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Multidisciplinary conceptual investigation for integrating stores, not in the original configuration of a subsonic airplane

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Multidisciplinary conceptual investigation for integrating stores, not in the original configuration of a subsonic airplane

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Abstract. Subsonic airplanes are widely used around the world in applications such as pilot training, transportation, sports activities, insect fighting, and field monitoring. This research deals with airplanes that already own the capability of carrying suspended loads. Increasing the airplane's capabilities and configurations by integrating different suspended loads like smaller or larger external fuel tanks or insecticide tanks that are not in the original configuration of the airplane is a great advantage. This modification can be done without dramatic changes to the airplane and with minimum cost. In this research, a multidisciplinary methodology is used to integrate a commercially-available premade external fuel tank into the Embraer E312 Tucano airplane which is not in the original configuration of the airplane. First, a geometrical analysis is performed to ensure the availability of proper installation. This study leads to the design of an adaptor between the tank and the airplane pylon, then, a computational fluid dynamics (CFD) modeling using ANSYS-CFX is performed to evaluate aerodynamic forces and moments applied on the new fuel tank. Furthermore, finite element modeling using ANSYS-Static structure is performed by applying the aerodynamic and inertial loads to calculate the adaptor's stresses and structure safety factor. Finally, vibration fatigue analysis-based power spectral densities are developed using ANSYS-Random vibration to calculate the adaptor's estimated lifetime to ensure the store system's safety by applying airplane vibration acceleration spectral density pattern selected from applicable standard. In this typical example, the above-mentioned methodology is applied and the results are acceptable.

1. Introduction

Basic military and civil airplanes are usually carrying several kinds of wing-mounted external stores, also, loading an external store with a pylon connection part is the essential configuration of modern military airplanes. External stores can change the aerodynamic and aero-elastic characteristics of a wing [1].

Many authors studied different procedures to realize the effect of external stores on airplanes. TK et al. [2] demonstrate the concept of store grouping using the structure aero database of a high-performance airplane. using aerodynamic similarity between the various store configurations. stores showing matching or a minimum of very similar aerodynamic characteristics are categorized into a single group. The results show that aerodynamically alike stores are often grouped to minimize the flight-testing effort necessary for the validation of the wind tunnel aero database.

Sulaeman et al [3] studied the optimization of a composite wing with external stores to attenuate wing weight. The variables of optimization are the material of the wing, the composite ply angle, skin thickness, the wing rib, and its control surfaces. The optimization is presented to find the best material orientation for each layer of the wing skin. The results show that the external store and so the anisotropic behavior of the composite laminate affect the vibration mode shapes and also the flutter mode.

Okur et al. [4] study fatigue analysis of a missile structure throughout captive carriage at the underwing of an F-16 jet airplane. A data measurement was aimed to measure loads during carriage for five different sorties. Strain data and acceleration were gathered during the test. For the vibration tests and fatigue analyses, power spectral densities (PSD) were generated by accelerometers. Strain gauges were positioned at the most critical places for fatigue calculations. The results of this study are to get the fatigue performance of an external store under a fixed-wing airplane during random vibration. Acceleration data were used for PSD calculation for a perfect regular sortie for the F-16 airplane. The critical vibration direction appears to be the z direction.

Bilal et al. [5.6] model and study the store-carrying rack of a fighter airplane to develop its aerodynamic performance. They use different CFD methods to catch the flow physics parallel and perpendicular to the rack. The results offer a clear sign that for complex flow properties the k-ε is more dependable for force guess.

Dhandabani et al. [7] study a scheme for flutter clearance of a fighter airplane lugging a new external store. The method is validated by using it in an airplane where the finite element model is available. Then, the identical methodology is assumed for the airplane under concern with the new store. The results show that the flutter speed of the new store design lies between that of the certified store design.

Manaf et al. [8] study the effect of the external store on the aerodynamics behavior of a lightweight airplane model in that the external store is positioned under the wing using wind tunnel tests. The results show that the external store decreases the lift and increases the drag. The lift is decreased because the flow was interrupted by the fixing of the external store. Meanwhile, the drag is reduced because of the bigger wake behind the model as the wake made by the external store combined with the wake made by the fuselage.

