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Normal mode finite element analysis of aerofoil wing structure with different materials

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Abstract. There are a lot of study regarding on the aircraft components. One of the critical components for an aircraft would be the wings. The wing structure of an aircraft is one of the complex structures of a designed aircraft. This paper is about identifying the modal properties which are the mode shape and the corresponding natural frequencies of the aircraft wing structure. The modal properties of the wing structure would be compared for two different materials applied towards the wing structures which are the aluminium alloy AA-7075-T6 and AA-2024-T3 which currently being widely used by the aircrafts. The study for this aircraft wing structure would be using the approach of finite element analysis (FEA) method. The 3D model is design by using SolidWorks. The modal properties are identified with the help of MSC PATRAN and MSC NASTRAN. The results obtained for both materials for 10 mode shapes are compared and it could be observed that AA-7075-T6 are much lower compared to AA-2024-T3. Hence, from the result, AA-7075-T6 is more suitable to be used for the wing structures.

1. Introduction

There are several types of aircraft. A typical aircraft that are easily to be seen would be on the fixed wing aircraft or known as airplane, aeroplane or planes. The airframe of the aircraft consists of five major components which are fuselage, wings, stabilizers, flight controls surfaces and landing gears [1]. There are many studies that had been done related to the aircraft itself as well as its components especially on the wing structure of the aircraft itself [2].

A major portion of the lift for an aircraft is developed from the wings itself. It could be found that the wing structures itself do carry some of the loads found by the aircraft structure especially when the aircraft are flying [1]. The components that are affected the most due to the loads are at the fuselage as well as the wings where the stresses of bending and compression would occur the most for both components either when it is statics on the ground or when it is flying or landing [1]. In addition to that, for both components' fuselages and wings, it could be distorted in two ways – bending and twisting if it were subjected to flutter [3]. When flutter occurs, resonance is one of the contribution towards the structural failure [4]. The wings could also face vibrational problem due to the rotation of the engine rotor for the aircraft with attached engines below the wings.

As for this paper, the only component that would be analyse would be on the wings structure of the aircraft. And the main concern in analysing this structure is to identify the dynamic properties of the structures which are the natural frequencies and the mode shape. By identifying the dynamic properties of a system, it could help in term of identifying the reasons of the occurred vibration that may cause damage towards the system components as well as it could reduce the noise emitted from the system to the surrounding [5]. Plus, in achieving an effective design and gain control of the vibrations of the structural components, it do depends on those vibrational behaviour [6-10].

A typical aircraft wing structures – in a simplest form does made up from a framework of spars, ribs and covered with metal [5, 11-12]. Figure 1 shows a typical aircraft wing structure. Generally, for a typical aircraft – metallic, non-metallic and composites materials are used throughout all the components of the aircraft. Originated from wood, and nowadays replaced by alloys and the latest technology enable composites to be used, the most important criteria to be considered for an aircraft wing are high strength and low in weight [13-14]. Although composites are much more reliable compared to aluminium alloys, but aluminium alloys are currently used widely in the civil aircraft industries as its low cost, lightweight and easy to be manufactured and treated and this material (aluminium alloy) would be the materials to be analyse for this paper [15]. The objectives for this study are to find the difference in the modal properties of the wing structure with different material used by the wing structure itself.

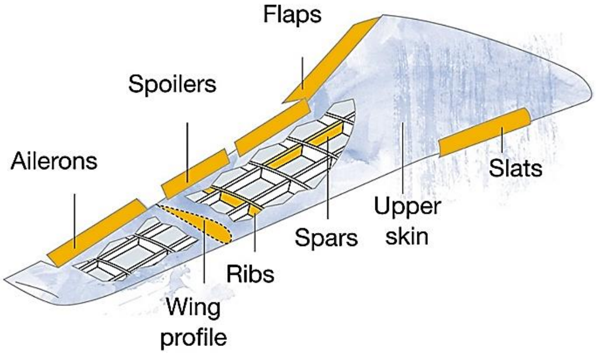


Figure 1. Aircraft wing structure.

