Limit Cycle Oscillation (LCO) Flutter of Advanced High Modulus Graphite/epoxy Composite Oscillating Supersonic Wing

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ABSTRACT

This paper presents an optimisation process of reducing the structural weight of the supersonic wing by constraining the structural durability due to limit cycle oscillation. The application of composite material in aeroelasticity contributes to the modification of the expected aeroelastic failure on flutter speed. The composite material such that Graphite/epoxy gives high modulus compared to the metallic material such as aluminium. The objective of this tailoring process is to optimise the wing weight while the flutter performance might be improved. As the optimisation process performed, the flutter speed and the plate manufacturing thickness become the restriction in the wing weight reduction. The study shows good agreement to the objective where the reduction of weight for the High Modulus (HM) Graphite/Epoxy wing skin for the skin weight, clean wing and total wing with missile launcher external stores are 75.82%, 61.96% and 22.09% respectively compared to the baseline aluminium wing model. For the tailoring process, it is found that the flutter Mach number increases more than 81% using the as the Graphite/epoxy composite replaced the aluminium as the skin.

Keywords: Structural Durability, Limit Cycle Oscillation, Aeroelastic Failure, Supersonic Composite Wing, Optimisation.

INTRODUCTION

Aeroelasticity is referred to as the field of study related to the interaction between aerodynamic forces and elastic structure deformation (Wright & Cooper, 2015). The combination of bending-torsion modes under linear supersonic aerodynamics is the primary problem for fixed-wing aeroelasticity. Hence, it is classified as a linear problem. For this reason, the analysis of eigenvalues and mode shapes are needed. The mode shapes plot will determine the type of bending or torsion. It is related to the eigenvalues since the range of frequency is calculated through this parameter and responsible in differentiating every change of mode that triggers excitation until fracture at certain speed (flutter).

The application of composite material in aeroelastic tailoring as mentioned in (Jones & Davin, 1999) shows the composite material wing only bend without twisting for the forward-swept wing, which in this case, the wing will not experience the divergence. Composite materials can be used to produce highly-tailored aircraft structures that meet stringent performance requirements, but these properties also present unique challenges for analysis and design (Kennedy, 2014). The aeroelastic analysis performed in this study follows the guideline of flutter analysis from the military specification in MIL-A-8870C, (A), 1993.

For Graphite/epoxy composite laminate, the loading rate and temperature are sensitive due to made of high modulus fibres and low modulus polymeric matrix (Wu & Dzenis, 2000). The optimisation of aeroelastic tailoring of this study is the continuation of the study performed by Abdullah & Sulaeman, 2014. As the analysis performed completed using MSC Nastran, it is guided, as indicated by MSC. Nastran Version 68, 2004. The study also showed the analysis at negative boundary altitude to validate the flutter analysis in several tropical countries (Sulaeman, 2012).

STRUCTURAL WING MODEL

The structural present wing data is taken from Abdullah & Sulaeman, 2014 in which shown in Table 1. There are 3 locations of external stores placed under the wing.

Table 1. Supersonic Wing Planform Data

Wing Swept Angle	Taper Ratio	Aspect Ratio	Average Chord Length (m)	Wing Root (m)	Wing Tip (m)	Half Span (m)
30º	0.5	5	1.5	2	1	3.75

The composite material properties for high modulus Graphite/epoxy are as in Table 2.

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Table 2.HM Graphite/epoxy material properties [8]

Elastic Properties	E_1 (GPa)	230
	E_2 (GPa)	6.6
	G_{12} (GPa)	4.8
	ν_{12}	0.25

Physical properties	Density, (kg/m³)	1630

AEROELASTIC ANALYSIS AND OPTIMISATION

The first is a structural analysis which is covering the modal analysis using the Lanczos method. The final analysis is the flutter analysis which is using the PK method solution, as displayed in equation (1).

$$\left[M_{hh}\,p^2 + \left(B_{hh} - \frac{\frac{1}{4}\rho\bar{c}VQ^{I}_{hh}}{k}\right)p + \left(k_{hh} - \frac{1}{2}\rho V^2 Q^{R}_{hh}\right)\right]\{u_h\} = 0 \tag{1}$$

The objective of the optimisation for this study is to reduce the wing weight using composite material; optimisation variable is the plate thickness while the constraint is the flutter speed and manufacturing factor. The fibre orientation of the present composite has been optimised The optimisation suspends until the possible manufacturing thickness is achieved.

RESULTS AND DISCUSSION

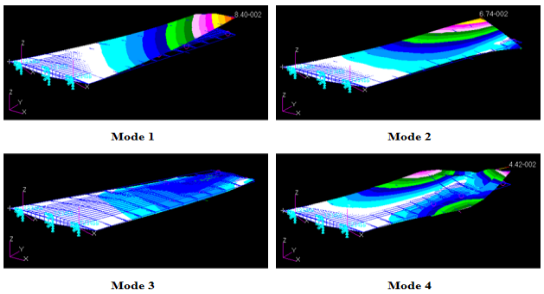

Fig. 1 Mode shapes of the present HM Graphite/epoxy composite wing

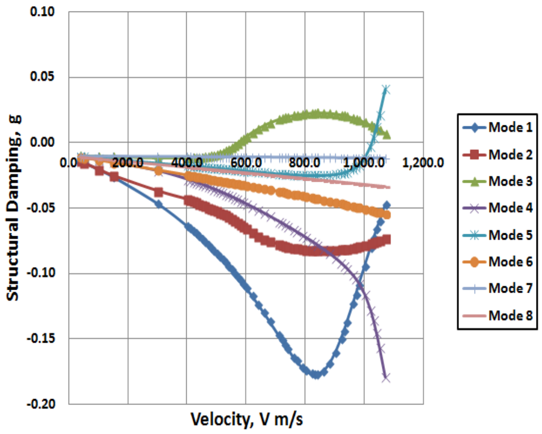

Fig. 2 V-g diagram

Table 3. Flutter Speed Comparison

Case	Flutter Speed (m/s)				
	-7943 ft	0 ft	10,000 ft	20,000 ft	30,000 ft
Base line (Al. wing)	502.2	561.2	651.2	764.9	911.8
Present HM graphite/epoxy wing	909.9	1024.6	1192.3	1404.4	1678.6

CONCLUSION

Present work shows the largest reduction of wing mass and highest flutter speed at several altitudes by setting the baseline aluminum skin wing as constraint. The total mass reduction of 22.094% in the present study that will contribute in less fuel consumption for any mission and longer endurance of flight. This is the reason of high modulus composite such as HM Graphite/Epoxy is being used in manufacturing the military aircraft wing since the performance is better than high strength of any other composite material. The optimum clean wing weight of the HM Graphite/Epoxy wing is 127.01 kg. The reduction of weight for the HM Graphite/Epoxy wing skin for the skin weight, clean wing and total wing with missile launcher external stores are 75.82%, 61.96% and 22.09% respectively compared to the baseline aluminum wing model.

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