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Improvement of spacecraft structure Dynamic Characteristics by Using Honeycomb Sandwich panels

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ABSTRACT

Honeycomb cored structures are considered one of the most efficient composite structures which are commonly used in different industrial applications. These structures are characterized by high strength to weight ratio and good impact resistance thus it is suitable for aerospace structures. Structural properties of honeycomb structure depend on its lower, upper skin sheet thickness, the core material thickness, cell dimension, cell angle and foil thickness. Using of honeycomb structure panels in satellite main structure provide the opportunity to reduce satellite mass in significant manner. This study concerns with the static and dynamic performance of honeycomb sandwich panel structures and its applications in spacecraft construction. This work studies the static and dynamics characteristics of a spacecraft structure including an intermediate plate made of two different materials; the first one with an Aluminum intermediate sandwich plate while the second with honeycomb sandwich plate. The obtained results show that the satellite structure supported with honeycomb intermediate plate produces higher value of the fundamental resonant frequencies compared to the corresponding ones in satellite structure with Aluminum intermediate plate which is better for the launch vehicle requirements. Moreover, the spacecraft structure mass was reduced by around 15%.

1. Introduction

Specific weight reduction is one of the major challenges for design engineers. This led designers to continuous looking for more efficient structure materials. In 1938, a company in the U.K called Aero Research Limited registered an application for honeycomb manufacture, Gohardani et al. [2011]. Their main idea was to use the honeycomb between two skins as a shear carrying element. The development of epoxy Resin in 1954 make it possible of bonding of aluminum skins to aluminum honeycomb. Since then many developments in the honeycomb field have taken place. Honeycomb sandwich panels now used in various applications of civil, aerospace, and mechanical structures because of their high strength-to-weight ratios and desirable acoustic properties, Balakrishnan et al. [2016]. Also using of honeycomb eliminates buckling of thin skins and give exact required shear strength. Polymer matrix composites (PMCs) constitute a main category of composite materials with a huge range of applications, in which fibers or any other reinforcing agent is embedded in the polymer matrix with properties can be compromised to the

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desired requirements by selecting matrix, fibers, fiber configuration, Pavlik [2011].

Fiber reinforced polymers (FRPs) are distinguished by eliminating corrosion concerns and also giving a longer lifespan without requiring frequent maintenance. The FRP sandwich panel is composed of two thin facings that are bonded to a thick core. FRP skins are of a high strength and high Young's modulus, Kar [2016]. To improve the structural performance of FRP, honeycomb core sandwich panels used. Carbon Fiber Reinforced Polymers bound with a polymer or resin (such as epoxy) used in a variety of applications with high durability even in harsh environments which make it suitable for space application. Properties of the carbon fiber composite defined by the carbon fiber reinforcement direction, the polymer resin matrix that binds it together, and any additives introduced to the resin, Ralph et al, [2015]. To improve the stiffness and buckling responses of sandwich structures, the geometry of this sandwich structures are designed including continuous support of core elements with the face laminates Hazizan, and Cantwell [2003], as shown in Fig. 1

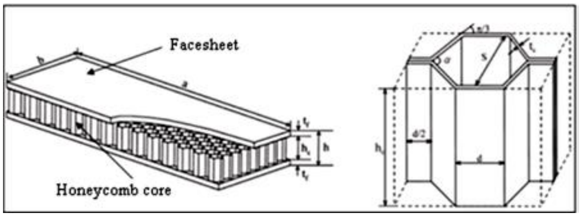


Figure 1 Honeycomb Sandwich Structure

Morcous et.al, [2010] developed numerical finite element model to obtain the structural behavior Fiber-Reinforced Polymer Honeycomb Sandwich Panels [FRHSP]. The obtained numerical solution includes modeling FRP using three FE method plus simplified I beam, FEM includes one-layer modeling, three layer modeling, and actual configuration modeling. While the fourth method is designated as simplified I-beam modeling, is based on the analysis of an equivalent I-beam using transformed area method. Based on the numerical solution, simplified I is the most efficient and reliable method to study the overall performance of the FRP.