In this paper, a 150-liter external fuel tank designed and fabricated for L-29 aircraft which is a single-engine military trainer aircraft designed and built by Aero Vodochody for Czechoslovakia is to be studied for integration into Embraer E312 Tucano aircraft, which is a tandem-seat, single-turboprop basic trainer developed by Embraer for Brazil. E312 Tucano has the capability of carrying a 330-liter external fuel tank, which is more weight than the 150-liter fuel tank. The study first performed a geometrical analysis, this study leads to the design of a mechanical adaptor to fit the tank to the E312 Tucano airplane pylon. Then the computational fluid dynamics (CFD) analysis is then performed to get the aerodynamic loads, and after that structure and vibration analysis are performed to get the safety factor and fatigue life of the model. The results show that this fuel tank as a case study could be integrated into the E312 Tucano airplane.

2. Geometrical analysis

A 150-liter external fuel tank as shown in Figure 1 designed for mounted under the wing for L-29 aircraft, which is a single-engine military trainer aircraft designed and built by Aero Vodochody for Czechoslovakia, is chosen in this case study to be integrated into Embraer E312 Tucano airplane, which is a tandem-seat single-turboprop basic trainer developed by Embraer for the Brazilian Air Force.

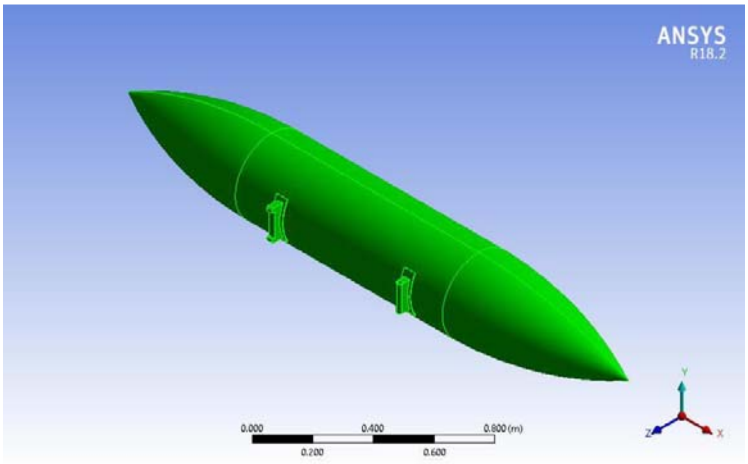


Figure 1. 150-liter external fuel tank.

The geometry and dimensions of suspension lugs for the 150-liter fuel tank are different from the pylon hooks of the E312 Tucano so a mechanical adaptor is designed to fit between the tank fixation lugs and E312 Tucano airplane pylon hooks as shown in Figure 2. The original E312 Tucano fuel tank suspension lugs are NATO standard lugs also used for other suspended stores with a deference distance of 15 in (355.6 mm). The suspension lugs are fitted between the pylon hooks and the two threaded holes in the mechanical adaptor as shown in Figure 3. The L-29 fuel tank is fitted from its lugs to the mechanical adaptor using a standard Russian connector used for this fuel tank and also for other suspended stores fitted from the center hole of the mechanical adaptor.

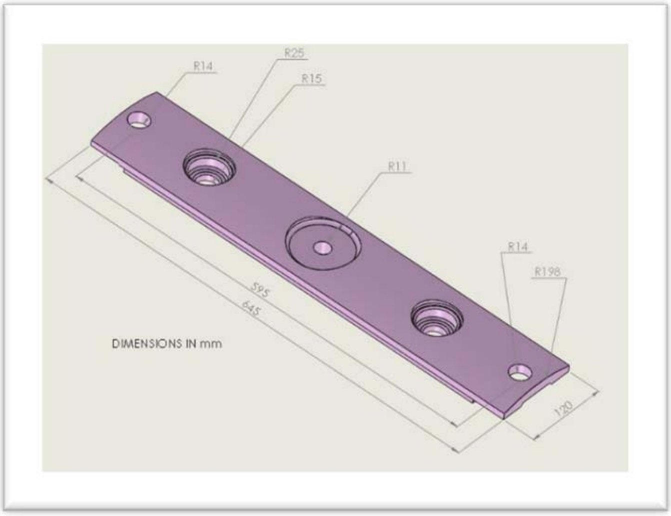


Figure 2. Mechanical adaptor.

