VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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RANDOM VIBRATION ANALYSIS OF MECHANICAL HARDWARE OF FLIGHT DATA RECORDER

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ABSTRACT

Flight data recorder (FDR) is an electronic device installed in the aircrafts for the purpose of investigation of the accidents. FDR is an assembly of both mechanical and electronic components. It is necessary to design the FDR with high strength and stiffness for both static and dynamic loads to avoid the failure when accidents or crash of the flights occur. Typically the parts of the FDR will manufactured by both metals and non-metals. The parts of the FDR are experienced by different types of loads like harmonic, random, and shock vibration loads. High deformations and stresses will be developed during these loads and internal collisions of parts can take place and then leads to individual part or assembly failure. So it is very important to analyse the response of the FDR subjected to these loads. In the present work, FDR is analysed under random vibration loads in the form of base acceleration in X, Y and Z directions by using finite element simulation software Ansys Workbench. The parts and assembly are modelled in Ansys workbench. The response of the structure is analysed for with and without rib FDR cases. Later the best case is analysed with composite materials. Carbon epoxy and E-glass epoxy 3-D composite materials are chosen to perform the analysis. Proper boundary conditions, mesh and contacts between parts are assigned to the FDR assembly. It is observed that FDR shown better stiffness with ribs for all directional random vibration loads than without ribs. The deformations in FDR with ribs and without ribs are found to be within the limits of clearance available. Hence there is no risk of collision between the parts. It is observed that there is 28.26% of weight reduction in carbon epoxy composite FDR compared to the typical FDR with ribs.

Keywords: flight data recorder, random vibration analysis, composites, FEM, ansys.

1. INTRODUCTION

Flight data recorder used in aerospace vehicles to investigate flight accidents. It is also known as black box. FDR contains different parts, out of those the main parts are control board, crash survivable memory unit, PCMCIA interface, under water locating beacon, memory chip and ARINC connector. FDR undergoes various dynamic loads during the flight and launching time. A Random Vibration is a motion which is non-deterministic in nature i.e., we cannot precisely predicted the future behaviour. The loads which are coming from the random vibration are random in nature. The time history of the load is unique at every point. These loads are also not periodic in nature and it includes a group of frequencies along with the time history. This spectrum is called power spectral density. The loads applied in the form of PSD. PSD is a table of spectral values vs. frequencies. The square root of the area under the PSD curve represents the root mean square (RMS) value of the load. Unit is G^2/Hertz. The general units are acceleration [G2/Hz] vs. frequency [Hz].

G.S.Aglietti [1] performed the mechanical analysis and testing of typical electronic enclosures to a random vibration in a space vehicle. Dynamic response of the PCB is calculated by the FEM and theoretical. Applications of CFRP over aluminium alloy and anti-vibration frames over anti vibration rod are discussed. Jie Gu [2] performed a vibration analysis on the PCB which contains different types of electronic components. The response at different locations on the PCB is achieved by the modal analysis. It is validated with the experimental test values. G.Durga Prasad [3] performed a vibration analysis on the aerospace structure. 20 mode shapes were extracted. From the random vibration analysis, PSD response at 9 points is taken. And it is validated with the experimental values at those 9 points. Experimental results very close to the analysis results. Arshad khan [4] is conducted a FEA analysis on the bracket by random vibration excitations to study the fatigue failure of the component. Razvan [5] performed a random vibration analysis on the car component by the FEA. PSD Response of the structure is calculated. A practical test is performed on the car component for the partial validation. Ren Guoquan [6] performed the vibration analysis of the PCB and studied the effect of PCB thickness. He compared the results of FE model with theoretical and experimental data. The result shows that the natural frequency of the PCB increases with the increase of the thickness. Hamid Reza Zandipour and Hasan Jalali [7], Michael Nikkhoo [8], conducted vibration analysis on electronic devices and studied the response of the parts. The present study is chosen to analyze the FDR for random vibration loading conditions using finite element software ANSYS Workbench.

