Structural analysis of coreless spoiler

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Abstract. In this paper, a coreless spoiler is proposed to be an alternative solution for moisture absorbed honeycomb core. The honeycomb core is removed from the spoiler and the coreless spoiler is analyzed by using finite element tool, Abaqus. The results show that the upper skin fails at region near to the actuator, Tsai-Hill is more than 1. Few options, such as rib, spar and Carbon Fiber Reinforced Plastic (CFRP) patch are introduced to support the weak region of coreless spoiler. The effectiveness of these notions is evaluated based on Tsai-Hill failure. The spar outperformed the other options. Only the spar is capable of giving sufficient support to the coreless spoiler and the structure does not fail in term of Tsai-Hill index.

1. Introduction

The phenomenon of water ingress in honeycomb panels is very common in aviation field. Water infiltrates the honeycomb components and leads to corrosion or adhesive bond degradation, which compromises the structural integrity of the components. The catastrophes caused by the distortion of moisture absorbed honeycomb panels have attracted attentions from researchers.

Efforts have been invested in understanding the reasons of water present in the honeycomb panels. Water ingression into honeycomb panels has been categorized into two types: direct and indirect entry of liquid [1]. Direct entry of water was through capillary action where structural imperfections took place, such as poor seals around fasteners. The second was moisture entered into the core via diffusion through composite skins. Moisture movement [2] and expansion [3] in honeycomb panels have been studied. Numbers of methods to detect water moisture inside honeycomb structures have been proposed. Nonetheless, the degradation mechanisms of node bonding caused by moisture were yet not fully understood. Drying and curing methods for wetted control surfaces were widely used in industry and new methods also have been developed by researchers.

Prevention of disasters due to bond degradations in honeycomb panels suggested by researchers was removal of honeycomb core from control surfaces. Studies regarding this matter have been carried out on the wing spoiler, but at very limited amount. Wing spoiler is made of sandwich structure where the main stiffness depends on its honeycomb core. Therefore, spoiler was a suitable material for such investigation. has worked on generic spoiler without the present of honeycomb core. Various problem formulations and structural topology and sizing optimization algorithms were implemented on the spoiler for structure design features efficiency recognition purpose. They have concluded that the spoiler torsion box stiffened by span-wise structures was in favour [4]. On the other hand, a group of method of Evolutionary Structural Optimization (ESO) has introduced a group removal method applied in optimization. According to their research, a spoiler with a wide range of orthogonal and angled ribs was needed to start with. These ribs fully filled across the design space of the spoiler and were represented by groups of vertical shell elements. As the optimization proceeded, groups of finite
elements were conditionally eliminated rather than individual elements [5]. A conceptual design from group ESO was to ease of manufacturing and structurally efficient. As an alternative approach, a brick-based topology optimization on spoiler design has been executed in place of the existing FEA based structural optimization methods [6]. This optimization was based on the Density method along with the checkerboard fill-in algorithm. The results showed a number of members were extended from the actuator position in order to withstand loading. Consequently, the researcher suggested a novel concept of ‘semi-span spars’ in his optimized design.

The characteristics of the spoiler without honeycomb core were determined by using Finite element method (FEM) and Abaqus software was the analytical tool. Alternative options rather than honeycomb, such as rib, spar and skin patch were evaluated based on their effectiveness in supporting the thin skin spoiler.

2. Finite element modelling

A320 airbus spoiler was used as reference for this study, known as baseline throughout this report. The spoiler is a sandwich structure with Carbon Fiber Reinforced Plastic (CFRP) as skins and core made of honeycomb. It is attached to aluminum hinges and an actuator in the middle as shown in Figure 1. The lamina properties were given in Table 1. Honeycomb core was fabricated from paper material in Table 2. Aluminum properties for hinges and actuator were tabulated in Table 3.

Assumptions were necessary for finite element modelling, for instance, the laminate was perfectly bonded, interlaminar failure or delamination was not in concern and CFRP was still in elastic behaviour. Therefore, the upper and lower skins were applied with S4R conventional shell elements since S4R was a robust, general-purpose element that was suitable for a wide range of applications [7]. Furthermore, all contact surfaces between components within spoiler were represented by tie constraint and fastener bonding were neglected due to the main focus was on interior structures. Tie constraint was adequate to represent adhesive joint [8].