2. Methodology

The method that is used in this study is finite element analysis (FEA). The fundamental steps in any finite element analysis (FEA) method would consists following steps as shown in Figure 2:

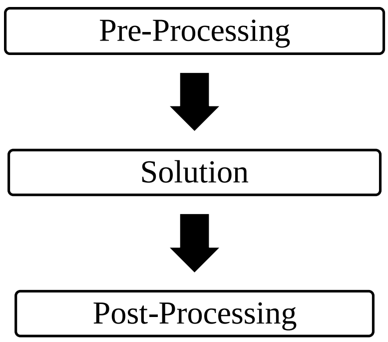


Figure 2. FEA process

2.1 Modal Analysis

Modal analysis determines the modal properties of a structure in form of natural frequencies and mode shapes due to vibrational excitations. For this study, damping ratio is not to be considered as well as any applied loads. For aircraft wing structure, vibration does occur due to the rotating engine mounted under the wing. This analysis is important in order for a structure to be identified for the dynamic loading conditions [11, 16].

2.2 Finite Element Analysis (FEA)

FEA approach was used in term of normal mode analysis in order to obtain both modal properties of the wing structure which are the natural frequencies and the mode shape. The software to be used for FEA would be MSC PATRAN for both pre-process and post-process. The analysis was done by using the solver software which are MSC NASTRAN. The 3D model was designed in SOLIDWORKS 2017 before it was imported into MSC PATRAN. The consistency of the analysis is then validated by refining the mesh size. The mesh size was reduced until convergence was achieved for the magnitude of the natural frequencies during post-process as in Figure 4.

2.3 Simplification

Aircraft wing structures are complex structures. Typical aircraft wing structure would have the framework made up from several structural components which are ribs, spars, stringers, skin, flaps, fuel tanks, aileron and wing tips. And for every type of aircrafts would have different type of wing designs and configurations depending on the uses of the aircraft [3]. Some of the simplification was made for this model based on the following assumption:

- The material used is homogenous and isotropic.
- The material is elastic.
- The complex structure was simplified to only the spars and the rib as the study would cover for only the wing skeleton structure.

2.4 Pre-Processing

The 3D model was imported from SOLIDWORK 2017 in term of parasolid (.x_t) file. As the simplification was applied for this model, the wing skeleton structure was design as a whole instead of assembling it part by part. The design for the wing structure is as in Figure 3. The geometric parameter as in Table 1. There are total 16 ribs in the wing skeleton structure based on literature [8]. The model was then assigned with the material properties as tabulated in Table 2. The boundary condition for the wing structure model was set to free-free in order to obtain the static modal properties. Once the material, boundary condition and constraint were set up, the model was proceeding to mesh. For meshing, a 3D solid meshing type was used with tetrahedral element shape, TetMesh mesher with Tet10 topology. Based on the mesh convergence study graph, the ideal mesh global edge length is 0.03mm as could be seen in Figure 4.

Table 1. Geometric parameter of the wing design

Airfoil	NACA 64215
Root Chord	2400 mm
Tip Chord	700 mm
Span Length	5500 mm
Front Spar	18% to 25% of chord
Rear Spar	62% to 70% of chord

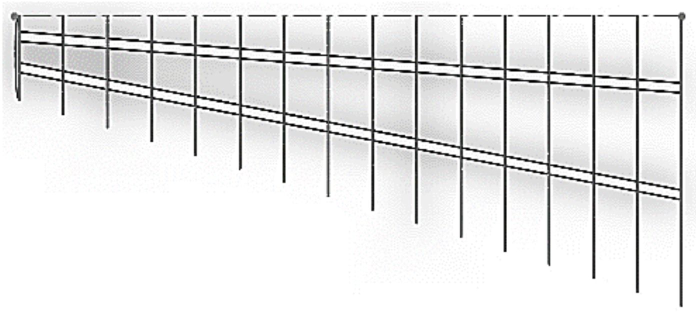


Figure 3. The plan view of the wing skeletal structure

Table 2. Material properties of wing structure

Class of material	Material	Elastic Modulus (GPa)	Density (kg/m^3)	Poisson Ratio
Aluminium (reference)	$7075 - T6$	71.70547	2810	0.33
Aluminium	$2024 - T3$	73.08443	2780	0.33

