Aerobatic Wing

Honeycomb variation

Contents

Dimensions and sizing

In this study, a wing for an aerobatic airplane was designed using the reference dimensions and geometry of the Zivko Edge 540 one-seater aerobatic airplane.

Wing was modelled using SolidWorks and surface features.

Front spar is placed on 15% of root chord and is parallel to leading edge of the wing.

Aft spar is located on the 70% of the root and tip chords.

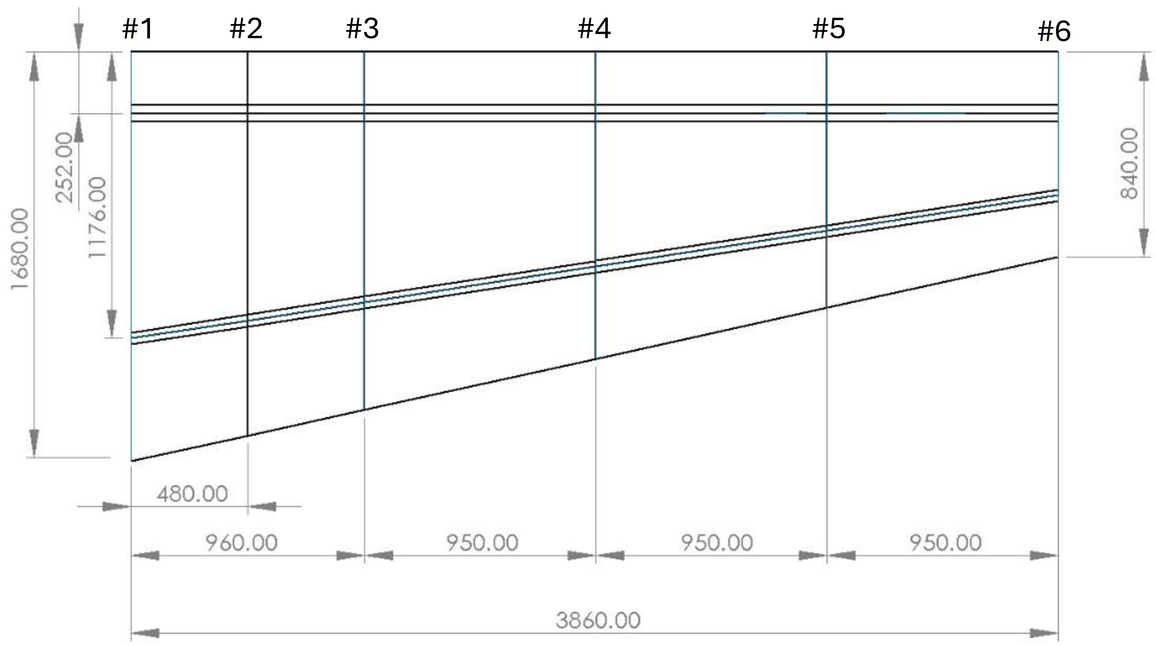
Spanwise, the wing has 4 internal ribs, with one root and tip rib.

First two internal ribs are made with lesser spacings as to facilitate higher twist loads found near the root of the wing.

Control surfaces in this model are mounted to the end of the ribs #4 and #5. (Further explanation in FEM chapter of the report).

To stiffen the skin between the spars, honeycomb core will be inserted.

Rest of the relevant dimensions are found in the drawing below.



Material properties

Carbon fiber layups will be modelled using UD plies made from CFRP CCF800/AC531.

UD plies will have a thickness of 0.155 mm.

CCF800/AC531		
Symbol	**Unit**	**Value**
ρ	kg/m^3	1600
E_1	MPa	163800
E_2	MPa	8630
G_{12}	MPa	4120
G_{13}	MPa	4120
G_{23}	MPa	4120
ν_{12}	-	0.31
X_T	MPa	2209
X_C	MPa	1052
Y_T	MPa	70
Y_C	MPa	199
S	MPa	131

Since Tsai-Wu criterion will be used to analyze boundary behavior of the composite material, corrective coefficient for Tsai-Wu interaction was calculated and implemented into the material model with value of 2.78e-6.

For the honeyecomb (HC) material, aramid was chosen (EC). Honeycomb core material model will be defined using 2D Orthotropic model, same as it was used for CFRP plies.

Shear modulus and strengths were obtained using Ashby's approximations.

Cell size is 4.8 mm, while honeycomb core height is 5 mm. Honeycomb core height was tested through manual iterative process where diminishing returns were noticed after height value surpassed 5 mm, and the skin began to buckle.

ECA 4.8 mm		
Symbol	**Unit**	**Value**
ρ	kg/m^3	48
E_1	MPa	101.1
E_2	MPa	9.9
G_{12}	MPa	1.6
G_{13}	MPa	33.3
G_{23}	MPa	19.6
ν_{12}	-	0.24
X_T	MPa	2.4
X_C	MPa	1.5
Y_T	MPa	2.4
Y_C	MPa	1.5
S	MPa	3

HC material model had Tsai-Wu criterion corrective coefficient of 0.08165.

To increase the stiffness of the spar webs, foam material is inserted into the middle.

Foam was modelled as an isotropic material, with properties that represent the weakest values from an orthotropic material model of the foam.

