Design and Experimental Verification of Vibration Testing Fixture for Flight Control Panel

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Abstract

In this research, experimental design and testing of the vibration test fixture were carried out. The designed vibration test fixture is used to test the FCP, which is one of the components of avionics in aircraft. FCP vibration testing is carried out using the DO-160 test standard. The test has a test frequency range from 5 to 500 Hz. Therefore, the vibration test fixture must have a natural frequency above 600 Hz. The vibration test fixture is designed using a T-type model with modifications to get optimal results. The raw material used to make the test fixture is aluminum. The test fixture has a natural frequency value above 500 Hz, and both were tested using FEM simulation and experimental tests. Therefore, the vibration test fixture that is made meets the requirements for vibration testing on FCP. The difference in the natural frequency value from the FEM simulation and experimental test results on the vibration test fixture is 14.61% on the Z-axis, 10.61% on the X-axis, and 9.74 on the Y-axis.

Keywords*: Test Fixture, Vibration, Natural Frequency, Shaker*

1. Introduction

Vibration is one of the causes of damage to avionics or aircraft instrumentation equipment in aircraft (Fábry & Češkovič, 2017). Avionic equipment installed in aircraft must be resistant to vibration so that it is not easily damaged. The avionic equipment must be tested for vibration before being installed in the aircraft to determine its strength and resistance if subjected to continuous vibration.

Testing of the avionic equipment can be carried out in the laboratory with vibration test equipment. The vibration test equipment consists of a vibration control module, accelerometer, power amplifier, shaker, and test fixture (De Barros & Souto, 2017). The test fixture holds the test sample during the testing process and connects it to a vibration shaker on the other side (T. S. Reddy et al., 2010). The test fixture must have specific properties, such as being strong, rigid, and having low damping but with the lightest mass possible (E et al., 2020).

The test fixture was designed for vibration testing on the Flight Control Panel (FCP) in this research. FCP is a human-machine interface (HMI) placed on the avionics panel in front of the pilot. One of the functions of the FCP is to display information related to flight parameters to the pilot (Wirawan & Jayanti, 2019). This FCP will be vibration tested according to the DO-160 G standard. The vibration test category used is category S because this FCP will be installed on aircraft with fixed-wing specifications, single-engine turboprop type, and aircraft MTOW below 5700 Kg. Based on the location of the FCP installation, the test profile used is the M profile. The M profile has a test frequency range from 5 Hz to 500 Hz (RTCA), 2010).

The test fixture must have a natural frequency below or above the frequency range in the test profile (Rahman et al., 2016). This is intended to prevent resonance in the test fixture, resulting in inaccuracies in the test. Therefore, the test fixture is designed to have a natural frequency above 500 Hz.

This research aims to design and manufacture a test fixture with a natural frequency above 500 Hz, which can be used to place the FCP in the vibration test. The test fixture that has been made will be tested experimentally to determine its dynamic characteristics. Experimental testing is essential because the dynamic characteristics are generally far from the calculation. Testing is carried out before the test fixture is used to avoid failure (Klee et al., 1971) (De Barros & Souto, 2017).

2. Methodology

2.1. Related Works

Srivatsa E has also carried out similar research related to the design and analysis of test fixtures in 2020. In this study, the test fixture was designed for vibration testing of motors for airplanes. The test fixture design used is the L-type model. The raw material used to make the test fixture is steel because of its commercial availability and cost-effectiveness. The weight of the test fixture is 53,748 kg based on estimates from SolidWorks. The software used to design the test fixture is Solidworks and uses ANSYS for simulation (E et al., 2020).

In another study conducted by reddy, A test fixture was designed using aluminum because it has better strength, stiffness, and vibration damping properties than steel. The type used in the test fixture is the L and T type because it has high stiffness, strength to weight ratio, and ease of fabrication (A. Reddy et al., 2016).

Srinivas uses SolidWorks to design and simulate test fixtures in his research. In addition, he also uses a vibration testing tool for testing test fixtures experimentally (Srinivas & Ravikumar, 2017).

2.2. Problem Definition

When designing a vibration test fixture, consideration should be given to the properties that the vibration test fixture must possess. In this study, several problems were formulated related to the design and manufacture of vibration test fixtures, including:

A. What is the geometry shape of the vibration test fixture for FCP testing to have a natural frequency above 500 Hz?
B. What materials will be used to make a test fixture for FCP testing with a low cost and easy manufacturing process?