2. PROBLEM DESCRIPTION

a) Statement

To perform structural analysis of flight data recorder using FEA and to verify the design of components in stiffness point of view under random

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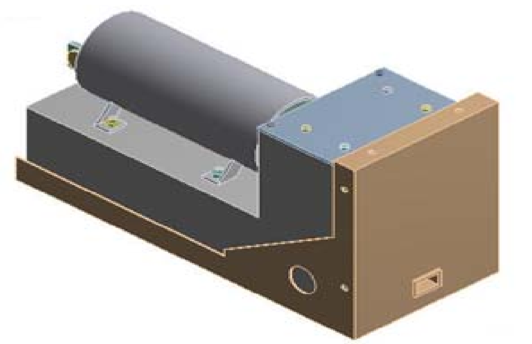
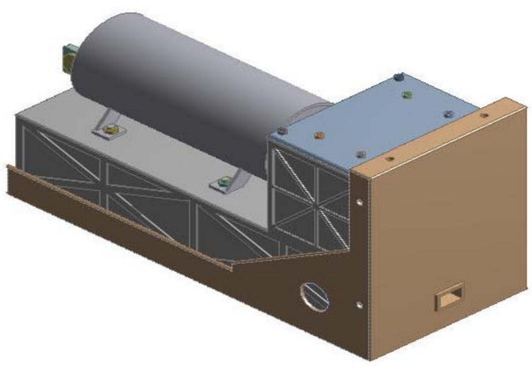
vibration loads in X,Y & Z directions by using isotropic and composite materials.

b) Problem modeling

The geometry of the flight data recorder is designed in the software ANSYS WORKBENCH. The dimensions of the flight data recorder are taken from the technical data paper [9]. The isometric views of the FDR without ribs and with ribs are shown in the Figure-1.



(a)



(b)

Figure-1. (a) Isometric view of the FDR without ribs. (b) Isometric view of the FDR with ribs.

The exploded view of the FDR is shown in the Figure-2.

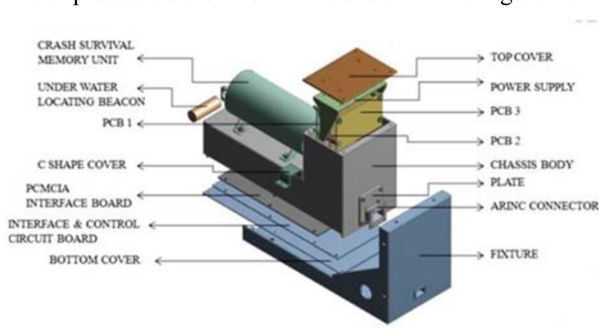


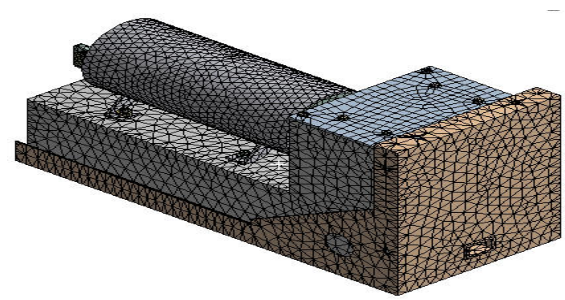
Figure-2. Exploded view of FDR.

c) Meshing

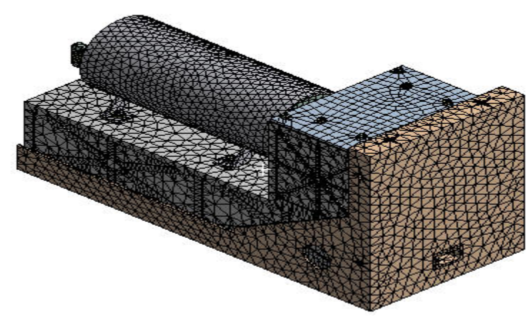
Meshing is the process of converting geometry entities to finite element entities. Proper fine mesh is done to the FDR assembly for mesh convergence. The mesh of the FDR with ribs and without ribs is shown in the Figure-3. Higher order 20 node quadratic elements are used for plane portions and higher order 10 node tetrahedral elements are used for curved portions. The mesh statistics are listed in the Table-1.

