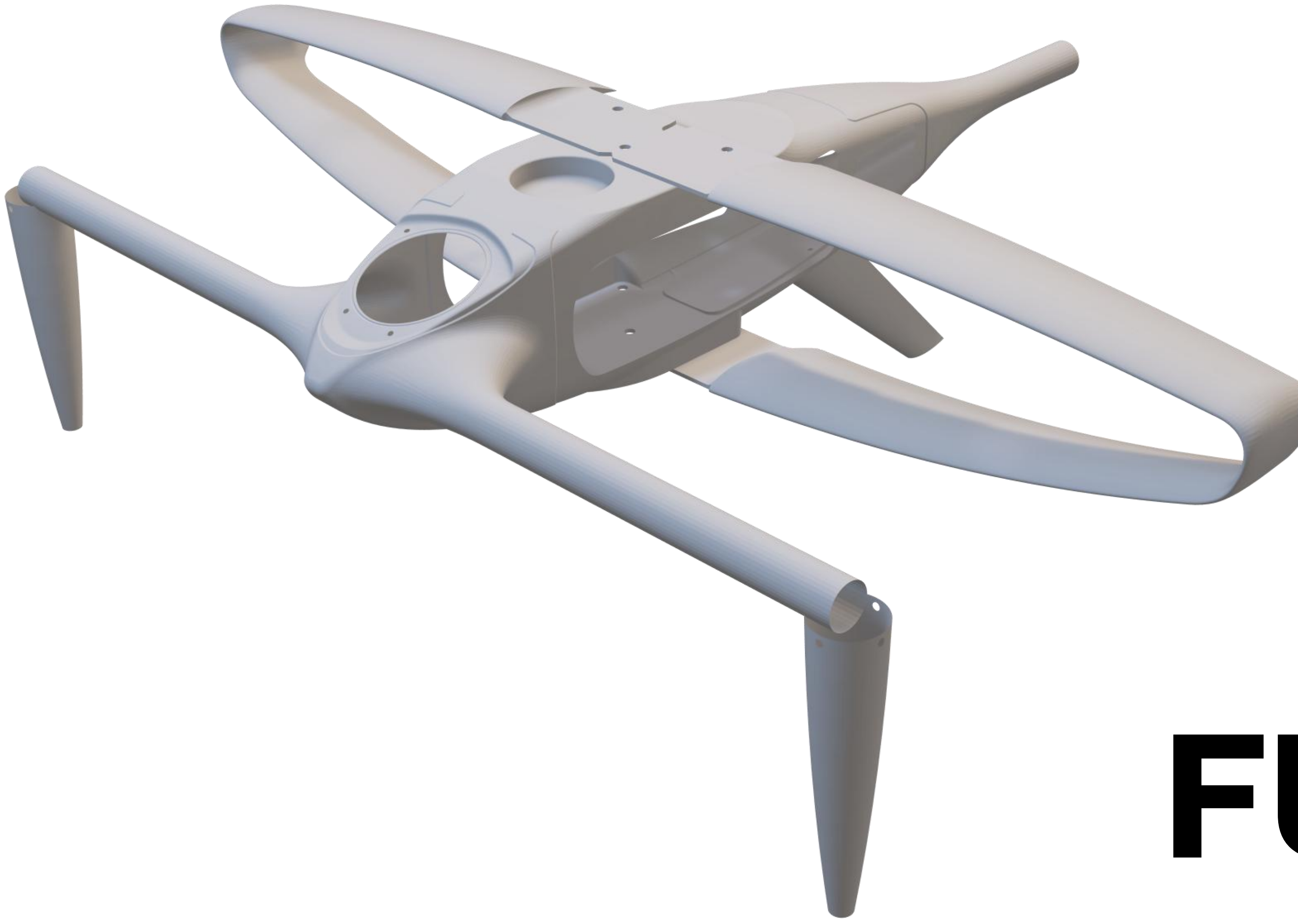
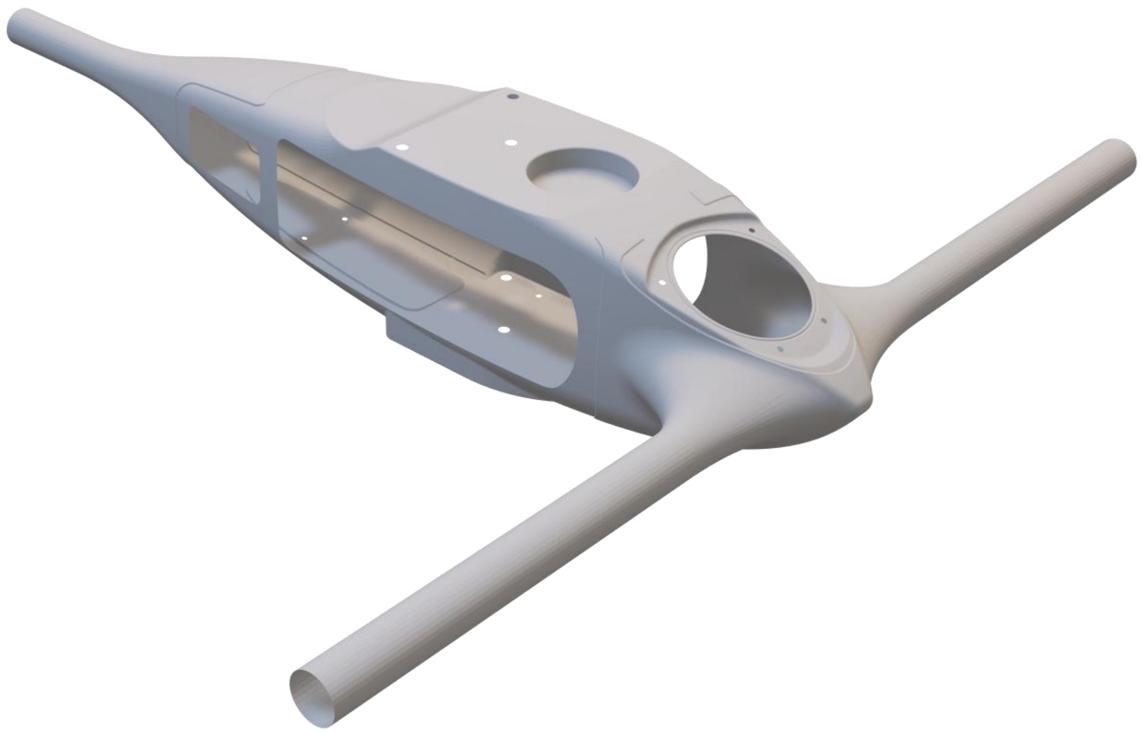
PROJECT



FUKO

INTRODUCTION AND OBJECTIVES



Drone specifications:

- Max Speed - 200 km/h
- Autonomy - 1h
- Range - 100km

Objectives:

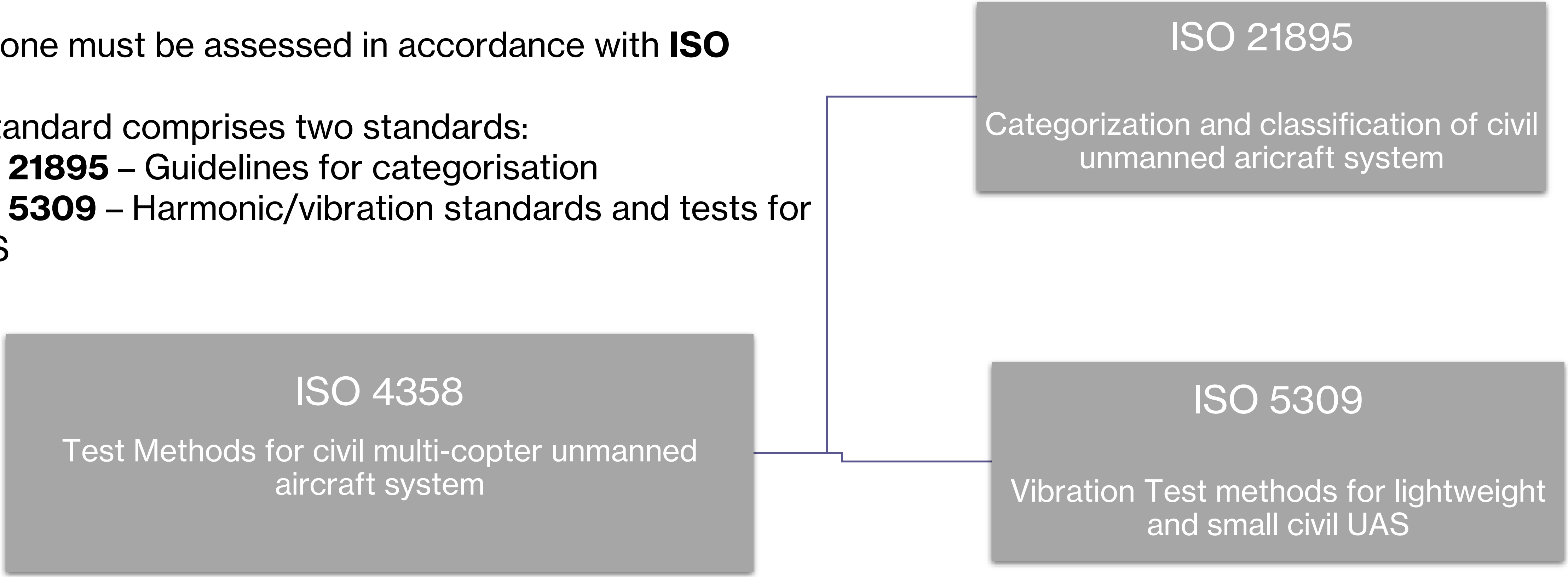
• Minimise the mass of the drone through the use of composite materials.

• Comply with current regulations.

TESTS AND REGULATIONS

The drone must be assessed in accordance with **ISO 4358**.
This standard comprises two standards:

- **ISO 21895** – Guidelines for categorisation
- **ISO 5309** – Harmonic/vibration standards and tests for UAS



TESTS AND REGULATIONS

According to ISO 21895, the drone falls into Level IV, with an estimated mass of around 6-7kg.

Level	Maximum take-off mass kg
I	0 < mass ≤ 0,25
II	0,25 < mass ≤ 0,9
III	0,9 < mass ≤ 4
IV	4 < mass ≤ 25
V	25 < mass ≤ 150
VI	150 < mass

For testing methods, according to ISO 5309, reference must be made to both proposed categories:

- **Multicopter** – equipped with 3 propellers.
- **Fixed Wing** – having 2 rigid wings.

Two tests have been added to those required by law:

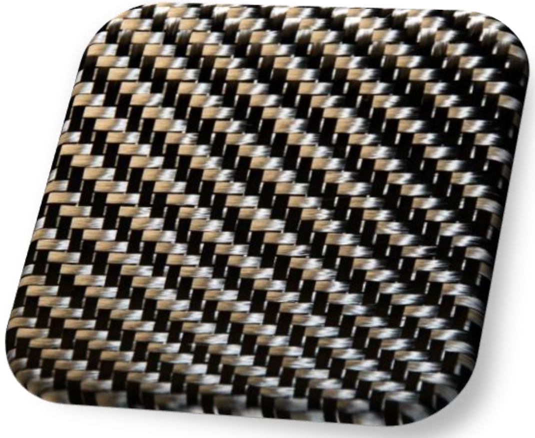
- Oscillatory load on motors (harmonic analysis)
- Impact in the event of a fall (0.5 m)

UA configuration	Engine/power plant type	Maximum take-off mass kg		Type of vibration	Magnitude
Multicopter	Electric motor	Level II, III, IV		Random; Sine	Refer to Table 3 and Table 4 for details.
		Level V	≤ 50	Random; Sine	Refer to Table 3 and Table 4 for details.
			> 50	Random; Sine	Refer to Table 5 and Table 6 for details.
	Turbine engine, piston engine	Level V		Sine-on-random (known frequency)	Refer to Figure 1 and Table 7 for details.
				Random (unknown frequency)	Table 8
	Mixed power plant	Envelope value according to the type of mixed power plant.			
Fixed-wing	Electric motor	Level II, III, IV, V		Sine	Refer to Table 9 for details.
	Turbine engine, piston engine	Level V		Sine	Refer to Table 10 for details.
	Mixed power plant	Envelope value according to the type of mixed power plant.			