2.3. Method

This research begins with the design of the vibration test fixture geometric shape. The geometry of the test fixture is adjusted to the dimensions and conditions of the FCP installation. Next, choose the material for making the test fixture. Material selection must accommodate the mass factor, cost, and level of complexity in its manufacture.

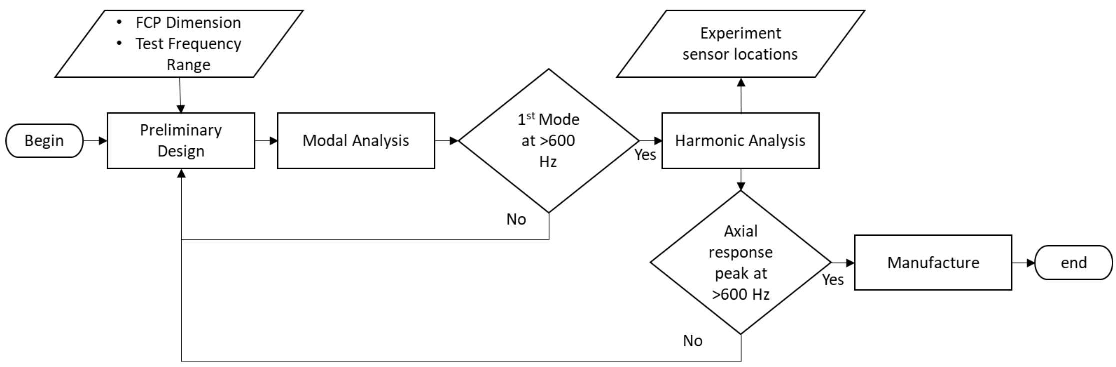


Figure 2-1: Research flow process.

The natural frequency of the test fixture in this study was set at 600 Hz. Next, create a 3D model and perform a modal analysis using FEM. If the natural value of the first frequency is above 600 Hz, the design can continue in harmonic analysis. At this stage, the design is simulated again whether the natural frequency value is above 600 Hz. If the natural frequency value exceeds 600 Hz, then proceed to the manufacturing stage. If it is still below 600 Hz, then the design iteration process is carried out again. Test fixtures resulting from the manufacturing process are tested experimentally to determine their dynamic characteristics. The research flow can be seen in Figure 2-1.

2.4 Experimental Set-Up

The dynamic characteristics of the test fixture can be determined by performing a vibration test. By conducting a vibration test first on the test fixture, it can minimize errors due to resonance between the test object and the test fixture. Before doing the test set up, it is necessary to prepare, such as determining the sensor's location, determining the test frequency range to be used, and determining the parameters of the vibration testing system. The experimental test flow can be seen in Figure 2-2.

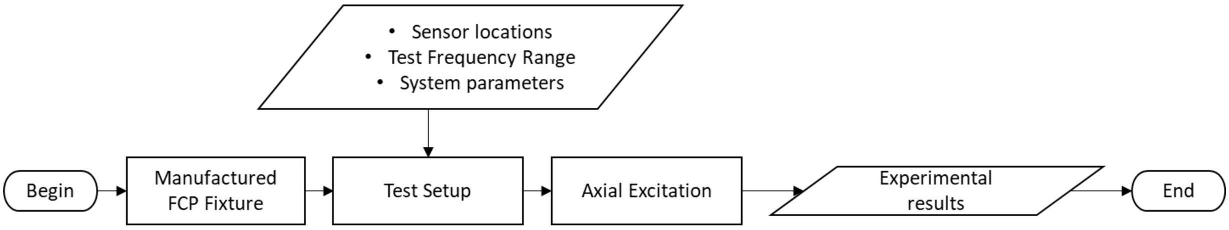


Figure 2-2: vibration data retrieval flowchart.

The experimental setting for testing a test fixture on vibration test equipment is shown in Figure 2-3. It consists of a shaker that functions to provide vibrations to the test object. The place or holder of the test object is the test fixture. The vibration control module is used to control and monitor the vibration of the shaker. The power amplifier is used to amplify the power from the vibration control module so that it can drive the shaker.