Foam inserts for both the front and aft spar have a thickness of 2 mm.

Mycell M80 (Airex)		
Symbol	**Unit**	**Value**
ρ	kg/m^3	80
E	MPa	53
G	MPa	25
ν_{12}	-	0.1
Tension Strength	MPa	1.63
Compressive Strength	MPa	1.03
Shear Strength	MPa	0.92

Composite layups

After the iterative process of defining the baseline composite layups and adding additional plies to different sections of the wing, a satisfactory composite layups were achieved.

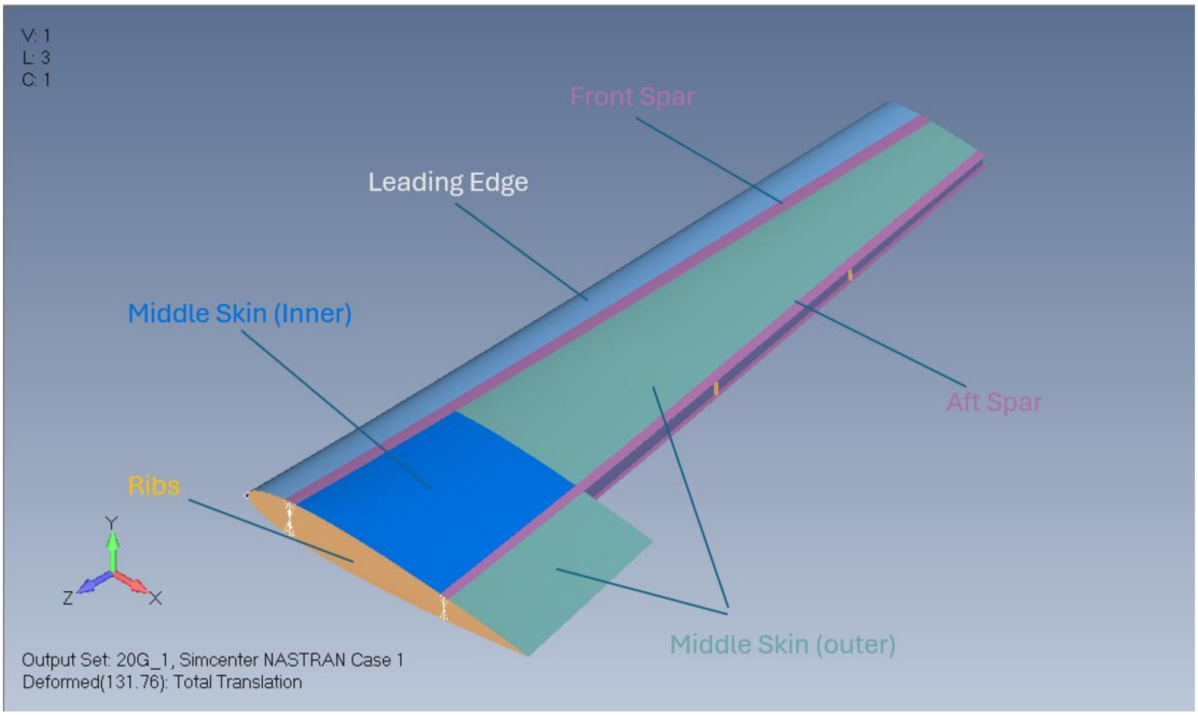
Main parameter of iterative process was the failure index, whose value had to be below 0.9 at the locations with critical stress values.

Wing surface was separated into two sections: inner and outer, with former being greater in thickness.

With this layup configuration, final mass of the wing equals to 52.49 kg.

Important notice is that mass of the wing does not include any grounding connections that would be used to connect wing to the fuselage. In this simplified shape, the model experiences potentially greater mass, and peaks in stress values near the boundary conditions. To eliminate this, more detailed execution of the CAD model should be made which would enable more accurate definitions of the BCs.

Structure section	Layup	Thickness
Middle skin (outer)	[45/0/-45/HC/-45/0/45]	5.93 mm
Middle skin (inner)	$[[45/0/-45/30]_5/[+-45/30]]/HC/[[30/-+45]/[30/-45/0/45]_5]$	12.13 mm
Leading Edge	= Middle skin (outer)	5.93 mm
Front Spar Cap + Skin + Reinforcement	$[+-45/[0/30/0/-30]_{28}/[45/0/-45/30]_{2s}]$	20.15 mm
Front Spar Web	$[+-45/90]_2/Foam/[90/-+45]_2]$	3.86 mm
Aft Spar Cap + Skin + Reinforcement	$[+-45/[0/30/0/-30]_8/[45/0/-45/30]_{2s}]$	7.75 mm
Aft Spar Web	[+-45/90/Foam/90/-+45]	2.93 mm
Ribs	$[+-45/90/+-45]_s$	1.55 mm


V: 1
L: 3
C: 1
Front Spar
Leading Edge
Middle Skin (Inner)
Aft Spar
Ribs
Y
Z
X
Middle Skin (outer)
Output Set: 20G_1, Simcenter NASTRAN Case 1
Deformed(131.76): Total Translation

