Comparison of Dynamic Behaviour of Structures Subjected to Blast Loads

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Abstract— *An investigation has been carried out to examine the dynamic behaviour of crew module fairing subjected to blast loading. The objective of the present study is to determine the dynamic response of the crew module fairing with different type of construction such as metallic isogrid and metallic sandwich subjected to blast load. The crew module fairing is modelled as a shell structure with rings provided at different levels with different thickness. The sandwich structure consists of Aluminium honeycomb core with Aluminium face skin. The blast load acting on the structure is applied as a pressure- time curve and it is a triangular pulse with a rise time of 1 milliseconds and decay time of 6 milliseconds. The dynamic response of the metallic sandwich and isogrid crew module fairing structure are compared. The linear dynamic analysis is carried out using the software ABAQUS.*

Keywords— *Crew Module Fairing, Blast load, Transient Response Analysis*

I. INTRODUCTION

A launch escape system is a crew safety system connected to a space capsule, used to quickly separate the capsule from its launch vehicle in case of a launch abort emergency, such as an impending explosion. The system is typically controlled by a combination of automatic rocket failure detection, and a manual backup for the crew commander's use. The crew module fairing is likely to be subjected to blast load due to an explosion happening in flight or at launch pad. During abort, Crew Escape vehicle (CEV) will separate from the parent launch vehicle and carry the Crew Module (CM) to a suitable altitude and range. After attaining suitable altitude and range, the CM will be separated from CEV. For a safe separation of CM from CEV, CM aerodynamics plays a major role. One of the important study is to achieve the capability to launch a space vehicle carrying human into a low earth orbit and return them safely. This requires designing a vehicle which is much more challenging job, because of the complexities and risks. The crew fairing has to protect the occupants from the space environment/travel, provide life support systems in addition to the propulsion modules. M. P. Murray, G. Wilson And M. D. Cloke(2004) presented analytical study of vehicle structures subjected to a transient blast overpressure. Experimental studies were conducted to determine the characteristics of resulting pressure wave and to assess a number of attenuation devices designed to reduce the peak overpressure. Analytical study was conducted for the prediction of both the transient blast overpressure and its effects on the composite panel attached to the sides of the launch vehicle. And good correlation between the experimental and resulting simulation is demonstrated. Abdelkrim Kadid (2010) conducted studies for understanding the behaviour of stiffened plates subjected to uniform blast loading. Dynamic response of the plates with different stiffener configurations is determined. The effect of mesh dependency, loading duration and strain rate sensitivity is considered. The non-linear dynamic analysis carried out to examine the behaviour of fully fixed stiffened plates under blast loading. However, the strain effects taken in to account, when analyzing structures subjected to blast loading. In this paper, the present study is aimed at assessing the dynamic response of crew fairing system subjected to blast loads with different construction such as metallic isogrid and metallic sandwich. The acceleration response and dynamic stress under blast loads are studied for the two shell structures and compared.

II. DESCRIPTION OF THE STRUCTURE

The crew module fairing is modelled as shell structure. The top diameter of the crew module fairing is 0.793 m and bottom diameter is 3.678 m and overall height of the model is 2.63 m. Three conical portions of different thickness and rings are provided at different levels.

III.FINITE ELEMENT MODELLING

Finite element analysis is performed using the finite element software ABAQUS. Abaqus/Implicit is a special-purpose analysis product that uses an implicit dynamic finite element formulation. It is suitable for modelling, transient dynamic events, such as impact and blast problems, and is also very efficient for highly nonlinear problems involving changing contact conditions, such as forming simulations.

IV.MODEL GEOMETRY

ABAQUS offers an element library for a wide range of geometric models. In this study, four noded shell element S4R was used to model the geometry of the crew fairing system. The thickness of the structure is varying top to bottom. Rings were provided at different levels in the crew module fairing. The mesh size used for the structure is 0.05 m. The

shell structure is modelled with full fixity at top and radially constrained at bottom.
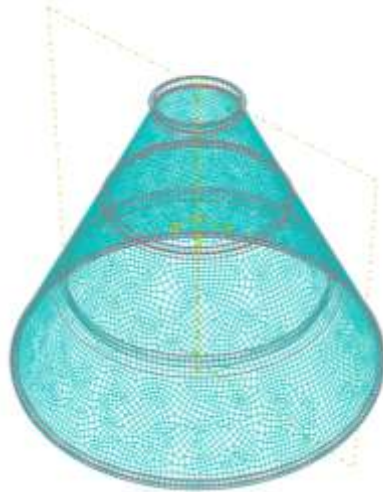