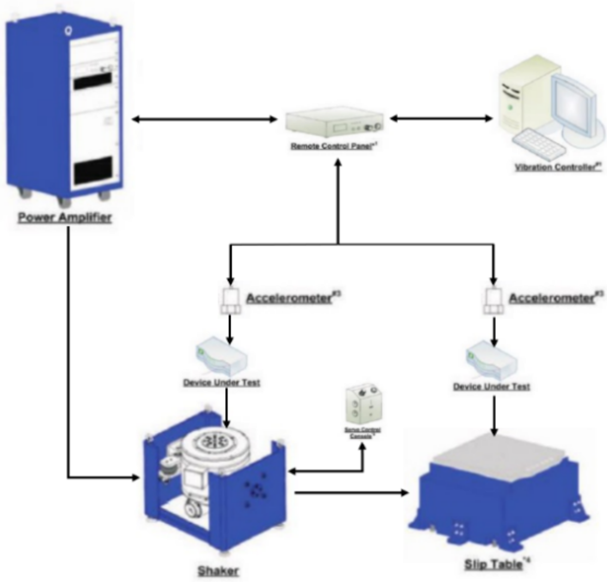


Figure 2-3: Experimental test set-up

The accelerometer is used to measure the acceleration generated by the shaker and is used as a feedback vibration control module. In this study, two accelerometers were used, the first accelerometer as feedback control and the second accelerometer as a response. The accelerometer used is a SENZ product with a piezoelectric type. This accelerometer has a sensitivity of 100 mV/G. The position of the accelerometer sensor can be seen in Figure 2-4.

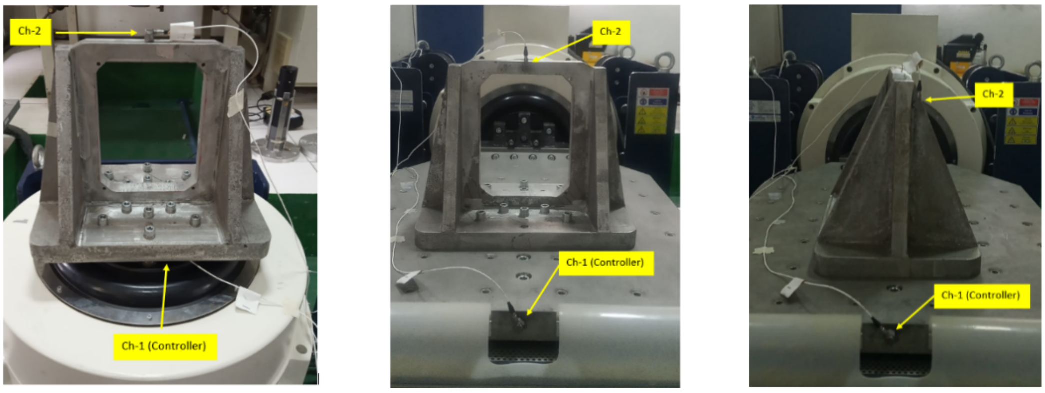


Figure 2-4: Accelerometers position on each test axis.

The dynamic characteristic that is sought by means of vibration testing on the test fixture is the natural frequency. Vibration testing using a shaker is considered a motion system with one degree of freedom. This system consists of damper, spring, mass, and excitation force, as shown in Figure 2-5 (Ula et al., 2020).

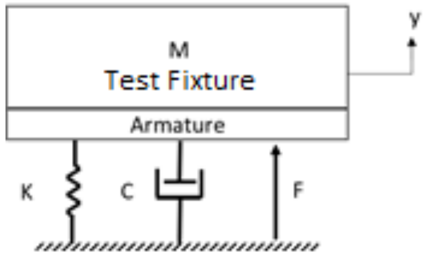


Figure 2-5: Shaker system in one degree of freedom.

The type of vibration test used in the test fixture is sine swept vibration testing. The frequency that will be used in the test profile starts from 5 Hz to 2000 Hz. The swept rate setting used is 1 Octave/second.