Loading conditions

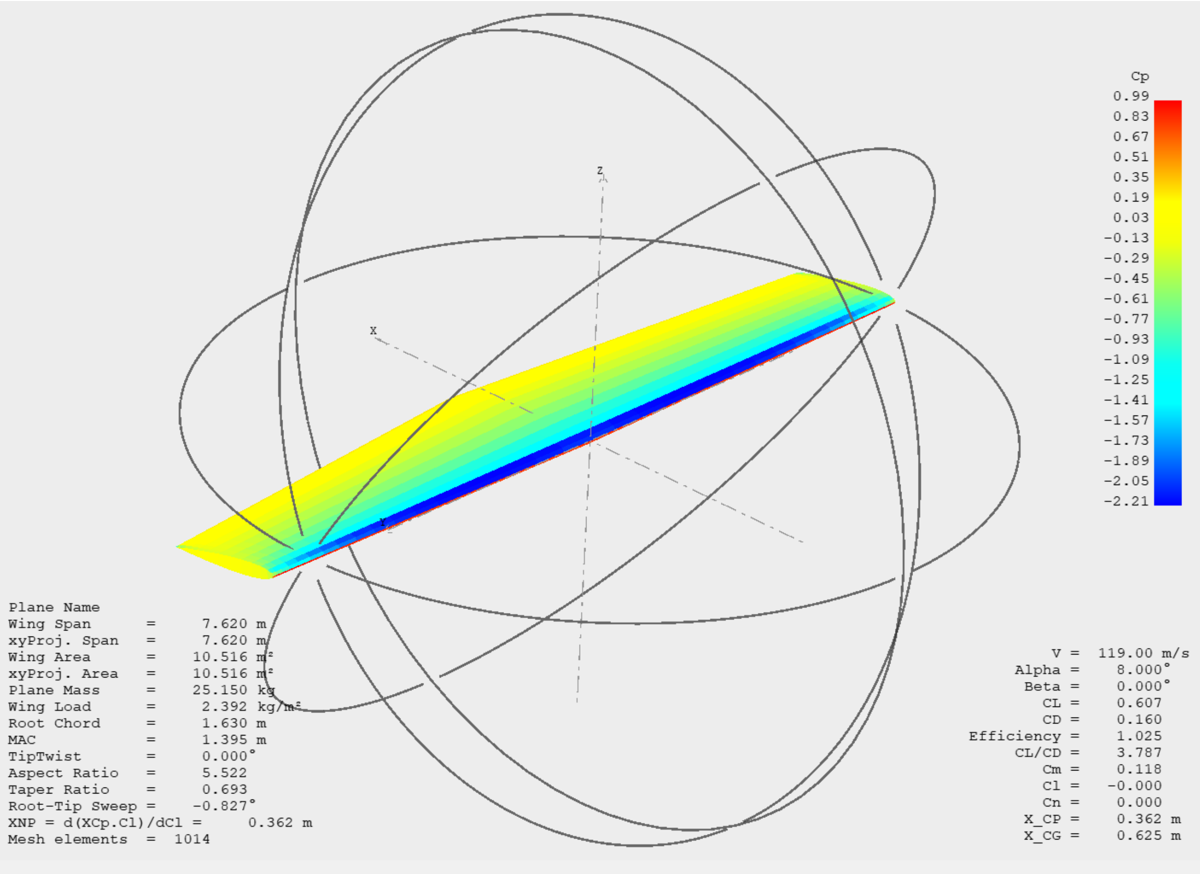
For the purpose of obtaining the appropriate pressure field distribution, the wing was analyzed using Xflr5 where appropriate graphs for Cp(x) and Cl(y) were curve fitted.

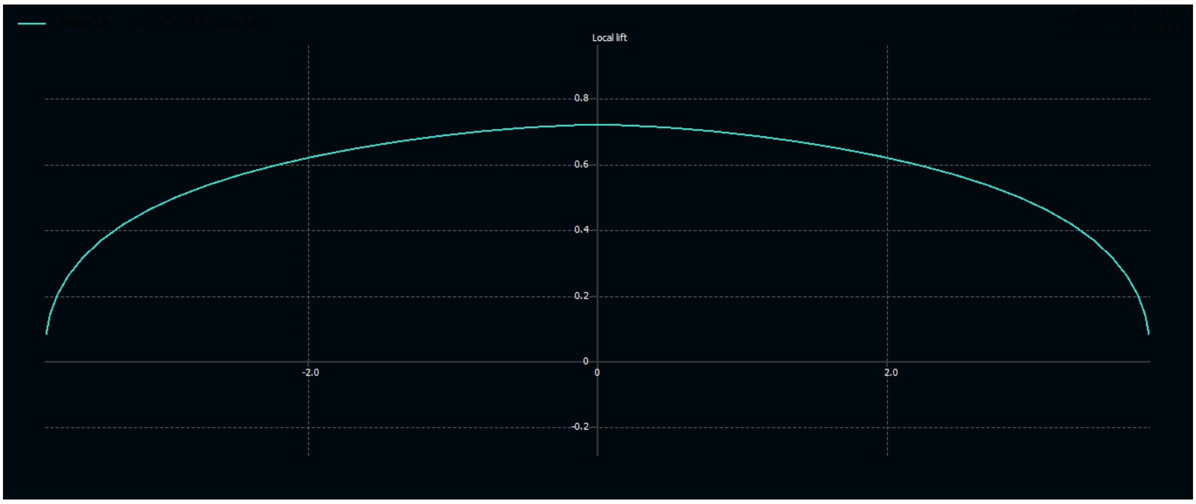
After the equations for Cp(x) and Cl(y) were obtained, they were multiplied and normalized so the pressure field values could be controlled using magnitude of nW in the FEM software.W = ½mg, where m is mass of the airplane and n being the loading factor.