Table-1. Mesh statistics of FDR.

	FDR without Ribs	FDR with Ribs
Nodes	174094	206982
Elements	71515	90071



(a)



(b)

Figure-3. (a) Mesh of the FDR without ribs. (b) Mesh of the FDR with ribs.

d) Connections

Bonded contacts are given between bolt and nut. Pre-tension is assigned to bolt based on torque. The remaining contacts are assigned as frictional contacts with frictional coefficient of 0.1(average value).

e) Loads and boundary conditions

The load [10] is given in the form of base acceleration between 20 to 2000 Hz frequency ranges in X, Y & Z direction. So the load is given to the fixed supports. The magnitude of the load is listed in Table-2 and shown in Figure-4.

Table-2. Random vibration load.

S.No.	Frequency (Hz)	Acceleration (G^2/Hz)
1	20	0.0210
2	72	0.2180
3	660	0.2180
4	2000	0.0279

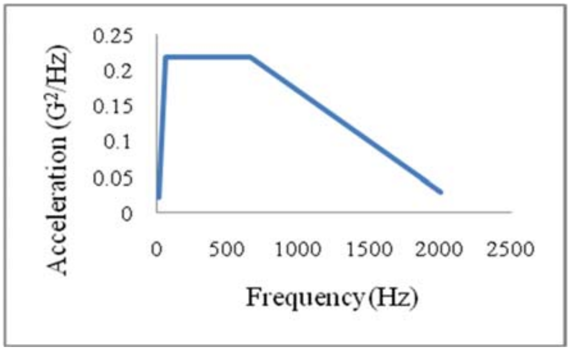
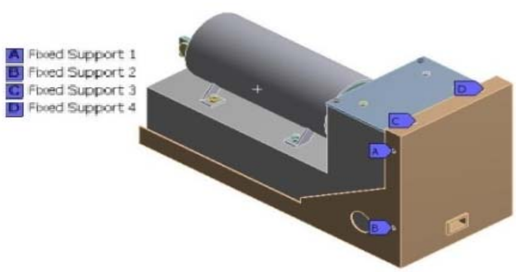
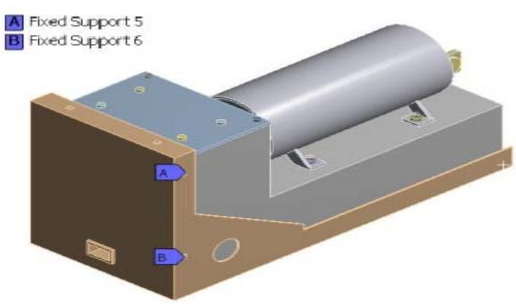


Figure-4. Random vibration load.

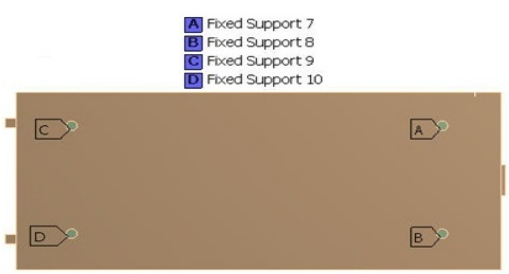
Fixed support boundary conditions are assigned to FDR where the tray is positioned on the data acquisition system. The boundary conditions are shown in the Figure-5.



(a)



(b)



(c)

Figure-5. (a), (b), (c) Fixed supports.

f) Material properties

The preliminary material properties are listed in the Table-3.

Table-3. Material properties.

Material Name	Density (g/cm3)	Poisson's Ratio	Young's Modulus (MPa)
Aluminum Alloy 7010	2.82	0.33	72000
FR4/Copper Laminate	5.4	0.3	63400
Stainless Steel	7.75	0.31	193000

The parts of the FDR are assigned with different types of materials as listed in Table-4.

