Aircraft Engine Control Unit (FADEC) Design Assessment for Extreme Vibration and Shock Loads

Preethi J[1] Dr. B.M Nandeeshaiah[2]
[1]M.Tech. Student [2]Professor
[1,2]Department of Mechanical Engineering
[1,2]Dr. Ambedkar Institute of Technology, Bangalore

Abstract— Full Authority Digital Engine Control (FADEC) system consisting of an electronic engine controller and its related parts to control all aspects of aircraft engine. The main purpose of this analysis is to design engine control system for commercial aircraft jet engine and focuses on modeling of FADEC system, static and dynamic response of system under different loading condition. The objective of this analysis is to optimize design of FADEC and to allow the engine to perform at maximum efficiency for a given flight condition.

Key words: Extreme Vibration & Shock Loads, FADEC

I. Introduction

True full authority digital engine controls have no form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer. If a total FADEC failure occurs which resulted failure of engine. FADEC works by receiving multiple input variables of the current flight condition is dependent on air density, throttle lever position, engine temperatures, engine pressures, and many other parameters. The inputs are received by the EEC and analyzed up to 70 times per second. Engine operating parameters such as fuel flow, stator vane position, bleed valve position, and others are computed from this data and applied as appropriate. FADEC also controls engine starting and restarting. The FADEC's basic purpose is to provide optimum engine efficiency for a given flight condition and is shown in fig.1.

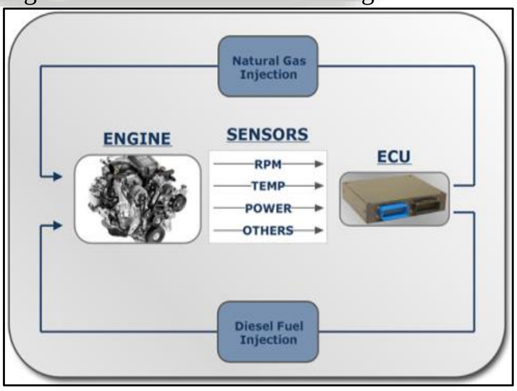


Fig. 1: Working of FADEC system

II. Problem statement

FADEC experiences a severe acceleration crash safety, vibration and thermal loads under maximum operating condition. Incorrect performance in FADEC leads to fatal aircraft accidents and hence designs and optimization of engine control system is important to improve the engine performance. The FADEC's basic purpose is to provide optimum engine efficiency for a given flight condition. FADEC not only provides for efficient engine operation, it also allows the manufacturer to program engine limitations and receive engine health and maintenance reports. 20 % of all failure observed in aircraft electronic components are due to vibration failure. PCB board out-of plane displacement prediction under random and harmonic analysis is an important milestone in the current study. Steinberg relation is used to substantiate the design to meet the RTCA DO-160 guidelines.

III. Objectives and methodology

The methodology adopted to achieve the required goals involves finite element analysis for the aircraft FADEC system. The 3D CAD model of the FADEC system is developed using Unigraphics (NX-CAD) software. ANSYS V 16.1 workbench is used to evaluate the static strength margins for FADEC system to meet the RTCA DO-160 guidelines design guidelines. Finite element analysis has been used to estimate the FADEC PCB's out-of plane displacement based on Steinberg relation. The combination of all the analysis results were used to develop virtual model created using FEM tools and results are correlated based on empirical relation. Basic system understanding has been achieved through RTCA DO-160 design guidelines and Steinberg requirements along with FADEC design data sheet.

IV. Major methodologies used for analysis

FADEC system will be evaluated for acceleration crash safety requirements

- Steady state thermal analysis to predict the heat dissipating/power loss through heat flux
- Engine fan blade loss, short duration vibration test curve R
- Vibration Analysis – standard vibration test in accordance with RTCA DO-160 guidelines.
- Aircraft FADEC has been evaluated for static strength margin against 20G acceleration loads in X, Y and Z direction
- FADEC has been analyzed for modal analysis for 0-2000 Hz
- Perform random analysis for a frequency range of 0-2000 Hz to meet the material allowable yield strength for 3sigma requirements
- Perform harmonic analysis for a frequency range of 0-700 Hz to determine the fatigue strength margin
- Determine the PCB out-off plane displacement using Steinberg relation to meet the design requirement as per RTCA-DO160 guidelines

V. Geometrical configuration of FADEC system

Unigraphics software provides key capabilities for fast, efficient and flexible product development such as Advanced solutions for conceptual design, 3D modelling and documentation, multi-discipline simulation for structural, motion, thermal, flow and multi-physics applications, Complete part manufacturing solutions for tooling, machining and quality inspection. Figure 2 shows 3D CAD view of the finalized model for aircraft FADEC system.