All of these calculations were made using MATLAB.

Below are the images that represent, in order: Pressure field on the wing in Xflr5; Lift distribution on the wings (spanwise); Pressure field distribution of the airfoil (root chord - chordwise); Pressure field implemented in FEMAP and multiplied by loading factor of 20G.

The same pressure field will be used for all wing variations and iterations




Local lift
0.8
0.6
0.4
0.2
0
-0.2
-2.0
0
2.0

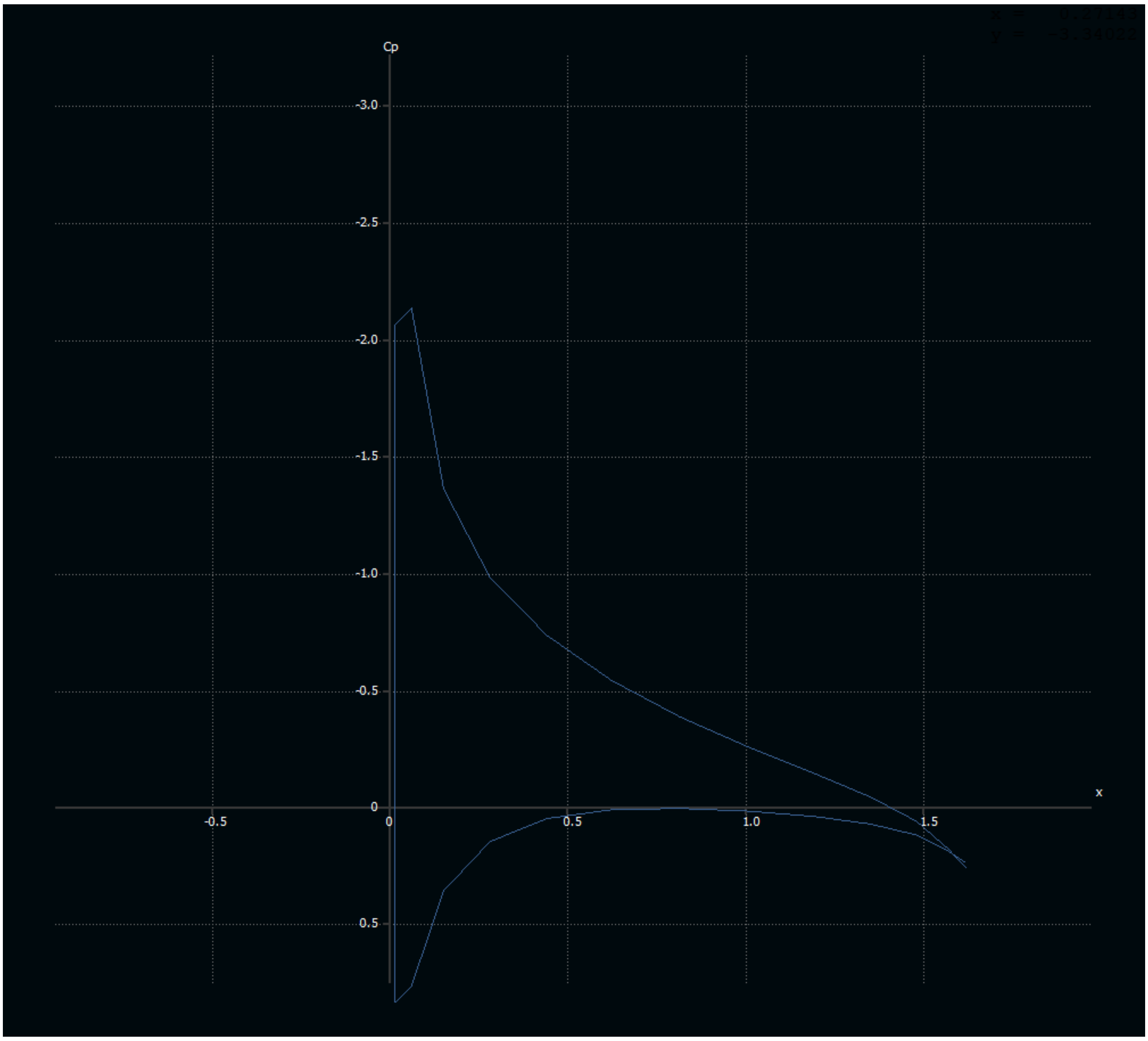
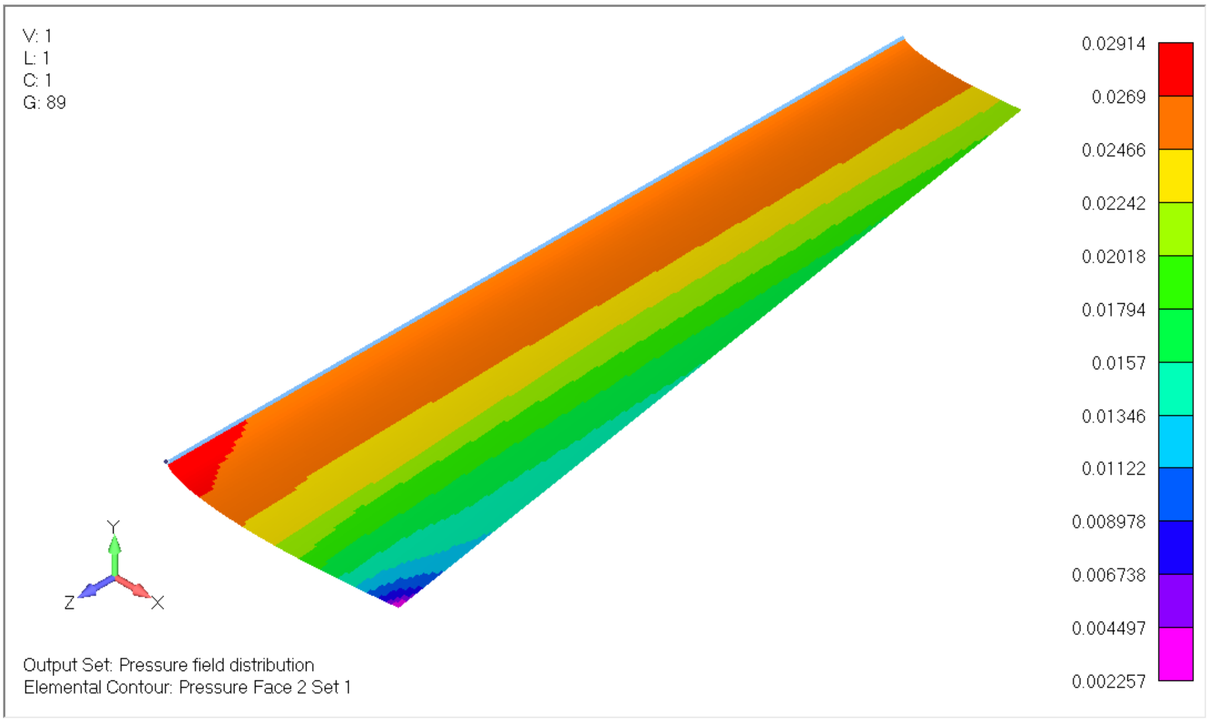