Fig 1: FE model of CM Fairing

V. IDEALISATION OF BLAST LOADIG

An explosion is defined as a large-scale, rapid and sudden release of energy. Explosion resulting from gaseous, chemical or nuclear charges leads to blast loading on the structure. These explosions may occur externally or internally with respect to the structure and may take place below or above the ground. A large amount of energy is released during the blast in terms of sudden increase in temperature and pressure near the surrounding medium. . The pressure time-history is divided into a positive and a negative phase. In the positive phase, maximum overpressure is developed and decays to atmospheric pressure. For the negative phase the maximum negative pressure has much lower amplitude than the positive overpressure. The duration of the negative phase is much longer compared to the positive duration. The positive phase is more relevant in studies of blast wave effects on structures. In the present study the blast wave loading taken for the analysis is shown in figure 2(ref 5). The pressure time graph is simplified to a triangular pulse with a rise time of 1milliseconds and decay time of 6 milliseconds with a peak pressure 60 kPa.
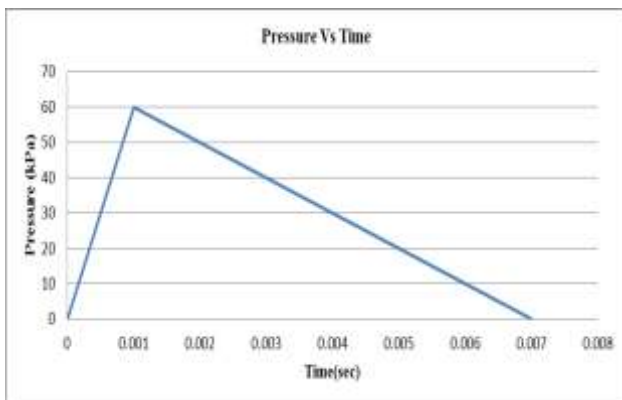

Fig 2: Pressure-Time Graph

VI. METALLIC ISOGRID CONICAL SHELL

An Isogrid panel is a plate (or face sheet) with triangular integral stiffening ribs (often called stringers). The triangular pattern was found to be very efficient because it takes advantage of the fact that triangular trusses are very efficient structures.

VI.–A   MATERIAL PROPERTIES

The material used is aluminium alloy. The adopted material properties were Young's modulus, E = 70 GPa, Poisson ratio, ν = 0.3, and density ρ =2700 kg/m^3.
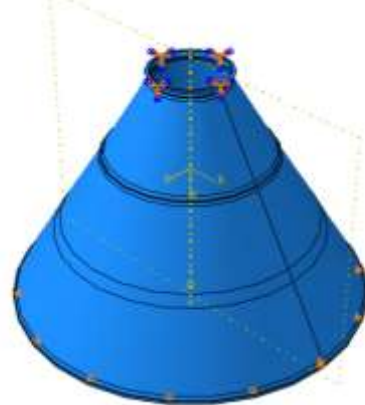

Fig 3: Isogrid model

VII.   METALLIC SANDWICH CONICAL SHELL

A sandwich panel consists of three or more layers materials bonded together, so that they act in unison. The outer facing or skin are usually dense strong material like aluminium. Sandwich construction is playing an increasingly important role in structures because of its exceptionally high flexural stiffness to weight ratio compared to monocoque and other structure. As a result, sandwich construction result in lower lateral deformation, higher buckling resistance and higher natural frequencies than do other construction.

VII.- A MATERIAL PROPERTIES

In sandwich construction the outer face material used is aluminium and the inner core is honeycomb aluminium structure, the properties of materials used for the sandwich construction are shown in tables below.