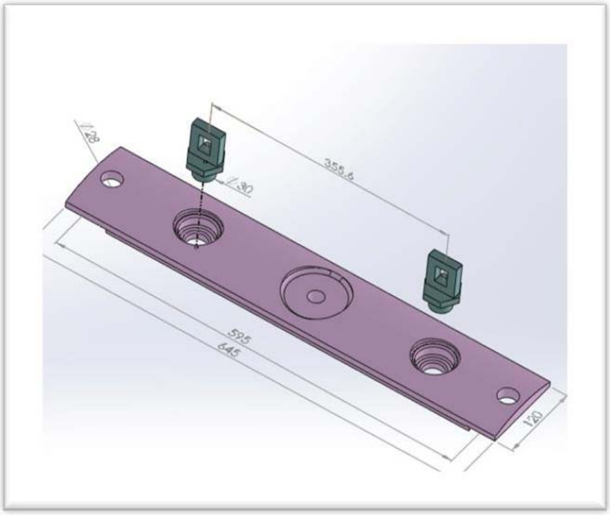


Figure 3. Mechanical adaptor with NATO suspension lugs.

3. CFD simulation

To calculate the aerodynamic forces and moments that affect the external fuel tank, computational fluid dynamics (CFD) simulation is conducted using ANSYS-CFX. The CFD model in 3D consists of the EMB312 Tucano wing, pylon, and mechanical adaptor. The CFD model is shown in Figure .

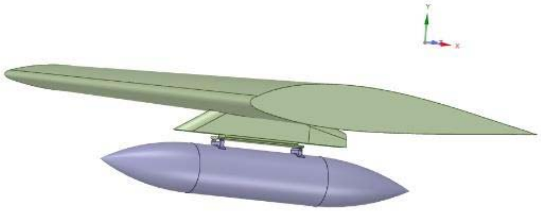


Figure 4. CFD model in ANSYS-CFX.

The 3D model is imported into ANSYS and computational fluid dynamics (CFD) simulations were performed using ANSYS-CFX. The necessary domain is created in ANSYS-Space Claim as a cube. The mesh was then created using a tetrahedral mesh with an advanced size function in ANSYS-CFX. This function can be effective for creating high-quality meshes around solid walls. The number of nodes is 298064 the number of elements is 1668522 as shown in Figure 5.

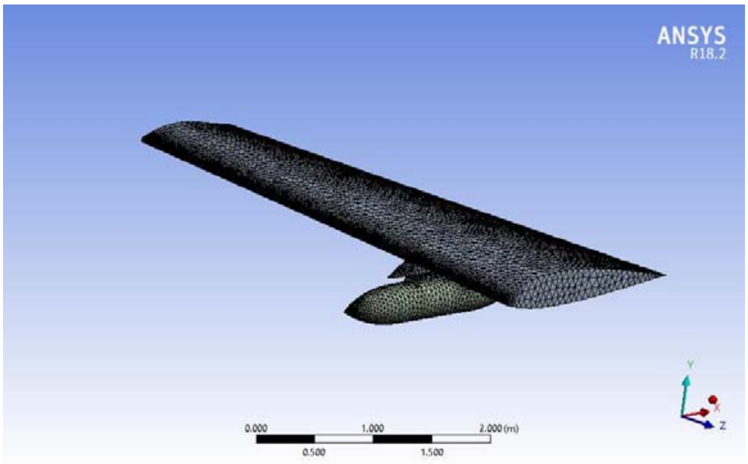


Figure 5. 3D model mesh.

The boundary domain is chosen that the upstream of the wing is equal to the length of the wing (along span), the downstream is equal to 2 times the length of the wing. The inlet flow domain is equal to half of the wing length while the outer domain of the flow is equal to 2 times the wing length. The altitude is assumed at sea level because it is the maximum pressure so the maximum resultant forces and moments. The type of fluid is assumed to be air at 25°C. The boundary domain inlet is assumed at the positive X-axis of the cube. The boundary domain outlet is assumed to be (opening) for the other five boundary domains of the cube as shown in Figure . The turbulence model is chosen to be k- ε since it is widely accepted as a typical model for aerodynamic applications. The air inlet's normal air velocity is assumed to be 125 m/s, which is the maximum speed of the EMB312 Tucano airplane, at 0 angle of attack. In the CFD solution, the results show that the residuals of mass and momentum converged below $1e^{-4}$ which is good.

