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STRUCTURAL DESIGN AND MASS OPTIMISATION OF GRID FIN FOR LAUNCH VEHICLES

AJAYAKUMAR A G[1], VIPIN G P[2], SARATHCHANDRADAS[3]

[1]*Vidya Academy of Science and Technology Technical Campus Kilimanoor*
[2]*Scientist ASMG ISRO Valiyamala*
[3]*Professor, Dept. of Mechanical Engineering, SCTCE college, Trivandrum*

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Abstract - *Grid fins (or lattice fins) are a type of flight control surface used on rockets and bombs, which consist of lattice shaped structure attached together to form a fin. The major advantage of such fins are, they can easily assembled to the launch vehicle and can be operated for stipulated time duration whenever required. The deployment mechanism imparts more dynamic loads on to the fin and so the structural dynamics play a vital role in its design. To get maximum stability, the fin mass should be minimum as possible by the functional point of view. But the structure should withstand all the static and dynamic loads for the operation period. The lattice structure makes the structure more complex as per the realization aspects. A metallic version of the grid fin structure is attempted to evolve a design methodology. The aero loads and its moments are taken as the design inputs and the structural design is carried out in this work. Modal analysis of structure is also carried out or the design. The finite element tool (ANSYS Workbench) is used for design optimization.*

Key Words: Grid fin, static loads, etc.

1. INTRODUCTION

The grid fin, also known as a lattice control surface or a wing with internal framework, can provide a missile with stability and control as well as a planar fin. Advantages of the grid fin over the conventional planar fins are higher strength to-weight ratio and lower hinge moment. Therefore it can contribute to mitigate the requirements for a control actuator of the fin. On the other hand, its higher drag is a significant disadvantage. The most common grid fin has a square grid pattern. Grid fins are widely used in Crew Escape Systems (CES) of manned space missions of many countries.

The Indian human spaceflight programme is a proposal by the Indian Space Research Organization (ISRO) to develop and launch the ISRO Orbital Vehicle, which is to carry a two-member crew to Low Earth Orbit. HSP requires a Crew Escape System (CES) which is employed for a rapid recovery of the crew in case of exigency at launch pad or during initial phase of the mission. To provide the required static aerodynamic stability at the time when Crew Escape System (CES) is activated, 4 numbers of Grid fins are used.

During the normal launch phase functioning of these grid fins as aero stabilizers are not required. Then they are stowed against the cylindrical body which helps to reduce overall dimension of the vehicle and minimize aerodynamic disturbance. In case of launch abort situation the four grid fins deploys to its desirable value for effective functioning.

In the current investigation, a metallic version (Aluminium alloy 2014-T6) of the grid fin structure is attempted to evolve in order to develop a design methodology. The aero loads and moments are taken as the design inputs and the structural design is carried out. The dynamic loads due to deployment is also checked with the design.

Initial grid fin configuration is taken from results of initial aerodynamic studies is shown in figure . Which consist of an outer rectangular fin box of 1500*1500*150 and an inner grid of intersecting small chord planar surfaces through which the air passes.

2. LOADS ON GRID FIN

The aerodynamic loads produced due to its structure are considered as static loads (Table 1).

Table -1: Loads on grid fin

Rolling moment M_R	Yawing moment M_Y	Pitching moment M_P
-62.59 kN-m	28.73 kN-m	2.57 kN-m

In deployed condition of grid fin, its tendency to rotate about bottom hinge point is controlled by telescopic attachments. When the telescopic attachment makes the stoppage to deployment that will exert an impact load on to the fin. This effect is also studied in the present work and is considered as dynamic load. Figure 2 shows the conceptual arrangements of grid fin system.

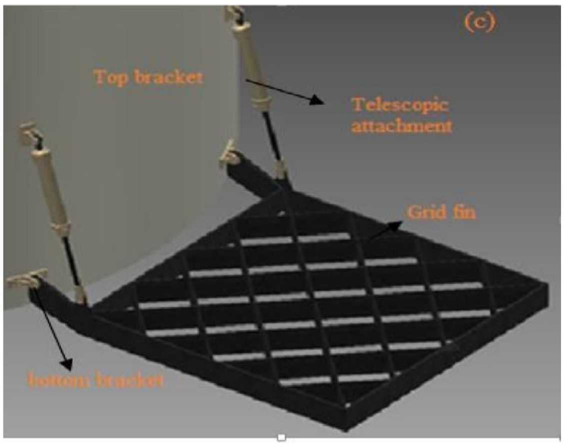

Fig -2:Grid fin configuration

3. FINITE ELEMENT ANALYSES

Finite element analyses were carried out for structural design of grid fin. Highest moment is taken as the first design load then checked for other loads too.