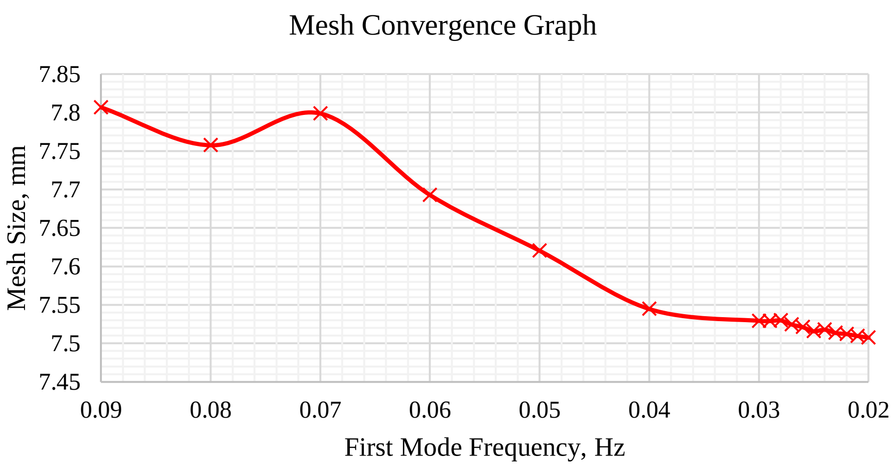


Figure 4. Mesh Convergence Graph

2.5 Post-Processing

The acceptability of the model design of the wing structure are depending on the result of the modal analysis. The generated results of the modal properties were cross checked with other findings from the literature. In the comparison, the most important finding to be checked would be the mode shape of the structure in which it should have the same mode shape for every number of the mode shape. The intended mode shape and natural frequencies would be only 10 mode shapes.

3. Results and Discussion

The normal mode analysis allows computing normal mode of the input structure and visualization of the computed modes by animating the displacement of the structures. It is critical in obtaining the natural frequencies as well as the corresponding mode shape in order to identify the dynamic behaviour of a system. The results obtained for the modal properties that was run by using the MSC PATRAN/NASTRAN are as displayed in Table 3, Table 4, Table 5 and Table 6.

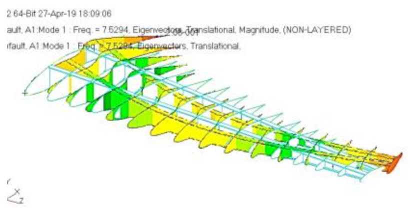
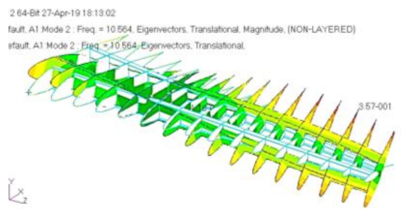
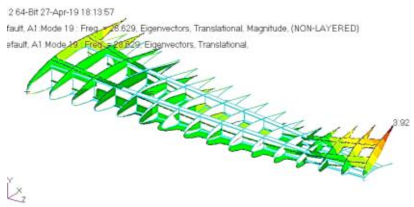
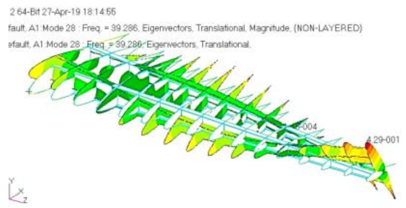
Table 3. Modal properties of AA-7075-T6

Mode	Frequency (Hz)	Maximum Deformation (m)	Description
1	7.5294	0.206	Bending
2	10.564	0.357	Torsion
3	28.629	0.392	Bending
4	39.286	0.429	Torsion
5	71.832	0.531	Torsion
6	91.388	0.853	Bending
7	130.80	0.516	Torsion
8	144.46	1.060	Torsion
9	168.85	0.348	Torsional Bending
10	205.44	0.772	Torsion

Table 4. Modal properties of AA-2024-T3

Mode	Frequency (Hz)	Maximum Deformation (m)	Description
1	7.6424	0.207	Bending
2	10.723	0.359	Torsion
3	29.059	0.394	Bending
4	39.875	0.431	Torsion
5	72.910	0.534	Torsion
6	92.759	0.858	Bending
7	132.76	0.519	Torsion
8	146.63	1.064	Torsion
9	171.38	0.350	Torsional Bending
10	208.52	0.776	Torsion

