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Comparison of lattice core topologies in sandwich structures

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Abstract. Hybrid sandwich structures are often used in the aviation industry thanks to their high strength-to-weight ratio and resistance to bending and buckling. Today, through Additive Manufacturing technologies, it is possible to use different materials to create topology-optimized structures with complex shapes using lattice structures. In this work, a numerical approach is proposed to study the behaviour of a hybrid sandwich structure which can be used as a reinforcement for a control surface of a lightweight aircraft. A comparative analysis is conducted between a conventional honeycomb lattice core and lattice truss core structures.

Introduction

The use of sandwich structures in the aeronautics field has gained significant attention due to their high stiffness-to-weight ratio and buckling loads [1]. However, the reliability of the bond between the core and face-sheets remains a challenge, as adhesive bonding can limit the strength of the sandwich panel [2]. Additive Manufacturing (AM) allows a direct connection between the core structure and face sheets. Furthermore, thanks to its free-form tailoring ability, it is possible to create a topology-optimized core through the use of lattice cells. Multiple studies have demonstrated the structural advantages of truss core sandwich panels, which, owing to their open geometric configuration, can also be employed for multifunctional purposes. These types of structures have shown remarkable structural performance against bending and compression loads, as demonstrated by Wicks and Hutchinson [3]. Additionally, truss core sandwich panels can be used in heat transfer, such as anti-icing systems [4], and have proven effective in damping vibrations [5] and for impact absorption.

In this paper, the mechanical properties of three different lattice structures, namely lattice honeycomb, truss lattice Body Centred Cubic BCC and sine-Waved truss lattice Body Centred Cubic WBCC [6] are investigated. These lattice structures are evaluated in the context of an asymmetric sandwich core, which is intended for application in a new-generation tilt rotor control surface.

Lattice core homogenisation

In order to reduce the computational costs on the macro scale numerical analyses, the equivalent homogenised properties of the three selected lattice structures, shown in Figure 1, have been determined. All three specimens are manufactured through a standard Aluminium alloy, $E_{Al} = 71.0\ GPa$, $\nu = 0.33$ and have the same specific density $\rho^* = Volume_{cell}/Volume_{box} = 0.094$. The solid size length $L = 10\ mm$ is chosen, while the other geometric parameters are accordingly selected in order to guarantee the desired density.

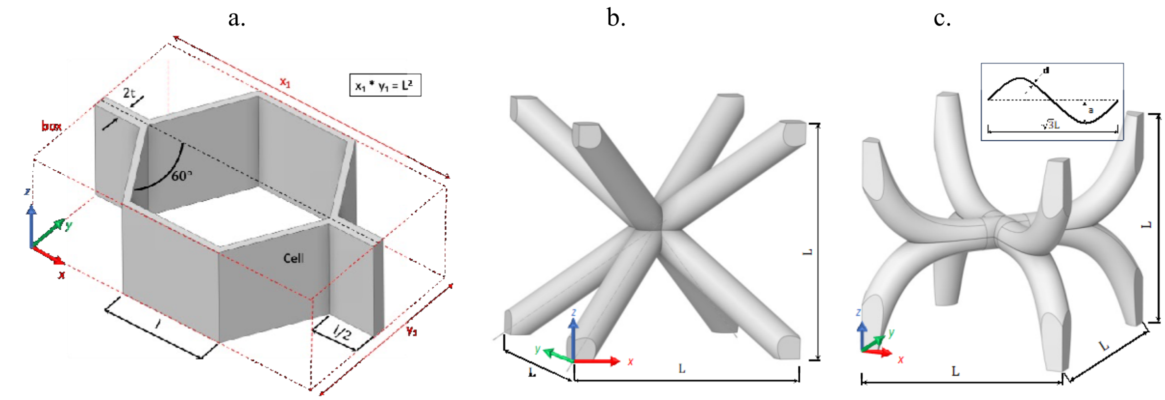

Figure 1 – Lattice cells configuration. a. Honeycomb (Hex) $l = 4.38\ mm, t = 0.29\ mm$*, b. Body Centred Cubic (BCC)* $d = 1.4\ mm, a = 0\ mm$*, c. Waved Body Centred Cubic (WBCC)* $d = 1.5\ mm, a = 2.0\ mm$*.*

The homogenised properties of the Hex cell are retrieved analytically from the work of Kumar et. al. [7], while an ad-hoc routine on Ansys Parametric Design Language (APDL) was developed for the BCC and WBCC lattice cells. More specifically, each node on the lateral faces is paired with its respective node on the opposite face through constraint equations:

$$u_{i^-} - u_{i^+} = \Delta u_p \tag{1}$$

with: u displacement along the x, y and z directions, i^- and i^+ nodes on two opposite faces sharing the same relative position. Δu_p is the difference in displacement of two pilot points chosen on the two faces.