Table-4. Material assigned for different parts.

Part Name	Material
Chassis Body, Fixture, Top Plate, Bottom Plate, Plate, C Shape Cover, Power Supply, ULB, ULB Mounting Boss, ARINC Connector, Bolts, Nuts, Screws and Washers	Aluminum Alloy 7010
CSMU And CSMU Door	Stainless steel
PCMCIA Interface, Control Board, PCB 1, PCB 2, PCB 3, Memory Chip	FR4/ copper laminate

The important faces of the FDR for analysing the PSD responses are shown in the Figure-6.

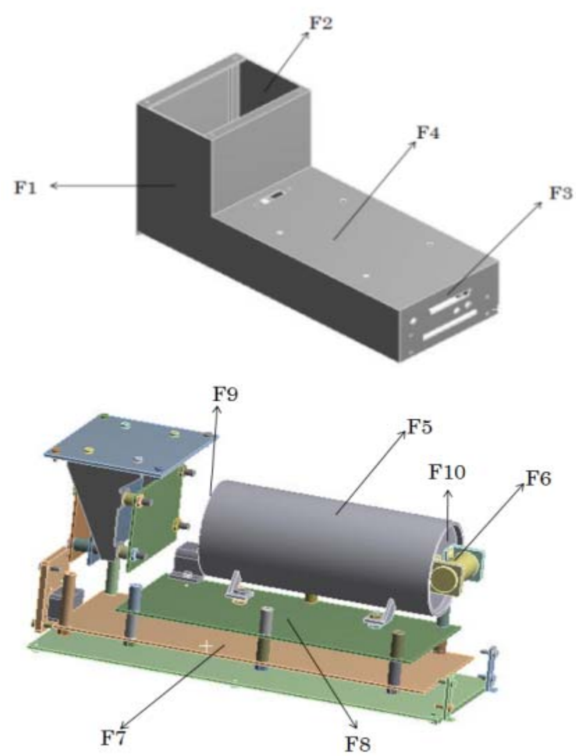


Figure-6. Selected faces for random vibration analysis.

The face to face minimum clearances in all directions are listed in the Table-5.

Table-5. Clearance of the faces.

Face	Direction		
	X (mm)	Y (mm)	Z (mm)
F1	10.16	12.7	5
F2	10.16	12.7	5
F3	12.12	∞	6.35
F4	10.16	12.7	17.78
F5	5.08	5.08	∞
F6	5.08	28.956	∞
F7	5.08	16.256	5.08
F8	24.384	20.32	5.08
F9	5.08	5.08	∞
F10	5.08	5.08	∞

From the Table-5, the minimum clearance available in all directions is 5 mm.

3. ANALYSIS RESULTS

Random vibration analysis requires free vibration analysis as prerequisite. So the free vibration analysis is done.

a) Modal analysis

The modal frequency ranges between 0 to 3000 Hz, which is 1.5 times greater than the random load range. The basic 6 modes contain 3 linear motions and 3 rotation motions. The natural frequencies of the FDR are listed in the Table-6.

Table-6. Natural frequencies of the FDR.

Natural Frequency (Hz)		
Mode No	Without Ribs	With Ribs
1	121.37	153.6
2	138.9	207.91
3	164.33	225.62
4	195.45	242.33
5	235.6	298.93
6	363.86	447.75

From the Table-6, it is observed that natural frequencies of the FDR with ribs are having higher frequencies than the FDR without ribs.

b) Random vibration analysis

The structure is analyzed under random vibration load in X, Y & Z directions. The resultant PSD response (deformation) of the critical faces of FDR parts are shown in the Figure-7, 8 & 9.