A. Rolling moment

1) Boundary conditions

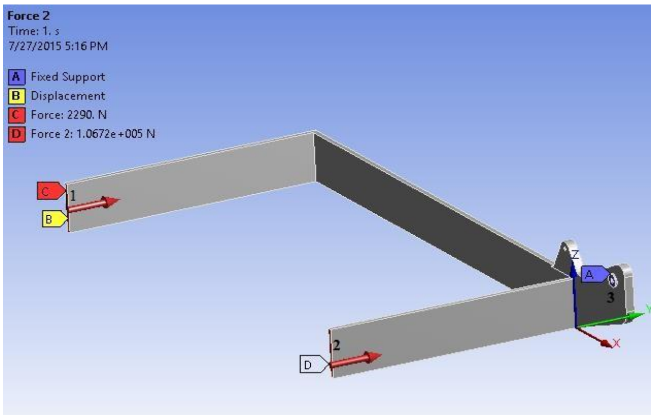

Fig -3: Rolling moment- boundary conditions

The figure 3 shows the boundary conditions for rolling moment. Where region 3 is fixed to bottom bracket. The moment load is converted in to two forces on regions 1 and 2.

2) Results and discussions

From the ansys workbench static structural analysis for rolling moment load shown above. It is found that the maximum Von mises stress induced in structure is 3183.7 MPa. Aluminum alloy 2014-T6 is incapable of taking this high stress. Its ultimate tensile stress value is about 483 MPa. So it is needed to modify the structure to reduce this high stress range. Figure 4 shows the step wise reduction of this high stress value and optimization of mass.

From analysis of aero model it is clear that the stress is higher at regions around frame- shroud bracket end. For share this high load an additional rib structure is introduced with a size of 760 mm*150 mm*15mm in model A. In model B to reduce mass to desire level, materials are removed from frame except junctions (junctions are those regions where grids are jointed to frame). The modified model B is weighted 10.385 kg. The model's maximum Von mises stress under rolling moment is 1139.5 MPa. Higher stress regions are represented in fig itself. In model C two set of diagonal ribs are introduced for further reducing of stress value. In this model the two cross diagonal ribs helps to decrease the stress value to 621.4 MPa. The additional material added increases the model mass to 13.911.

