RECONSTRUCTION OF MODAL ANALYSIS FOR BAH WING BY SOLID AND SHELL ELEMENT

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Abstract

A jet transport wing plan form which commonly cited as BAH Wing (Bisplinghoff, Ashley, Halfman, 1971) has been used in various researches as one of the standards in aeroelasticity field. BAH wing in its origin, was utilized to perform modal analysis and also static (divergence) and dynamic (flutter) aeroelasticity analysis.

In this paper, BAH wing modal analysis is reconstructed by solid and shell elements using MSC PATRAN/NASTRAN software. The normal modes and natural frequencies are compared with the original platform analysis by (Bisplinghoff, Ashley, & Halfman, 1971) and also the results by (MSC.Nastran Aeroelastic Analysis User's Guide, 2002). The results of this paper will be further utilized to construct flutter analysis using solid and shell elements.

Keywords: BAH wing, modal analysis, normal mode, natural frequency, lumped mass, shell element, solid element

Nomenclature

ω : natural frequency (rad/s)
f : natural frequency (Hz)

1. INTRODUCTION

1.1 Modal Analysis Approach

The modes of a structure of a system could be obtained from two different modal analysis approaches:

a. Mathematical Models (Bisplinghoff & Ashley, 1962),
b. Experimental analysis.

In their most basic form, mathematical models discretize a structure into a formation of masses and springs system. The analysis could be done using simple lumped mass and spring system or using Finite Element Analysis (FEA). The approach then is to construct and solve an eigenvalue problem to obtain the natural frequencies, and mode shapes of the given mass and stiffness distribution.

As for aeroelasticity analysis, obtaining the natural frequency and mode shapes of the structure is one of the main processes which further lead to the construction of aerodynamic load and the methods to be used.

In this paper, modal analysis approach is using mathematical models that lead to a finite element analysis using shell and solid elements.

1.2 BAH wing

BAH wing is a jet transport wing plan form which is used in (Bisplinghoff, Ashley, & Halfman, 1971) as an example to perform modal analysis and aeroelasticity analysis. At the time of its first appearance, BAH wing is one of a delicate example which shows a quite complete form of a wing which could be utilized for a basic though comprehensive 3D aeroelasticity analysis. Tapered wing plan form with non-uniform distributed mass and stiffness has made it a basic reference for modern aircraft / wing aeroelasticity analysis.

The addition of half-fuselage mass and also mounted engine has also made BAH wing could be utilized for various form of analysis, e.g. restrained and unrestrained modal analysis of wing to the fuselage. As for flutter analysis, the plan form also provides adequate complexity and has been utilized for basic unsteady aerodynamic method such as strip theory.

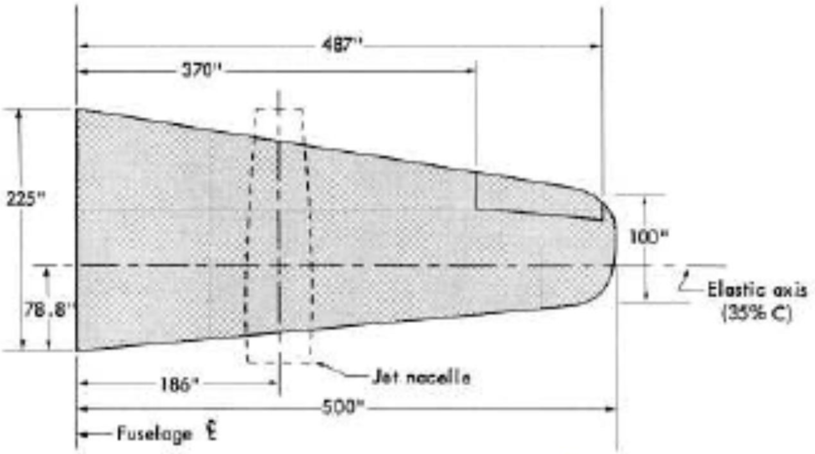


Figure 1-1 BAH wing plan form (Bisplinghoff, Ashley, & Halfman, 1971)

2. FINITE ELEMENT MODELS

2.1 Eight Node Hexahedral Solid Element

Solid elements are 3D finite elements that could be used to model solid bodies and structures with minimum simplification on the geometry; therefore it could represent the structures more realistic. There are 3 standard types of solid element: tetrahedron, wedge and hexahedron; these have 4, 6 and 8 corners with 3 faces meeting at each corner (Logan, 2012).