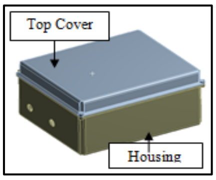


Fig. 2: FADEC 3D model

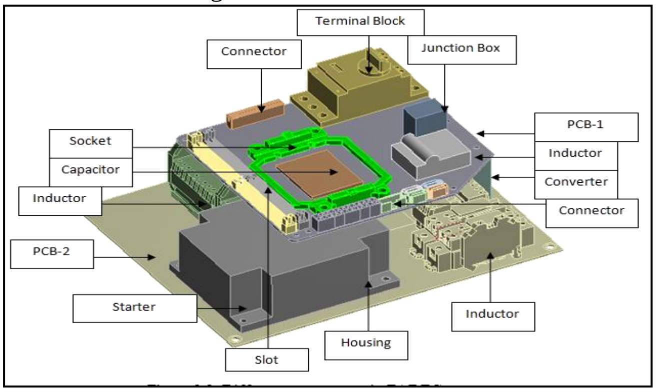


Fig. 3: Parts of FADEC system

A. *Finite Element Model of FADEC System*

The1CAD1models1are1imported1to ANSYS 16.1 Work bench where the Meshing and Analysis is carried out. Here carefully, the critical regions are selected1for fine mesh such as Passage Holes and Critical fillet Region. 2nd order tetrahedral high quality element has 3 translational degrees of freedom per node for a total of 30 degrees of freedom per individual element. The tetrahedral are also known as simplex, which simply means that any 3D volume, regardless of shape or topology, can be meshed with tets. They are also the only kind of elements that can be used with adaptive mesh refinement. The SOLID 187 element is defined by 10 nodes having 3 Degree of freedom at each node. It has a quadratic displacement behaviour and is well suited to modelling irregular meshes. This element has plasticity, hyper elasticity, creep, stress stiffening, larger deflection and large strain capabilities.

FADEC has been modelled with combination of 2nd order tetrahedron and hexagonal dominant elements. Fine mesh is considered at the critical locations. Solid element type of 187 is used for modeling of FADEC system component1and below figure 4 shows the Meshing of FADEC system and table 1 shows the details of number of nodes and elements in FADEC system.

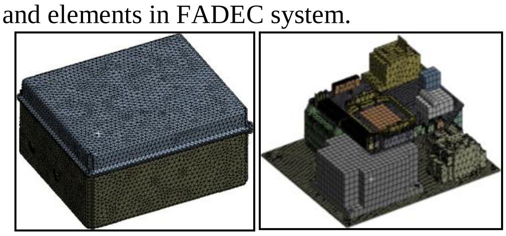


Fig. 4: FE Model of FADEC system

	Number of Elements	Number of Nodes
Total	178824	426946

Table 1: Meshing Details

VI. STATIC STRUCTURAL ANALYSIS OF FADEC SYSTEM

The structural analysis is a mathematical algorithm process by which the response of a structure to specified loads and actions is determined. This response is measured by determining the internal forces or stress resultants and displacements or deformations throughout the structure Analysis has been carried out with static loads and results are presented for displacements and von-mises stresses. The Von-mises stress theory is the main failure theory to find the failure of the components or factor of safety in the problem.

A. *Acceleration Shock Analysis*

FADEC system is analyzed for 20G acceleration in each X, Y and Z direction. The following loading conditions are the critical case conditions to which the FADEC has been analyzed. Acceleration crash safety - 20G shock in accordance with RTCA DO-160G Section 7

B. *Shock Analysis - 20G in Y Direction*

Acceleration load of 20G (1.9629E5 mm/s2) is applied in Y direction at CG of the assembly with respect to global co-ordinate system in Y-direction is shown in fig 5.

