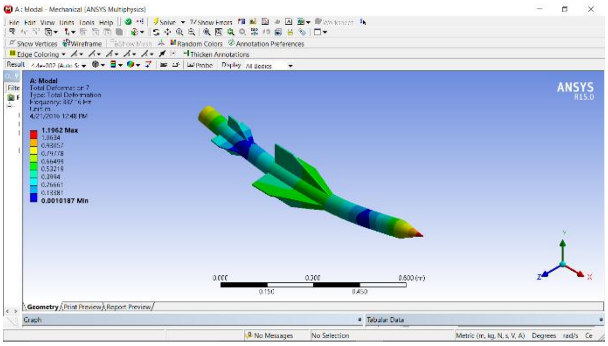

Fig 13: Mode 7- First elastic Bending

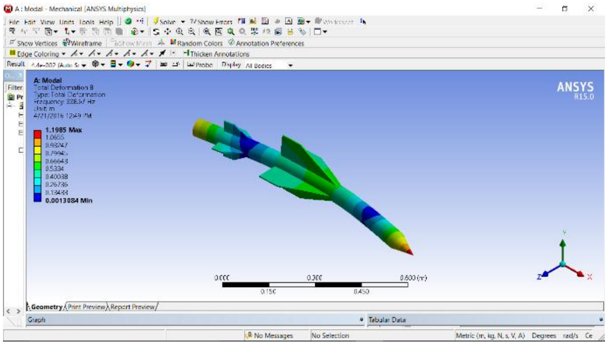

Fig 14: Mode 8- First elastic Bending

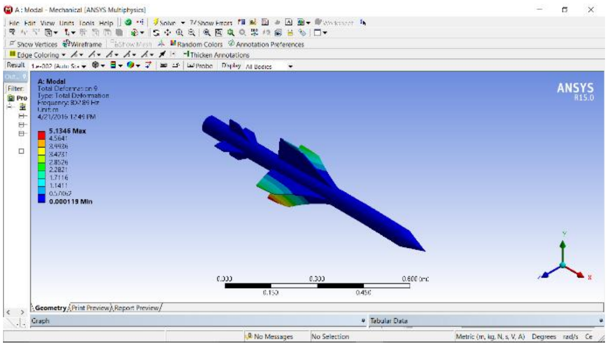

Fig 15: Mode 9- Wing Bending

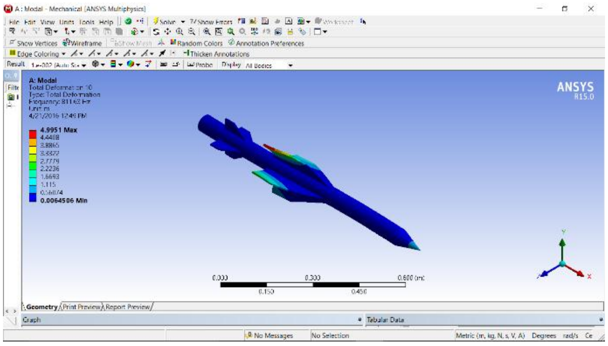

Fig 16: Mode 10- Wing torsion

4. FABRICATION AND EXPERIMENTAL ANALYSIS

4.1 Fabrication Details

Aluminum alloy 2024 is an Aluminum alloy, with copper as the primary alloying element. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. It is wieldable only through friction welding, and has average machinability. Due to poor corrosion resistance, it is often clad with Aluminum or Al-1Zn for protection, although this may reduce the fatigue strength. In older systems of terminology, this alloy was named 24ST. 2024 is commonly extruded, and also available in alclad sheet and plate forms.

Aluminum 2024 alloy solid rod is taken and tapering operation is performed on lathe machine to obtain the required nose cone section of missile configuration. Aluminum sheet of 5mm thickness is taken and cut into the dimension of wings and fins of missile. Nozzle part of the missile is made by using solid rod of aluminum 2024 alloy and performing drilling and tapering operations using lathe machine. All these parts made are assembled together and welded using MIG welding. Inert gas used in this welding procedure is argon and the filler rod used is aluminum ER4043. After welding the parts together finishing is done using a hand grinding machine to obtain a smooth finishing and accurate dimensions of the model.

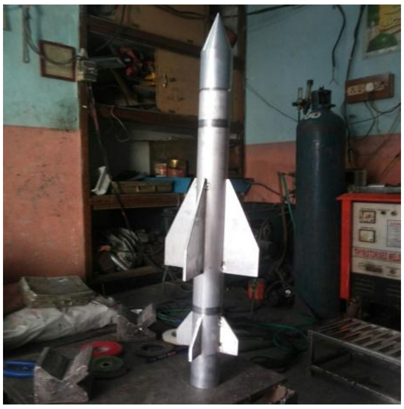

Fig 17: Fabricated Model

4.2 Experimental Analysis

Experimental analysis is performed by impact hammer test with free-free Boundary condition by hanging it with bungee cords at the pre assumed node points. The frequencies obtained are tabulated in table 3.

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Table 3. Experimental Frequencies

S.no	Frequency (Hz)
1	368.3
2	368.8
3	877.0

5. COMPARISON OF RESULTS

The computational and experimental frequencies obtained are compared here and the identified mode shapes are displayed below in the FRP.

Table 4. Experimental and Computational Frequencies

Computational Results (Hz)	Experimental Results (Hz)	Remarks
337.16	368.3	First Bending
337.16	368.3	First Bending
338.67	368.8	First Bending
811.63	877.0	Combined Wing body bending

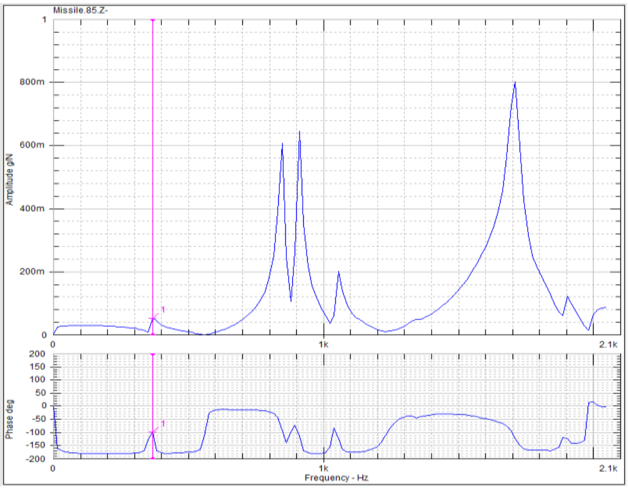

Fig 18: FRP with phase difference

6. CONCLUSION

This paper presents the Design and Modal analysis of the typical missile configuration. Once Geometric model is developed in the CATIA-V5-R21 computational Modal analysis is performed in Ansys Workbench. Fabricated geometric model is made to undergo experimental modal analysis by Impact test procedure.

The Results obtained are in the range of (0-1000) Hertz where three observable frequencies are obtained and their mode shapes were identified.

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