Table 1: Mechanical properties of Aluminium

Property	Value
Young's modulus(E)	70E9 N/m2
Density (ρ)	2700 kg/m3
Poisson ratio	0.3

Table 2: Mechanical properties of Aluminium honeycomb core

Property	Value
Compressive modulus in Z direction(E_z)	400 E6N/m^2
Shear modulus in YZ direction (G_{tz})	103 E6N/m^2
Shear modulus in YZ direction (G_{lz})	220 E6 N/m^2
Density (ρ)	36.8 kg/m^3

VIII.   STATIC ANALYSIS

Static analysis calculates the effects of steady load on a structure, and it ignores the effect of inertia and damping caused by time-varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads. Static analysis is carried out for the specified load 60 kPa acting on one face of the shell structure. For the static analysis the maximum Von-mises stress obtained for isogrid and metallic sandwich crew module fairing are 152.7E6N/m^2 and 204.3 E6N/m^2 respectively as shown in fig 4 and 5.
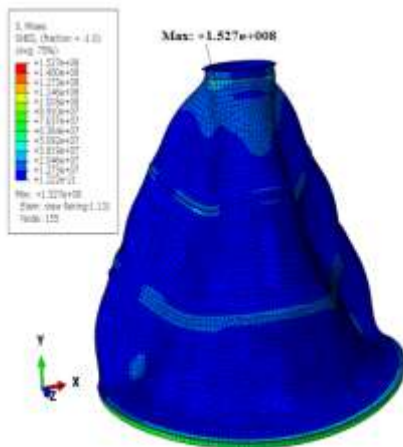

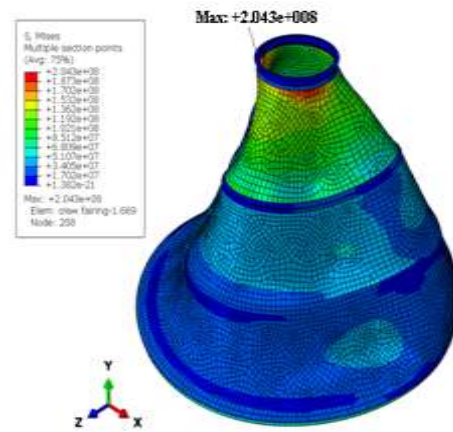Fig 4: Von-mises Stress Distribution for isogrid

Fig 5: Von-mises Stress Distribution for metallic sandwich

IX.DYNAMIC ANALYSIS

Dynamic analysis is performed to assess the integrity of structures under a loading which is rapidly varying with time. Dynamic analysis is a time dependent analysis. Complexity in analysing the dynamic response of blast-loaded structures involves the effect of stress and the time-dependent deformations. In this study P_{max}= 60kPa is acting on the structure with a time duration of 7 ms.

A modal analysis is conducted to obtain the natural frequencies of the shell model for determining the ratio of the duration of the loading over the natural period of the structure. The natural frequency of the two structures is shown in table 3 and the different mode shapes for the isogrid structure is shown in fig 6. Mode shapes for the metallic sandwich structure are similar to the above.

Table 3: Natural frequencies for isogrid and metallic sandwich structure

Frequency (H_z)	Isogrid	Metallic sandwich
1	38.91	36.72
2	75.56	90.80
3	75.72	91.86
4	78.68	110.62

Mode 1   **Mode 2**
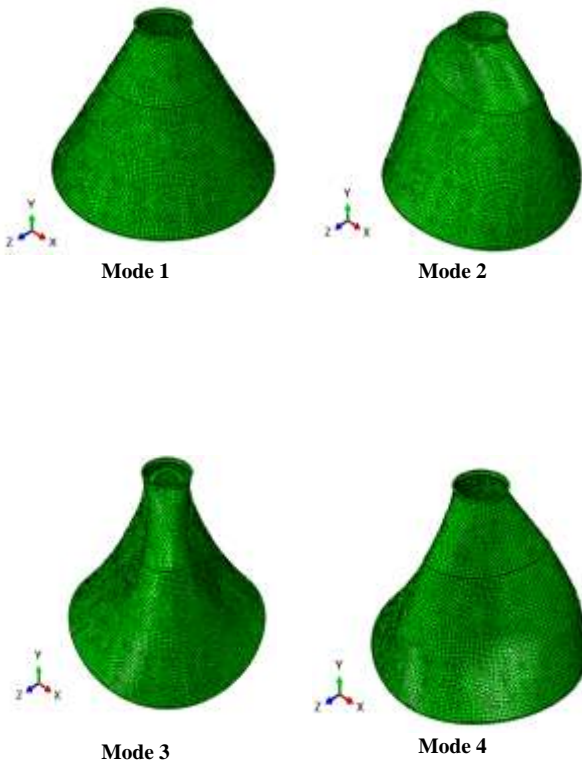

Mode 3   **Mode 4**

Fig 6: Different mode shapes for the structure

Linear transient dynamic analysis is performed for both isogrid and metallic sandwich construction to determine the dynamic response.