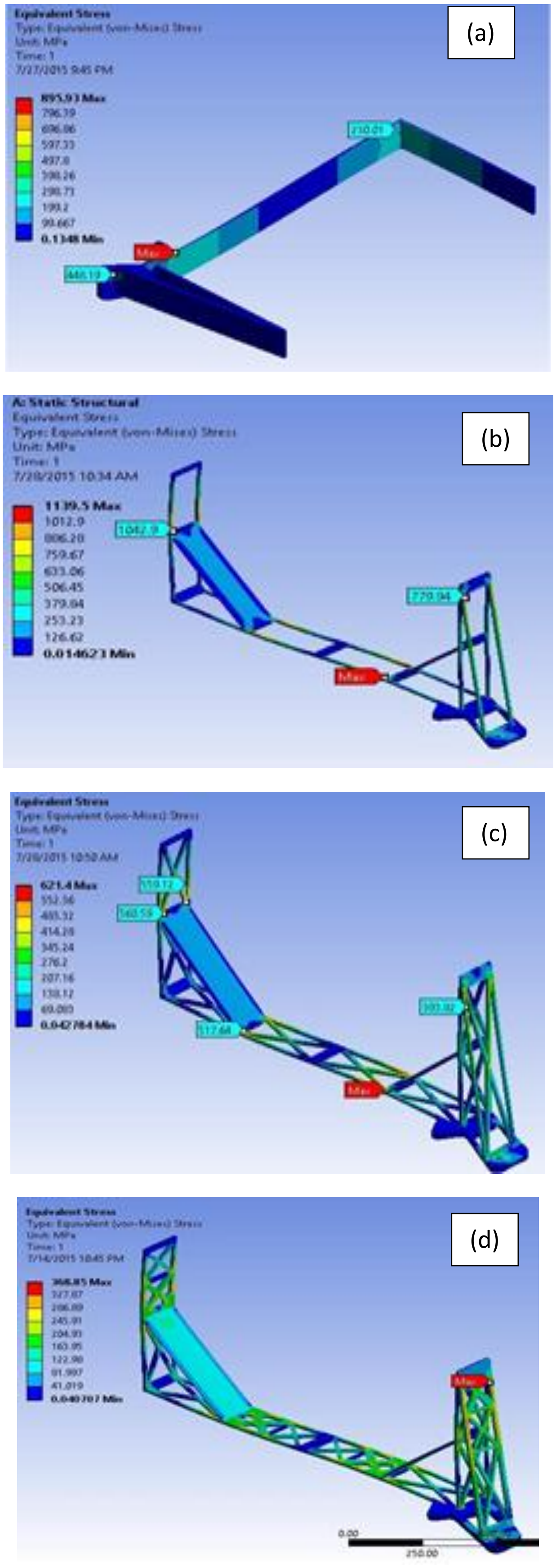

Fig -4: FEA results of Rolling moment

In model D cross rib structures multiplied in the high stress regions. Fillets are used to reduce stress concentration at corners of ribs, the thickness at the hinge point increased to 35mm from 25mm. From the FEA results it is found that the maximum stress value is reduced to 368.85 MPa is shown in figure 5. The factor of safety increased to 0.24 for the final model.

B. Yawing moment

Yawing moment is the moment which tends to bend the frame downwards. Its magnitude is 28.73 kN-m. The yawing moment can converted in to a force acting at the centroid of the grid fin. For the load application in FEM this load is converted in to equivalent pressure profile. The resultant pressure is evaluated as 0.086 MPa. The boundary conditions and analysis results for yawing moment are shown in figure 5. Final model of rolling moment analysis is considered as the model for yawing moment analysis. The yawing moment model have mass of 29.001 and the maximum vonmises stress under yawing moment analysis is 234.85 MPa and have a margin of safety 0.51. So the same model selected in rolling moment is good for yawing moment also.

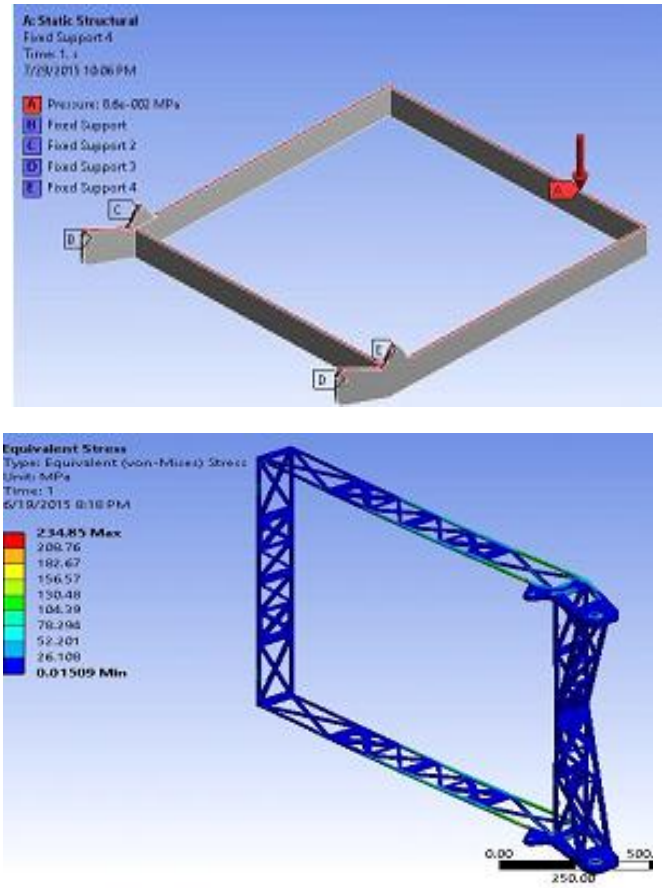

Fig -5: Yawing moment- boundary conditions,FEA results

C. Pitching moment

Pitching moment is the lowest moment acting on the grid fin and its value is 2.57 kN-m. The selected in rolling and yawing is checked for pitching moment analysis. Pitching moment analysis.