3. Result and Analysis

3.1 Design of the Vibration Test Fixture Results

The types of test fixtures used are T - type and L - type test fixtures. With these two types, a 3D CAD model is then created. The test fixture material to be used is aluminum. This material was chosen because of its rigid nature, affordable price, and easy-to-make test fixtures with aluminum raw materials. Determination of mass in the test fixture (M5) using the following equation (Venkat et al., 2016):

$$\frac{W_s}{M_1 + M_2 + M_3 + M_4 + M_5} \geq G$$

Based on these equations to get the total weight (M total) of objects in vibration testing are:

$$M_{Total} = \frac{W_s}{G}$$

So that the value of M5 can be known by using the following equation:

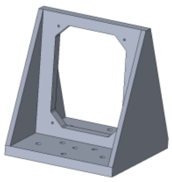
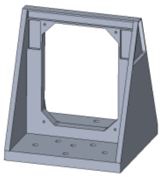
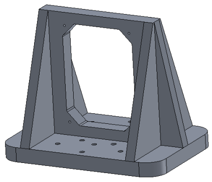
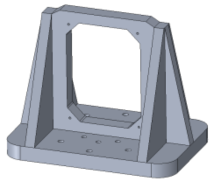
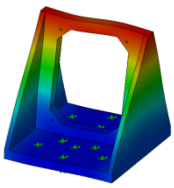
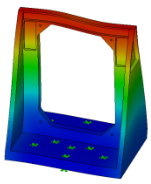
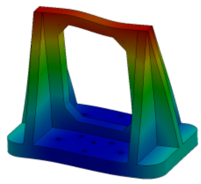
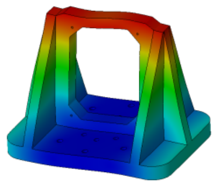
$$M5 = M_{Total} - (M_1 + M_2 + M_3 + M_4)$$

Where Ws is the maximum force capacity of the shaker, M1 is armature weight, M2 is table shaker weight, M3 is head expander weight, M4 is specimen weight, and M5 is a test fixture weight. Furthermore, G is the acceleration specified in the vibration test profile. The FCP weight is 2,95 Kg. Table 1 shows specifications for the vibration test equipment used. Based on the equations and specifications of the vibration test equipment used, the maximum allowed mass for the test fixture is 20 Kg. With such a maximum mass, the test equipment can be used for tests with an acceleration of up to 13.75 g.

Table 3-1: The Specification of vibration test equipment

Parameter	Description
Maximum force (Sine) - W_s	1000 Kgf
Maximum acceleration (Sine) G_s	981 m/s2
Maximum Velocity (Sine) - V_s	1.8 m/s
Armature weight - M_1	10 Kg
Table shaker weight - M_2	35 Kg
Usable frequency range - f	5 to 4000 Hz
Armature Diameter - d	240 mm

Table 3-2: The Design's iteration results

Parameter	Case 1	Case 2	Case 3	Case 4
Parameter feature	4 Ribs Model	Lightened 4 Ribs Model	6 Ribs Model	Lightened 6 Ribs Model
CAD Model				
Fundamental Mode Shape				
First Frequency (Hz)	605.06	746.2	681.12	712.88
Mass (Kg)	6.07	5.62	13.05	12.85
Advantages	• Lightweight • Cheap to manufacture • Good stiffness to weight ratio	• Lightweight • Cheap to manufacture • high natural frequency • Good stiffness to weight ratio	• Natural frequency minimally affected by loads • high natural frequency	• Natural frequency minimally affected by loads • high natural frequency • Lighter than 6 ribs model
Disadvantages	• Low natural frequency • Natural frequency highly affected by loads	• Natural frequency highly affected by loads	• Heavy • Expensive to manufacture	• Heavier than 4 ribs model • Expensive to manufacture

The design iteration process is carried out to obtain the optimal design of a test fixture. The parameters that must be achieved are natural frequency and mass, which should not exceed the desired limit. Iteration is done by adding ribs or supports to add rigidity to the test fixture. The more rigid the test fixture is expected, the higher the natural frequency value. Modifying the addition of rigidity must still pay attention to the total mass in the test fixture. The iteration process carried out can be seen in table 3-2.

Based on the results that showed in the table 3-2, case 4 is the fixture design that best fits the required of specifications. Case number 4 have high natural frequency and it is not highly affected by loads.

The manufacturing test fixture process is carried out using casting and machining methods. The casting method is manufacturing method that is prone to defects such as the presence of cavities in the product, while machining is highly dependent on the maker's expertise. The quality of making this test fixture is not good, such as the presence of defects in inconsistent base plate thickness and improper placement of holes. These defects cause a significant mass deviation between the design mass (12.85 kg) and the manufactured mass (13.6 kg), causing differences in stiffness due to geometric deviations. This is what makes the difference in the natural frequency value of the test fixture between the simulation and experimental results. Vibration test fixture results from the manufacturing process can be seen in Figure 3.1.

