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Dynamic Analysis of a Missile Shield Using Finite Element Analysis

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Abstract: Shell structures, especially cylindrical shells, are widely used in aerospace industries. Missile bodies can be idealized as cylindrical shell structures. The study of vibrations of cylindrical shells is an important aspect in the successful applications of the cylindrical shells. Missile shields have been, and are arguably still, the most efficient means of controlling a missile and guiding it to a target. They can efficiently generate the required maneuvering force by a direct action near the centre of gravity. The free vibration characteristics of a missile shell have an important influence on the strength signature of the missile.
In this project, the main focus is on the free vibration characteristics of stiffened and unstiffened missile shields. The analysis is carried out mainly in two parts. First, the unstiffened missile shield is modelled, and static analysis is done. Later free vibration problem is analyzed for the unstiffened missile shield. Then the missile shield with ring stiffeners is modelled, and static analysis is done. The free vibration problem of the stiffened missile shield is also studied for the stiffened missile shield. The project is later extended to buckling analysis to determine the critical loads at which missile shield become unstable. NX-CAD and Ansys software are used to do modelling and analysis respectively. The hyper mesh is used to generate finite element model of the missile shield.
Keywords: Missile Shield, Structures, NX-CAD, Dynamics

I. INTRODUCTION

A missile is a self-propelled precision-guided munitions system, as opposed to the unguided self-propelled munitions, referred to as a rocket (although these too can also be guided).
Missiles have four system components: targeting and missile guidance, flight system, engine, and warhead. Missiles come in types adapted for different purposes

A. Surface-to-surface and air-to-surface missiles (ballistic, cruise, anti-ship, anti-tank, etc.),
B. Surface-to-air missiles (and anti-ballistic),
C. Air-to-Air missiles and Anti-satellite weapons.

Missile bodies can be idealised as cylindrical shell structures. These shell structures are made up of Al alloys.
Function: Missile shields have been, and are arguably still, the most efficient means of controlling a missile and guiding it to a target. They can efficiently generate the required manoeuvring force by a direct action near the centre of gravity.
Importance:
1) Used as load bearing structures for entire missile body.
2) Achieve better strength, stiffness and buckling characteristics.

II. LITERATURE SURVEY

BurakUstundag has published a paper on "On the Free Vibration Behaviour of Cylindrical Shell Structures". The abstract of the paper says Shell structures, especially cylindrical shells, are widely used in aerospace and naval architectural industries. Submarine hulls and aircraft bodies can be idealized as cylindrical shell structures. The study of vibrations of cylindrical shells is an important aspect in the successful applications of the cylindrical shells.
The free vibration characteristics of a submarine hull have an important influence on the noise signature of the submarine. That makes the free vibration problem of the submarine hull a particular interest for the submarine community. The natural frequencies of cylindrical shells are clustered in a very narrow band, and they are thus more prone to becoming involved in resonant vibrations. The determination and control of these frequencies are significant to manage the acoustic signature of the submarine.

Shi-Rong Li a, Xiao-Hua Fub, R.C. Batrac has published a paper on "Free vibration of three-layer circular cylindrical shells with functionally graded middle layer". The summary of the project is we study free vibrations of a simply supported three-layer circular cylindrical shell with the inner and the outer layers made of the same homogeneous material and the middle layer composed of a functionally graded material. We use Flügge's shell theory to derive governing equations, express mid-plane displacements regarding trigonometric functions that identically satisfy the boundary conditions, and compute natural frequencies regarding the geometrical and the material parameters. Computed results show that the fundamental natural frequency decreases with an increase in the radius-to-thickness ratio, and increases with an increase in the ratio of Young's modulus at the mid-surface to that of the outer (or the inner) layer.

Charles W. Bert, Chun-Do Kim has written a paper on "Vibration of composite-material cylindrical shells with the ring and stringer stiffeners". The abstract of the paper is Free vibration is analysed for thin-walled circular cylindrical shells constructed of composite materials and provided with the ring and stringer stiffeners. Numerical results are presented for graphite-epoxy shells: unstiffened and stiffened with rings only, stringers only, and both things and stringers.

Martin M. Mikulas, Jr., and John A. McElman has written a paper "on free vibrations of eccentrically stiffened cylindrical shells and flat plates". The summary of the paper is "Dynamic equilibrium equations, and boundary conditions are derived from energy principles for eccentrically stiffened cylinders and flat plates. In the plane, inertias are neglected, and frequency expressions are obtained for simple-support boundary conditions for both the cylinder and the plate. In the form of plots of frequencies as a function of the mode, shape illustrates the effects of eccentricities. It is found that these eccentricities can have a significant effect on natural frequencies and should be investigated in any dynamic analysis of stiffened structural members.