Cp
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0
0.5
x
-0.5
0
0.5
1.0
1.5

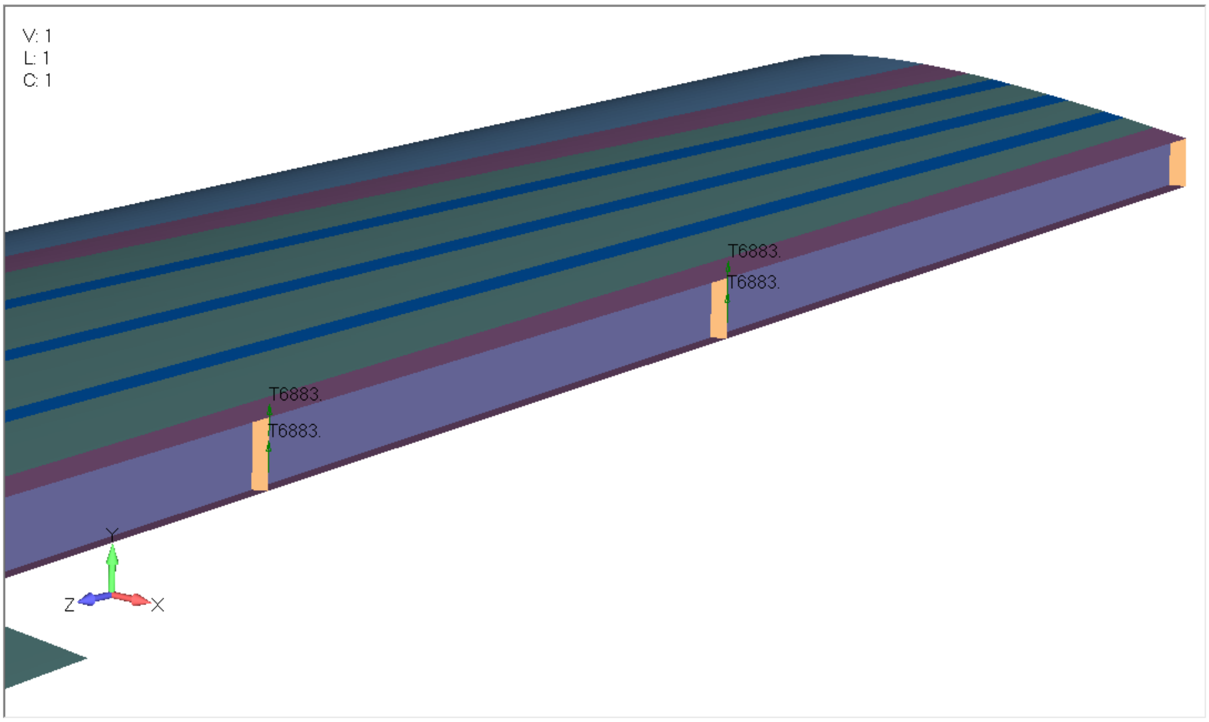
Image below shows pressure distribution over the lower surface of the wing with absolute pressure values in MPa.