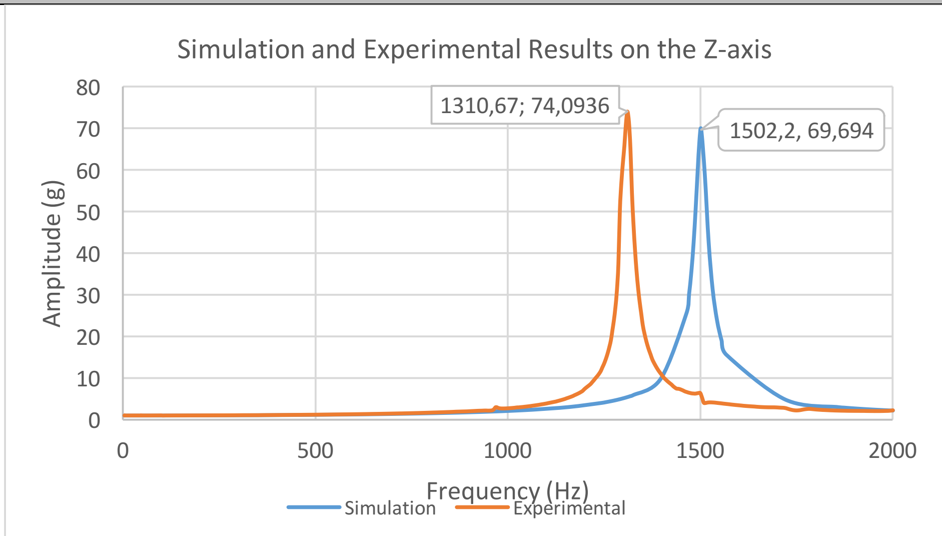
Figure 3-1: Shaker system in one degree of freedom.

3.2 Experimental Results

Vibration testing on the test fixture is carried out on three different axes. This activity was carried out because the vibration testing of aircraft avionic components based on the DO-160 standard was also carried out on three different axes. The results of the test can be seen in table 3-3. In table 3-3 there are also simulation results to find the natural frequency in the vibration test fixture.

Based on Table 3-3, the experimental test results on the vibration test fixture produced the first natural frequency value of 1310.67 Hz on the Z-axis. On the X-axis, the frequency value of the test fixture was 1148.73 Hz. While on the Y axis, the natural frequency value is 789,785 Hz. These results are then compared with the test values using FEM simulations to produce the first natural frequency of 1502.2 Hz on the Z-axis. On the X-axis, the frequency value of the test fixture is 1026.9 Hz. While on the Y axis, the natural frequency value is 712.88 Hz.

Table 3-3: Results of Design and Experimental test.