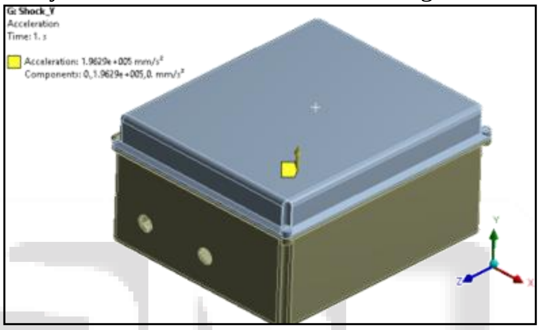


Fig. 5: Acceleration load of 20G in Y-direction

C. *Results and Discussion*

1) *Total Displacement Plot*

Maximum total deformation of 0.4049 mm is observed on the PCB in Y-direction as shown in figu.6

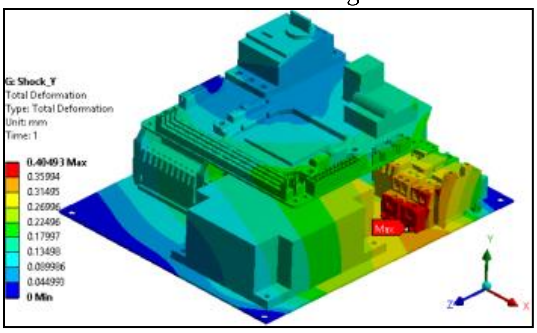
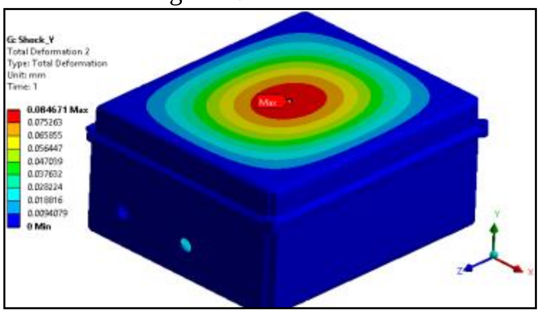


Fig. 6: Maximum total deformation of PCB in Y direction.

Deformation plots for components of FADEC system is shown in figure 7.



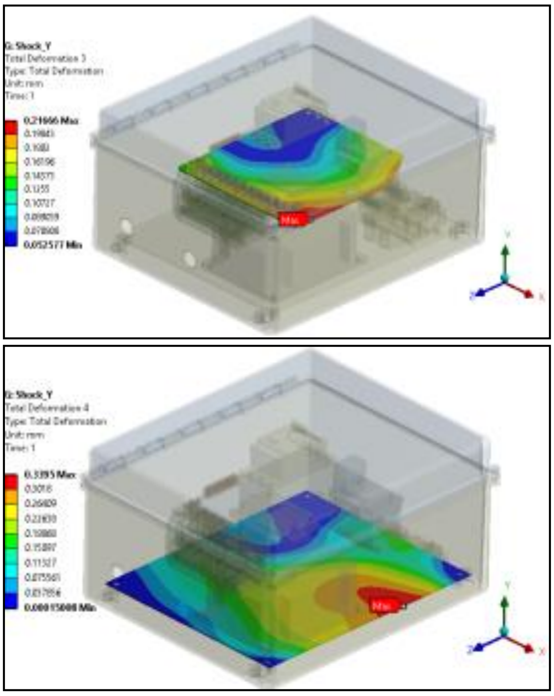


Fig. 7: Deformation plots for components of FADEC system

D. *Maximum von-Mises Stress Plot: Top Cover*

Maximum von-Mises0stress of 9.23 MPa is observed at clamping location. The maximum stress of 9.23 MPa is less than the material allowable yield limit of 145 MPa. Von-Mises0stress of top cover as shown in below figure.8.