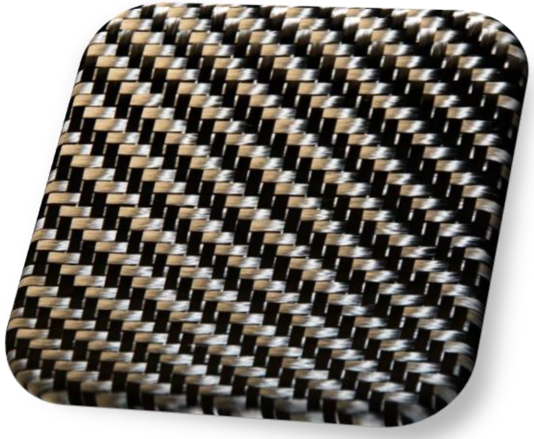
MATERIALS

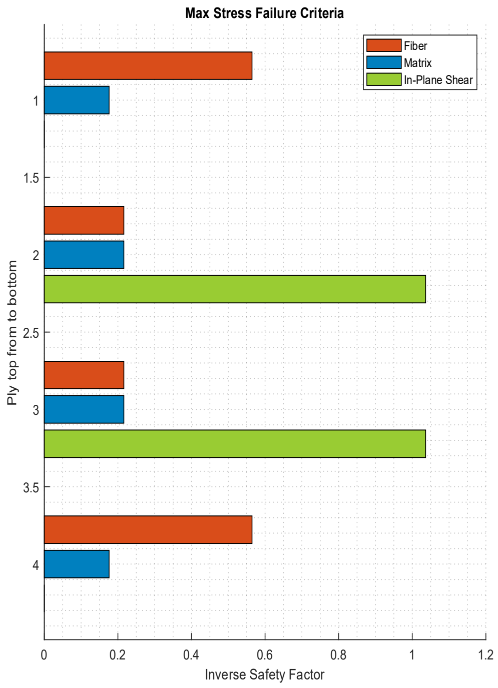
Material	Tk	E1	E2	ν12	G12	Xt	Xc	Yt	Yc	S12	ρ
[unit]	[mm]	[Gpa]	[Gpa]	[]	[Gpa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[g/cm^3]
Tw 200g T300 3K (CFRP)	0,234	45	45	0,046	5,2	800	500	800	500	65	1500
Tw 630g T700 12K (CFRP)	0,63	60	60	0,038	7,3	720	530	720	530	60	1500
Tw 380g T700 12K (CFRP)	0,42	60	60	0,049	4,3	820	530	820	530	60	1500

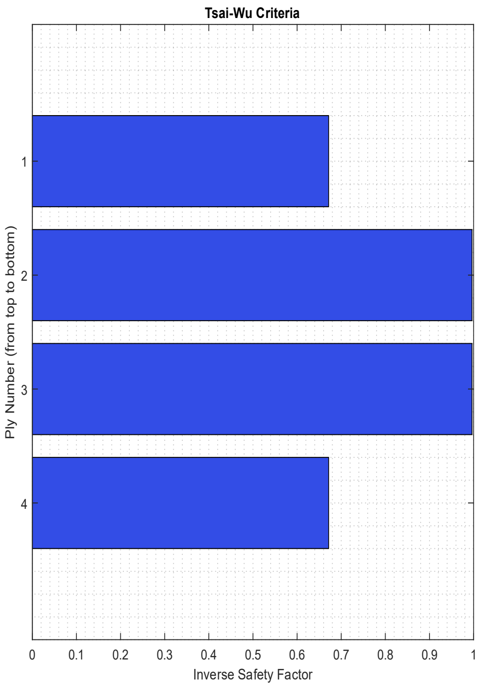
Three different fabrics were used, all with the same twill weave.
The fibres used are T300 and T700.
All three have different weights and numbers of fibres per tow.



LAMINATE QUASI-ISOTROPO







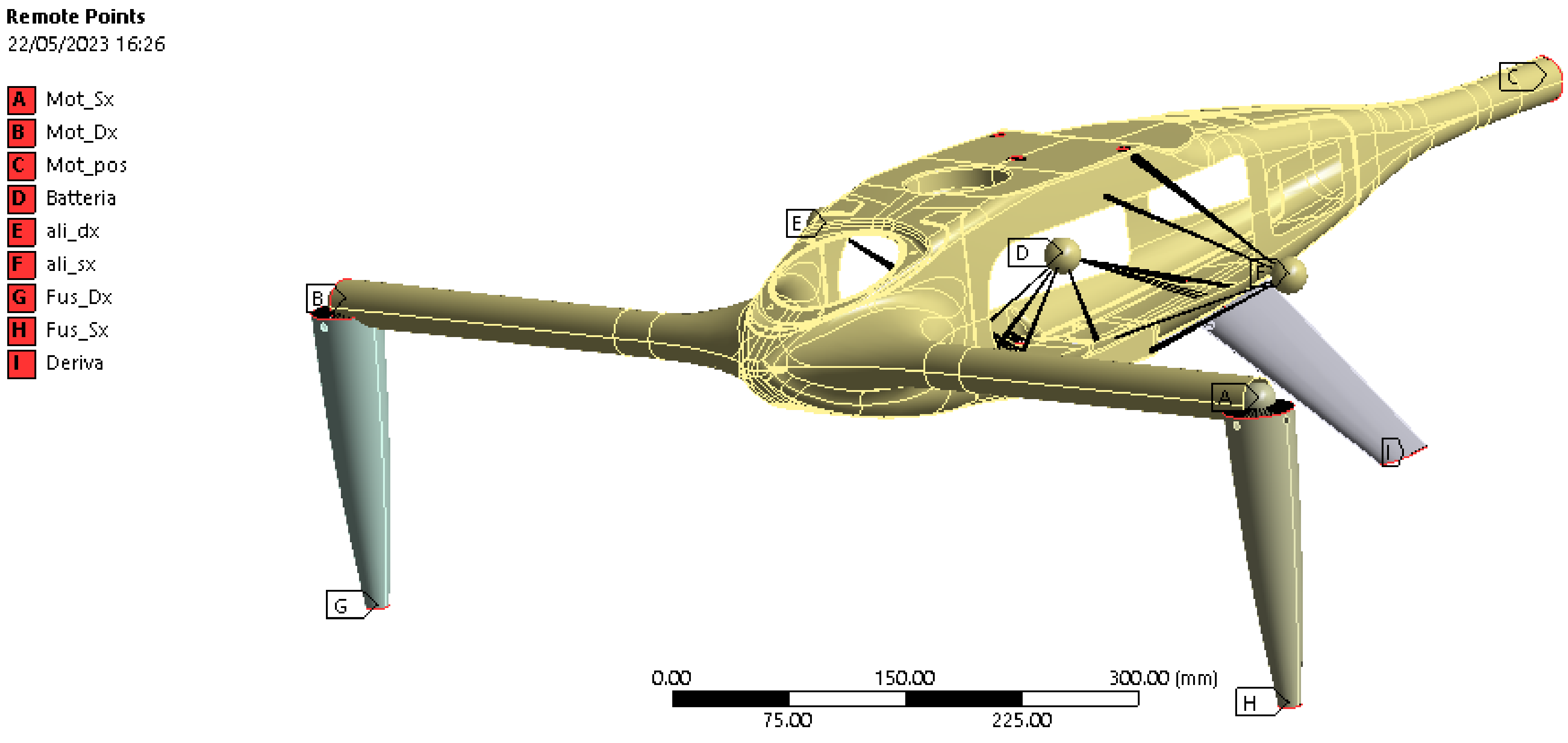
Properties	Tk	E1	E2	v12	G12
[unit]	[mm]	[Gpa]	[Gpa]	[]	[Gpa]
T300 200g [0/45]s	0,972	34,1	34,1	0,277	13,3

Properties	Xt	Xc	Yt	Yc	S12
[unit]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
T300 200g [0/45]s	650	405	650	405	315

The resistance assessment was performed on Matlab using failure criteria, simulating uniaxial tension/compression.

CONCENTRATED MASSES

LUMPED MASS:			
M Motor (kg)		0.5	
N motor		3	
	M Tot Motor		1.5
D Yfront (mm)		230	
	Yfront (mm)		400
D Xback (mm)		80	
	Xback (mm)		850
M Battery (Kg)			3
M Wing (Kg)		0.25	
n Wing		2	
	M Tot Wing (Kg)		0.5
Ywing (mm)		200	
M Tot Lumped Mass (Kg)			5

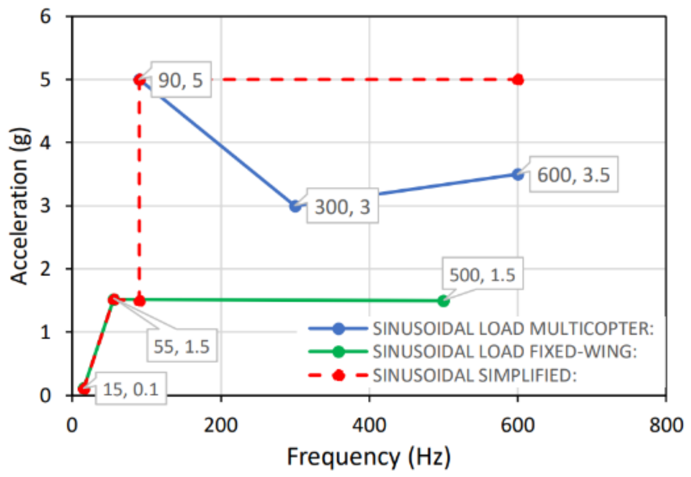


- All remote points are rigid except for the batteries and wings.
- The mesh is 5 mm in size with adaptive curvature.
- The remote points G, H, and I are used as constraints:
  - G,H ramped on X and Z
  - I ramped on Y and Z

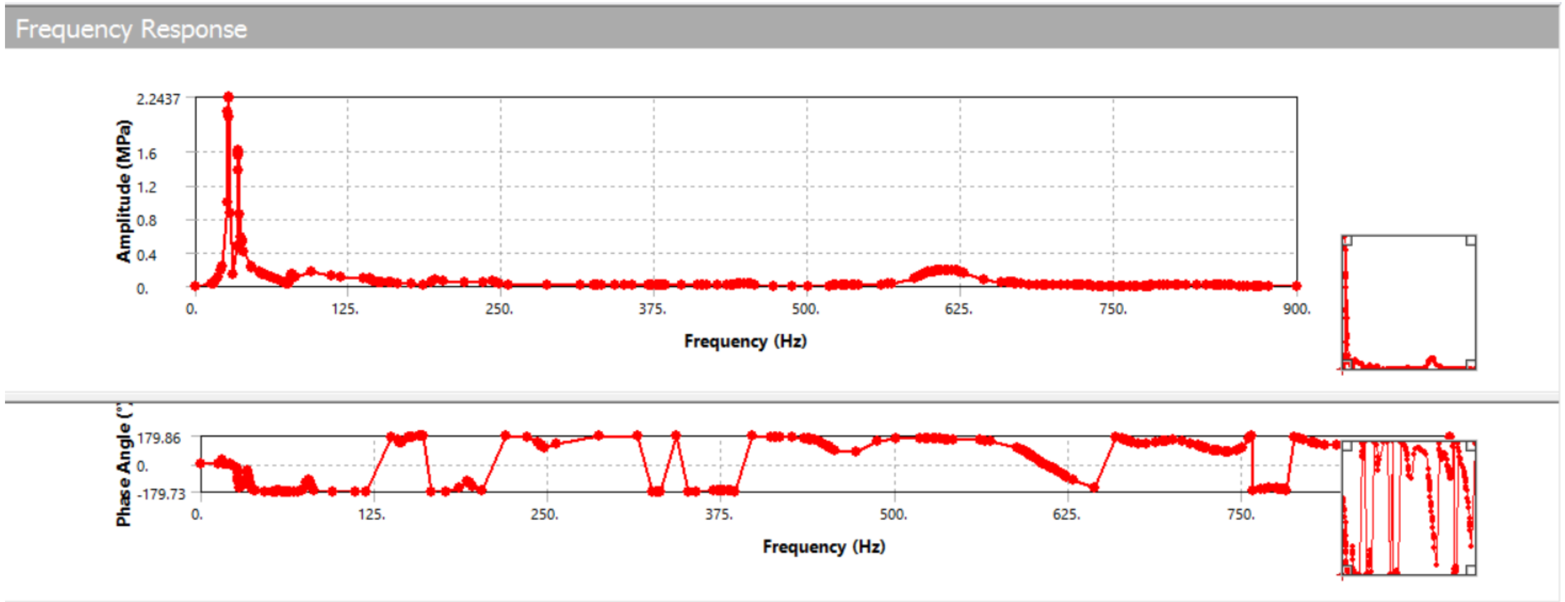
HARMONIC ANALYSIS-SHAKER

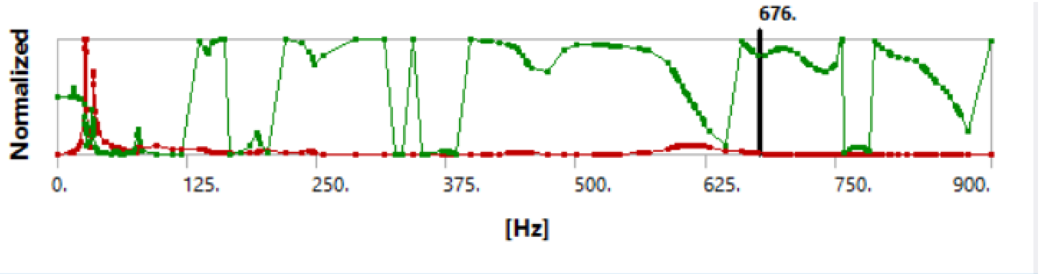
These are the test results according to ISO 5309. The correct values were used in favour of safety:

	Frequency [Hz]	X [mm/s²]	Y [mm/s²]	Z [mm/s²]
1	0.	0.	0.	0.
2	15.	1000.	1000.	1000.
3	55.	15000	15000	15000
4	89.	15000	15000	15000
5	90.	50000	50000	50000
6	900.	50000	50000	50000
*				



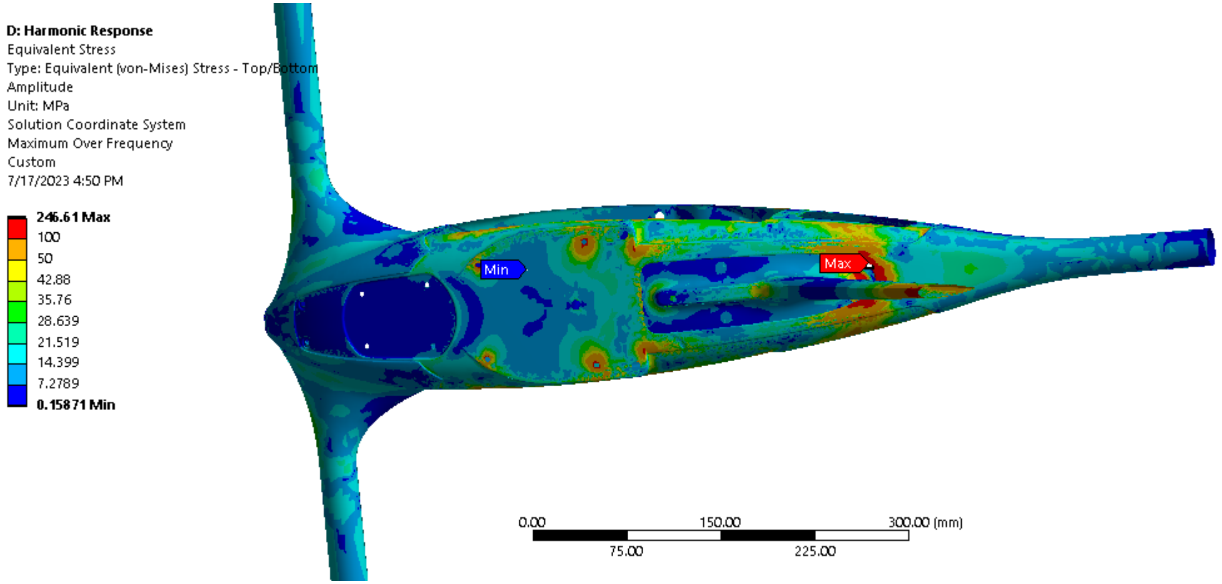
The results obtained from the analysis show this frequency responsewith the corresponding normalised graph.

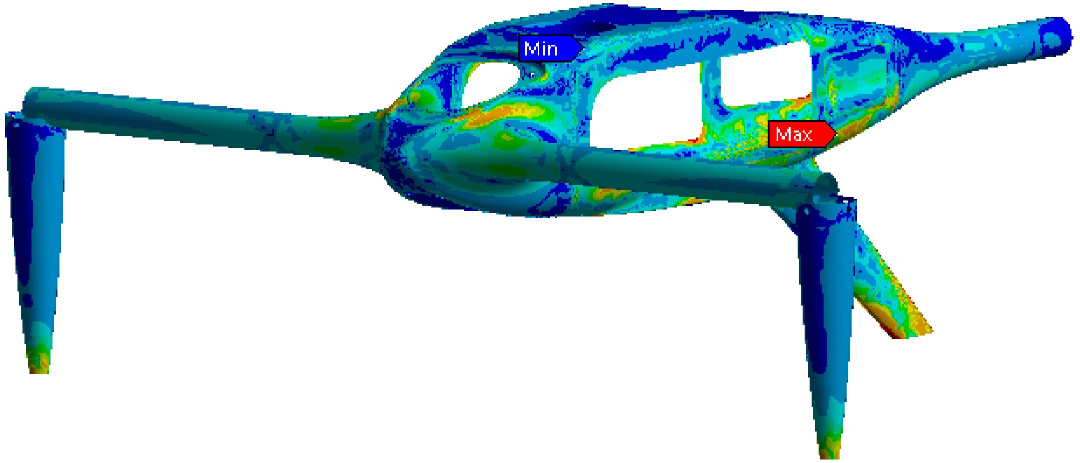




HARMONIC ANALYSIS-SHAKER

As regards equivalent stress, the most stressed point is the rudder attachment. This is consistent with other analyses carried out, which also report the highest values in that area. The maximum stress is 246 MPa.





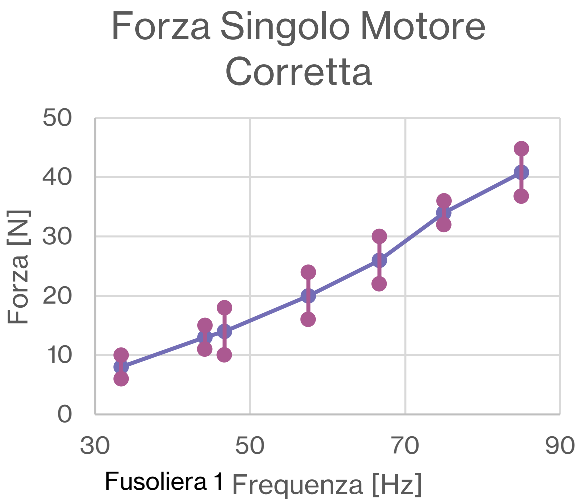
HARMONIC ANALYSIS OF MOTOR LOAD

The analysis of the load on the motors was evaluated using two complementary approaches:

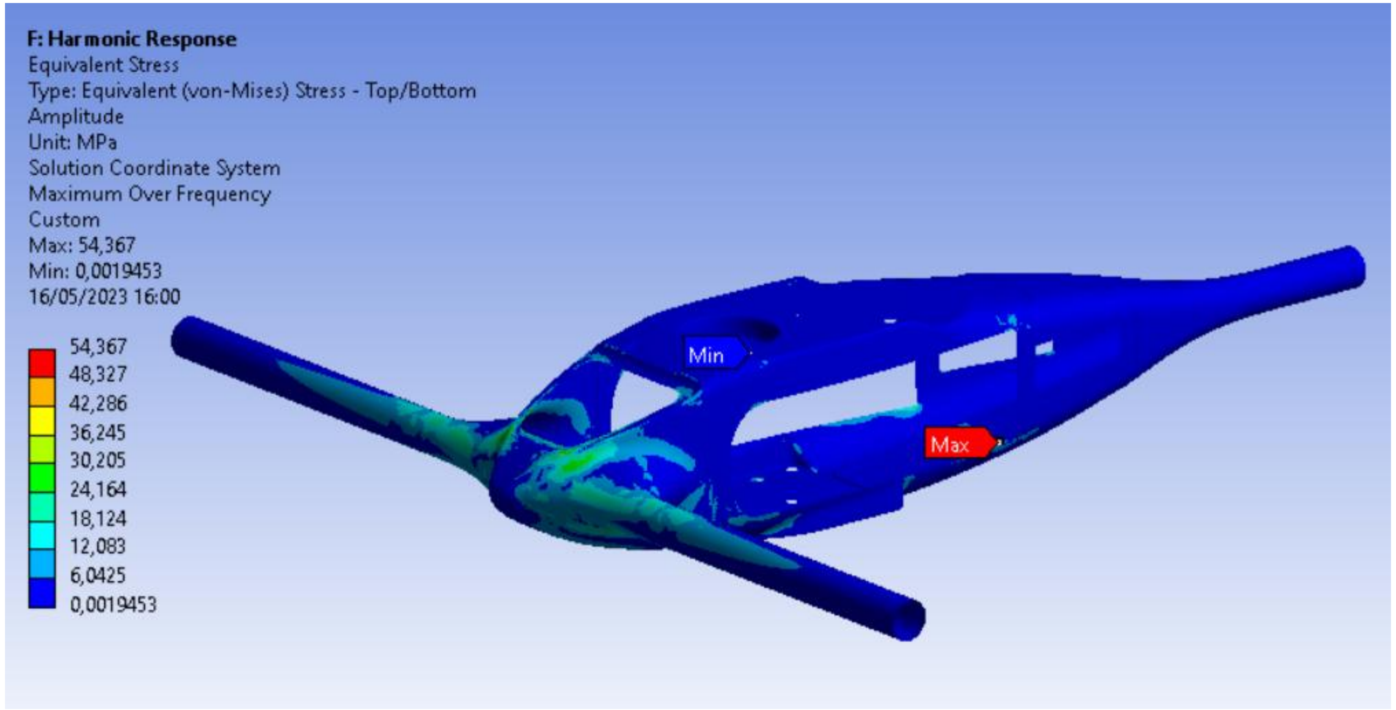
- Unconstrained drone and oscillating forces on the motors (in phase and out of phase)
- Constrained drone in the motors and resulting force applied as acceleration of the entire drone body.

The most severe conditions were then combined in Matlab.

Frequency [Hz]	Acc z [mm/s^2]
0	0
33	2000
44	2000
47	2000
58	1000
67	2000
75	2000
85	2000
90	2000



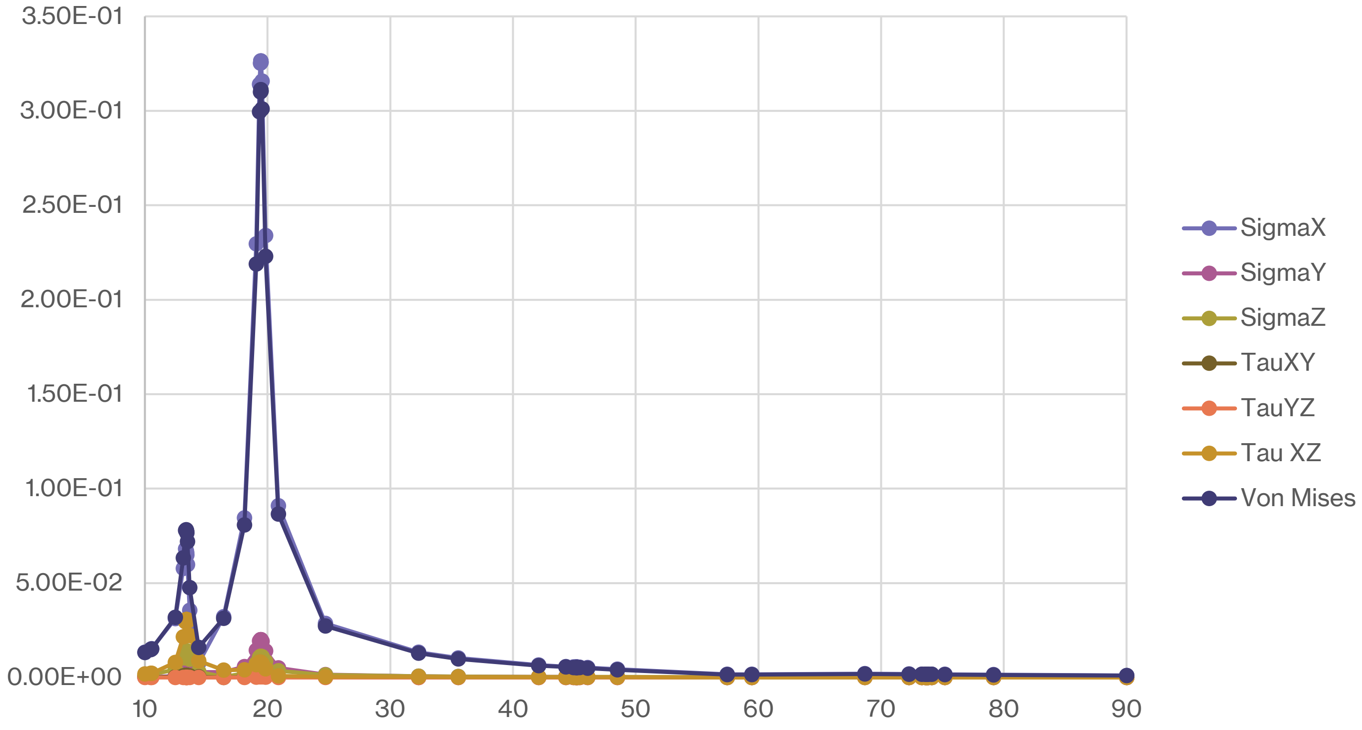
Fusoliera 1



This solution has a Max Stress of 54 Mpa, but it's a singularity

HARMONIC ANALYSIS OF MOTOR LOAD

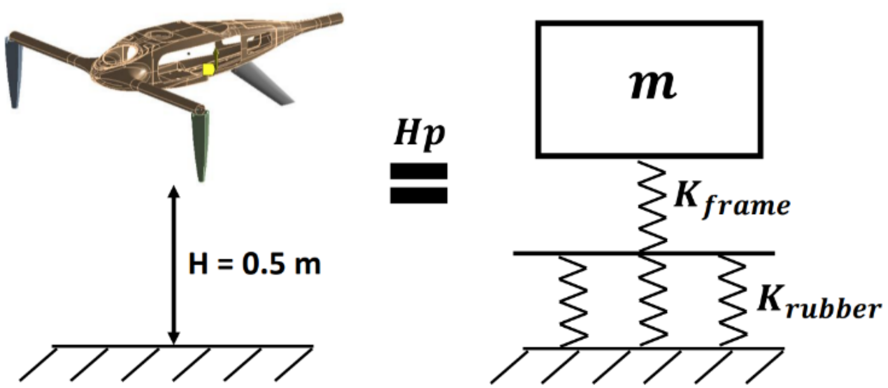
- The results showed a resonance frequency of around 20 Hz.
- At this frequency, the thrust of the motors is not sufficient to make the drone fly. Therefore, it does not present a serious problem for the fuselage.