III. 3D MODELLING OF MISSILE SHIELD

3d modelling of missile shield was modelled using the NX-CAD software. NX-CAD is one of the CAD software used in modern society.3d model of missile shield from the 2d drafting of previous papers.

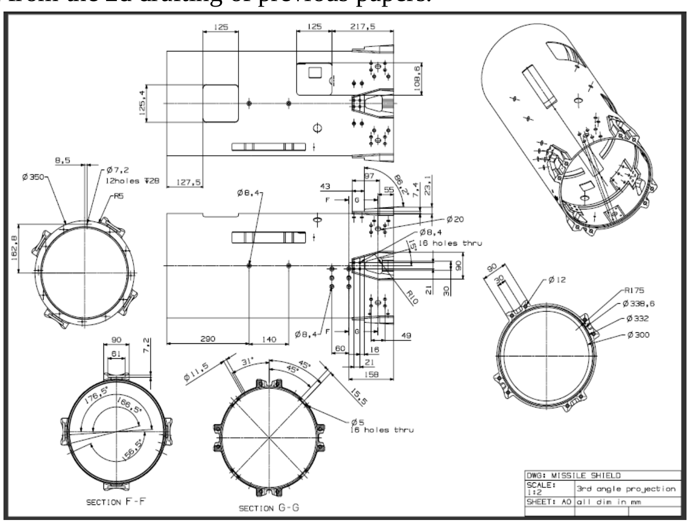

Fig. 2D drawing of missile shield

Below image shows 3D models of the missile shield.

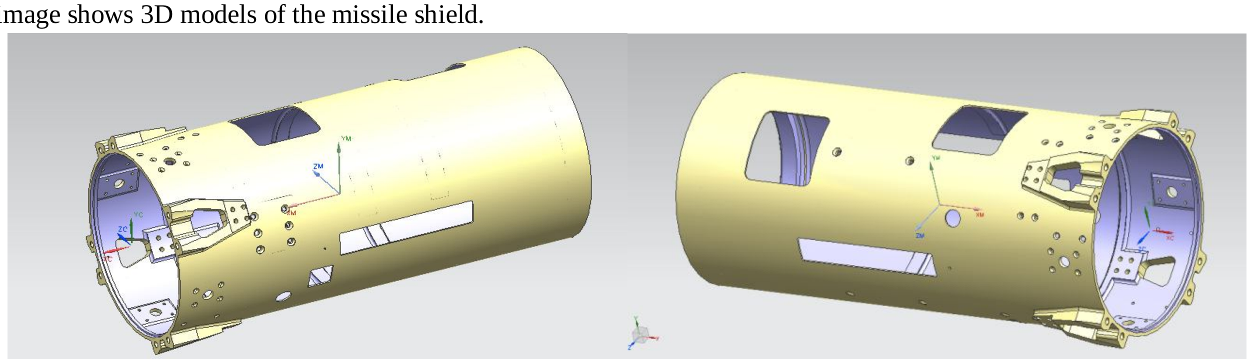

Fig. 3Dmodels of missile shield

IV. FINITE ELEMENT ANALYSIS OF MISSILE SHIELD

A. *Finite element modeling*

3D model of the missile shield was developed in NX-CAD. The model was then converted into a Parasolid to import into HYPERMESH. A Finite Element model was developd with shell elements. The elements that are used for idealizing the missile shield are described below. A detailed Finite Element model was built with shell elements to idealize all the components of the missile shield. The finite element model is imported to ANSYS software for analysis of missile shield.

1) *Modal analysis of missile shield without stiffeners:* Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a seismic analysis.

Modal analysis was carried out on missile shield to determine the first ten natural frequencies and mode shapes of a structure. From the modal analysis, a total of 10 natural frequencies are observed.

2) *Material properties of aluminium alloy2024:*
a) Young's modulus (e) = 68.2GPa
b) Density (ρ) = 2700 kg/m3
c) Yield strength = 340MPa
d) Poison's ratio = 0.25

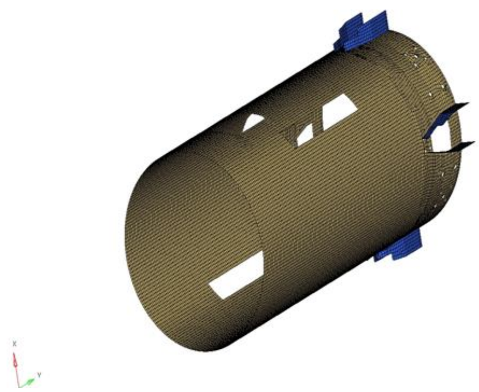

Fig. Shows the FE Model of the Missile shield

e) No. of elements = 23992
f) No. of nodes = 24517.