Hinge moment was discretized with approximations found in Chapter 8 of Roskams book of Airplane Design.

Force simulating the forces of control surfaces are equal to 6883 N.

Those forces are applied on the ends of the ribs #4 and #5, specifically on curves on those edges.

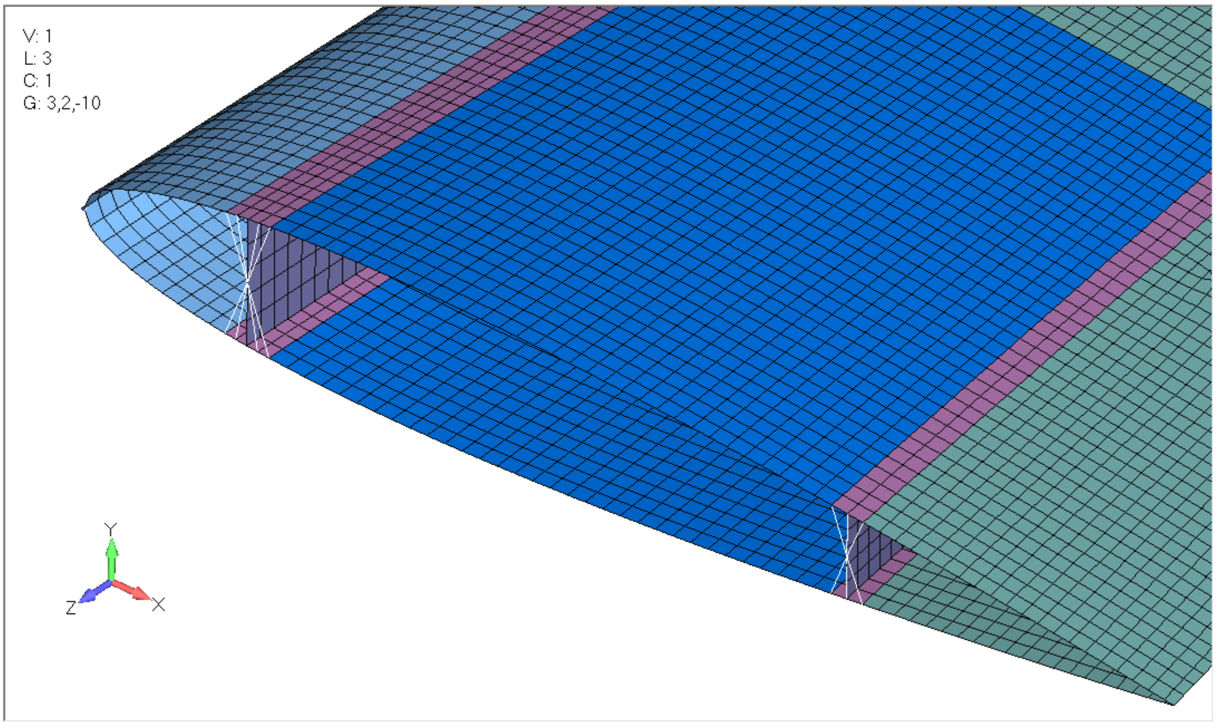


FEM model and results

Chosen configuration of composite layups has proven satisfactory for the load condition of 20 G.

For boundary conditions of an encastre an RBE2 element was used.

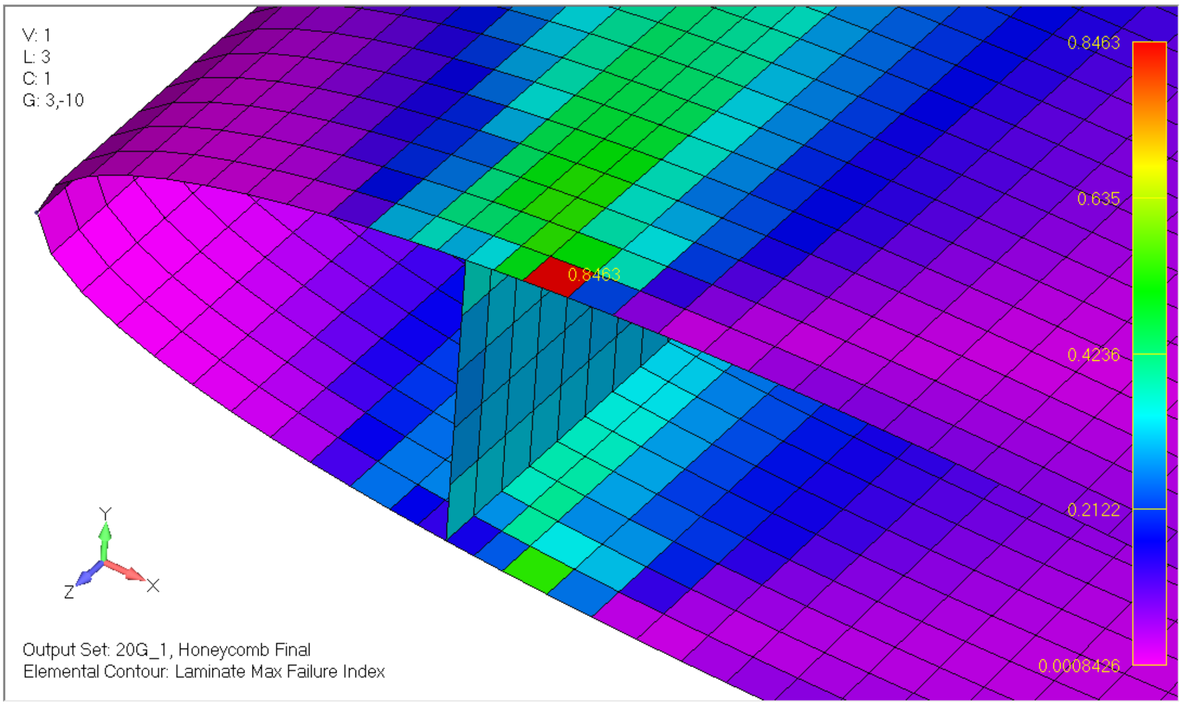
At RBE2 independent node a fixed BC was applied.