In general, the stresses obtained from the flight load simulation were not found to be critical. Therefore, this simulation is not to be considered for design purposes..

IMPACT TEST

Assumptions:
- Elastic behaviour
- Concentrated parameter model



Input:
Acceleration: 100 N/m^2
Mass: 5.5371 kg
Force: 553.71 N
Average deformation: 5.4587 mm

We calculate K (force/deformation): 100,913.1 N/m

We introduce Kb (bushing): 194,386 N/m

We assume the behaviour of springs in series (1/(1/K+1/(Kb*3)): 86,026.53 N/m

Acceleration can also be written as: $a = \frac{F}{m} = \sqrt{\frac{2\,k\,g\,h}{m}}$

We therefore have the new acceleration: 390.2007 m/s^2

With a CS = 2 and Cfatica = 1, we have a maximum deformation of 200 N/mm^2

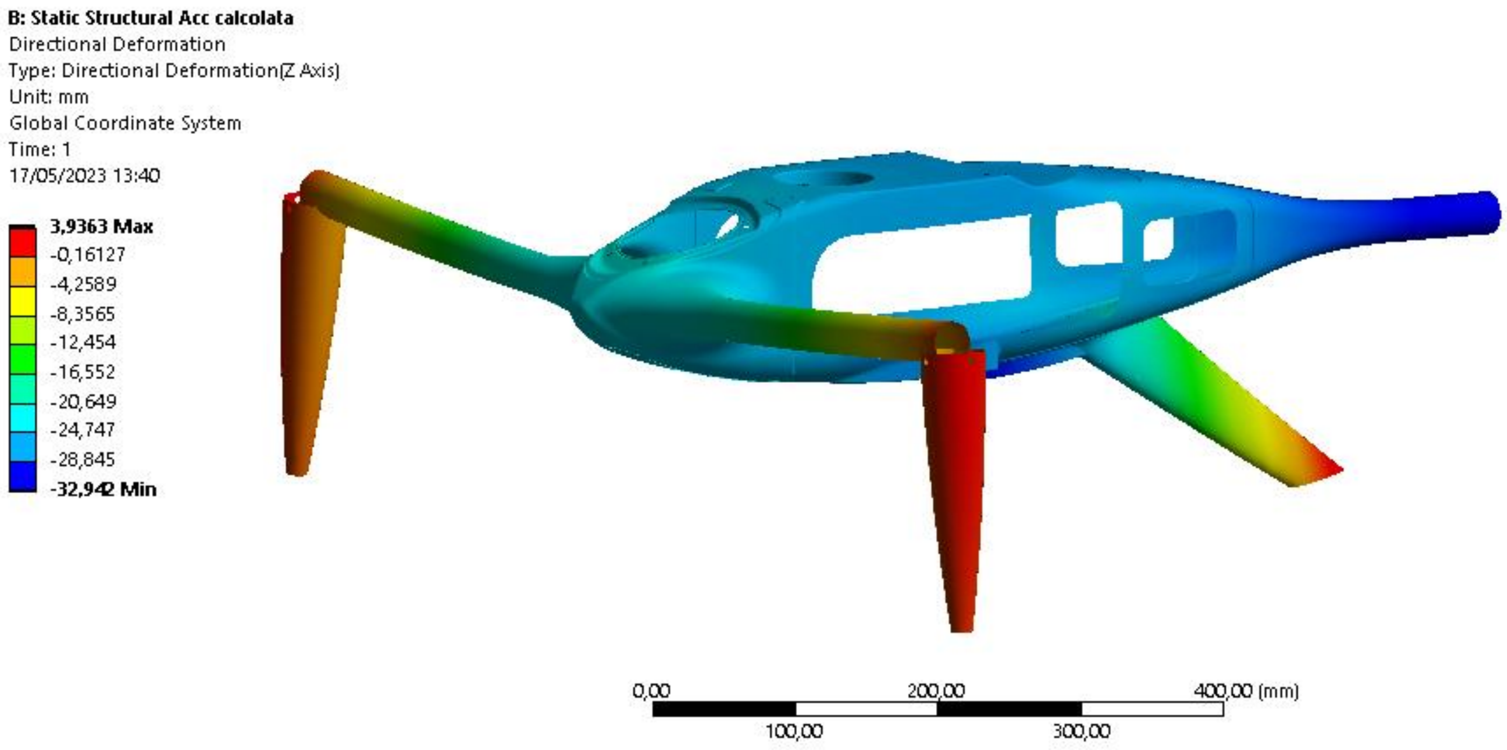
IMPACT TEST

Input:
Acceleration: 390200.7 N/mm^2

The front legs are constrained only in X and Z, to ensure lateral opening.

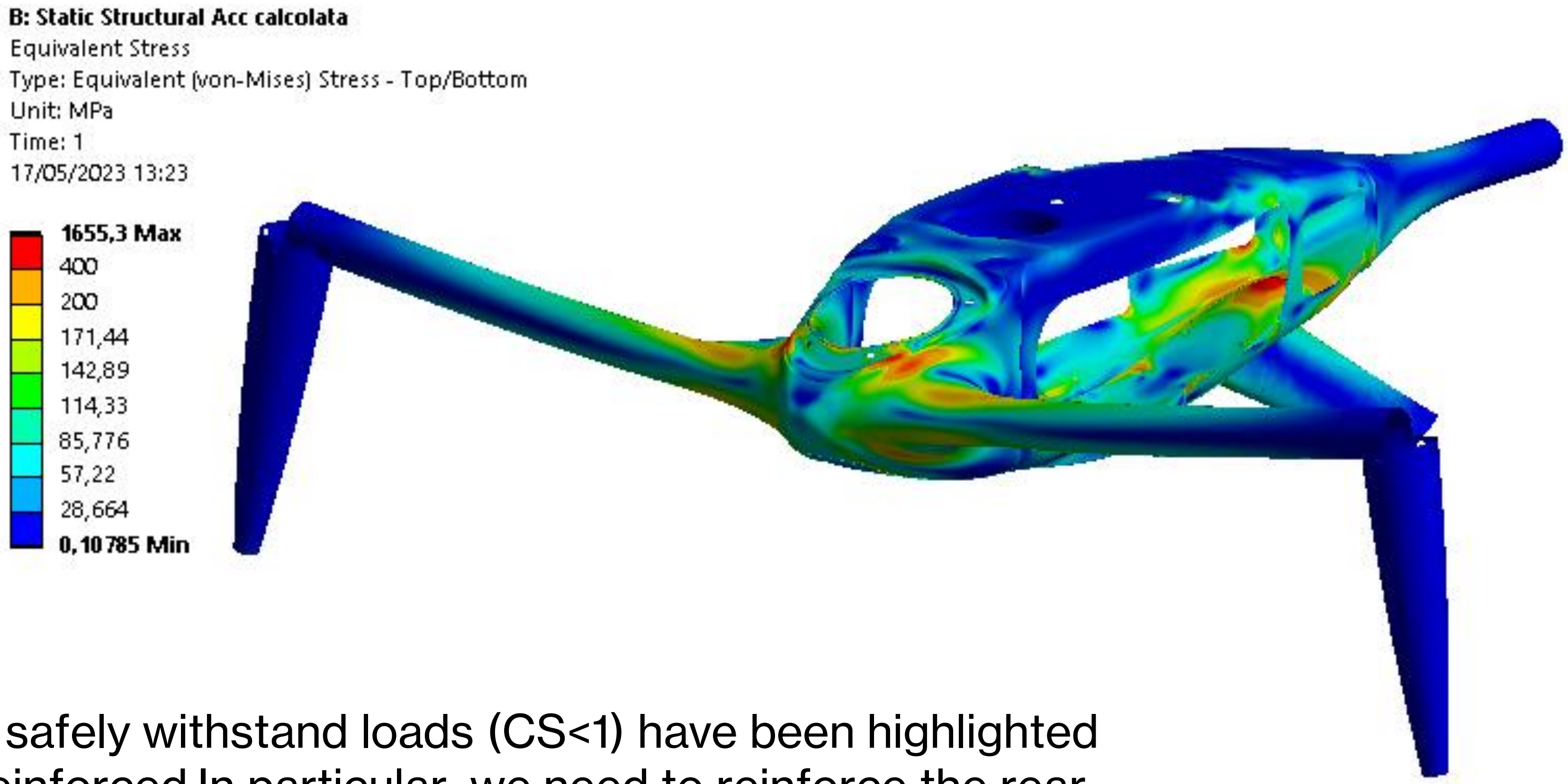
The rear leg is constrained only in Y and Z, so that it can deform correctly.

We also calculate the directional deformation as in the previous simulation.



Now we see that the drone has an average deformation of 21.3 mm with a maximum deformation of 32.942 mm. This is much higher than the previous one, so we need to pay attention to this deformation.

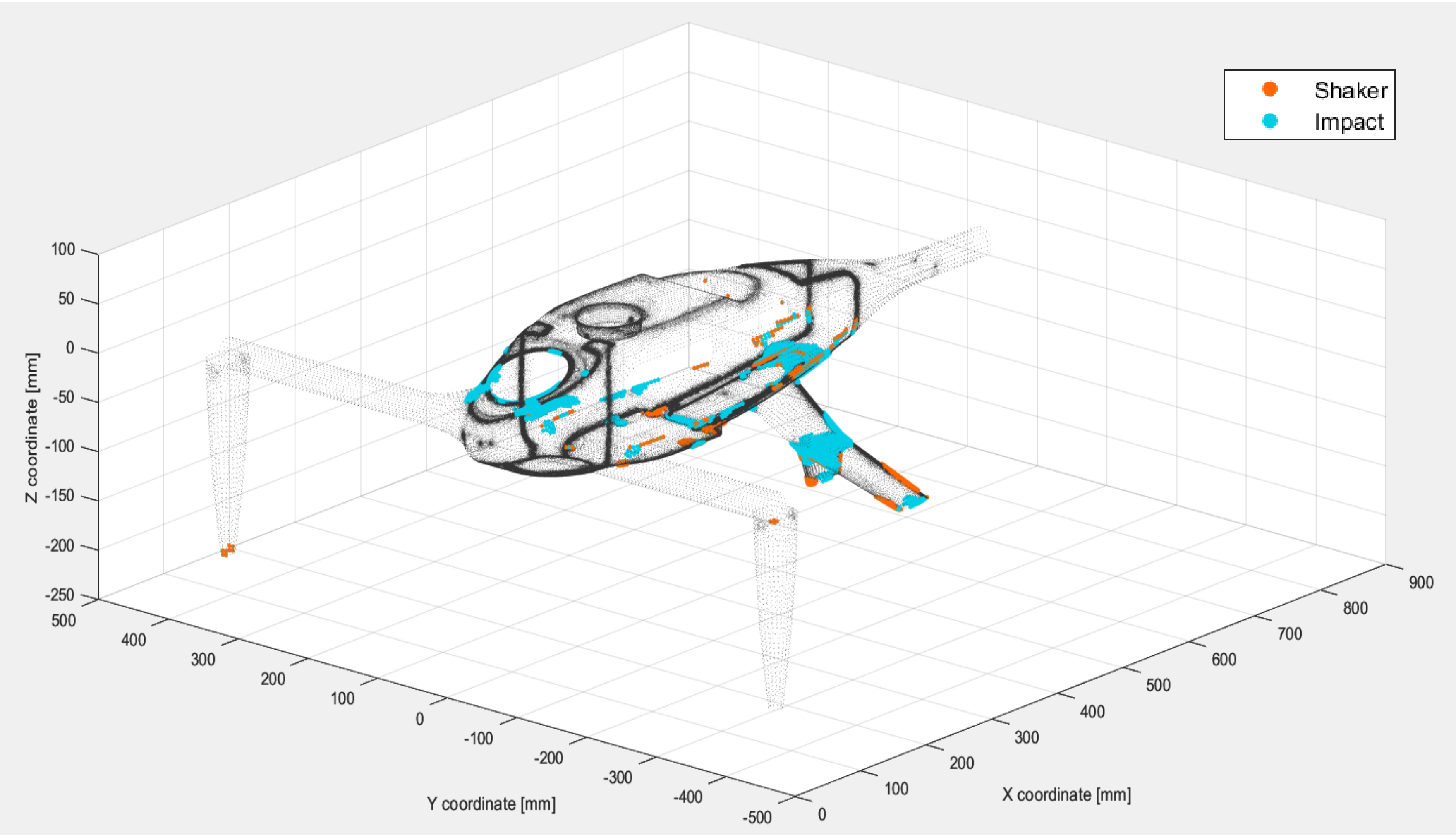
IMPACT TEST



Areas where the drone cannot safely withstand loads (CS<1) have been highlighted and will therefore need to be reinforced.In particular, we need to reinforce the rear section, near the tail fin, and the front section, near the parachute opening and the arms.