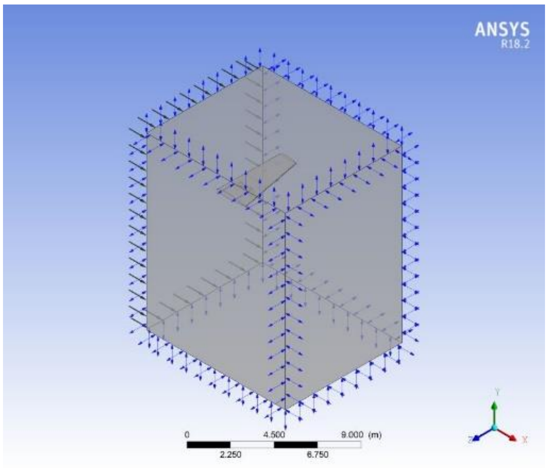


Figure 6. Boundary domains in ANSYS-CFX.

CFD results show the pressure contours and air velocity streamline as shown in Figure 7. And Figure 8 respectively. The pressure contours figure shows the maximum pressure at the wing's leading edge and the external fuel tank nose.

The resultant aerodynamic loads are: force in X direction is equal to 1307 N, force in Y direction is equal to 8532 N, force in Z direction is equal to 435 N, and the moment around Y direction is equal to 444 Nm.

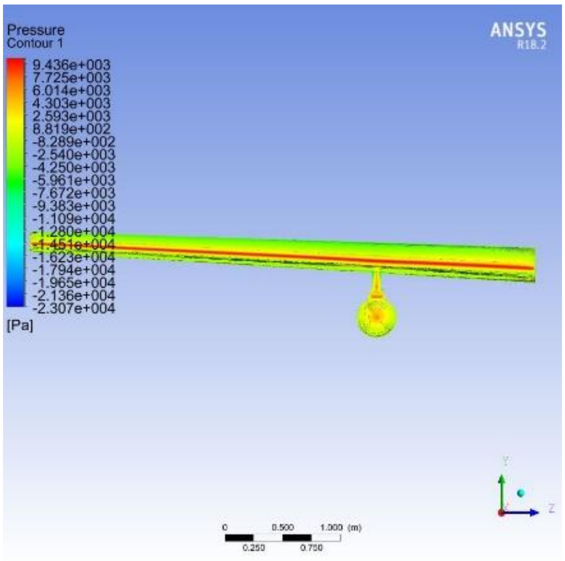


Figure 7. Pressure contour for CFD model.

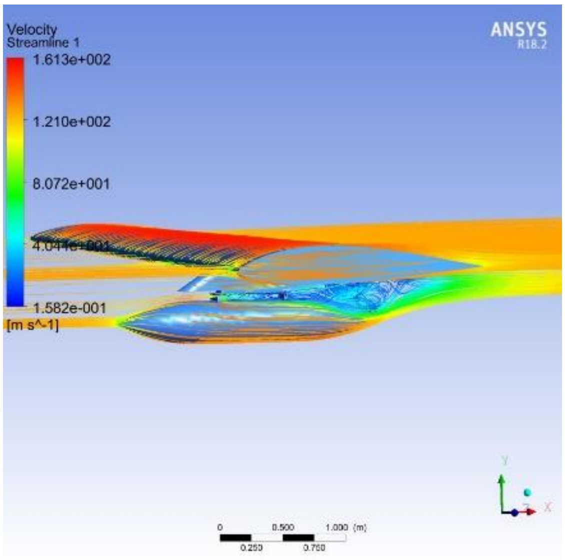


Figure 8. Air velocity streamlines in CFD.

4. Static structure analysis

Finite element modeling using ANSYS-Static structure is performed on the mechanical adaptor. The adaptor material is chosen to be aluminum alloy 7075-T6 for its high mechanical properties and lightweight. A mesh convergence study is conducted to ensure that the cell-based smoothed finite element method is stable and offers acceptable accuracy results with 26893 elements and 45775 nodes. After the mesh is created then, applying the aerodynamic forces and moments from CFD simulation to the adaptor, and also the weight of the filled fuel tank multiplied by the maximum load factor of the EMB 312 Tucano which is equal to 7 g.