The boundary conditions on the lugs were allowed to rotate in one axis and the middle support point was fixed. Moreover, the pressure loading applied was non-uniform and calculated,

\[ P_1 = \frac{6 \cdot HM_{ext}}{(SC)_{sp}} \]  

(1)

where \( P_1 \) is chordwise pressure, \( HM_{ext} \) is hinge moment and \((SC)_{sp}\) is reference area and chord of spoiler. The working condition of spoiler was assumed to be deflected 10° upward. thus, the computed chordwise pressure was about 38kPa which was similar to reference [9].
Table 1. Unidirectional carbon fiber prepreg properties: anisotropic material properties and strengths [10].

| E_{11} (GPa) | E_{22} (GPa) | G_{12} (GPa) | G_{23} (GPa) | G_{13} (GPa) | ρ (kg/m$^3$) | σ_{f11} (MPa) | σ_{f22} (MPa) | σ_{c11} (MPa) | σ_{c22} (MPa) | τ_{allow} (MPa) |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 192         | 10.6        | 0.31        | 6.1         | 6.1         | 3.7         | 1800        | 2715        | 56          | 1400        | 250         | 101         |

Table 2. Sandwich core: material properties (similar to Aramid Fibre Honeycomb HexWeb HRH-10-1/4-3.1, [11]).

| E_{11} (MPa) | E_{22} (MPa) | E_{33} (MPa) | G_{12} (MPa) | G_{23} (MPa) | G_{31} (MPa) | ν_{12} | ρ (kg/m$^3$) |
|--------------|--------------|--------------|-------------|-------------|-------------|-------|-------------|
| 1.0          | 1.0          | 145.0        | 44.8        | 20.7        | 1.0         | 0.4   | 0.496       |

Table 3. Aluminum material: isotropic material properties and allowable fatigue and residual stresses [10].

| E (GPa) | ν_{12} | ρ (kg/m$^3$) | σ_{vMises,fatigue} (MPa) | σ_{vMises,fracture} (MPa) |
|---------|-------|-------------|--------------------------|---------------------------|
| 72      | 0.3   | 2800        | 110                      | > 270                     |

3. Coreless spoiler
Honeycomb core was removed from the spoiler and replaced with two spars and two ribs to retain the initial shape of the spoiler. This coreless spoiler was analyzed by Abaqus and failure determination of the structure was via first ply failure, Tsai-Hill failure. Few options, such as rib, spar and CFRP patch were proposed to support the weak region of the coreless spoiler. Again, Tsai-Hill failure was applied to evaluate their strength.

4. Results and discussion
Baseline was studied and it passed the Tsai-Hill index (Figure 2) and maximum deflection was around 12mm in Figure 3. However, the most critical ply of the coreless spoiler was the outer ply of upper surface with Tsai-Hill more than 1, around 1.9 (Figure 4). The structure was considered fail based on the first ply failure criteria. It was observed that the critical regions of plies were near to actuator due to the piston support at the actuator. Figure 5 showed that the maximum deflection was about 40mm at the middle. These results were as expected thus this proved the reliability of the finite element model.

![Figure 2. Displacement of baseline (top view).](image-url)
Figure 3. Tsai-Hill of baseline (bottom view).

Figure 4. Displacement of coreless spoiler (top view).

Figure 5. Tsai-Hill of coreless spoiler (top view).

The region near coreless spoiler actuator was the most critical where support was required around that region. Four options were generated such as middle spar (Figure 6), middle rib (Figure 7), rib (Figure 8) and CFRP patch (Figure 9). They were applied with same thickness and material in order to keep the consistency. Also, there were considered as co-cured ribs and spars. Comparisons amongst all results, the middle spar structure outperformed the others. Only the middle co-cured spar gave the sufficient support and the structure did not fail. Tsai-Hill in this case fell back to safe zone, around 0.48, less than 1. This result agreed with reference [4].

Figure 6. Tsai-Hill of middle spar structure in coreless spoiler (top view).
5. Conclusions
In this paper, the behavior of coreless spoiler was predicted by FEA. The most critical ply of coreless spoiler had Tsai-Hill index more than 1, the structure was considered failed according to first ply failure. The most critical region was near to the actuator. Moreover, it was observed that co-cured spar was more effective in supporting the coreless spoiler than co-cured rib and CFRP patch. Only co-cured spar gave sufficient stiffness to the structure and Tsai-Hill was less than 1, the others violated the criteria. This is agreed by reference [6] which suggested semi-spar to be located at the center near to the actuator.

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