In this paper, the hexahedron element is used to reconstruct the BAH wing plan form. This element is chosen due to its simplicity on the geometry, where it is only needed to modify original BAH wing plan form with additional relevant thickness align with the stiffness distribution. .

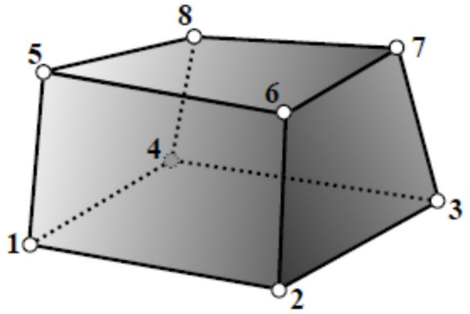


Figure 2-1 Hexahedron Or Eight Node Hexahedral Solid Element

2.2 Four Node Quadrilateral Shell Element

Shell elements are 2D finite elements that could be used to model surface or thin plates (Ventsel & Krauthammer, 2001). In the application of finite element modeling, the shell elements even though considered as 2D elements always have the thickness as the material properties as for mass, stiffness calculation, etc (Logan, 2012). Shell elements could also be a derivation from hexahedron solid elements with flattened thickness such as shown in Fig. 2-2.

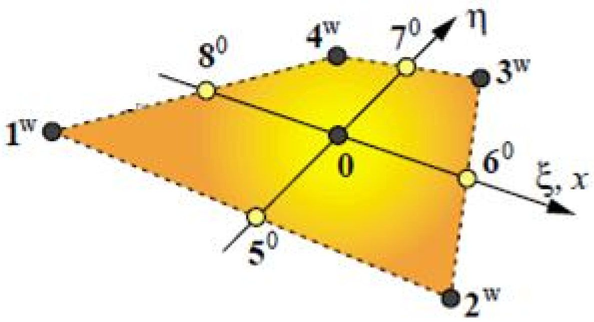


Figure 2-2 Four Node Quadrilateral Shell Element

In this paper Four Node quadrilateral shell elements is used to reconstruct the BAH wing surface. Thickness parameters still also be the properties of the element align with the stiffness distribution. .

3. MODEL RECONSTRUCTION AND ANALYSIS

3.1 Data Reconstruction

The data of BAH wing from (Bisplinghoff, Ashley, & Halfman, 1971) are mainly consist of:

a. Dimension and geometry
b. Stiffness distribution
c. Lumped mass distribution
d. Lumped moment of inertia distribution

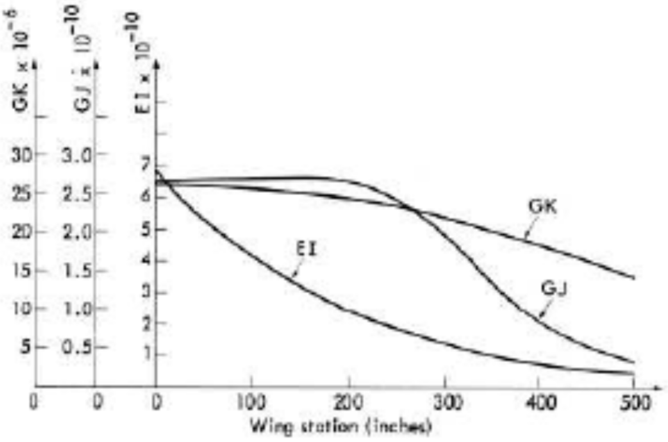


Figure 3-1 BAH wing spanwise stiffness distribution (Bisplinghoff, Ashley, & Halfman, 1971)

$$[M] = \frac{1}{386}\begin{bmatrix} 17{,}400 & & & & & \\ & 6{,}030 & & & & \\ & & 10{,}200 & & & \\ & & & 4{,}200 & & \\ & & & & 3{,}400 & \\ & & & & & 680 \end{bmatrix} \frac{\text{lb-sec}^2}{\text{in.}}$$