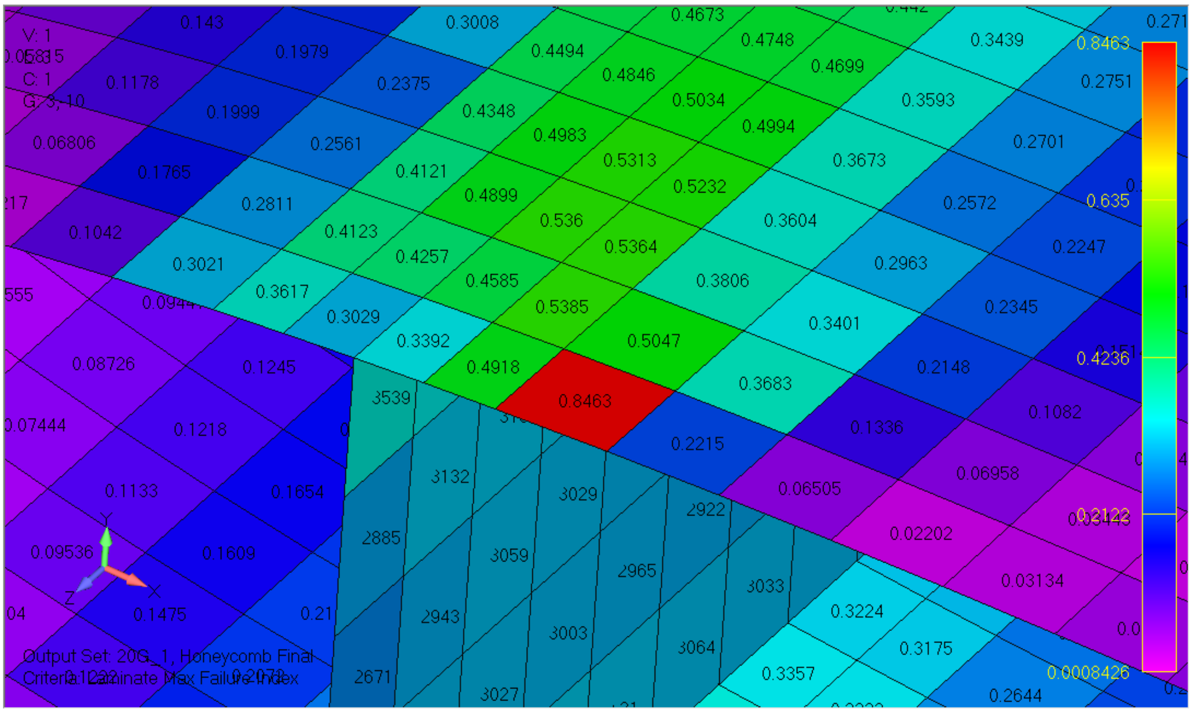


Maximum failure index, according to Tsai-Wu theory, has critical value at the connection site of the inner skin and front spar cap which equals to 0.8463.

Observing the surrounding elements, we can notice the sudden peaks in value might be attributed to differences in stiffness of the inner middle skin and front spar cap.

Same peaks can also be explained by the boundary conditions which are applied near it.