As shown in figure 5 regions A, B, C and D are fixed in all directions. The regions A and B are connected to shroud through frame-shroud brackets. The regions C and D are connected to telescopic attachment. In deployed condition these four regions are restricted to move in any directions and are assumed to be fixed regions.

The maximum Von mises stress induced in grid fin due to pitching moment is 209.14 MPa. So the model is in safer region for material aluminum alloy 2014-T6 with a margin of safety 0.57. The FEA results of pitching moment is shown in figure 6.

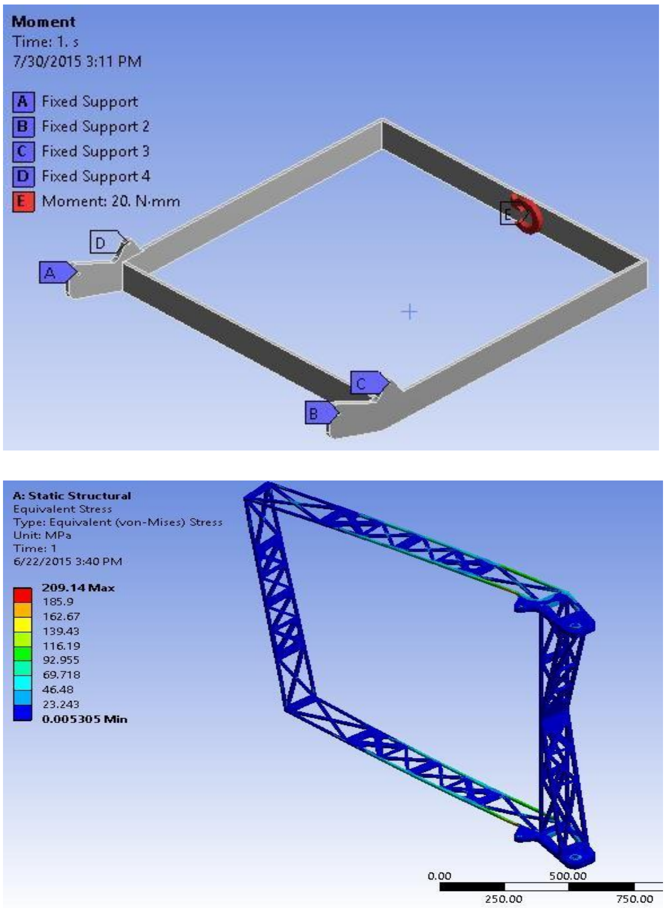

Fig -6: Pitching moment- boundary conditions,FEA results

D. Pressure load on grid

In deployed condition air flow should happen through the rectangular grid pattern. The air passes through the grid pattern exert a pressure force on the grid. The highest value of this pressure is considered as the static pressure on the grid fin and its value is 35 kPa. The solid model of grid has a total weight of 81.909 kg and it must have maximum stiffness to withstand this pressure. The design of grid as solid is an over design and increase the total weight of grid fin. To avoid over weight and it is better to design grid as a shell structure. The shell need a minimum thickness in order to avoid shell buckling. The design requirement is to find a suitable shell thickness with a buckling factor range of 8 to 10. To avoid more computation difficulty before proceeding with the full model the smallest unit of grid fin is analysed to optimize grid thickness.