An acceleration of 40g was used for future analyses.

Comparison of simulations



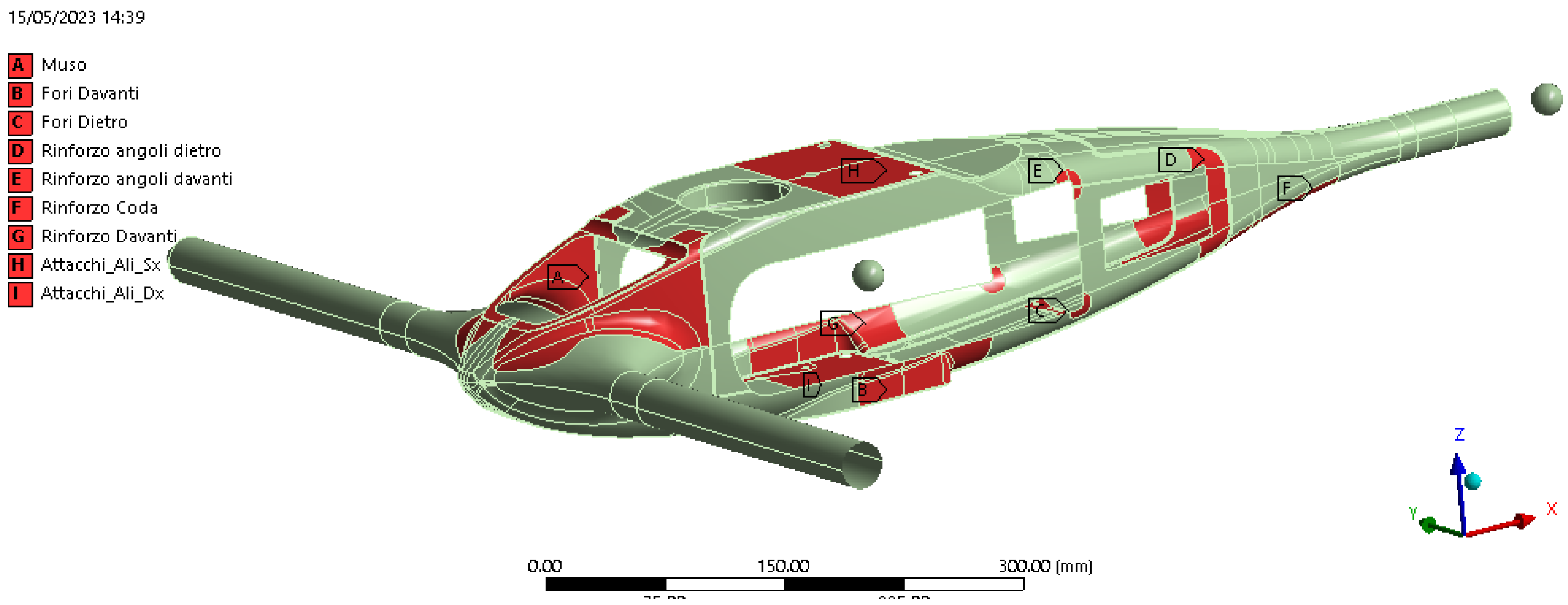
To assess which of the simulations had the greatest impact, a Matlab script was also used to compare the most stressed points of the two simulations.The reference values for the two are:

- 50MPa Shaker
- 200MPa Impact

FINAL THICKNESSES

To determine the optimal thicknesses of the fuselage areas, a parametric optimisation was set up on the Shaker simulation.
The constraints used for the optimisation are:

- Minimise mass
- Stresses below the permissible limit
- Increases in thickness in steps of 0.5 mm.



Value of the thickness

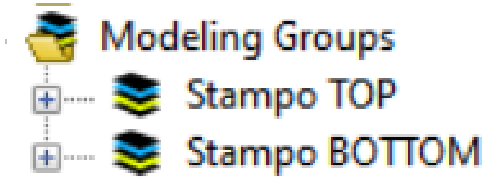
A	1mm
B	2mm
C	1.5mm
D	2.5
E	2mm
F	2mm
G	1.5mm
H	1.5mm
I	1.5 mm

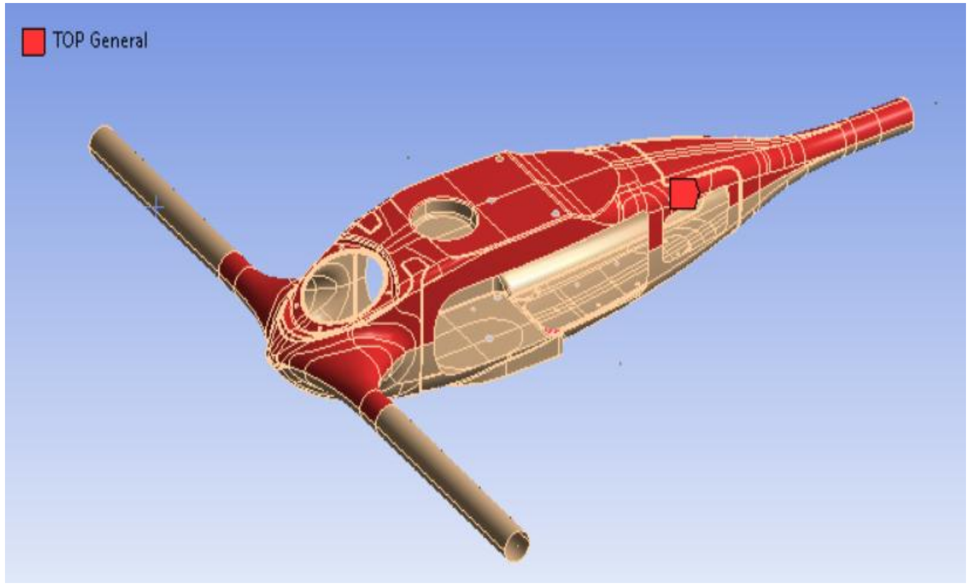
PLY

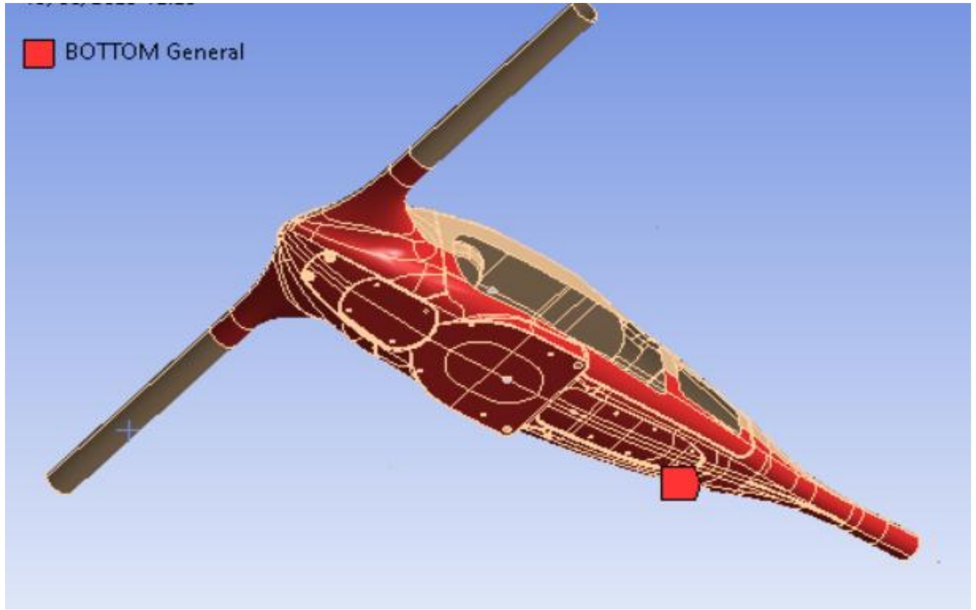
Objectives:

- Minimise the number of plies
- Maintain the symmetrical sequence
- Thicken only where necessary

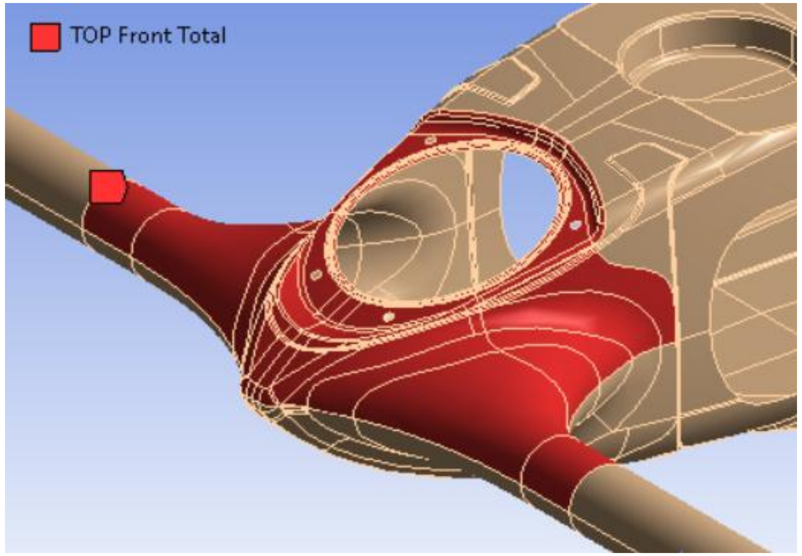
Having two moulds on which to laminate, the plies were divided into two groups, TOP and BOTTOM respectively.