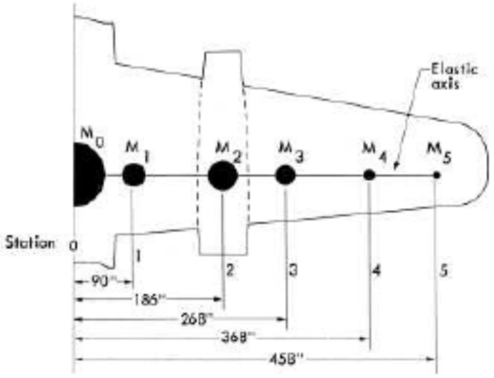


Figure 3-2 BAH wing lumped mass distribution (Bisplinghoff, Ashley, & Halfman, 1971)

$$[I_\theta] = \frac{1}{386}\begin{bmatrix} \infty & & & & & \\ & 8.723 & & & & \\ & & 93.16 & & & \\ & & & 3.725 & & \\ & & & & 2.775 & \\ & & & & & 0.40 \end{bmatrix} \text{lb·in·sec}^2.$$

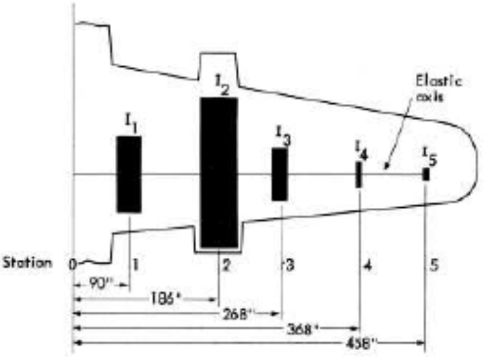


Figure 3-3 BAH wing lumped mass moment of inertia distribution (Bisplinghoff, Ashley, & Halfman, 1971)

From the original data of BAH wing, to construct shell and solid element, several processes is conducted:

a. Specific material properties (e.g. E, G and density) are unknown from the original data. Therefore need to assume a specific material as the structural component. In this paper, the material is assumed to use E and G values of aluminum; however the density is adjusted as explained in the next process.
b. BAH wing is modified with additional thickness align with the stiffness distribution over the spanwise direction.
c. The lumped mass in each point also regenerated to a specific area and material density of elements. To be noted that half-fuselage mass from the original data is not taken into account due to the scope of analysis will only for restrained wing to the root chord.
d. The mass distribution of the elements adjusted so then the center of gravity or elastic axis located on 35% of chord.

3.2 BAH Wing Modeling

As mentioned earlier, BAH wing will be reconstructed by shell and solid elements, using the reconstructed data as explained in 3.1 then the wing geometry is discretized accordingly.