The results are the equivalent stresses and safety factor as shown in Figure 9 and Figure 10 respectively. The safety factor result is 3.5 which is acceptable.

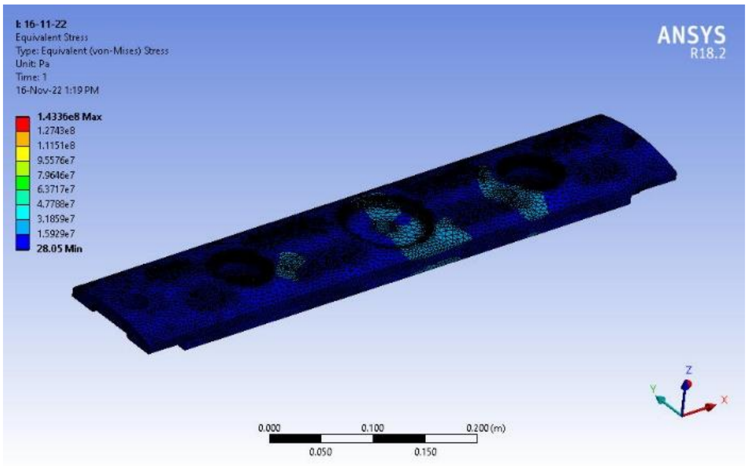


Figure 9. Equivalent stresses applied to the adaptor.

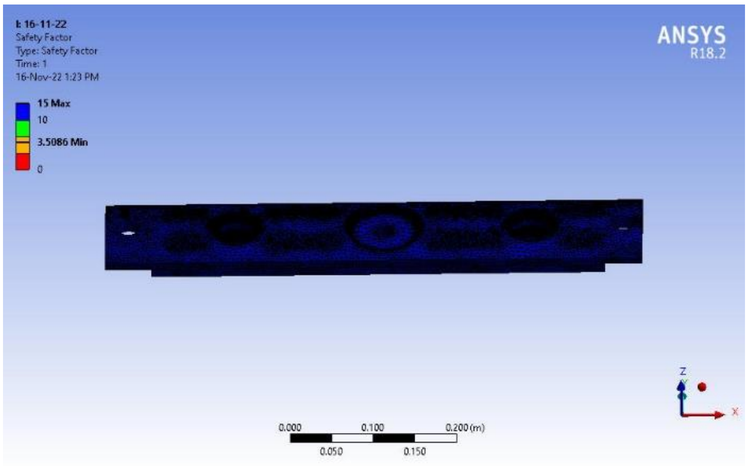
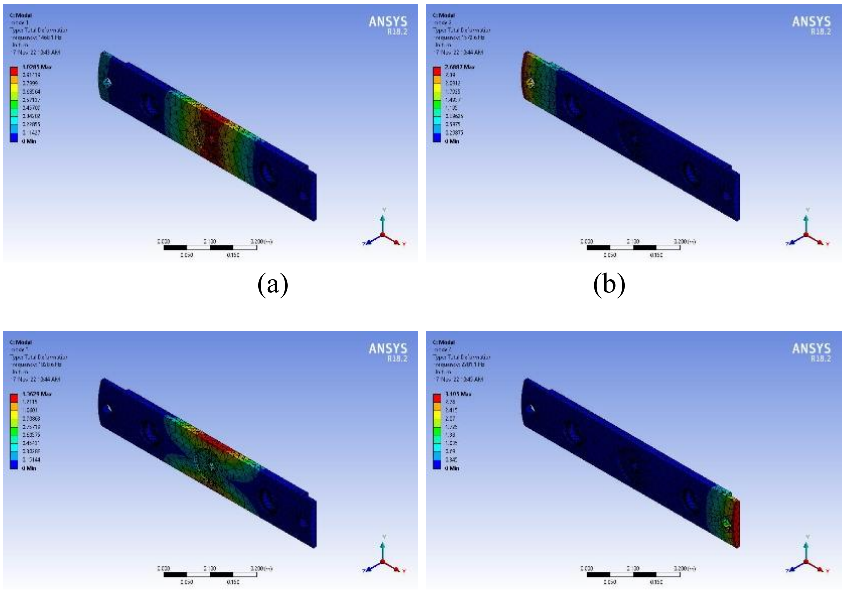


Figure 10. Safety factor for applied loads to the adaptor.