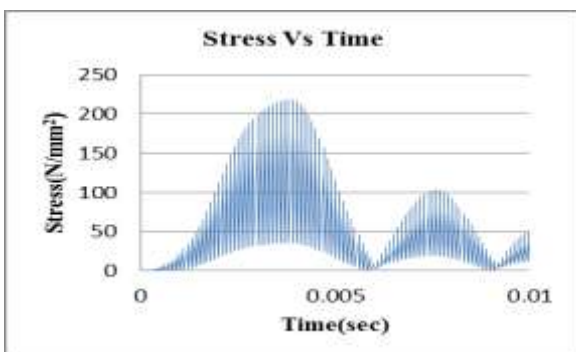The time plot of stress due to blast load for isogrid and metallic sandwich are shown in fig 7and 8.

Fig 7: Stress Vs time for isogrid

Fig 8: Stress Vs time for metallic sandwich

The peak value of stress obtained for isogrid is 201.2E6 N/m^2 and for metallic sandwich is 280.7 E6 N/m^2 at 4ms

The dynamic response is measured in terms of acceleration time history as shown in fig 9 and 10. The maximum acceleration response obtained for isogrid and metallic sandwich are 157.572m/sec^2 and 367.965m/sec^2 respectively.
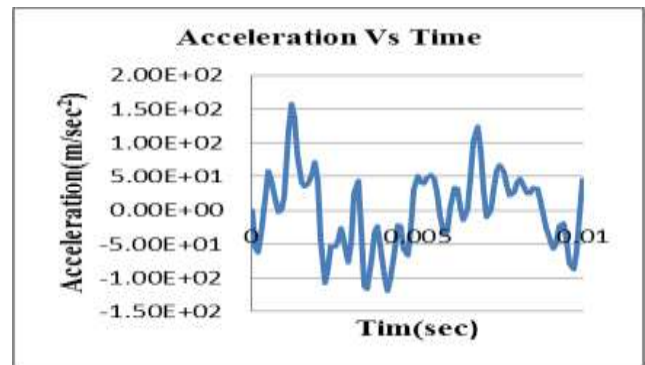

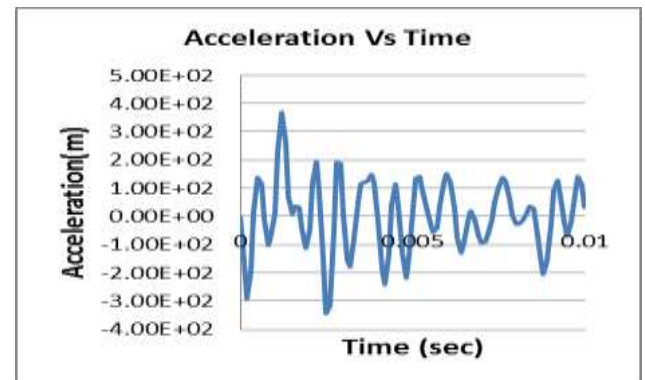Fig 9: Acceleration response for Isogrid Structure

Fig 10: Acceleration Response For Metallic sandwich Structure

X. CONCLUSIONS

This study deals with the comparison of dynamic response of a structures subjected to blast loading. Based on the results the following conclusions are drawn.

- The time duration is an important parameter since the ratio of time periods of the structure and loading has an impact on the amplification factor due to dynamic load.
- The frequency obtained for metallic isogrid and metallic sandwich is 38.919 H_Z and 36.720 H_Z respectively.
- The acceleration response obtained for metallic isogrid is 157.57m/sec^2 and that for metallic sandwich is 367.965 m/sec^2

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