1) Boundary conditions

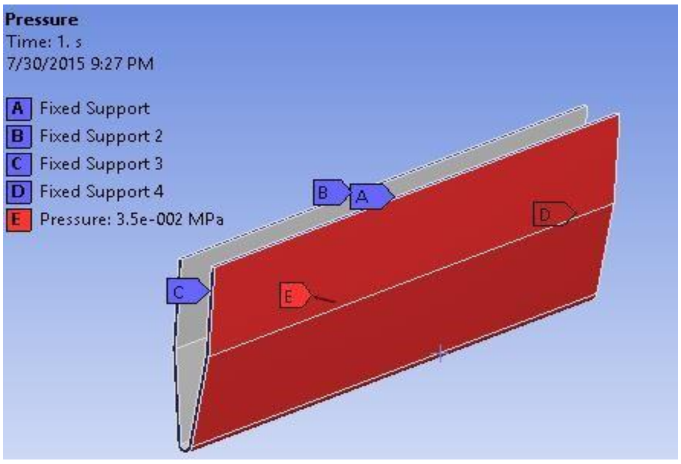

Fig -7: Pressure load – Boundary conditions

Figure 7 shows the half model and boundary conditions used in the FEA analysis. The regions A, B, C and D are assumed to be fixed. Where regions A and B are the faces at the symmetrical plane. The regions C and D are considered as fixed regions for analysis because these regions may be part of junction of similar four units of grid or in contact with grid fin frame. The outer surfaces are subjected to a pressure of 35 kPa. The thickness of grid shell is designated by 't'.

2) Results and discussions

The model is analyzed using linear buckling analysis in ansys workbench the results obtained for various shell thickness is shown in table 2.

Table -2: Grid size optimization

Model	Thickness of shell (t)	Buckling load factor	Mass of full grid structure
A	1	1.5719	13.882
B	1.5	6.5985	20.956
C	1.6	8.5294	22.012
D	1.7	10.811	23.267
E	1.8	13.577	24.606

The result has been found that for a shell thickness of 1 mm the buckling load factor is only 1.57. The required BLF of 10 is obtained for a shell thickness of 1.7mm. The approximate weight of grid fin's grid structure for shell thickness 1.7 is 23.267 kg. Grid fin's frame configuration of static analysis have a weight of 29.001 kg. Then from all the four analysis of static loads the final configuration weight is 52.268 kg.

4. Modal analysis

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. The analysis gives direct insight into the root cause of the vibration problems. Most often the desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the higher frequency modes. Modes are inherent properties of a structure, and determined by the material properties (mass, damping, and stiffness), and boundary conditions of the structure. If the material properties, structural design or the boundary conditions of a structure change, its modes will change. In modal analysis, damping and external force are neglected.

In case of grid fin it is needed to fade away all local vibrations. Since the air is flowing from top of grid fins horizontal plane to downwards the expecting first mode of vibration is similar to the vibration of a cantilever beam fixed at one end (transverse vibration). And from design requirement the first mode of vibration should be greater than 40 Hz.

A. Boundary conditions

In model analysis, damping and external forces are neglected. So the boundary conditions includes only the fixed regions. The figure 8 shows the model analysis boundary conditions. The regions A and B are connected to shroud through grid fin-shroud bracket and regions C and D are connected to telescopic attachments. In deployed condition all the four regions are considered to be fixed in nature.

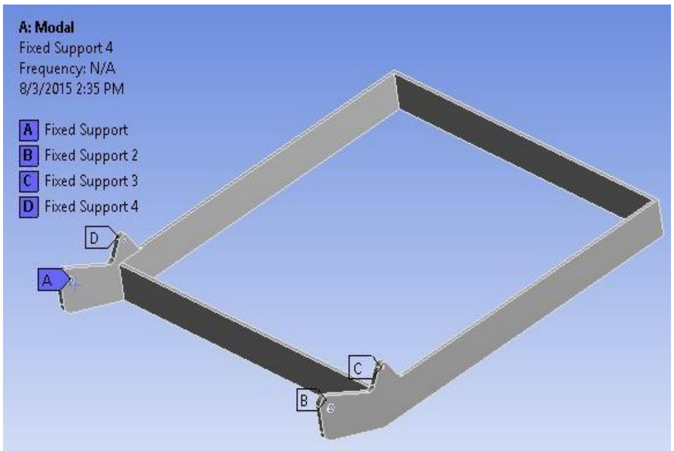

Fig -8: Modal analysis boundary conditions

B. Results and discussions

In modal analysis five configurations of grid fins are subjected to modal analysis using ansys workbench modal analysis. First model is the output model from static analysis, second model is the aero configured model of grid fin and other three models were modified models of model A. The three new configurations are based only on the depth of grid fin frame arm at frame-telescopic attachment region as shown in figures. It is noted that there were no local