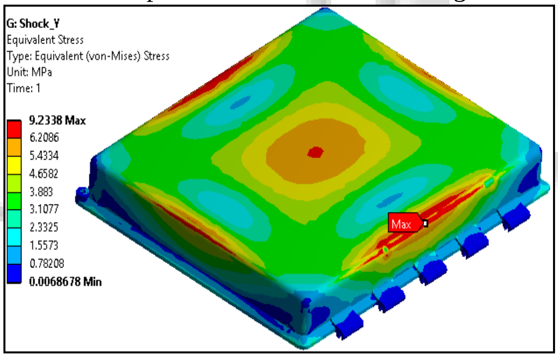
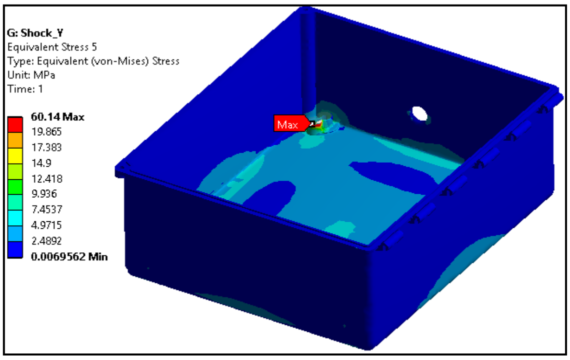


Fig. 8: Von-Mises Stress Plot of top cover in Y-direction

E. *Maximum von-Mises Stress Plot: Bottom Housing*

Maximum von-Mises stress of 60.14 MPa is observed at mounting pad location. The maximum stress of 60.14 MPa is less than the material allowable yield limit of 145 MPa. Von-Mises stress of bottom housing as shown in below figure 9.



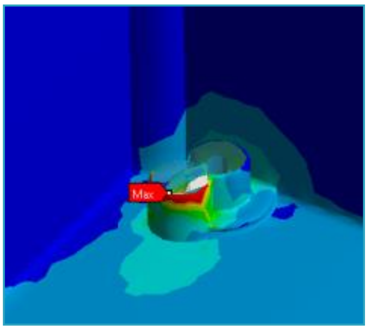


Fig. 9: Von-Mises Stress Plot of housing in Y-direction

VII. Conclusion

Maximum von-Mises stress is considered for margin of safety calculation and it is compared against the material allowable yield strength as shown in below table 5.2. The maximum stress observed in FADEC housing and top cover is less than the material allowable yield limit of 145 MPa and there by having a positive design margin.

- X-direction displacement= 0.593mm
- Y-direction displacement= 0.4049mm
- Z-direction displacement= 0.492mm

Total deformation observed in FADEC assembly is closely matches with the Z-direction displacement. Maximum displacement for PCB-1 and PCB-2 is 0.49 mm and 0.42 mm respectively.

Acknowledgement

We don't accomplish anything in this world alone and whatever happens is the result of the whole tapestry of one's life and all the weavings of individual threads from one to another that creates something. In my effort towards the realization of my project work, I have drawn on the guidance of many people for which I am glad to acknowledge.

With profound sense of gratitude and regards I convey my sincere thanks to my internal guide Dr. B M Nandeeshaiah, Professor, Department of Mechanical Engineering, Dr.AIT for his esteemed suggestions, sincere efforts and inspiration given to me in completing my project work.

I would like to express my heartfelt thanks to Professor Dr. B Ravindra, P.G coordinator, Department of Mechanical Engineering, Dr.AIT, for his valuable advice, encouragement, help, guidance and untiring support throughout the development of this project.

I express my deep gratitude to my institute, Dr.AIT, Bangalore which provided an opportunity and platform for fulfilling my dreams, and desire to reach my goal. I sincerely thank my respected Head of the Department Dr. Chandrasagar L and Principal Dr. T C Manjunath who is the constant source of inspiration, throughout the academics.

I also thank to one and all who directly or indirectly encouraged me to complete this project.

Reference

[1] K.P.Subramanya, Jiwan Kumar Pandit, C.S. Prasad, M.R. Thyagaraj "Vibration Analysis Study of Spacecraft Electronic Package" in 2014.

[2] Rudolf Andoga, Ladislav Fozo, Ladislav Madarasz "Digital Electronic Control of a Small Turbojet Engine MPM 20" in 2007
[3] Md. Akhtar khan, Md. Muqthar ghori, Syed Abdul Khaliqh, Md. Mohsin Ali "Experimental Study of Full Authority Digital Engine Control (FADEC) System on Lycoming Engine" in 2013
[4] Balakrishnan S.R "Control System Development Experience for Aero Gas Turbine Demonstrator Engines". Director-Aeronautical Nehru Institute of Engineering and Technology in 2013.