Table 5. The first 10 mode shapes for AA-7075-T6

Mode	Mode Shape	Mode	Mode Shape
1		2	
3		4	

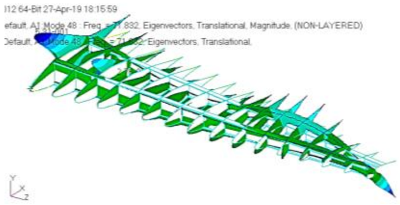
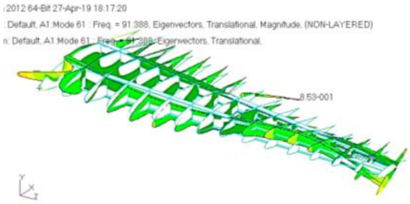
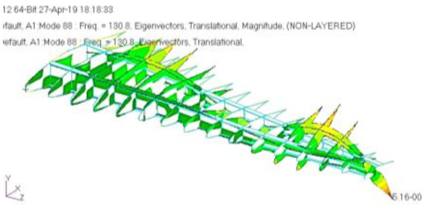
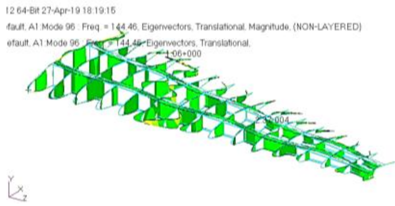
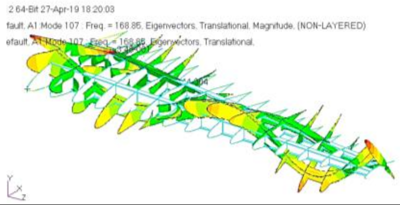
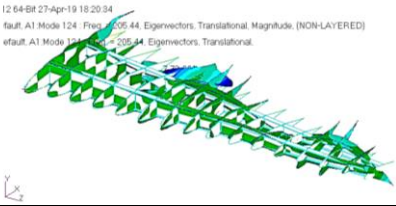
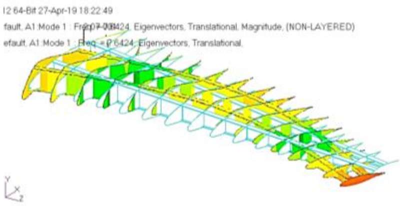
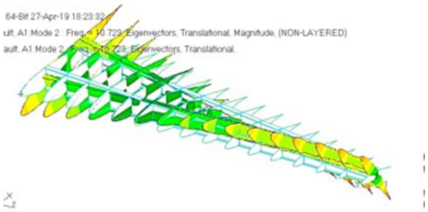
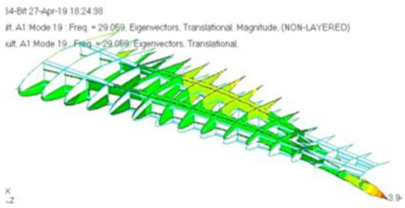
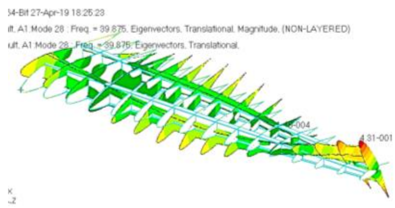
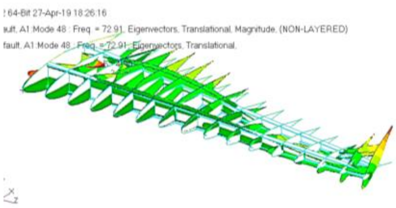
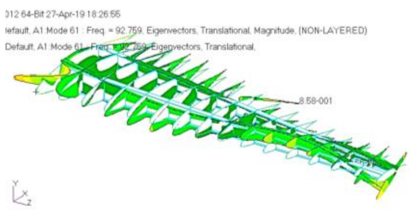
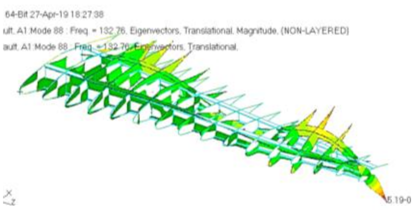
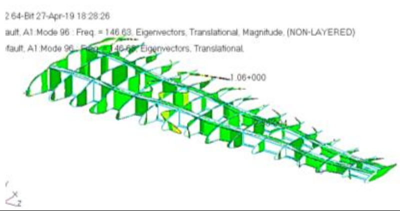
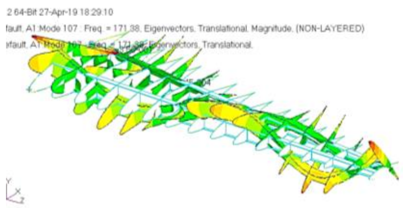
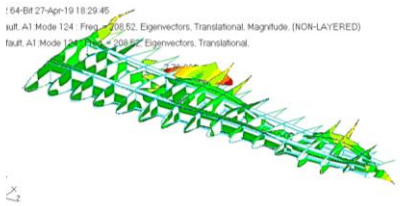
5		6	
7		8	
9		10	