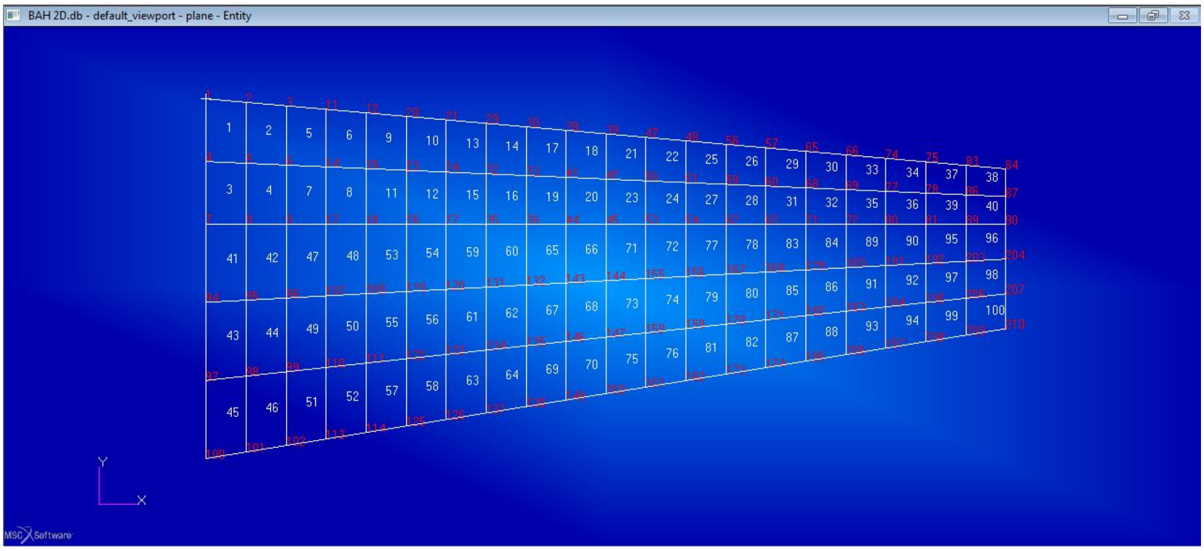
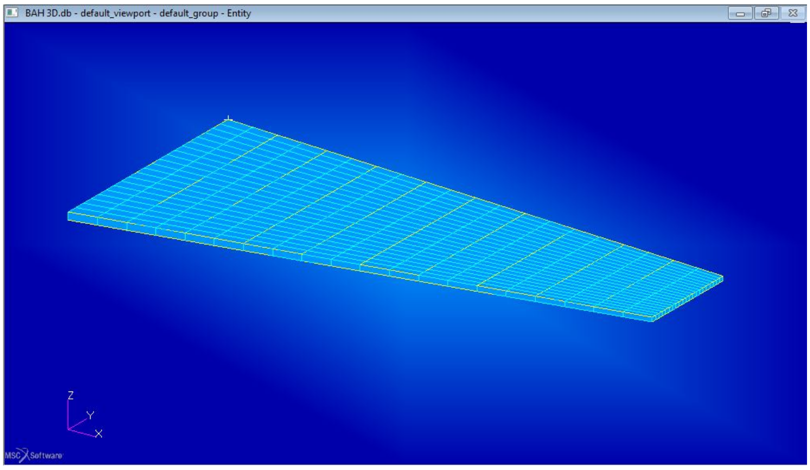
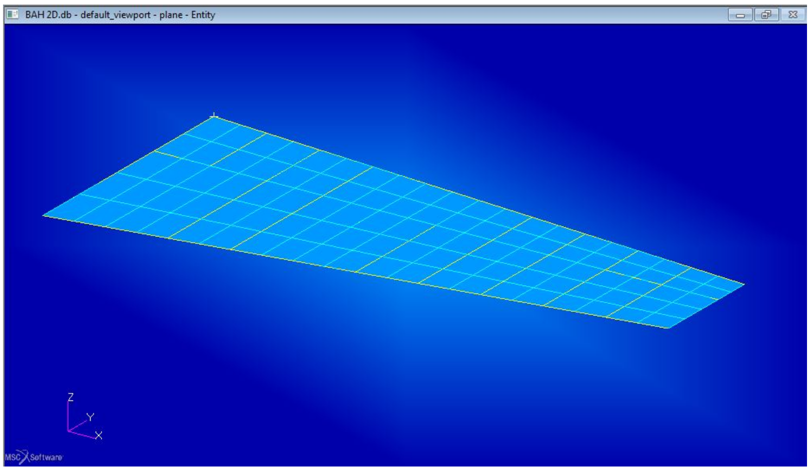


Figure 3-4 BAH wing geometry discretization



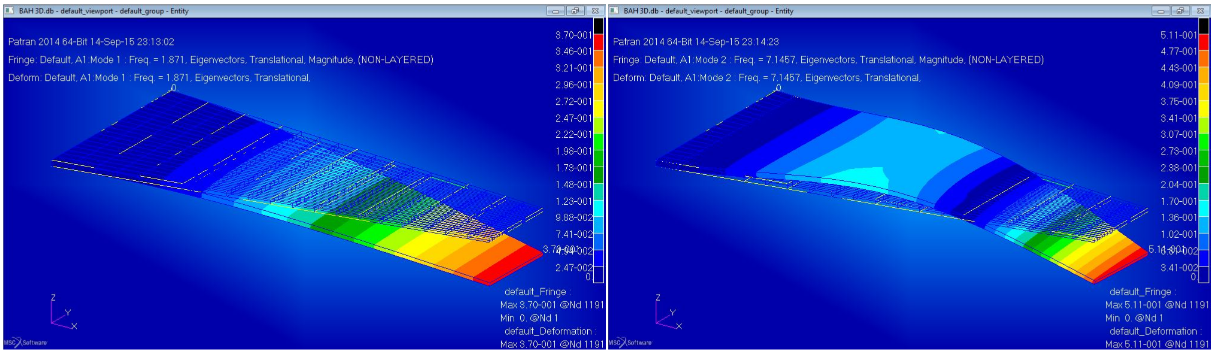
Figures 3-5 BAH wing solid elements model