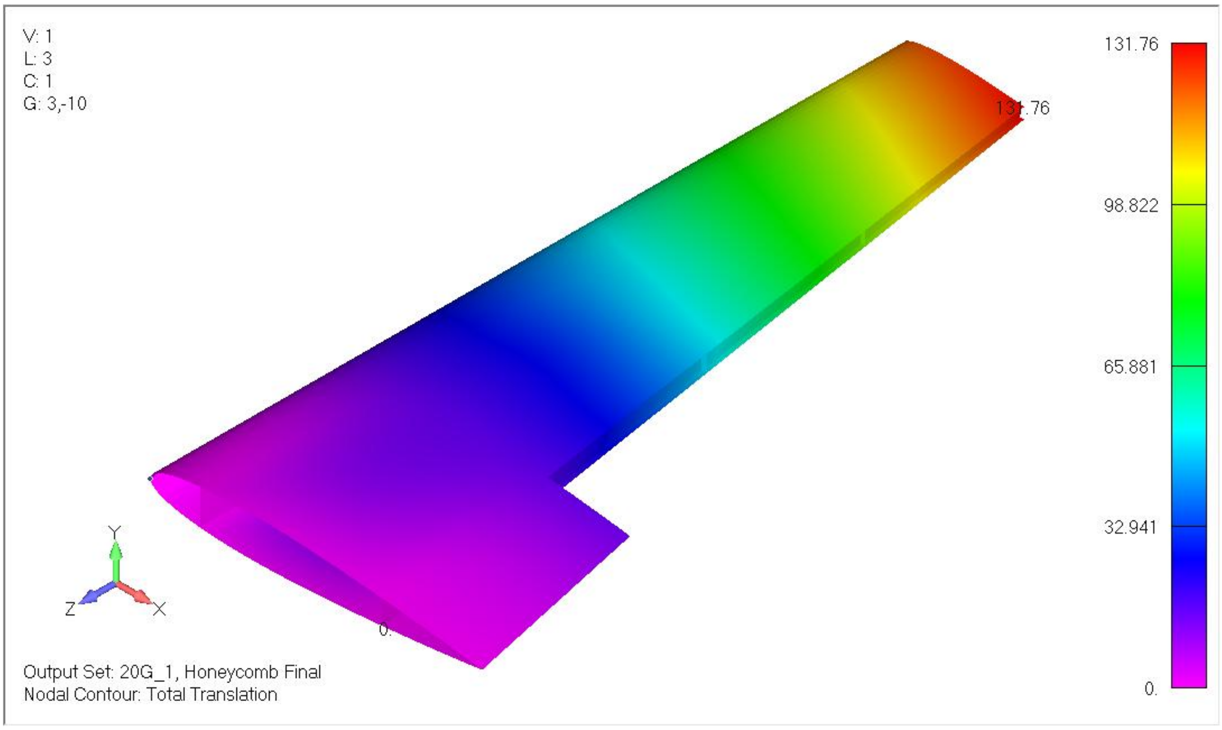


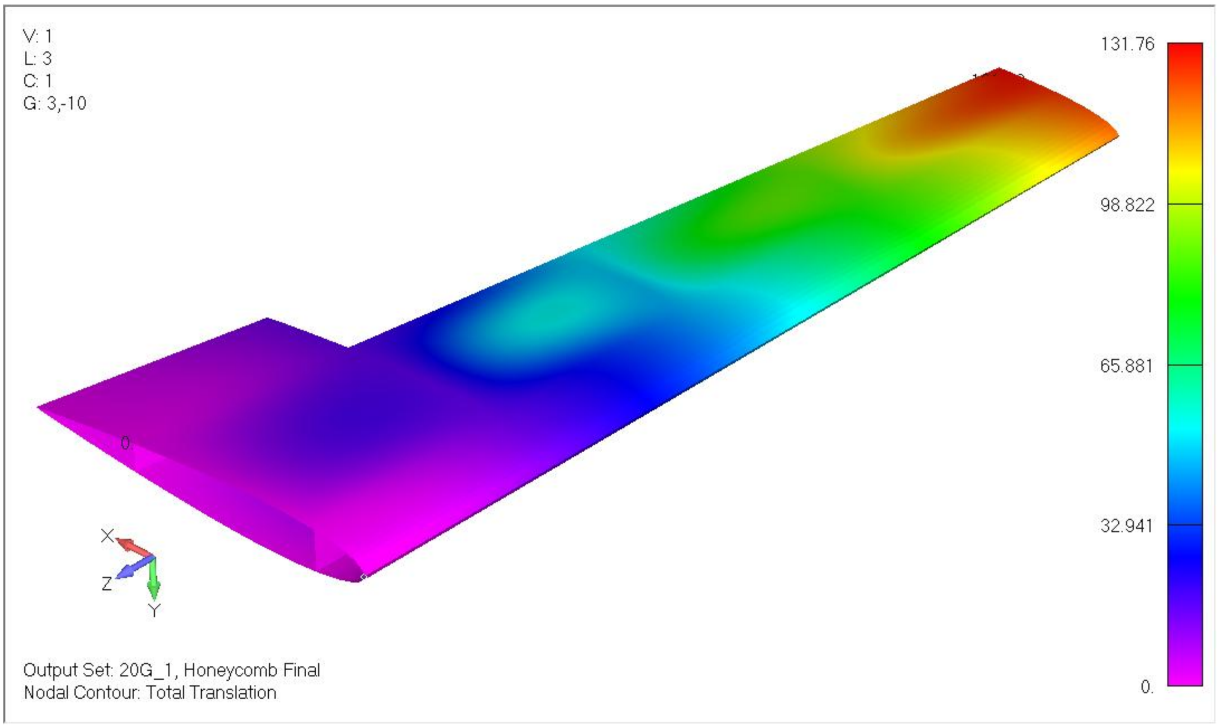


Maximum deflection is as expected at the wing tip with value of 131.76 mm.

Skin buckling is noticeable at the lower surface of the wing, and is a product of how the pressure field was applied to the wing.

Maximum skin deflection is located between ribs #3 and #4 at around 54 mm.





Enveloping the von Mises results for each layer, it is found that stress peaks appear to be on the 45th ply in the inner middle skin layup, which has orientation of -45°, at stress value of 958 MPa.

Ply numbered 129 that experiences peak stress values on the spar cap layup, has orientation of 0° and is one of the plies added as reinforcement.