Table 6. The 10 mode shapes for AA-2024-T3

Mode	Mode Shape	Mode	Mode Shape
1		2	
3		4	
5		6	
7		8	

9		10	

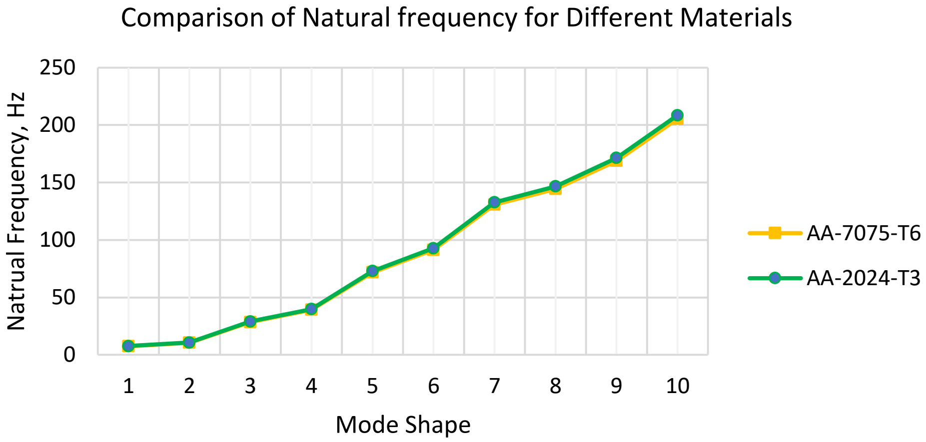


Figure 5. Graph for comparison of the natural frequency for the different materials

Based on the obtained results, it could be observed that the maximum deformation for AA-7075-T6 was 1.060 m which was correspond to the natural frequency of 144.68 Hz while for AA-2024-T3 was 1.064 m correspond to the natural frequency of 146.63 Hz. The fundamental frequency could be considered at 7.5294 Hz and 7.6424 Hz for both AA-7075-T6 and AA-2024-T3 respectively which the deformation value was the lowest which are at mode 1. The fundamental frequency was the lowest frequency obtained from the structures when being excite and the fundamental frequency would be the frequency to be concerned the most [17-19].

4. Conclusion

From the above results, it could be sum up that the difference of magnitude of natural frequencies and the mode shape of AA-7075-T6 and AA-2024-T3 are minimal. The result obtained are validated and verified. As the difference between the two results of the modal properties are minimal, it could be observe that AA-7075-T6 and AA-2024-T3 are both suitable to be used in building the wing structures as both do have alike properties but in term of strength levels, AA-7075-T6 are quite higher compared to AA-2024-T3 so the uses of AA-7075-T6 in aircraft components generally are much more accepted as in the finding [12]. In detail, although the modal properties were look alike, it could be observed that the natural frequencies for AA-7075-T6 was much lower compared to AA-2024-T3 which make AA-7075-T6 much more suitable material for aircraft wing structure. The resonance of the wing structure could be calculated by identifying the natural frequencies of the wing structure itself. Once the resonance is determined, it could prevent the failure in design of the aircraft component generally.

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