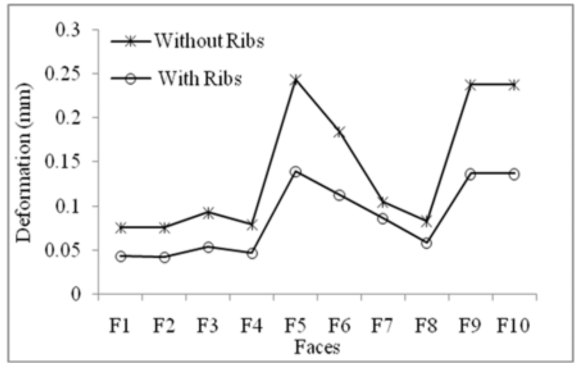


Figure-7. PSD Responses due to load in X-direction.

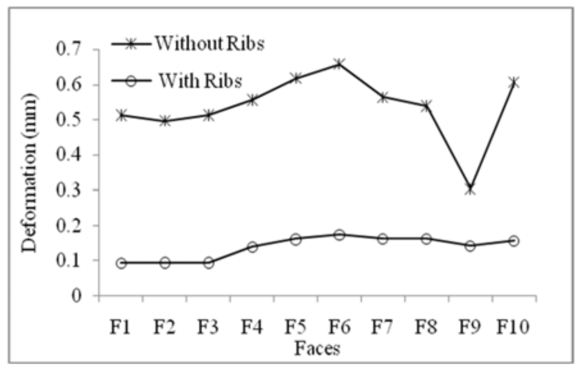


Figure-8. PSD Responses due to load in Y-direction.

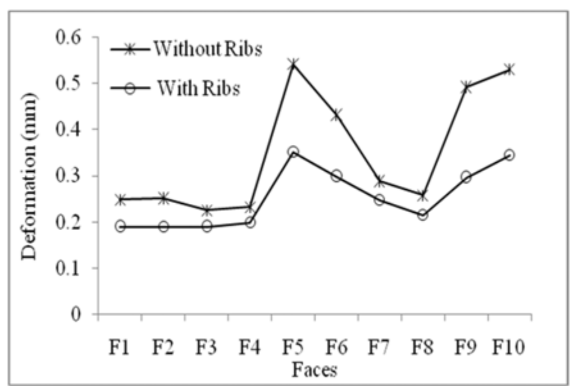


Figure-9. PSD response due to load in Z-direction.

From above figures it is observed that, the deformations are higher in the FDR without ribs than with Ribs for all directional loads. The maximum deformations in both FDR with and without ribs are lower than the minimum clearance available for all directional loads. Hence there is no risk of internal collision.

4. COMPOSITE FDR ANALYSIS

To study the effect of composite materials, few parts of the FDR with ribs are replaced by 3D composites those are carbon epoxy and E- glass epoxy. The properties of the 3D composite materials [11] are listed in the Table-7.

VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
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Table-7. Material properties.

Material/Name	Carbon/Epoxy	E-Glass/Epoxy
ρ (g/cm³)	1.6	1.98
E_1 (GPa)	36.6	19.98
E_2 (GPa)	46.8	19.64
E_3 (GPa)	30.3	14.21
ν_{12}	0.04	0.204
ν_{23}	0.289	0.312
ν_{31}	0.21	0.29
G_{12} (GPa)	4.9	5.8
G_{23} (GPa)	4.5	5.6
G_{31} (GPa)	4.9	5.8

The composite material is assigned to following parts of the FDR with ribs are listed in the Table-8.

Table-8. Composite material assigned parts.

S.No	Part Name
1	Tray
2	Top Cover
3	Bottom Cover
4	Supporter Plate
5	C Shape Cover
6	CSMU door

Note: The remaining parts are assigned with same material as mentioned in Table-3.

a) Modal analysis

The natural frequencies of the FDR with ribs using composite materials are listed in the Table-9.

Table-9. Natural frequencies of FDR with ribs using composite materials.