5. Modal analysis

Finite element (FE) modal analysis modeling is performed by using ANSYS-Modal for the adaptor. The goal of modal analysis is to determine the natural mode shapes and frequencies of the adaptor during free vibration. The natural frequencies are dependent only on the mass and stiffness of the adaptor structure and are independent of the load function. Figure 11 shows the adaptor's first four natural frequencies and mode shapes.



(a) (b)

(c) (d)

Figure 11. Modal displacement contours for the adaptor.

6. Vibration fatigue analysis

Vibration fatigue analysis is frequency-based because power spectral densities (PSD) loads are used. The vibration exposure PSD acceleration data for underwing suspended stores for propeller aircraft is taken from applicable standard MIL-STD 810 H. Aerodynamics and engine have effects on vibration for aircraft, so the vibration will be divided into 2 parts aerodynamic-induced vibration and turboprop engine-induced vibration to create acceleration spectral density by adding them to each other. To get vibration fatigue analysis exposures of a life cycle including synergistic effects of other environmental factors, materiel duty cycle, and maintenance to verify that materiel will function in and withstand the vibration exposures of a life cycle. Figure 12 shows propeller aircraft vibration exposure according to applicable standard [9].

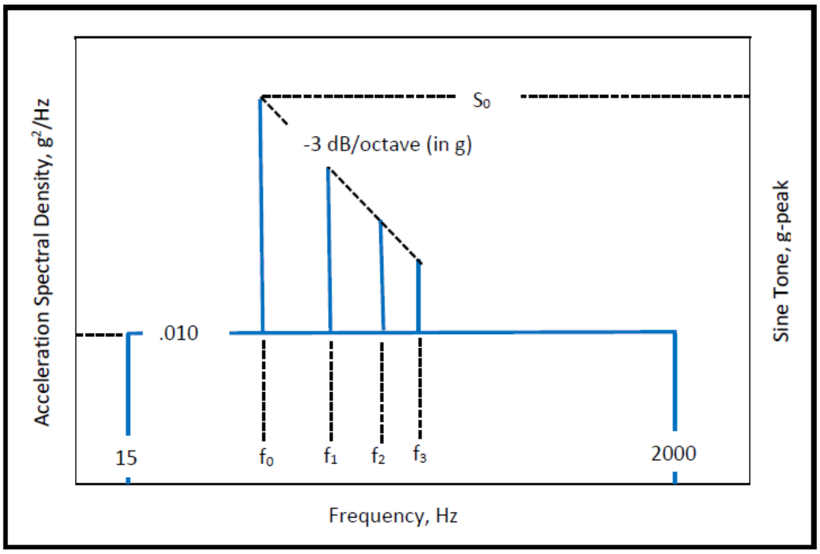


Figure 12. Propeller aircraft vibration exposure PSD acceleration data [9].

Where:
f_0 = blade passage frequency (propeller rpm times number of blades) (Hz).

$$f_1 = 2 \times f_0, f_2 = 3 \times f_0, f_3 = 4 \times f_0 \quad (1)$$

The test should be conducted as sine-on-random, with:

$$S_0 = 1.414 \times \sqrt[2]{0.1 \times f_0 \times l_0} \quad (2)$$

The collected data from Figure 10 according to the parameters of the EMB 312 Tucano airplane was calculated according to the above equations 1 and 2 and formed in a table and taken as input data in ANSYS–Random vibration. This simulation is performed after taking the solution forces and moments results from CFD analysis, static structure, and modal analysis from the ANSYS workbench to simulate actual vibration exposure to the adaptor. In ANSYS-Random vibration, the endurance test duration per axis is 1 hour which simulates 1000 hours of flight according to MIL-STD -810H [9]. Life results of the model obtained from the *PSD* for every axis separately are shown in Figure3- Figure5. The minimum life is 1.4e15 seconds at the z-axis which is acceptable. The most critical vibration direction at the z direction is because of the weight of the filled fuel tank for the horizontal position assumption of the model and the airplane.