Figures 3-6 BAH wing shell elements model

4. RESULTS AND ANALYSIS

4.1 Results



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Min 0. @Nd 1
default_Deformation :
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default_Deformation :
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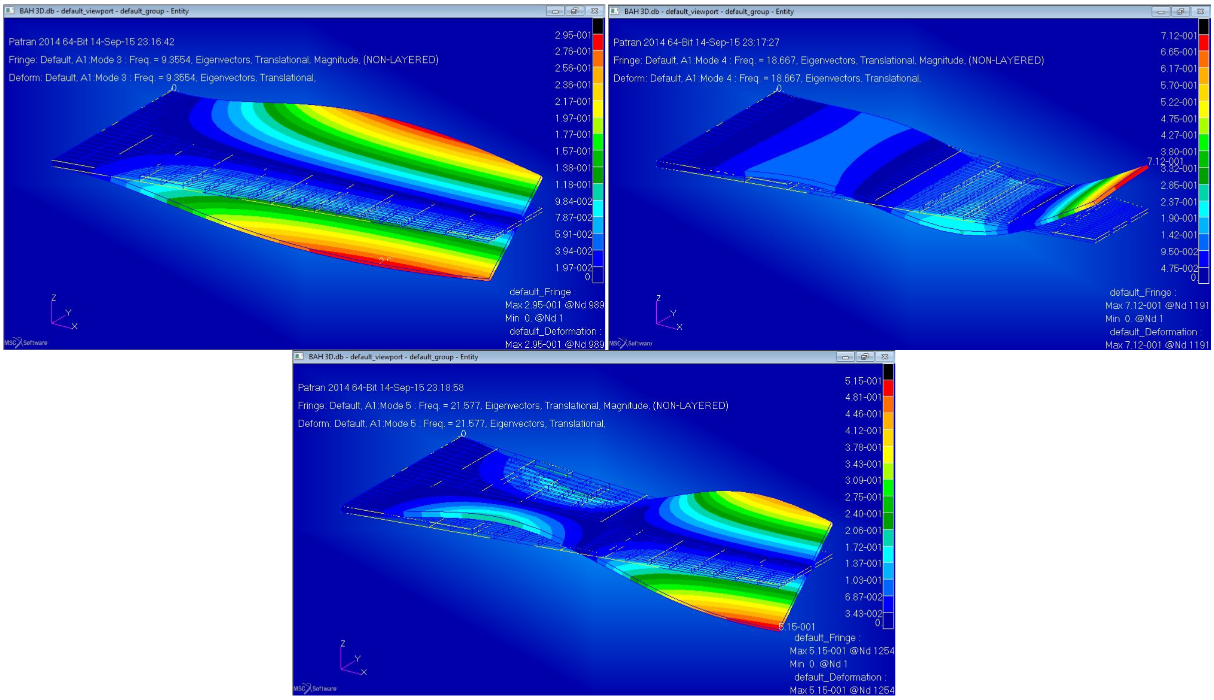