Natural Frequency (Hz)		
Mode No	Carbon Epoxy	E glass Epoxy
1	158.23	157.75
2	212.37	193.71
3	240.75	219.39
4	248.21	240.75
5	323.32	303.16
6	437.8	416.94

From the Table-9, it is noticed that the natural frequencies of the FDR with carbon epoxy are higher than the natural frequencies of the FDR with E-Glass epoxy.

b) Random vibration analysis

The structure is analyzed under Random vibration load in X, Y & Z directions. The resultant PSD response (deformation) of FDR parts are shown in the Figure-10, 11 & 12.

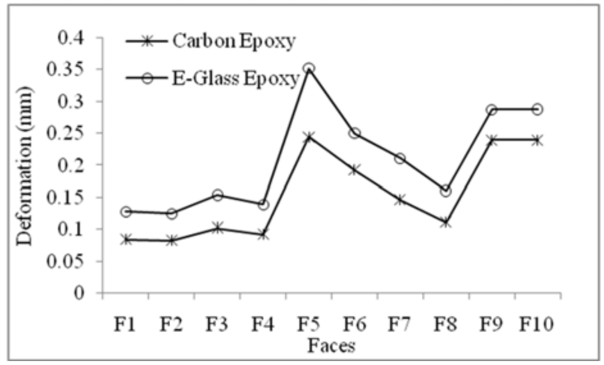

Figure-10. PSD response due to random vibration load in X direction.

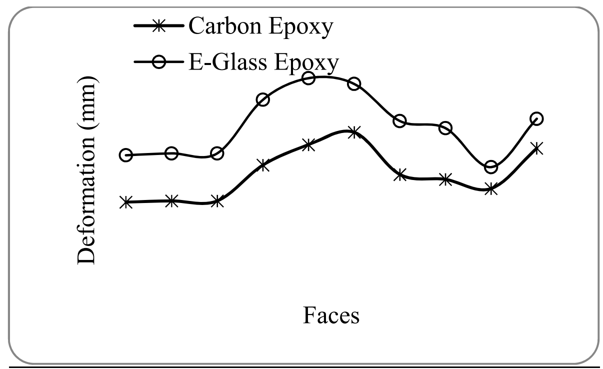

Figure-11. PSD response due to random vibration load in Y direction.

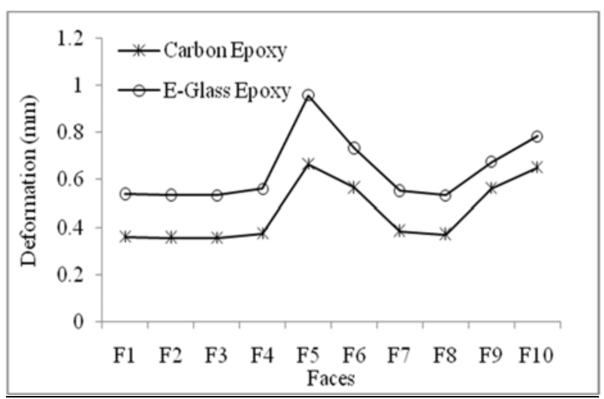

Figure-12. PSD response due to random vibration load in Z direction.

From the above figures, it is noticed that the deformations of the FDR are higher with E -Glass Epoxy than the Carbon epoxy in all directions. The maximum deformation in all parts is smaller than the minimum clearance available in all directions. So, there is no risk of internal collisions.

The weight of the FDR with and without composite materials for ribs case as listed in Table-10.

Table-10. Weight of the FDR with ribs.

Material	Weight of the FDR with Ribs (Kg)
Without composite	6.7010
Carbon Epoxy	4.8065
E-Glass Epoxy	4.9841

From Table-10, FDR with ribs using carbon epoxy has lowest weight compared to remaining materials.

5. CONCLUSIONS

From this present work it is observed that the deformations of the FDR are higher in without rib case compared to with rib case. The maximum deformations produced in FDR with and without rib are smaller than the minimum clearance available. Hence there is no risk of internal collisions. Then the FDR is analysed with composite materials for rib case. The deformations of the FDR parts are higher in the e-glass epoxy than the carbon epoxy. So carbon epoxy material is recommended that gives a maximum weight saving of 28.26%.

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