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STRUCTURAL ANALYSIS OF KUFASAT USING ANSYS PROGRAM

Firas T. Al-Maliky, Mohamed J. AlBermani,

Alkafeel University College/Department of Computer Engineering Techniques, Najaf, Iraq
e-mails:dr.albermani@yahoo.com, firasthair@yahoo.com

ABSTRACT. The current work focuses on vibration and modal analysis of KufaSat structure using ANSYS 16 program. Three types of Aluminum alloys (5052-H32, 6061-T6 and 7075-T6) were selected for investigation of the structure under design loads. Finite element analysis (FEA) in design static load of 51 g was performed. The natural frequencies for five modes were estimated using modal analysis. In order to ensure that KufaSat could withstand with various conditions during launch, the Margin of safety was calculated. The results of deformation and Von Mises stress for linear buckling analysis were also performed. The comparison of data was done to select the optimum material for KufaSat structures.

Keywords: CubeSat, modal analysis, structure analysis, natural frequency, FEA.

1. INTRODUCTION

A KufaSat is the first Iraqi cube sat developed by Iraqi students at Kufa university .It is 1U cube sat of dimensions (100 x 100 x 100) mm and mass 1.33kg. to be launched in near fucture into nearly-circular orbit of altitude 600 km and inclination angle is 97 deg (Mohammed, 2015). The main purpose of its mission is to image Iraqi borders and the conflicting areas in Iraq. In this paper ,finite element analysis of the structure by implementing ANSYS software was performed. Three alloys of Aluminum (5052-H32, 6061-T6 and 7075-T6) were selected in terms of modal analysis, deformation and Von Misses stress for comparison. static load of 51g was chosen. Buckling and vibration analysis were performed in order to verify the expected deformation during launch phases.

FEA under static load using ANSYS 14.1 were (9-13)g and the buckling analysis was also introduced by (Chiranjeeve et al, 2014). The deformation of the structure at various natural frequencies using buckling and vibration analysis were introduced. (Israr, 2014) did static and modal analysis of 1U Cubesat. The results of FEA were compared with theoretical predictions. Quasi-static and vibration analysis of 1U cubesat were presented by (Hyun et al, 2014). (SHEPENKOV, 2013) studied the effects of deployable tape spring boom on the structure of the satellite. KufaSat is three axis stabilized with gravity gradient boom deployment (Mohammed et al, 2014).

2. MODEL DESCRIPTION

In this paper, three types of Aluminum alloys were used in the structure which are (AL 5052-H32, AL 6061-T6 and AL 7075-T6). The mechanical properties of the three Aluminum alloys to be used for KufaSat structure are listed in table 1.

Table 1. Mechanical properties of Aluminum [(Bauccio,1993), (Boyer and Gall,1985) and (Holt,1996)].

Material	Aluminum 5052-H32	Aluminum 6061-T6	Aluminum 7075-T6
Physical Properties			
Density	$2680\ kg/m^3$	$2700\ kg/m^3$	$2810\ kg/m^3$
Mechanical Properties			
Ultimate Tensile Strength	228 MPa	310 MPa	572 MPa
Tensile Yield Strength	193 MPa	276 MPa	503 MPa
Modulus of Elasticity	70.3 GPa	68.9 GPa	71.7 Gpa
Poisson's Ratio	0.33	0.33	0.33

3. STATIC ANALYSIS

In order to estimate Von Misses stress, equivalent elastic strain and total deformation, the static analysis on satellite structure was applied. In this analysis 200 N load was applied in the centroid of all sides of the CubeSat structure while the design load of launching was (51 g) which can be calculated from following equation

$$g = 14.1\ G_{rms} \times 3\sigma$$

(Hyun et al, 2014) the qualification level of G_{rms} was depends on the mass of CubeSat (Robert C. Baumann, 1996). The design load was acted in the lower surface of structure. The boundary condition included fixing the legs of CubeSat structure.

In order to investigate the optimum material used in KufaSat structure we applied the (Margin of Safety) MoS rule with safety factor of 1.25 (Hyun et al, 2014).

$$MoS = \frac{\sigma_{allowable}}{SF \times \sigma_{max}} - 1 \geq 0$$

4. BUCKLING ANALYSIS

In this analysis, the buckling load ($statis\ load \times load\ factor$) that applied to the lower surface of structure was various from mode to other depends on the value of multiplier load. The buckling analysis was performed and the results of total deformation and buckling modes for Al-7075 structure was shown in figure 1.