The homogenised mechanical properties of each cell are reported in Table 1. It can be noted that the Hex and WBCC, whose material direction 3 is aligned with axis z in Figure 1, have an orthotropic behaviour.

Table 1 - Lattice cells homogenised mechanical properties.

	E_1 [Pa]	E_2 [Pa]	E_3 [Pa]	ν_{12}	ν_{23}	ν_{13}	G_{12} [Pa]	G_{23} [Pa]	G_{13} [Pa]
Hex	4.48E+07	5.10E+07	6.70E+09	9.24E-01	2.51E-03	2.21E-03	3.43E+07	1.05E+09	1.43E+09
BCC	1.11E+08	1.11E+08	1.11E+08	4.82E-01	4.82E-01	4.82E-01	9.08E+08	9.08E+08	9.08E+08
WBCC	1.61E+08	1.61E+08	1.11E+09	8.24E-01	7.46E-02	7.46E-02	8.51E+08	9.26E+07	9.26E+07

Finite element analysis comparison

To compare the mechanical properties of the three chosen lattice cores in asymmetric sandwich panels, a control surface of a new-generation Tiltrotor, illustrated in Figure 2.a, is selected. A schematic representation of the asymmetric sandwich panels placed on both the upper and lower skins is also depicted. The whole structure is modelled with two-dimensional surface elements using Ansys Composite PrepPost (ACP) module. The composite stabilizing and working skins use Epoxy-Carbon woven prepreg plies with the following properties: $E_{1,2} = 61.3\ GPa, E_3 = 6.9\ GPa, \nu_{12} = 0.04, \nu_{23,13} = 0.3$ and $G_{12} = 3.3\ GPa, G_{23,13} = 2.7\ GPa$.

In this preliminary study stage, a uniform pressure is applied to both the upper and lower skins, while displacement constraints are imposed as additional boundary conditions in accordance with the real aircraft model. The contour map deformation along the z-direction for the control surface with a honeycomb homogenised core is reported in Figure 2.b highlighting the most deformed region on the lower skin surface in accordance with the superimposed uniform load.

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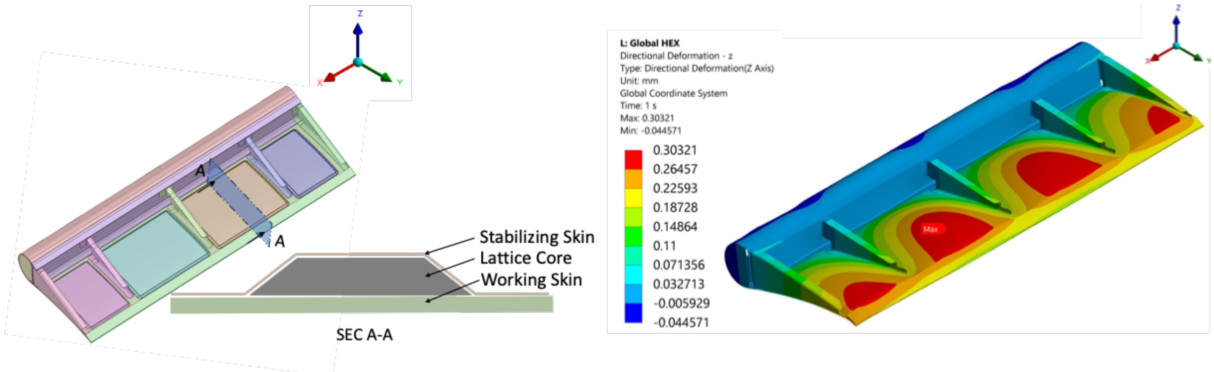
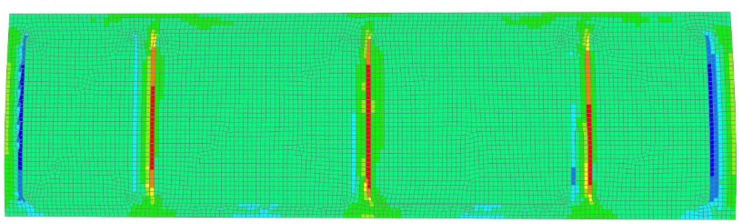


Figure 2 – a. Tiltrotor Control Surface: Schematic representation of asymmetric sandwich panel section view (Upper skin hidden). b. Hex-Core structure directional deformation [mm], z-direction (Upper skin hidden).