Comparison between both experimental and numerical models was developed by Şakar and Bolat [2015] to analyze Aluminum honeycomb sandwich panel using ANSYS software package. The considered boundary conditions are free - clamped (cantilever). Both natural frequencies and corresponding mode shapes were obtained. The obtained results show the effect of upper and lower panel thickness on the dynamic behavior of the sandwich panel. Also it was noticed that increasing the core radius the first natural frequency was decreased and vice versa, the natural frequency was not affected by cell angle, when the foil thickness and core height were increased the first natural frequency also increased and vice versa.

An analytical study on the fatigue behavior of GFRP bridge deck panels using ANSYS finite element software was investigated by Kurian et.al [2013]. The obtained results concluded that GFRP deck panel is a suitable alternative for RC panels. Arunkumar et.al, [2016] presented a FEM using ANSYS software to obtain the numerical vibration response and Matlab script code to solve the sound radiation for honeycomb sandwich panel, they are concluded the in sandwich core is affected by panel thickness and core thickness.

The static bending and dynamic response of honeycomb numerically sandwich panel was investigated by Qiu et.al [2009]. The study showed the effect of core size is extremely important for the honeycomb structural efficient analysis.

Xu et al. [2001] developed an analytical solution for two scale of a thin wall honeycomb core structure and the study is to evaluate the transverse shear stiffness and derivation of partial differential equations PDEs and solving them with the assumptions of free warping constraints through the core wall thickness the analysis are applied upon the three typical honeycomb cores consisting of sinusoidal, tubular, and hexagonal configurations and the solution of each one has validated with numerical FEA solver.

Tehrani et al. [2017] simplified the actual honeycomb model to equivalent and investigated the effect of geometric parameters such as core thickness, panel thickness, height, spot weld distance, and spot wind radius on the dynamic behavior of honeycomb cored structures.

This work aims to present a numerical analysis of spacecraft structure using finite element model through ANSYS software. To investigate the effect of material characteristics, both Aluminum and composite spacecraft structures are considered. Both static and dynamic responses are investigated and analyzed.

2. Problem Statement

2.1. Satellite Platform

The present spacecraft is a Low Earth Orbit three, axis stabilized microsatellite with a mass of 65 kg and a size of 570 mm x 500 mm x 285 mm. The platform carries two multiband imagers. The platform features a box design of six Aluminum milled plates in addition to one intermediate plate. The platform structure is composed of the six panels, the intermediate plate and set of retaining walls. The intermediate plate and the retaining walls are to suit most of the spacecraft components, Dunn [2016]. All panels are Aluminum milled plates with 10mm thickness milled to5mm to help in protection against harsh space environment keeping weight consideration. On the other hand, these relatively thick plates support thermal system design. The solid aluminum structure simplified the mechanical design, integration and testing. Furthermore, the platform supports a passive thermal control regime. Intermediate plate supports two multiband earth imagers systems in one side and the other side accommodates the GPS, PPDH, OBC, PCU, TMTC and X-band transmitter modules.as shown in figure 2

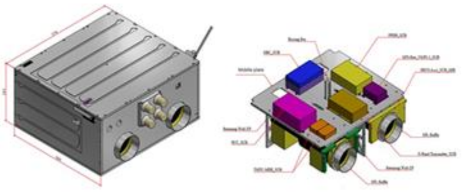


Figure 2 Satellite configuration

The two cameras supported on set of spring system to absorb shocks and vibrations as shown in figure 3.