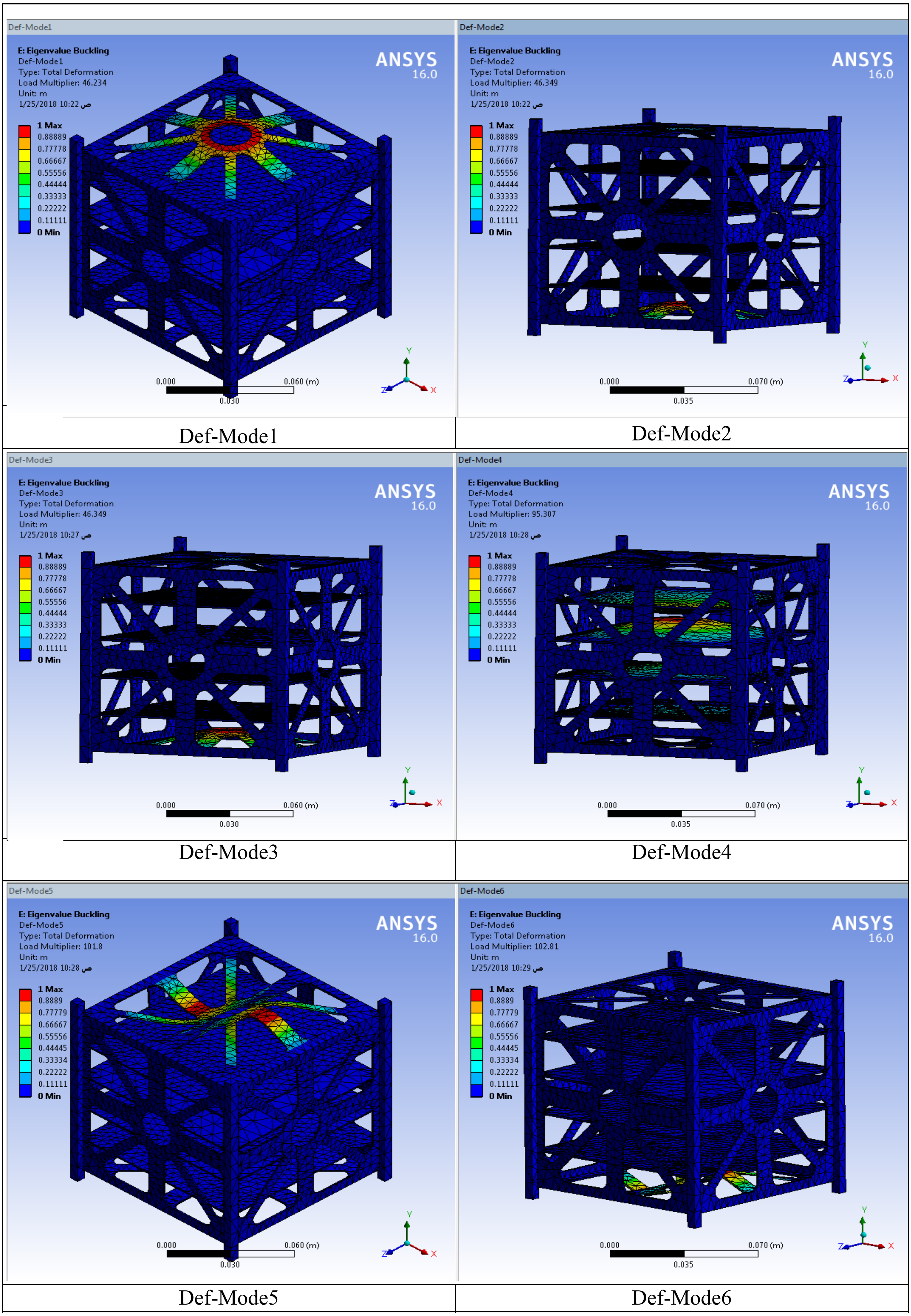


Fig. 1. Total Deformation and Buckling modes for Al-7075 structure.