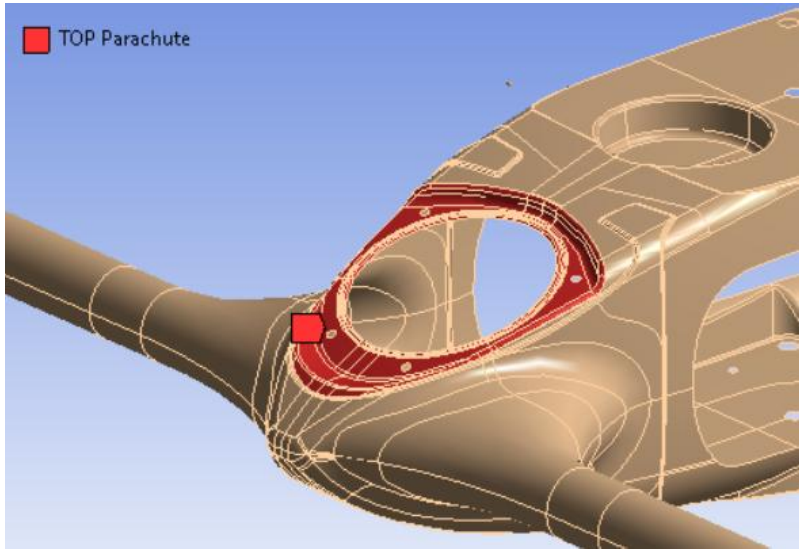




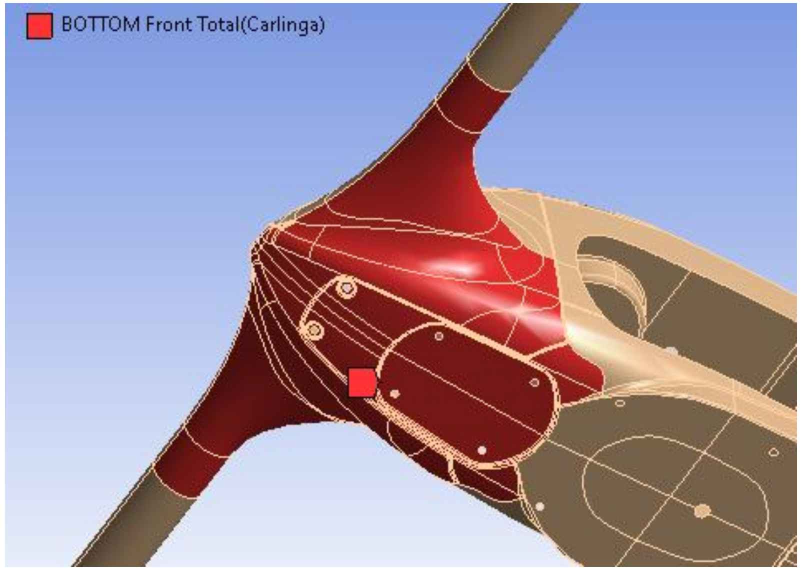


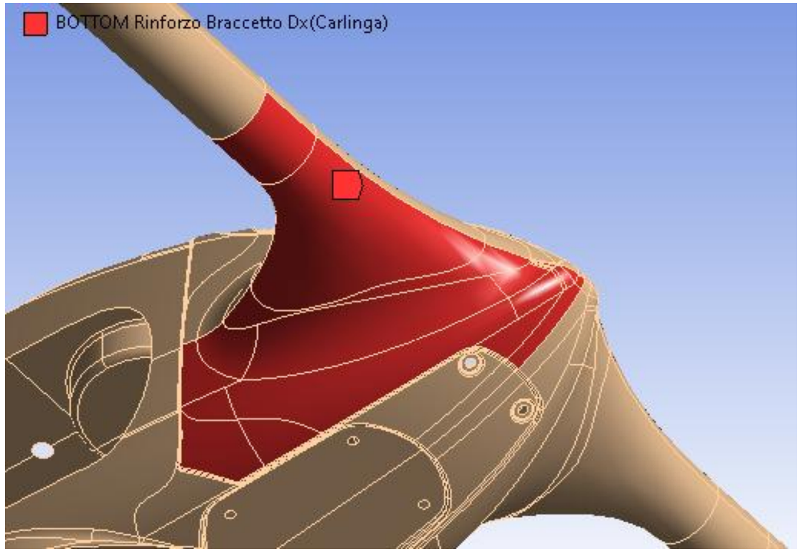
PLY FRONT



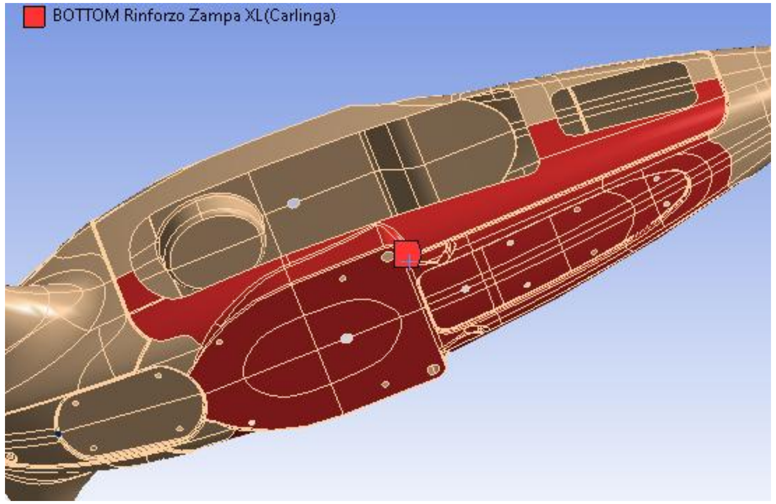


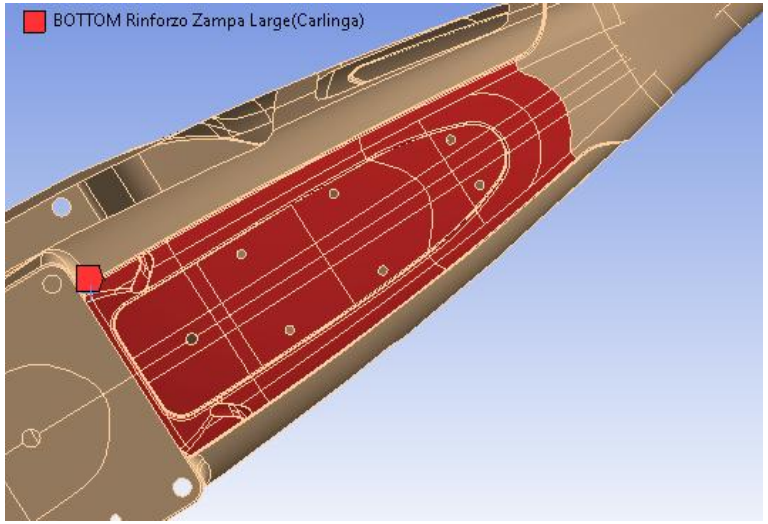
Front reinforcements



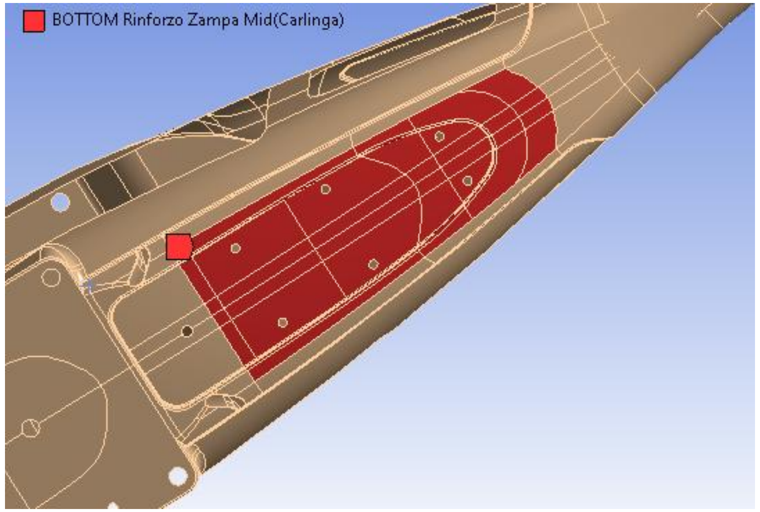


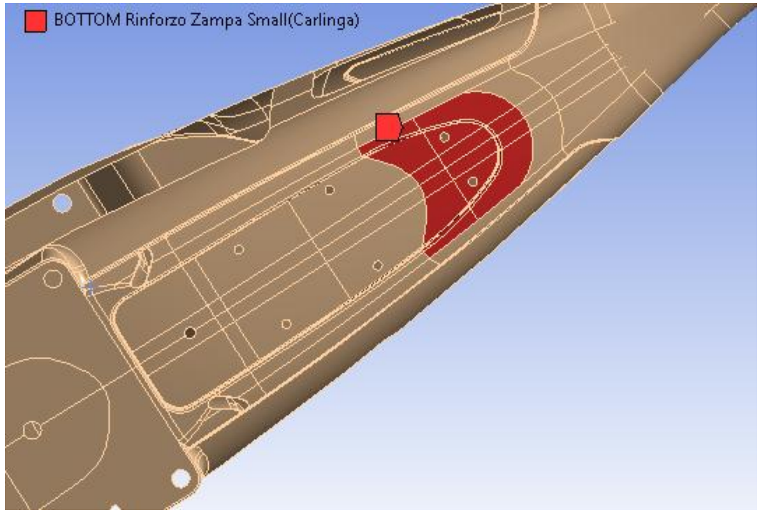
PLY DERIVA



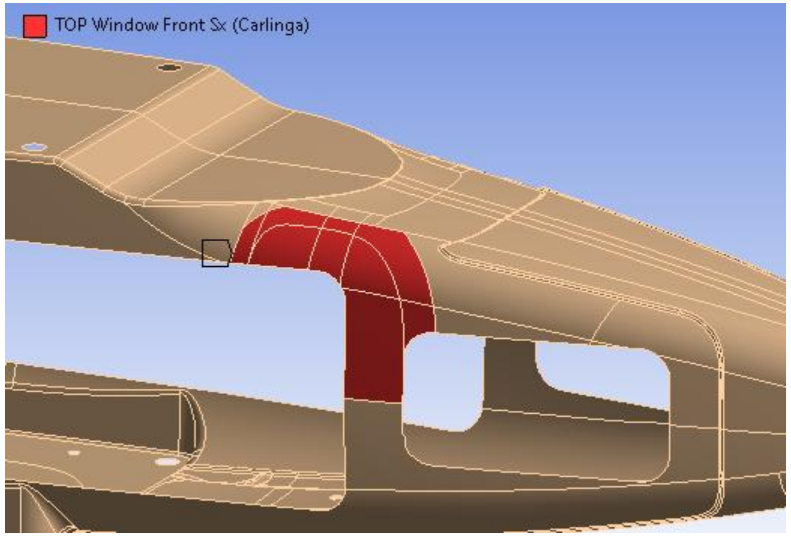


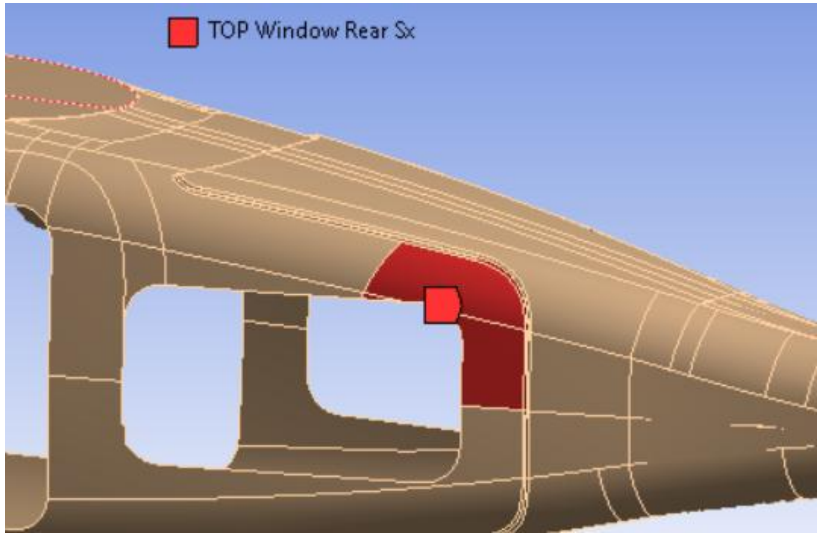
During impact, the tail fin's contact area is subjected to the greatest stress, which increases from the centre of the drone towards the tail. For this reason, the plywood layers are graded, giving greater thickness to the rear section of the drone.