3) *Boundary conditions*

Both sides of the missile shield are constrained in all degree of freedom.

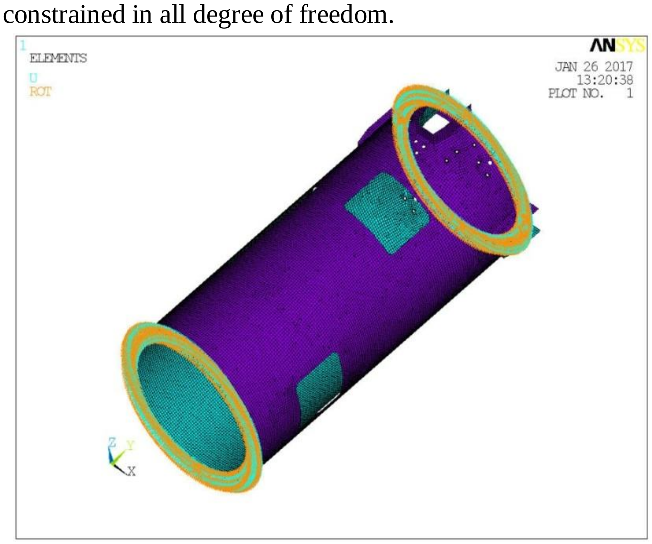

Fig. Shows the Load distributed on missile shield

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4) The mode shapes

a) 1st mode @451.91 Hz

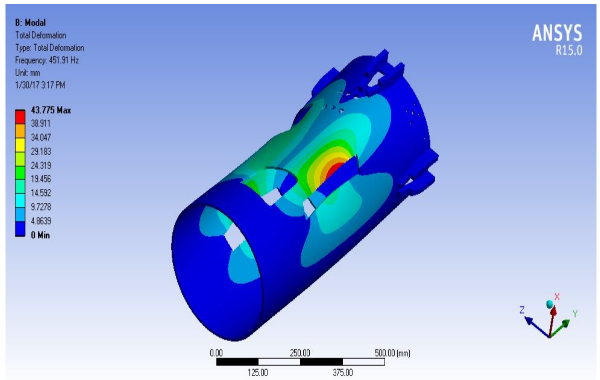

Fig shows mode shape of 1st frequency@451.91Hz

b) 2nd mode @511.14 Hz

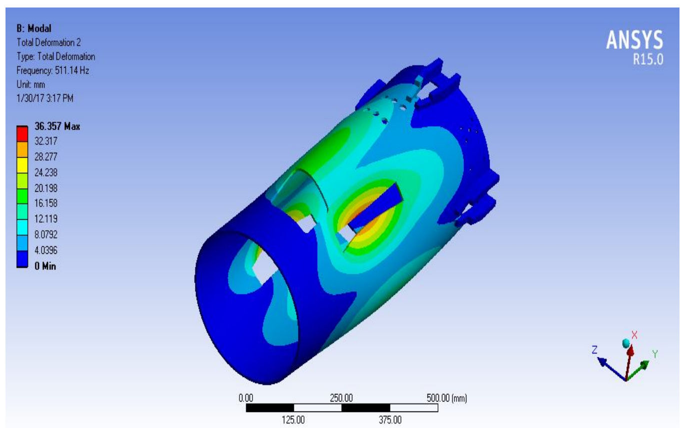

Fig shows mode shape of 2nd frequency@511.14Hz

c) 3rd mode @551.4 Hz

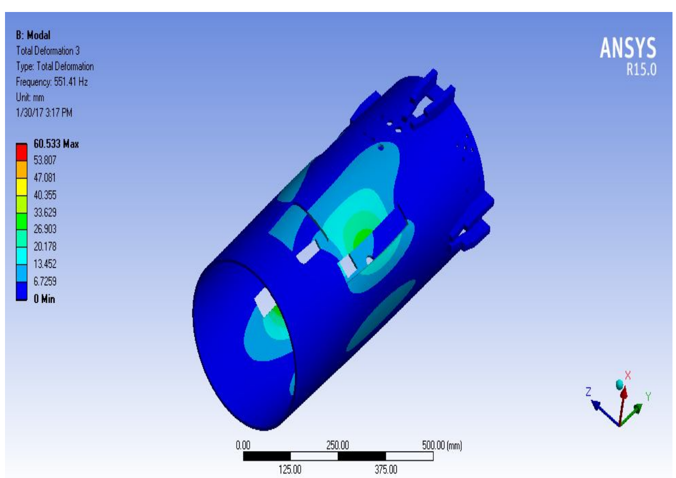

Fig shows mode shape of 3rd frequency@551.4Hz

The mode numbers and the corresponding frequency values are shown in the below table. The mode shapes for all the frequencies are plotted below.

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Comparison of frequencies of missile shield without stiffeners for two aluminium alloys

Material	AL-2024	AL-6064
Weight	17.038Kg	15.448Kg
1st frequency	505.400	516.650
2nd frequency	540.590	553.210
3rd frequency	583.270	594.570
4th frequency	628.750	640.160
5th frequency	727.490	744.5