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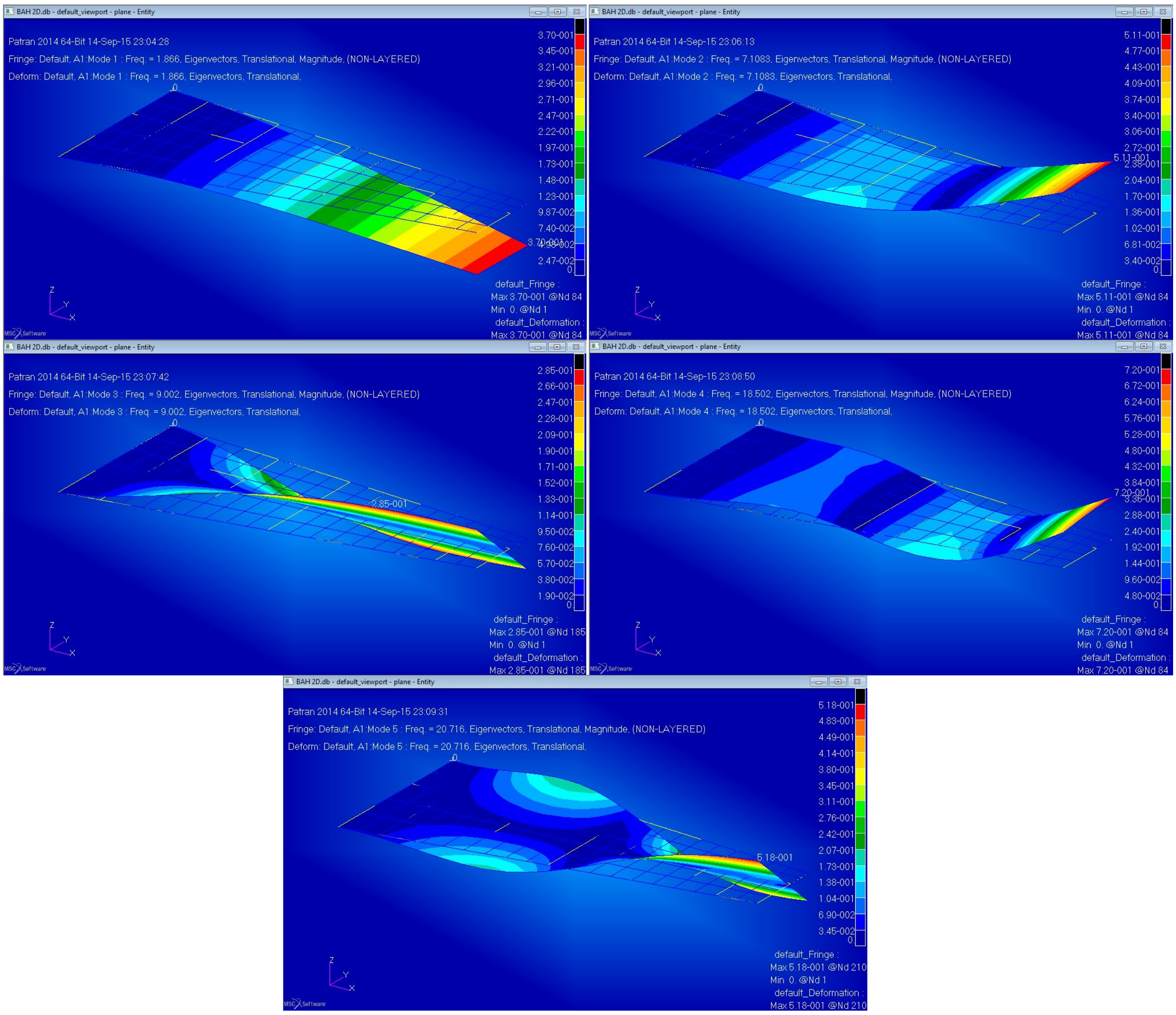
Figures 4-1 BAH wing solid elements frequencies and modes



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Figures 4-2 BAH wing shell elements model frequencies and modes

4.2 Analysis

Comparison of the present results and the references could be shown as follow:

Table 4-1 Natural Frequencies Comparison

	Bisplinghoff, Ashley, & Halfman, 1971	MSC.Nastran Aeroelastic Analysis User's Guide, 2002	Djojodihardjo, & Safari, 2006 (NASTRAN Shell model)	Present Results (Solid)	Present Results (Shell)
1st Mode	ω = 12.80 rad/s (f = 2.04 Hz)	ω = 12.80 rad/s (f = 2.04 Hz)	f = 1.85 Hz	f = 1.871 Hz	f = 1.866 Hz
2nd Mode	ω = 22.36 rad/s (f = 3.56 Hz)	ω = 22.32 rad/s (f = 3.55 Hz)	f = 7.14 Hz	f = 7.1457 Hz	f = 7.1083 Hz
3rd Mode	-	ω = 45.74 rad/s (f = 7.28 Hz)	f = 8.87 Hz	f = 9.3554 Hz	f = 9.002 Hz
4th Mode	-	ω = 73.50 rad/s (f = 11.70 Hz)	f = 18.57 Hz	f = 18.667 Hz	f = 18.502 Hz
5th Mode	-	ω = 92.04 rad/s (f = 14.65 Hz)	f = 20.68 Hz	f = 21.577 Hz	f = 20.716 Hz

From Table 4-1, it is clearly shown that there is a jump of natural frequency at the 2nd mode of the present results compared to the results of (Bisplinghoff, Ashley, & Halfman, 1971) and (MSC.Nastran Aeroelastic Analysis User's Guide, 2002). Meanwhile the results from (Djojodihardjo, & Safari, 2006) show more alignment with the present results. This variance could be explained by the mode shapes of those models.

For all the models mentioned in Table 1, the 1st mode shape is 1st pure bending mode. However, in (Bisplinghoff, Ashley, & Halfman, 1971) and (MSC.Nastran Aeroelastic Analysis User's Guide, 2002), the 2nd mode shape is 1st pure torsion mode, 3rd mode shape is 2nd pure bending mode and 4th mode shape is 2nd pure torsion mode. Meanwhile in the present results and (Djojodihardjo, & Safari, 2006), the 2nd mode shape is 2nd pure bending mode and the 3rd mode shape is 2nd pure torsion mode.

This shown that 1st pure torsion is not occurred in the present results model. Hypothetically, this could be happens due to different approach in the mass distribution which resulted to different moment of inertia distribution. In (Bisplinghoff, Ashley, & Halfman, 1971) and (MSC.Nastran Aeroelastic Analysis User's Guide, 2002), the mass distribution is represented by lumped mass located at several points as well as the lumped moment of inertia. But in the present results, due to application of shell and solid elements, the mass is distributed all along the wing, which might result to a different nature of mass moment inertia. In this case, it is resulted to a different nature of mode shape, the 1st pure torsion mode that is mainly influenced by the nature of the moment inertia is not occur in the shell and solid element models.

5. FUTURE WORKS AND CONCLUSION

Furthermore, the present results could be used for aeroelasticity analysis such as divergence or flutter analysis. However, further observation need to be taken due to modal analysis results variance that happens compare to the reference.

One of interesting phenomena that in (Bisplinghoff, Ashley, & Halfman, 1971) and (MSC.Nastran Aeroelastic Analysis User's Guide, 2002), the flutter is occurs in the 2nd mode which is 1st pure torsion mode. Meanwhile, for the present results need to be further elaborate in which mode shape the flutter will occurs.

Therefore, the results of this paper still widely open for further observation and analysis. The variances with the references could be used as the source for more comprehensive analysis.

REFERENCES

1) Bisplinghoff, R. L, Ashley, H, Halfman, R., *Aeroelasticity*, Addison Wesley, Reading, Massachusetts, 1955.
2) Blispinghoff, R. L, Ashley, *Principles of Aeroelasticity*, Dover Publications, New York, 1962.

3) Rodden, W. P., and Johnson, E.H., *MSC/NASTRAN Aeroelastic Analysis User's Manual*, Version 68, 1994, pp. 237-257.
4) Djojodihardjo, H. and Safari, I., *Unified Computational Scheme for The Calculation of Acoustic Disturbance to The Aeroelastic Structure*, paper IAC-06-C2.3.09, presented at the 57th International Astronautical Congress / The World Space Congress-2006, 1-6 October 2006/Valencia, Spain.
5) Logan, Daryl L., *A First Course in the Finite Element Method*, Cengage Learning, Stamford, 2012.
6) Ventsel, E. and Theodor Krauthammer, *Plates and Shells: Theory, Analysis and Applications*, Marcel Dekker, Basel, 2001.