5. MODAL ANALYSIS

The modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of the structure. It also can be a starting point for the harmonic response analysis.The natural frequencies and mode shapes of cubsat structure are very important parameters in the design of CubSat structure for dynamic loading conditions. The undamped basic equation solved by the modal analysis is (Hussain, 2005)

$$[M]\{\ddot{x}\} + [k]\{x\} = 0 \tag{1}$$

Equation (1) has a known solution that may be stated as follow, (Ali, 2011):

$$\bar{x}_i = \bar{X}_i si\,n(\omega_i t + \alpha_i)\,, (i = 1, 2, 3, \dots \dots, n) \tag{2}$$

Where, *n* is the number of degrees of freedom. In this harmonic expression, $\bar{X}_i$ is a vector of nodal amplitudes (the mode shape) for the ith mode of vibration. ω_i represents the angular (natural) frequency of mode i , and α_i denotes the phase angle. By differentiating equation (2) twice with respect to time *t* , it could be found that,

$$\bar{\ddot{x}}_i = -\omega_i^{\,2}\bar{X}_i si\,n(\omega_i t + \alpha_i) \tag{3}$$

Substituting equations (2) and (3) into equation (1) allows cancellation of the term $si\,n(\omega_i t + \alpha_i)$ which leaves,

$$([k] - \omega_i^{\,2}[m])\bar{X}_i = 0 \tag{4}$$

Equation (4) has the form of the algebraic eigenvectors problem. From the theory of homogenous equations, nontrivial solutions exist only if the determinate of the coefficient matrix is equal to zero. Thus,

$$|[k] - \omega_i^{\,2}[m]| = 0 \tag{5}$$

Expansion of this determinate yield a polynomial of order *n* called the characteristic equation. The *n* roots $\omega_i^{\,2}$ of this polynomial are the characteristic values, or (eigenvalues). Alternatively, each eigenvector may be found as any column of the adjoint matrix $[\mathrm{H}_i^{\alpha}]$of the characteristic matrix $[\mathrm{H}_i]$, obtained from equation (3.4), (Timoshenko et al, 2008) as follow:

$$[H_i]\bar{X}_i = 0 \tag{6}$$

Where

$$[H_i] = [k] - \omega_i^{\,2}[m] \tag{7}$$

The methods implied by equations (5), (6) and (7) are conductive to hand calculations for problems having a small number of degrees of freedom. However, a structure with a large number of freedoms (as in the present study) must be handled by a computer subprogram (or subroutine) for calculating eigenvalues and eigenvectors. Various schemes have been developed for a computer analysis to solve the eigenvalue problems for a complex structure, such as, the inverse iteration, Jacobean, subspace iteration, Lanczos iteration, etc. In the present work, ANSYS program is adopted to calculate the eigenvalues and eigenvectors of the system.

6. DISCUSSION AND RESULTS

In order to investigate the structural safety of KufaSat under the launch environment and by estimated results of stress from static analysis, the Margin of safety was calculated for each material as shown in table 2.

Table 2: Margin of Safety for KufaSat structure in Al-5052,6061 and 7075

	σ_{max} $stress$ $[Mpa]$	$\sigma_{allowable}$ $stress$ $[Mpa]$	SF	MoS
Aluminum 5052	26.026	192	1.25	4.9
Aluminum 6061	25.476	276	1.25	7.65
Aluminum 7075	29.870	503	1.25	14.09

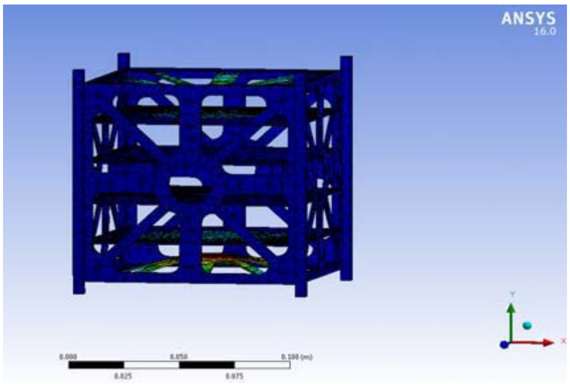
The results of Margin of Safety showed that Al-6061 and Al-7075 are suitable for KufaSat structure under launch environment.

The natural frequencies and deformation for first five modes that obtained from modal analysis in ANSYS program can be summarized in the table 3.

