A COMPOSITE WING WITH MORPHING HIGH LIFT DEVICE

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Introduction

At present an aircraft is designed to achieve an optimum performance at a certain flight condition. Applying morphing wing technology would lead to an optimal design in a wide range of flight envelopes. Several projects [1-5] focused their attention on developing adaptive wing concepts to vary the wing shape spanwise and/or chordwise. For a commercial aircraft however, it is a huge challenge to even just apply the concept to the high lift devices for the same aerodynamic performance obtained by the current systems. Despite the challenge, morphing high lift device has been attempted due to its potential drag and noise reduction during the device deployment or operation [6-7] and also potential overall weight saving. Many concepts have been developed for morphing trailing edge devices [8-11], but fewer have been developed for morphing leading edge (LE) [12-15]. This current paper presents a study on the design and structural analysis of a composite wing box with a morphing leading edge.

Composite Wing Box Design

Based on the thin walled box theory, a computer program has been developed for preliminary design of a composite wing box. An aircraft of MTOW=95600 kg and wing span of 40 m was taken as an example. Based on the loading condition, the primary structure design parameters such as spar, skin and stringer size and laminate layup were determined based on stress and buckling results in an iterative analysis. At the same time, the wing box bending rigidity EI, torsion rigidity GJ and twist angle of a 12 m long wing box at a certain flight condition were also calculated. Taking as reference a section of the wing box of 4 m chord along the span, an optimum 4 mm skin thickness was designed with the reinforcement of 14 and 11 z-shaped stringers on the upper and lower skin respectively. The analysis results at this section under shear load 437.5 kN, bending moment 2250 kNm and torque 300 kNm are listed in the Table 1.

Table 1. Results of the wing box analysis

EI (Nm^2)	GJ (Nm^2)	skin σ_{max} (MPa)	skin τ_{max} (MPa)	Twist angle
1.5E+08	1.9+08E	87.1	328	0.64°

Morphing Leading Edge

Effect of the Leading Edge Stiffness

An investigation was conducted to determine the influence of the LE material and stiffness on the overall wing stiffness in 2D and 3D model. The 2D model showed that if the stiffness of the LE lower skin part is reduced by 75% the wing box torsion rigidity decreases by 7% and the bending rigidity by 2%. The 3D model showed that in this case the twist angle of the wing box increases by 7%. The stiffness of the LE can be therefore tailored to allow for required deformation.

LE Geometry, Material and Actuation Force

The structural design and analysis using NASTRAN was carried out for a LE section of 0.9 m chordwise, 0.44 m height and 1 m long spanwise. Three different materials for the LE skin were studied; aluminium (*Al*), carbon fibre (CF) and glass-fibre/epoxy (GF). The *Al* skin was 4 mm in thickness while the carbon and glass-fibre/epoxy skins were 3 mm laminate of layup $[\pm45_3/0_4/90_2]_s$ and $[\pm45/0_3/90]_s$ respectively. An internal structure configuration and actuation system was designed to achieve the specified LE deflection shape and a vertical nose displacement of 0.36 m (9% of the chord). The skin was connected to a set of triangle shape frames, which were actuated at the jointed points by actuators. The frames transfer the actuation forces to deflect the LE up to the required shape. Fig.1 shows the 2-D LE structural model with boundary conditions and the internal forces.

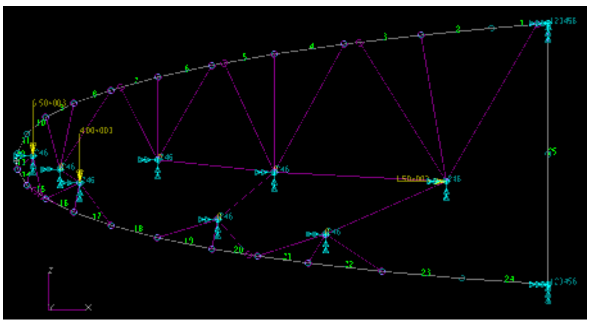

Fig.1 Actuation forces and boundary conditions

Stress and Strain Results

A stress and strain analysis was carried out for the three cases 1-3 of different materials *Al*, CF and GF. Each case was divided into a sub-case-a without considering the aerodynamic load and sub-case-b to take the aerodynamic load from a CFD analysis into account. Table 2 summarises the actuation force required to deflect the LE and the resulting local stress ($\sigma_{1\text{-}2}$) and global strain ($\varepsilon_{x\text{-}y}$) of the skin. It is also shown that although the strain level for the glass fibre skin is relatively high, the required actuation force and the stress levels are lower than the other two cases. Fig. 2 shows the location of maximum stress concentration in case 2b, which also coincides with location of maximum global strain.

Table 2. Summary of the actuation force, stress & strain

	Cases 1 - 3					
	1a	1b	2a	2b	3a	3b
Force (kN)	24.0	28.0	6.0	9.6	1.9	6.4
Von Mises stress (MPa)	886	897				
σ_1 (MPa)			438	595	125	255
σ_2 (MPa)			37.2	50.1	28.9	55.1
ε_x ($\mu\varepsilon$)	557	661	7920	8260	5920	10100
ε_y ($\mu\varepsilon$)	1080	1260	812	653	804	1420

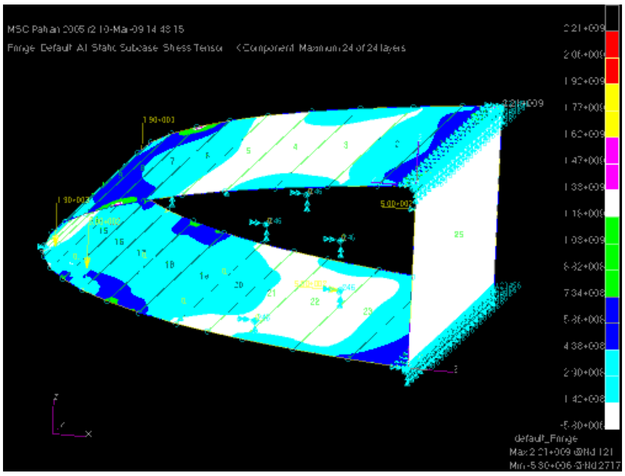

Figure 2. CF skin σ_1 stress distribution in case 2b

Further study was conducted to evaluate percentage of the actuation force required to overcome the deflected LE elastic force and the external aerodynamic force. It was found that for the aluminium skin case-1, 80% of the total actuation force was used to deflect the LE. For the carbon and glass fibre skins case 2 and 3 however, 57 and 40% of the actuation force was used to deflect the LE respectively.

Conclusion

Based on the design of the wing box and the LE structure, it was found that the LE skin local stiffness can be reduced to allow the LE morphing without significant effect on the overall wing stiffness. A simple and feasible internal structure configuration was designed to achieve the specified LE deflection. Based on the LE structure analysis subjected to both internal actuation forces and aerodynamic load, the GF/epoxy option is more efficient than the other two cases in terms of stiffness, strength and actuation power demand. Additional actuation force to overcome the elastic force of the morphing LE is significant. An optimum design is therefore carried out to minimise the maximum stress, strain and the actuation power.

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