6th frequency	803.090	824.85
7th frequency	848.860	866.15
8th frequency	915.330	932.49
9th frequency	930.230	949.800
10th frequency	947.870	969.610

B. The buckling analysis is carried out for the 5mm thick shell with and without stiffeners.
The results are documented below.

Case-1: Results for 5mm shell thickness with stiffeners

With Stiffeners	Load Multiplier(Critical Load in Newtons)	Max Deformation
1st Buckling Mode	1502800	1.1828mm
2nd Buckling Mode	1737900	1.1885mm
3rd Buckling Mode	1772500	1.0758mm

a) 1st buckling mode

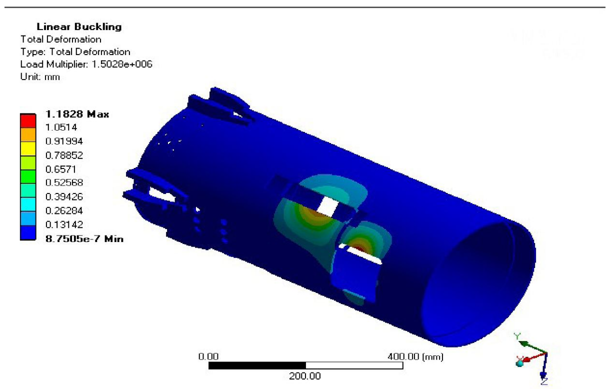

Fig shows mode shape at 1st buckling mode

b) 2nd buckling mode

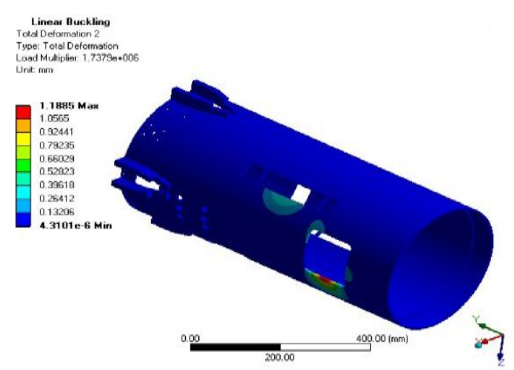

Fig shows mode shape at 2nd buckling mode.

c) 3rd buckling mode

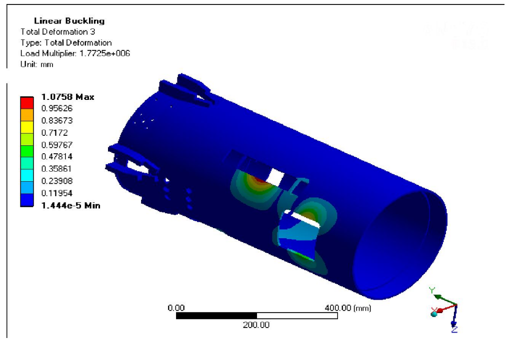

Fig shows mode shape at 3rd buckling mode

C. Case-2: Results for 5mm thickness without stiffeners

Without Stiffeners	Load Multiplier(Critical Load in Newtons)	Max Deformation
1st Buckling Mode	1117400	1.0812mm
2nd Buckling Mode	1539100	1.0854mm
3rd Buckling Mode	1657700	1.1004mm