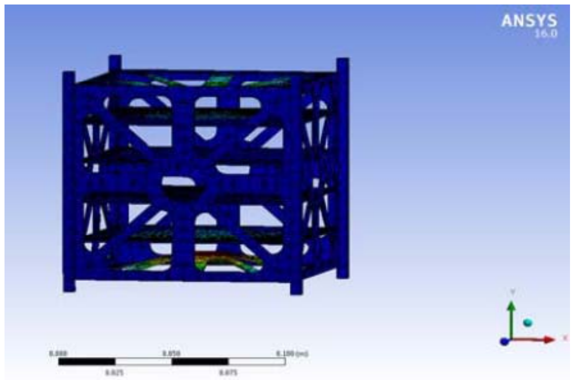
Table 3: Natural frequencies and deformation for five modes in Al-5052,6061 and 7075

Modes	Aluminum 5052		Aluminum 6061		Aluminum 7075	
	Freq. [Hz]	Def. [m]	Freq. [Hz]	Def. [m]	Freq. [Hz]	Def. [m]
1	643.819	0.146	654.738	0.146	654.705	0.143
2	646.573	0.152	657.454	0.151	657.422	0.148
3	726.275	1.101	736.065	0.997	736.029	0.978
4	736.421	0.111	746.073	0.110	746.036	0.108
5	805.090	0.123	813.803	0.122	813.763	0.120

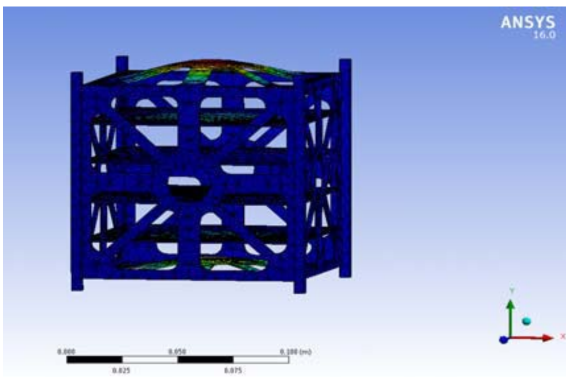
The comparison between Al-6061 and Al-7075 for first five modes show that there is a little difference in the deformation between them as shown in figure 2.