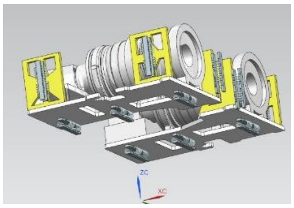


Figure 3 spring system for camera support

This study will deal with the static and dynamic behaviours of the spacecraft structure including intermediate plate inside the configuration as aluminium alloy 6061 milled plate and as composite sandwich both of thickness 10 mm. Composite sandwich plate consists of upper and lower covers of 1 mm thickness bonded with epoxy resin with aluminium honeycomb core of 8 mm thickness as schematically shown in figure (4).

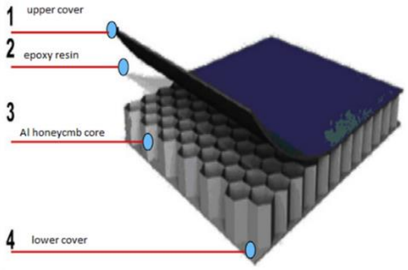


Figure 4 Composition of honeycomb sandwich

The case study analysis will utilize ANSYS 16 for the satellite structure with Aluminum milled intermediate plate and ANSYS 16(ACP)module for composites for satellite with intermediate composite sandwich.

3. Analysis and results

ACP module is a part of ANSYS deals with composites and solves it as shell element. In this study ACP module will be used to simulate the intermediate plate as shell elements and combine it with the rest of the satellite configuration as solid model. And show the effect of changing the intermediate plate from aluminum to composite sandwich on static, modal and harmonic analyses.

The upper and lower covers each consists of 4 plys stacked as (0, 45, 90, 135) from the middle plane to upper and lower sides respectively.

3.1. Geometric model description

Meshing the model gives the following number of elements

Satellite configuration	Aluminum	Composite
No. of elements	190358	169539

3.2. Boundary conditions

Fixed support was used as boundary condition at launch adaptor. PSLV launcher loading profile was selected to apply on satellite configuration load, by using ANSYS 16 for Aluminium and Ansys ACP module for composites. static, modal and harmonic analyses were solved with load factor1.5, according to PSLV launcher load profile

Table 1:: PSLV launcher static loading

Direction	Longitudinal	Lateral
Static load	9.5 g	4.5 g

3.3. static analysis results

According to ANSYS results of static analysis of the tow configuration will be as follows

Satellite with aluminum intermediate plate stress distribution

Figure 5 shows the stress distribution on satellite configuration with aluminum middle plate, Figure 6 shows the max stress on the proposed configuration of **39.7 Mpa** which is located on the launch adapter of the satellite that fixes the satellite with the launch vehicle

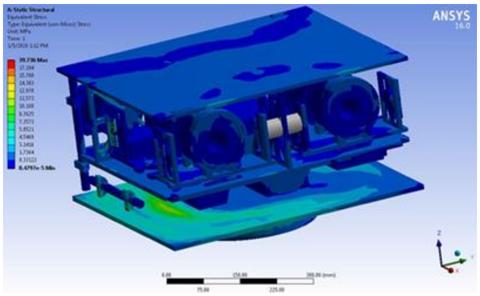


Figure 5 Satellite with Aluminum intermediate plate analysis

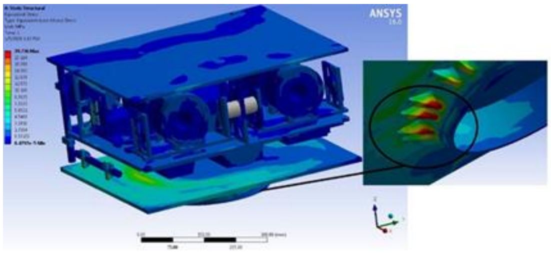


Figure 6 Max stress in Satellite with Aluminium intermediate plate, (launch adapter)

Figure 7 shows stress distribution on satellite configuration with Al-honeycomb composite plate and figure 8 shows the max stress concetrated on one of spring set support 44.17 Mpa