<table>
<tr><th>Axis</th><th>Simulation Experimental</th></tr>
<tr><td>Z</td><td>
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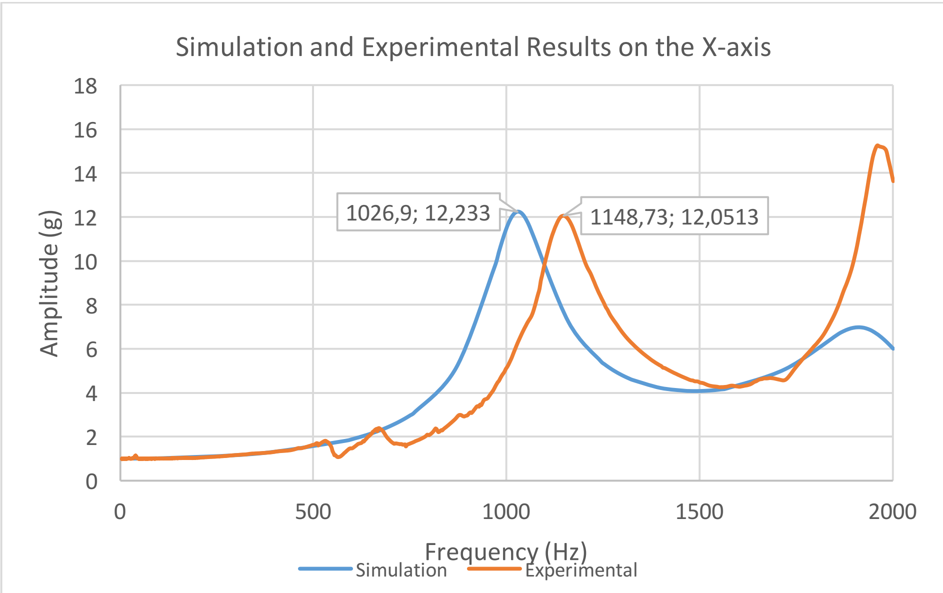
<tr><td>X</td><td>
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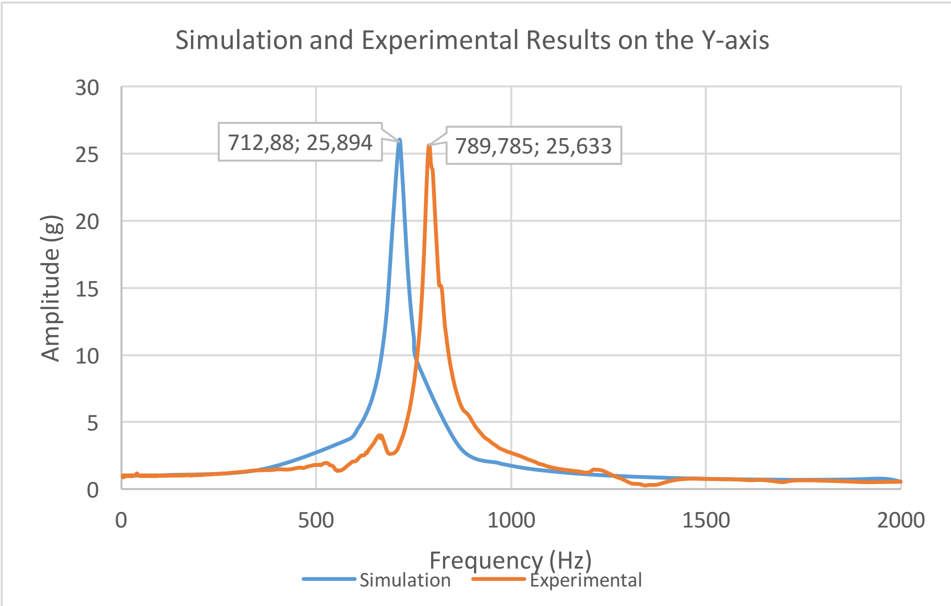
Y



The comparison of natural frequency values obtained from the FEM and experimental methods is shown in Table 3-4. Table 3-4 also explains the percentage difference between the simulation results and practical testing. The percent difference value is obtained from the following equation:

$$\left|\frac{Result_{simulatin} - Result_{experimental}}{Result_{experimental}}\right| X\ 100\%$$

The minor percent difference between the simulation and experimental results indicates an ideal relationship. The smallest percentage difference value is found in the results on the Y-axis, which is 9.74%. While the value of the most significant difference, namely 14.61%, is on the Z-axis. The value of the difference on the X-axis is 10.61%.

Tabel 3-4: Natural frequency of test fixture in each axis

Axis	Natural frequency (Hz)		Difference %
	By Simulation	By experimental	
Z	1502.2	1310.67	14.61
X	1026.9	1148.73	10.61
Y	712.88	789.78	9.74

There is a difference in the natural frequency value in the vibration test fixture between the FEM simulation results and the experimental test. Several factors cause this difference. The first factor is the existence of manufacturing defects that cause differences in geometry, mass, and stiffness. The next factor is the installation of a non-rigid test object in the test setup.

4. Conclusions

The vibration test fixture used for FCP testing is designed with a T-type model reinforced with six ribs. The vibration test fixture is made using raw material, namely aluminum. The test fixture has a natural frequency value above 500 Hz, and both were tested using FEM simulation and experimental tests. The vibration test fixture that is made meets the requirements for vibration testing with the DO-160G standard, because according to DO-160G for aircraft components with fixed-wing specifications, aircraft

MTOW below 5700 Kg, and these components are installed in the aircraft cabin are tested sine swept from a frequency of 5 - 500 Hz ((RTCA), 2010).

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Contributorship Statement

The main contributors to this paper are Yusuf Giri Wijaya and Nur Mufidatul Ula, who carried out data collection, data analysis, and conceptual research. The drawings and simulation of the test fixture were carried out by Mikhael Gilang P.P.P, the setting of the test equipment was carried out by Muksin. Agus Harno Nurdin Syah has carried out the supervision and final edit of this paper.

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