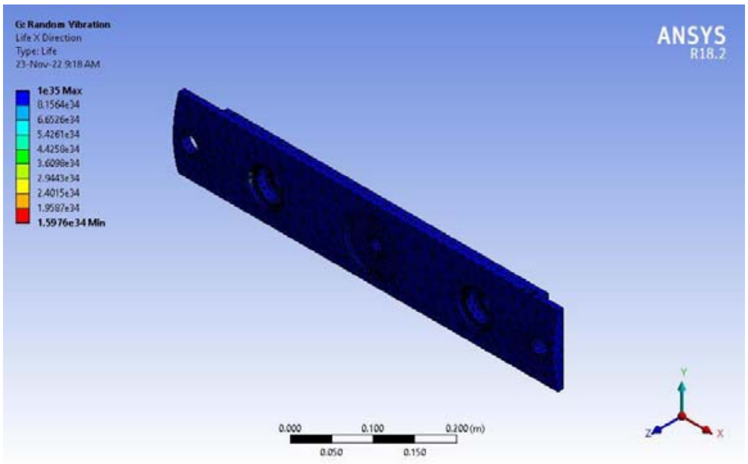


Figure 13. Life in the X direction.

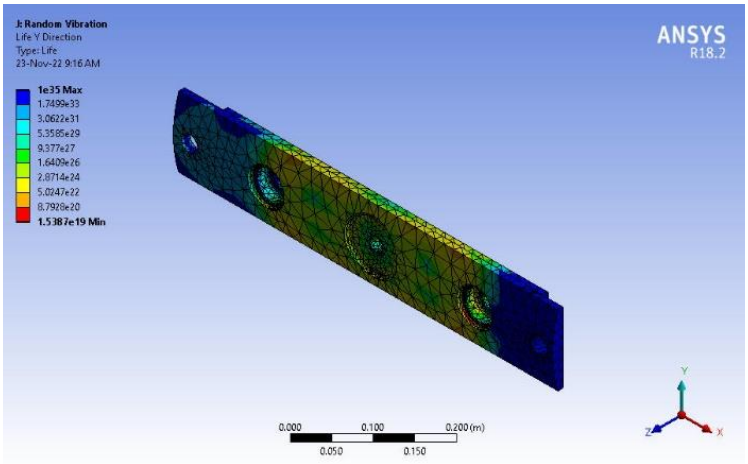


Figure 14. Life in the Y direction.

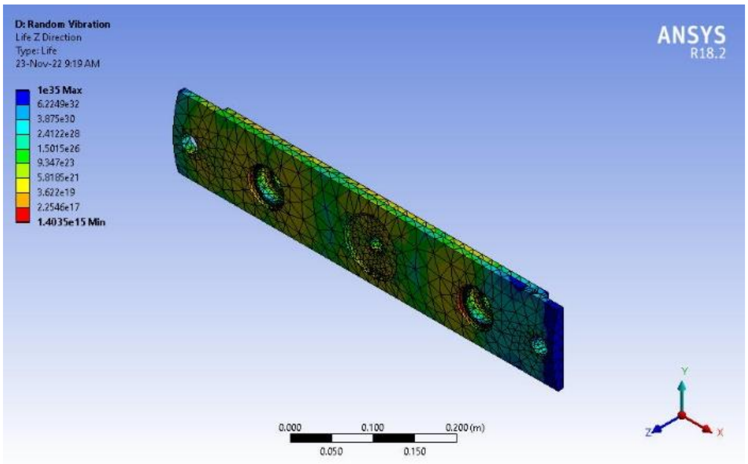


Figure 15. Life in Z – direction.

7. Conclusions

This paper investigates a case study of a 150-liter external fuel tank designed for an L-29 airplane to integrate into Embraer E312 Tucano aircraft. This case shows the simulation steps using ANSYS-Multiphysics to integrate the external fuel tank into the E312 Tucano airplane that is not in its original configuration of it.

First, the geometrical analysis is performed, this study leads to the design of an adaptor to fit the tank to the airplane pylon. Then the aerodynamic analysis is performed to get the aerodynamic loads and after that structure and vibration analysis are performed to get the safety factor and the fatigue life of the model.

The results show that the safety factor is 3.5. The results also show that the fatigue life of the model obtained from the *PSD* not lower life than 1.4e15 seconds and the most critical vibration direction at the z direction because of the weight of the filled fuel tank for the horizontal position assumption of the model and the airplane. These results show that this case study could be applicable.

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