Satellite with honeycomb intermediate plate stress distribution

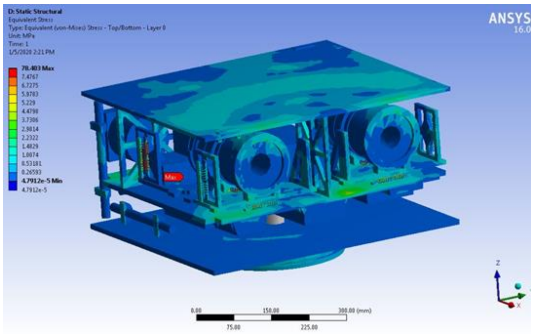


Figure 7 Satellite with composite intermediate plate static analysis distribution

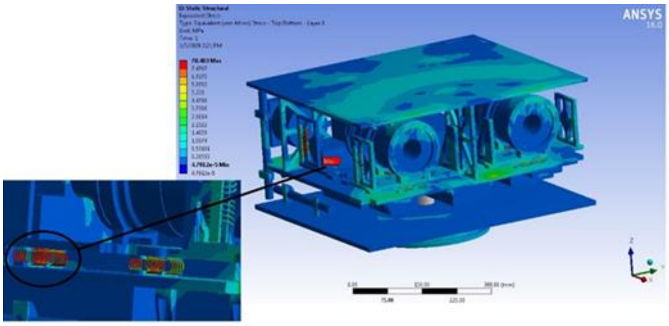


Figure 8 Max stress in Satellite with composite intermediate plate, (spring support)

Following table 2 showing the two plates weights versus maximum stress resulted on the two satellite configurations

Table 2 weight vs static stress of the two configurations

Intermediate plate	Al	AL honeycomb composite	
Mass from analysis (Kg)	7	*(Al) honeycomb Core	0.2
		*Upper cover	0.4
Total		*Lower cover	0.4
	7		1
Maximum Stress (MPa)	39.7	44.17	

Maximum stress in the case of aluminum intermediate plate exists on the so-called launch adapter, and in case of composite intermediate plate maximum stress located on one of the support springs of the camera.

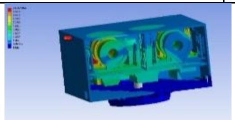
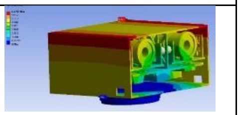
Satellite structure with intermediate plate as composite sandwich withstands higher stress than the case of aluminum one with significant decrease of mass from 7 kg aluminum plate to 1 kg for composite sandwich.

3.4. Modal Analysis

Modal analysis used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure in the early design steps of satellite configuration. When frequencies of applied loads match one of satellite natural frequencies, resonance takes place, and that's one of the most critical problems can face a spacecraft structure. Designer has to be sure that the first natural frequency of the satellite exceeds that of the selected launcher. The more difference in natural frequencies of satellite and launcher is the safer design.

Modal analysis is very important analysis because it is predicting natural frequency of satellite. Natural frequency must be avoided. In this section comparison between Aluminum Alloy and composite honeycomb is performed to study the effect of composite material.

Table 3 the two configurations first four mode shapes

Modes	Aluminium	Composite Material
1	90.869	404.76
2	118.88	426.72
3	159.4	445.24
4	438.27	453.96
Mode 1		

Modal analysis of satellite configuration with composite intermediate plate exceeds that with Aluminum intermediate plate by four times as the mass reduced for the plate from seven kilograms to one kilogram, and the stiffness increased from aluminum to honeycomb core composite sandwich

3.5. Harmonic analysis

PSLV launcher harmonic load requirements are:

Direction	Frequency range (Hz)	Vibration level (g)
Longitudinal	8-100	1.05
Lateral	8-100	0.9

And the results of amplitude vs frequency in the three directions will be as follows:

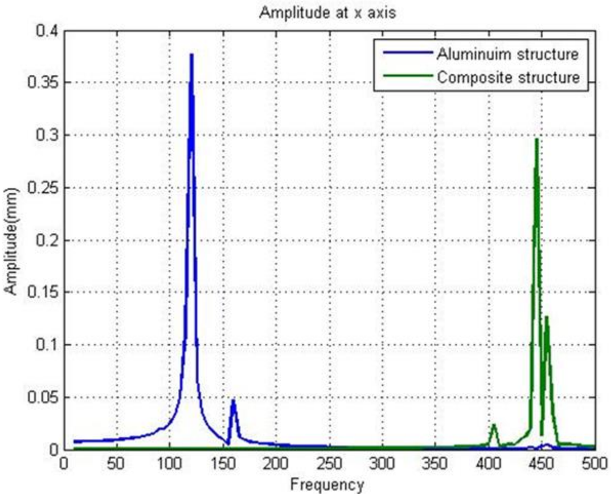


Figure 9::Frequency response at x direction

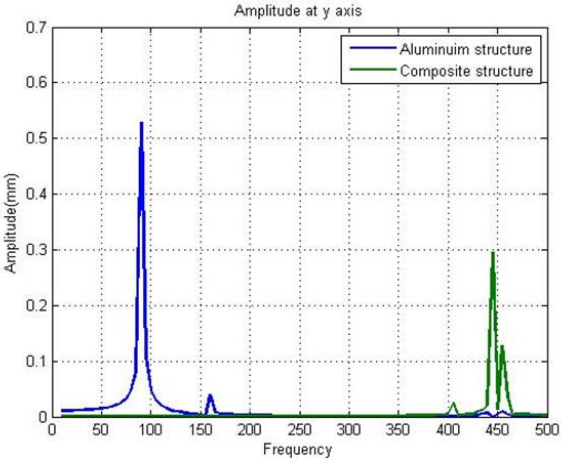


Figure 10: Frequency response at y direction

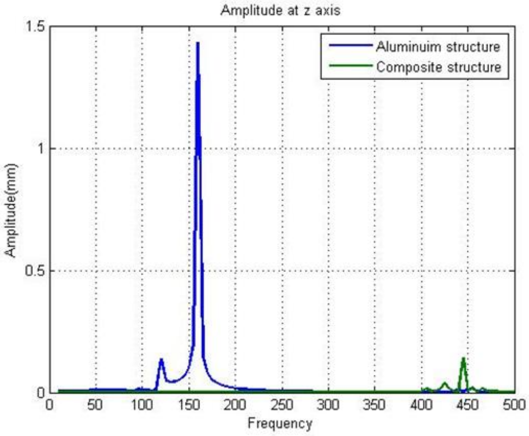


Figure 11: Frequency response at z direction

The previous Figures 9 to 11 show the frequency vs altitude of the two configurations and the advantages of replacing aluminum alloy plate with composite sandwich plate, the comparison of the frequency response show that the natural frequency was increased in case of composite plate and the deflection was decreased in accordance with the mass as the natural frequency of satellite increases the designer has a bigger safety margin in structure design and wide range of launcher selection.

4. Conclusion

Spacecraft structure plays an effective role in the compatibility of the spacecraft with the launch vehicle. A finite element analysis is developed to investigate the static as well as the dynamic behaviors of spacecraft structures. Both the spacecraft geometric and mathematical models are developed. Strength analysis of the spacecraft structure shows maximum static stress location in case of Aluminum milled plate (first case study) is almost the same in the case of honeycomb sandwich plate (second case study). While, the value of the maximum static stress based on Maximum Distortion Energy Theory in the first case study is 39.7 MPa which is 90% of that calculated in second case is 44.17 MPa.

Frequency analysis of the shows a considerable difference between the two case studies. The first case study calculation shows the first natural frequency is 90.86 Hz, while the first mode for the second case study 404.76 Hz, which is more than four times the first case.

From the previous, it can be conclude that, possible replacement of solid plates of spacecraft structure with honeycomb plats is the easiest way for improving the dynamic characteristics of spacecraft structure.

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