a) 1st buckling mode

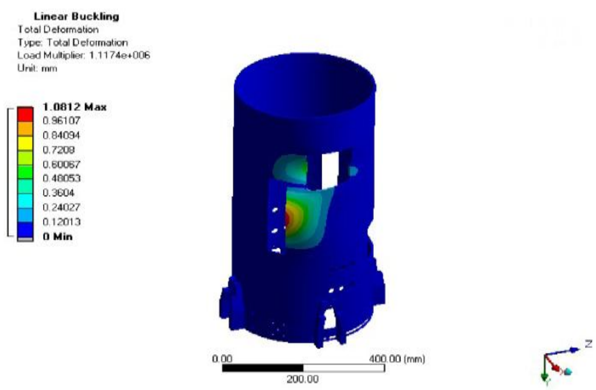

Fig shows mode shape at 1st buckling mode

b) 2nd buckling mode

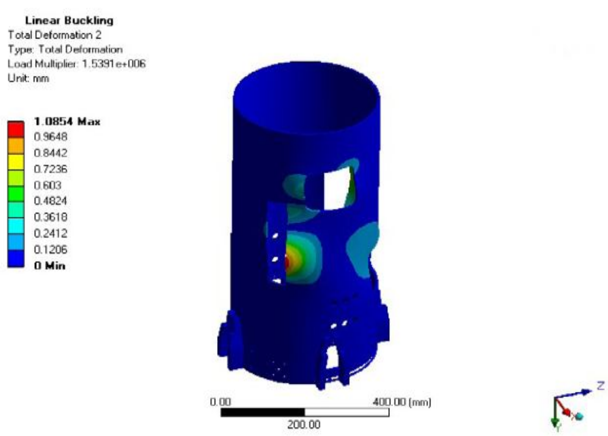

Fig shows mode shape at 2nd buckling mode *c) 3rd buckling mode*

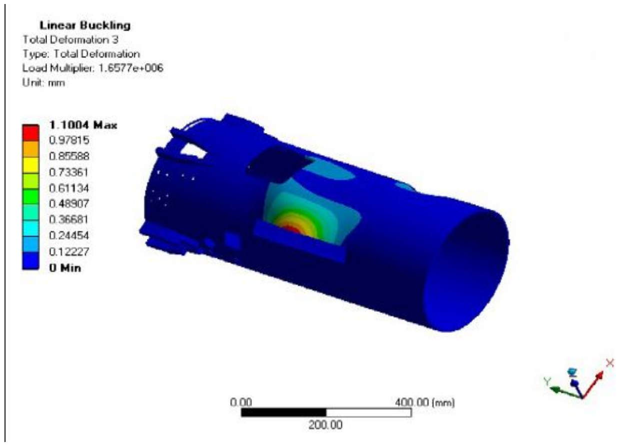

Fig shows mode shape at 3rd buckling mode.

The analysis was done for both stiffened and unstiffened missile shield with 2mm and 5mm shell thickness. From the analysis, it is observed that the buckling load is increasing with the addition of stiffeners. It is also observed that the buckling load is also increasing with the increase of the thickness of the shell. From the analysis, it is concluded that missile shield with stiffener having 5mm thickness can withstand the higher buckling load.

V. CONCLUSION

In this paper, missile shield model was modelled from 2d drafting input by using the NX-CAD software. Finite element model was generated in the HYPERMESH-11 software using shell element. Finite element model was imported to ANSYS 15 Workbench to find the natural frequencies of a Missile shield for two Aluminium alloys (i.e. AL-2024 and AL-6064). The natural frequencies of missile shield along with effective mass participation were documented for two materials. From the modal analysis, Missile shield with AL-6064 material has less weight and high fundamental frequency. Then, missile shield with stiffeners was modelled and analyzed for modal analysis for aluminium alloys. From the results, natural frequencies and effective mass participation were documented. From results, Missile shield with stiffeners for AL-6064 alloy has the high natural frequency, and less weight compares to the AL-2024 alloy. Now, comparing both missile shield without stiffeners and missile shield with stiffeners for AL-6064 alloy. Missile shield with stiffeners has the high fundamental frequency. Hence, it was concluded that the Missile shield with stiffeners has more strength compare than missile shield without stiffeners for vibrations.

This project was also extended to buckling analysis of missile shield. Buckling analysis was performed on the missile shield which is a thin cylindrical shell. The analysis was done for both stiffened and unstiffened missile shield with 2mm and 5mm shell thickness. From the analysis, it is observed that the buckling load is increasing with the addition of stiffeners. It is also observed that the buckling load is also increasing with the increase of the thickness of the shell. From the analysis, it is concluded that missile shield with stiffener having 5mm thickness can withstand the higher buckling load.

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