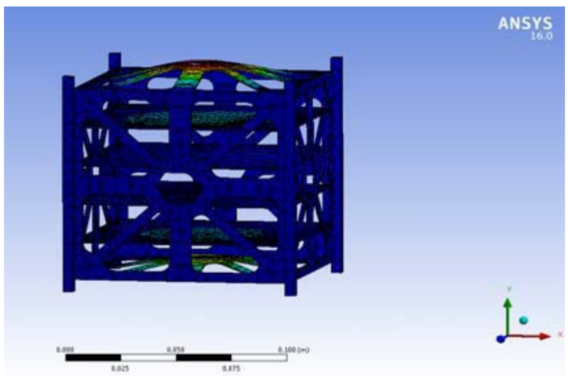
a. Mode 1: Al-6061: Def=0.146 m



b. Mode 1: Al-7075: Def=0.143 m

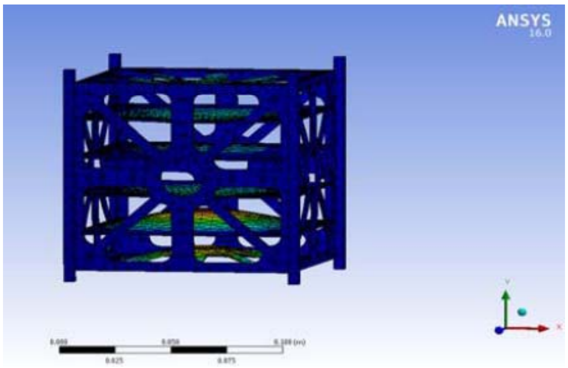


c. Mode 2: Al-6061: Def=0.151 m

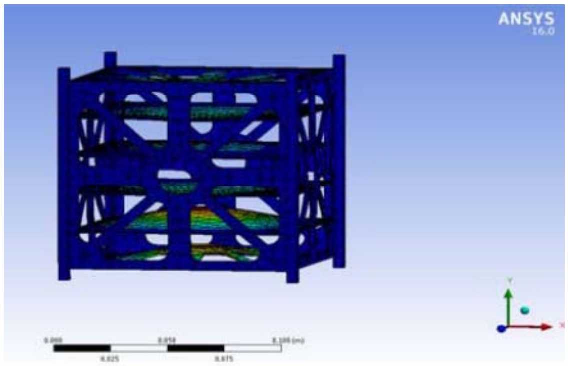


d. Mode 2: Al-7075: Def=0.148 m

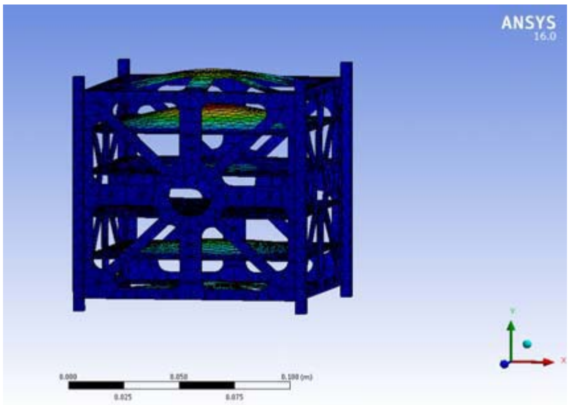
Fig. 2 (part one). The values of deformation in Al-5052 and Al-6061 structure for five modes.



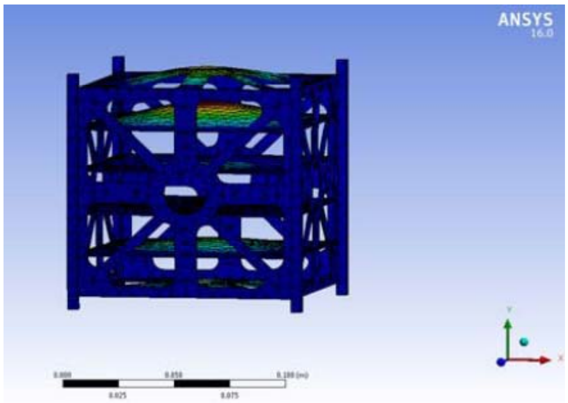
e. Mode 3: Al-6061: Def=0.997 m



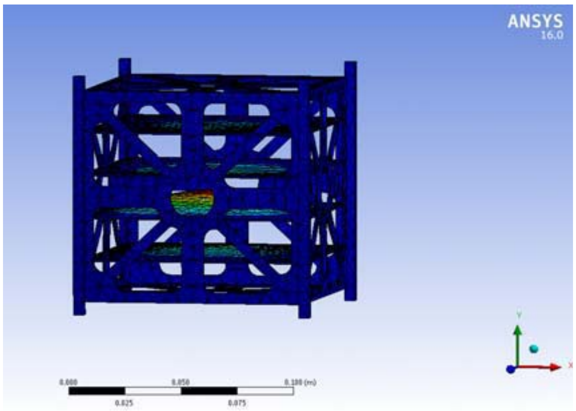
f. Mode 3: Al-7075: Def=0.978 m



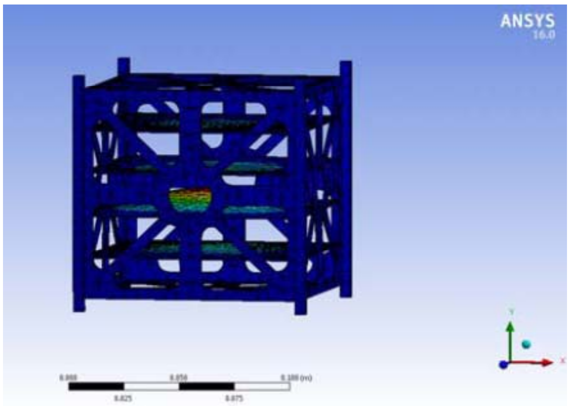
g. Mode 4: Al-6061: Def=0.110 m



h. Mode 4: Al-7075: Def=0.108 m



i. Mode 5: Al-6061: Def=0.122 m



j. Mode 5: Al-7075: Def=0.120 m

Fig. 2 (part two). The values of deformation in Al-5052 and Al-6061 structure for five modes.

7. CONCLUSIONS

The of Margin of safety showed that the KufaSat structures is more compatible for launching environmental. The results of natural frequencies that estimated from modal analysis for five modes and the deformation that calculated from linear buckling analysis showed that Al-7075-T6 is more stiffener. Since the increase in the natural frequency increases structure's stiffness.

8. FUTURE WORK

After finishing this present work we recommend the following remarks to be performed in future.

1. Vibration and modal analysis of the structure with mass so that the distance between center of mass and geometric center is no more 2 cm
2. The effects of boom deployments
3. The effects of space debris on the structure of the satellite.
4. The influence of harmonic response analysis on the satellite structure.

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