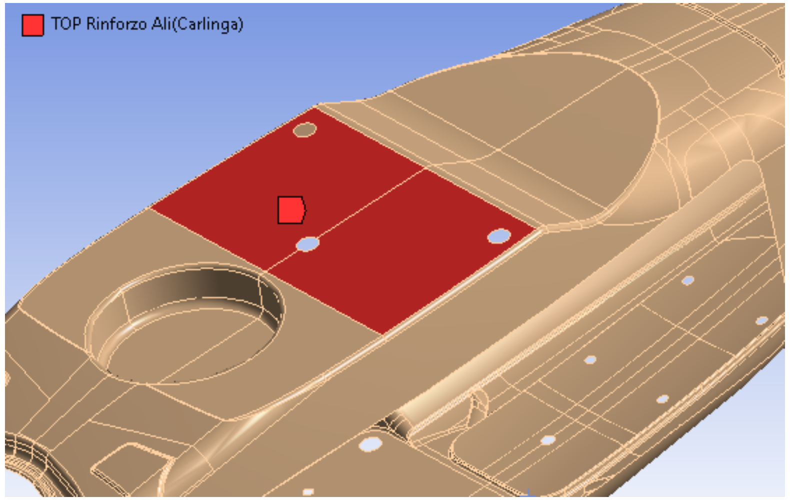


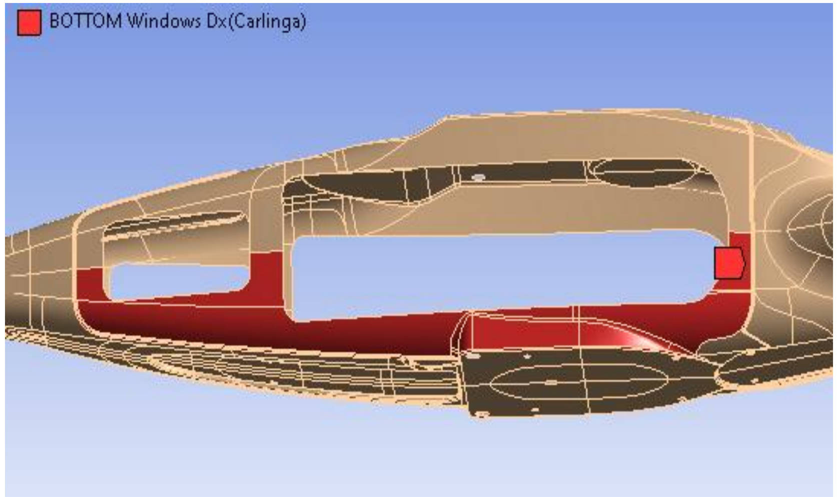


PLY REINFORCEMENTS

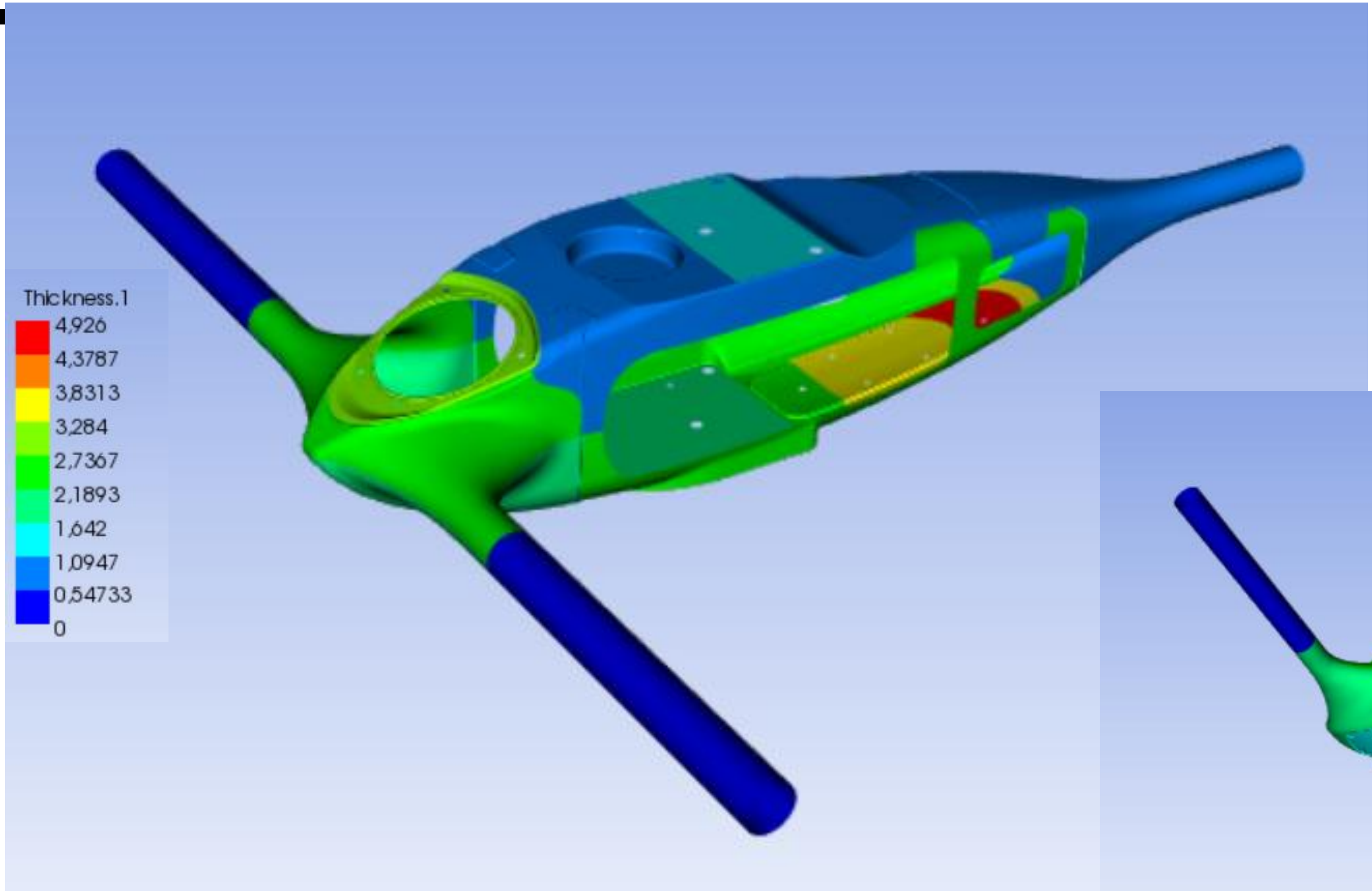




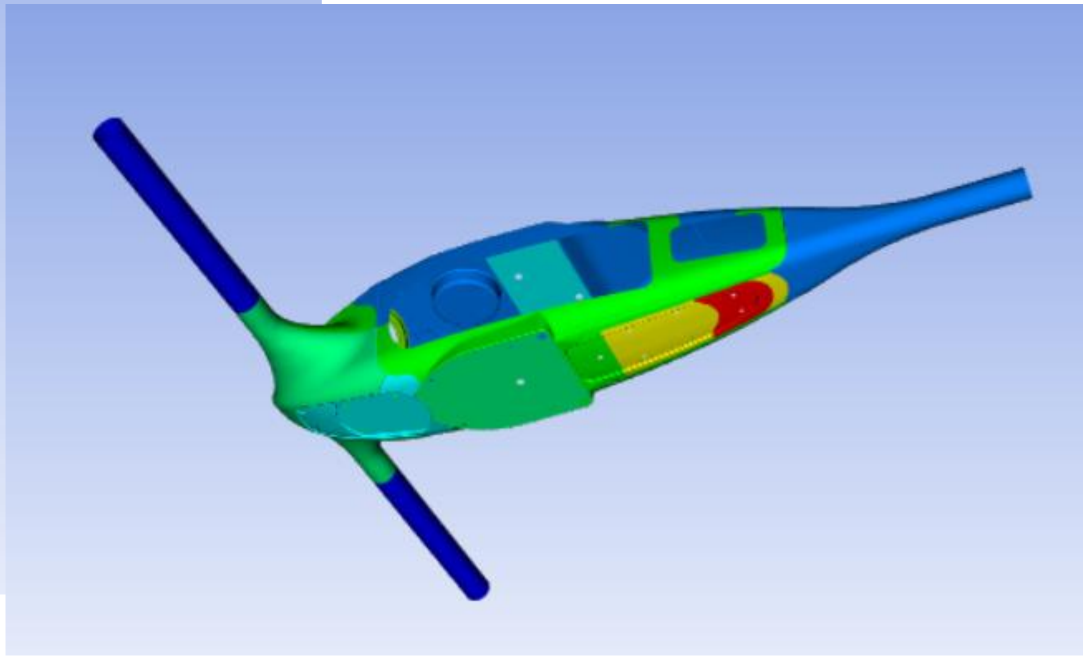




Final thicknesses



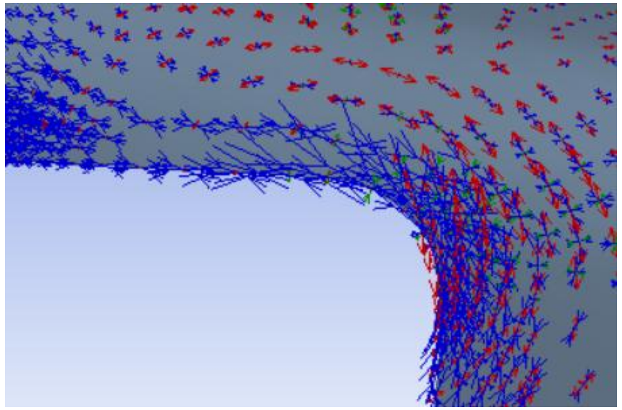
Increasing thickness towards the most stressed areas

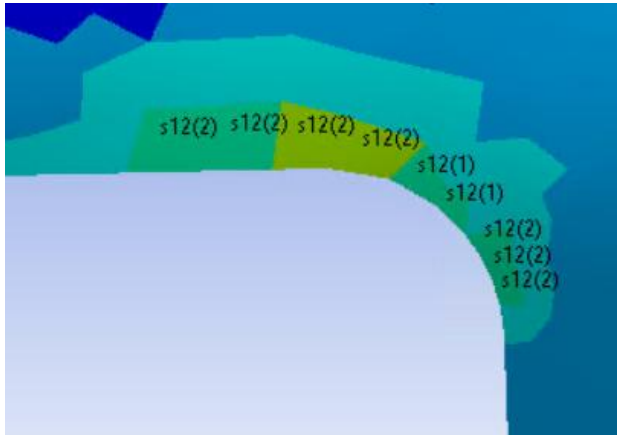


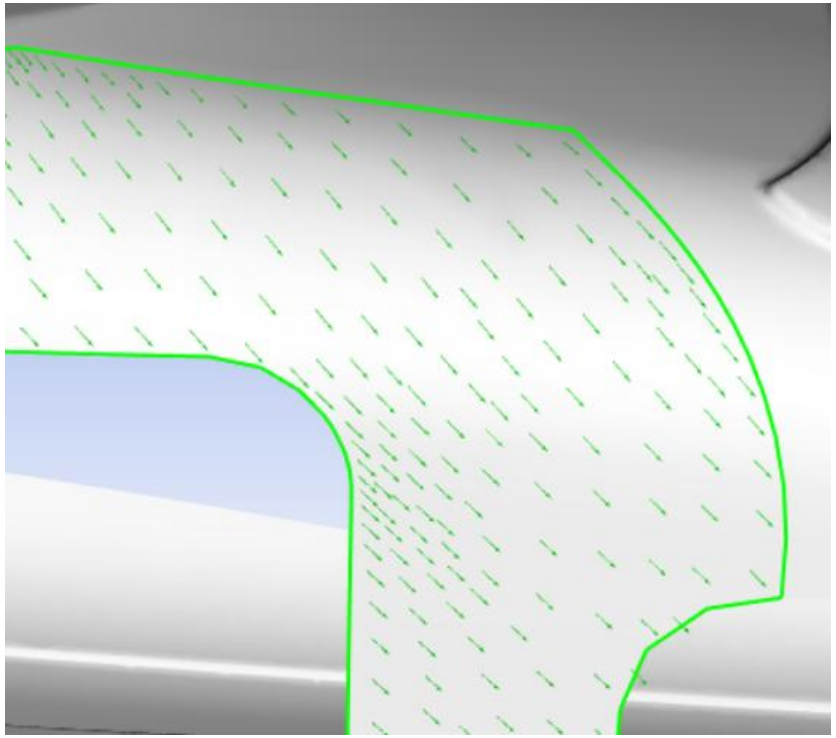
Orientation of the plies

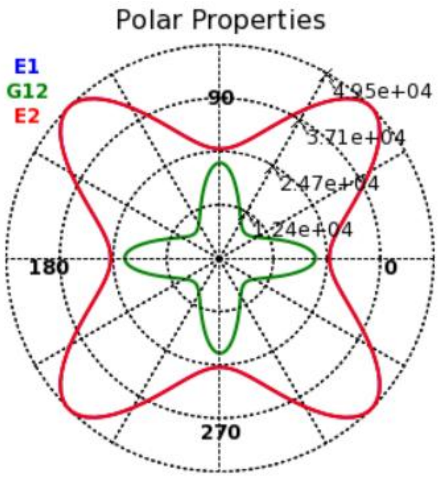
Two criteria were used to choose the orientation of the plies:

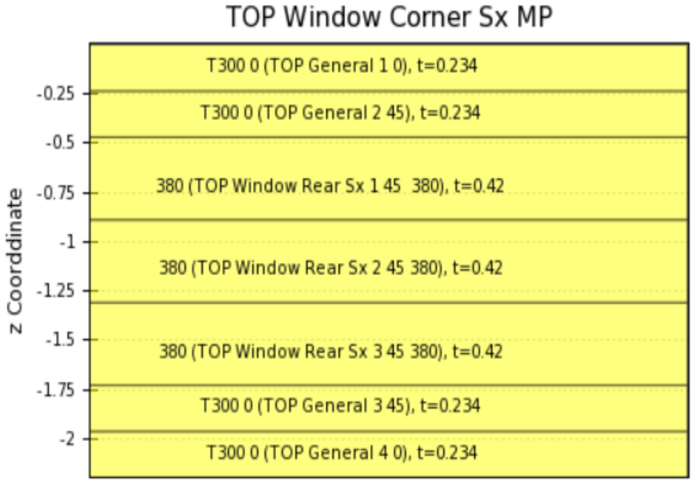
- Analysis of Principal Stress Vectors with quasi-isotropic material
- Use of failure criteria (Max Stress)