As shown in Table 1, the mechanical properties of the BCC cell are equivalent along the three cartesian directions; on the other hand, the WBCC, presents a preferred load direction along the three cartesian directions. For this reason, a second configuration WBCC2 is considered rotating the WBCC cell so that the material 3rd direction is parallel with global y-direction.

The z-direction displacements are investigated. Indeed, a global analysis of the homogenized core loses information on stress distribution in the lattice cell struts and the contact areas with the stabilizing and working skins. As a representative result in terms of stress, since no relevant difference appears in the four cases, Figure 3 presents the maximum stress values (σ_1) in the x-direction of the upper skin's 1st ply for the Hex configuration. No significant influence is appreciable on the σ_1 stress values at the observed layer. Figure 4 and Figure 5 show the z-direction deformation for upper and lower skins along the control surface span and chord. Overall, the Hex topology appears to be the more rigid solution, while WBCC1 is the least.



	σ_1 $[MPa]$	
	Max	Min
Hex	10.622	-7.967
BCC	10.775	-7.917
WBCC1	10.496	-7.970
WBCC2	11.045	-8.084

Figure 3 – Top skin 1st ply σ_1 stress contour map.

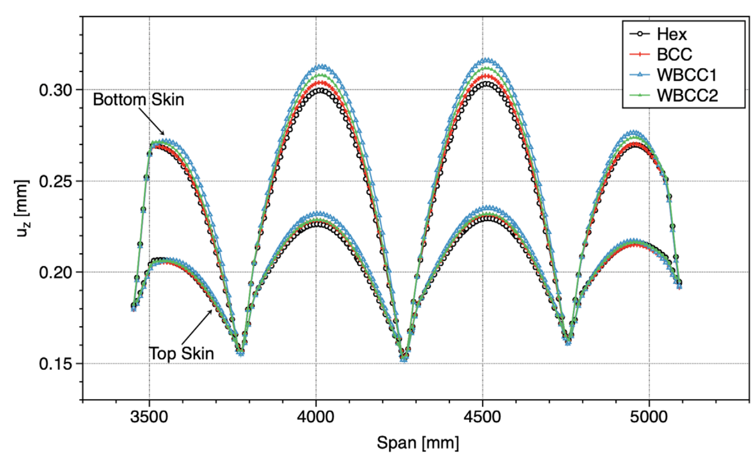


Figure 4 – Directional deformation along z-direction as a function of the control surface span. Top and Bottom skins.

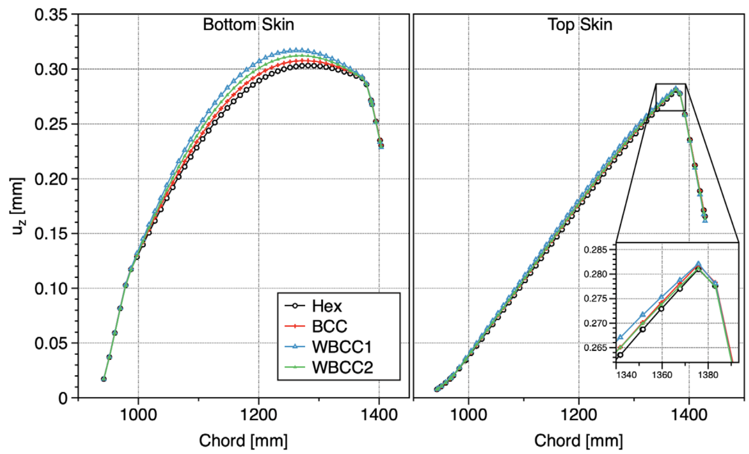


Figure 5 - Directional deformation along z-direction as a function of the control surface chord. Top and Bottom skins.

Conclusions

The DAVYD project sought novel structural configurations for the control surfaces of a new-generation tiltrotor. Various core options are proposed to reinforce the asymmetric sandwich panels. Displacements and stress contour maps indicate the potential use of topology-optimised lattice structures to enhance the overall response. Further studies will be carried out on the subject such as tailoring and optimising the orientation of the lattice cells.

Acknowledgements

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