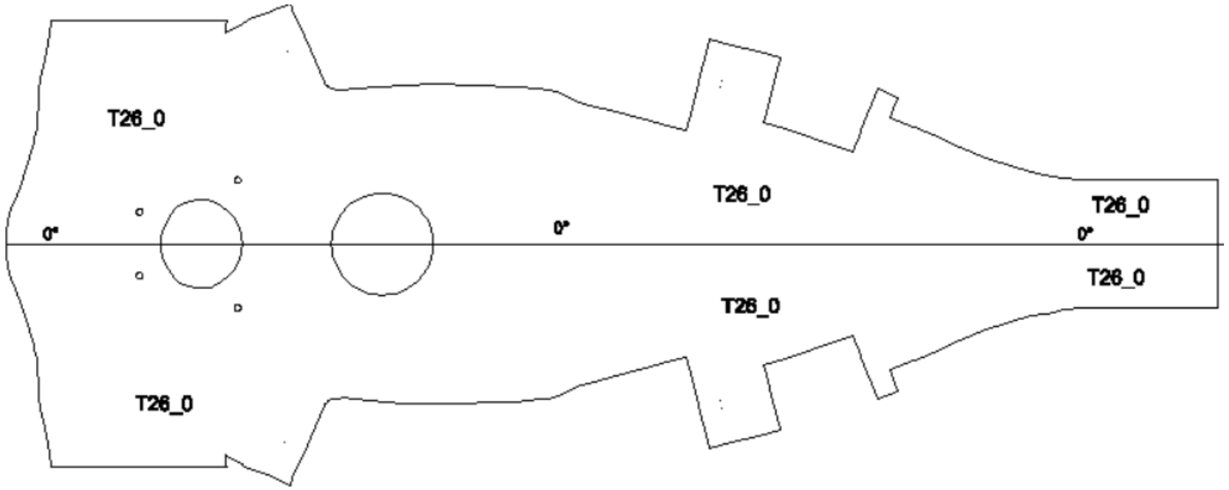


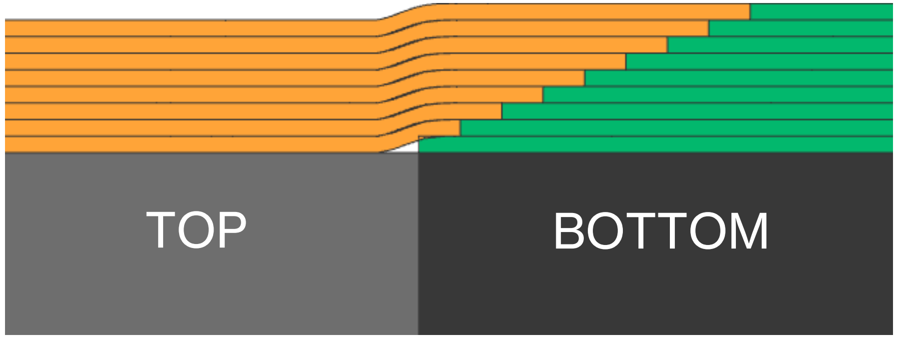


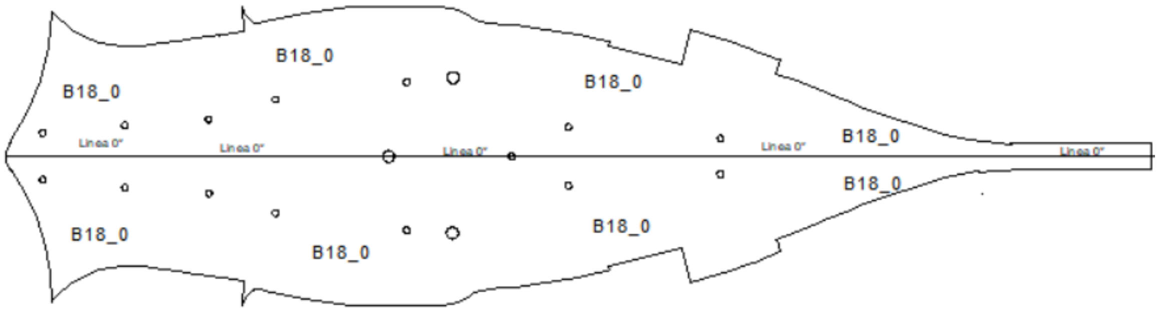


SCALING - OFFSET

The piece was made using two moulds, so continuity between the two half-moulds must be ensured. To do this, overlaps must be used. To minimise the risk of fractures, the overlaps must move with the laminating sequence.

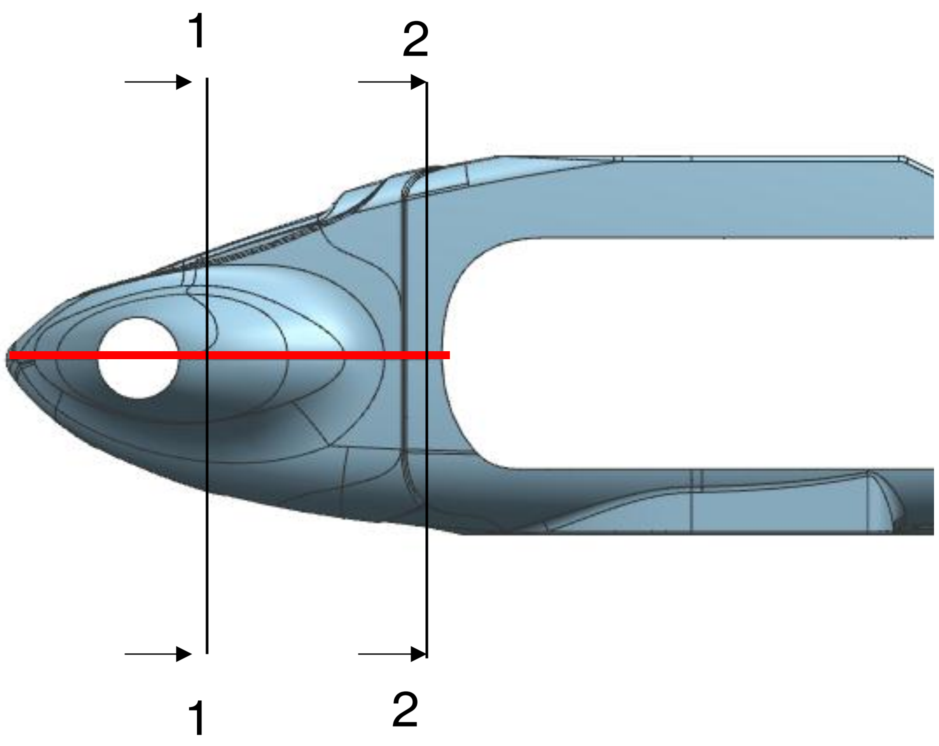


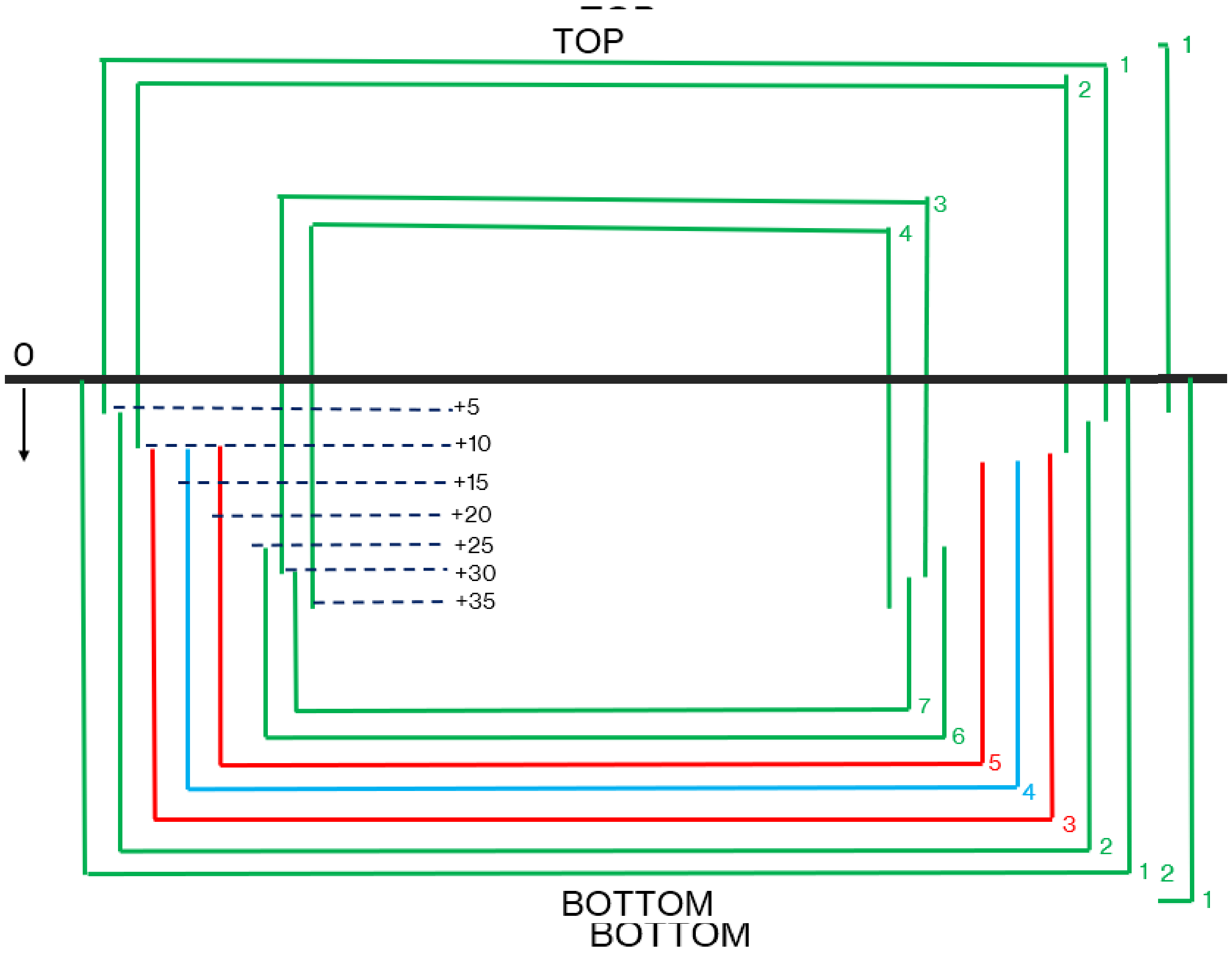




SCALING - OFFSET

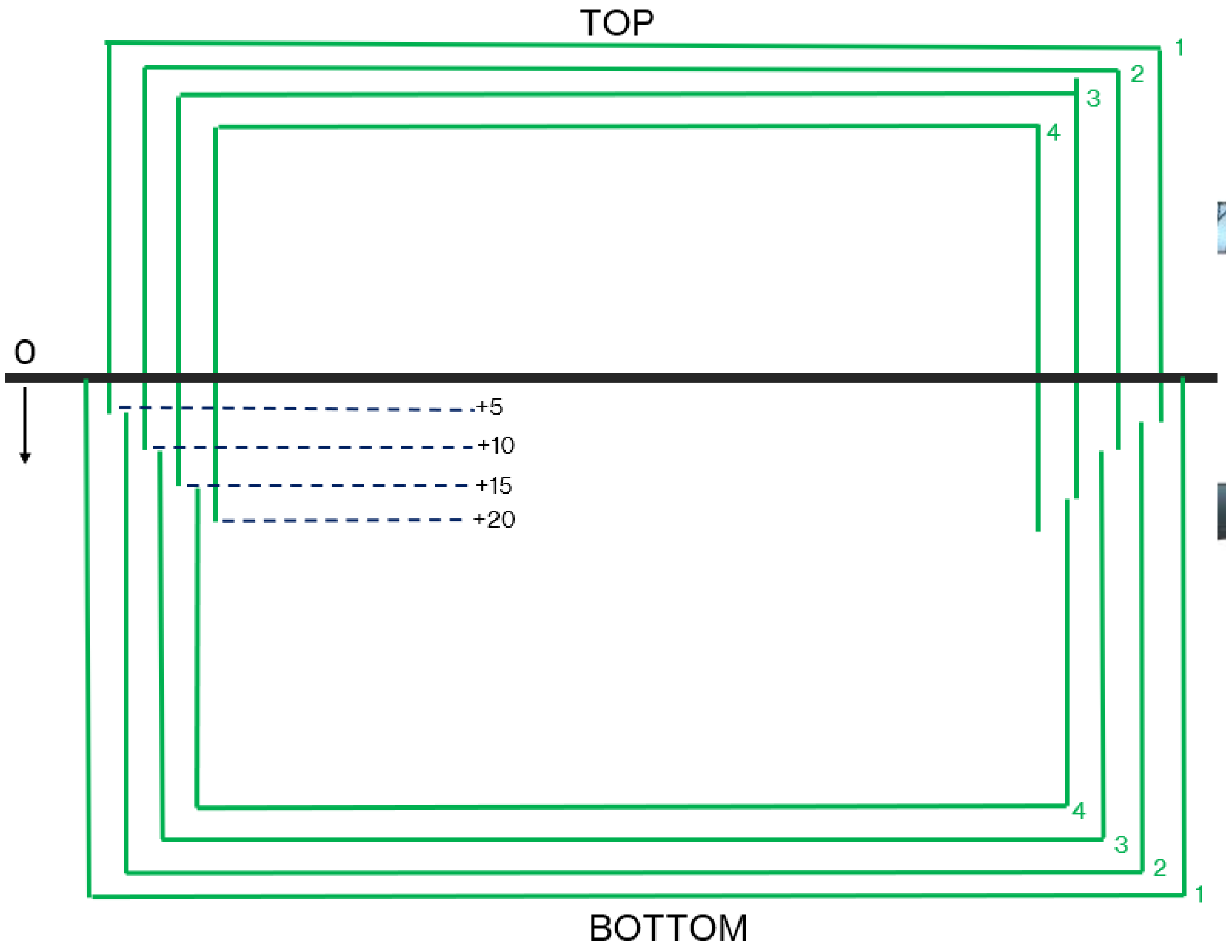
SEZIONE 1
SEZIONE 2

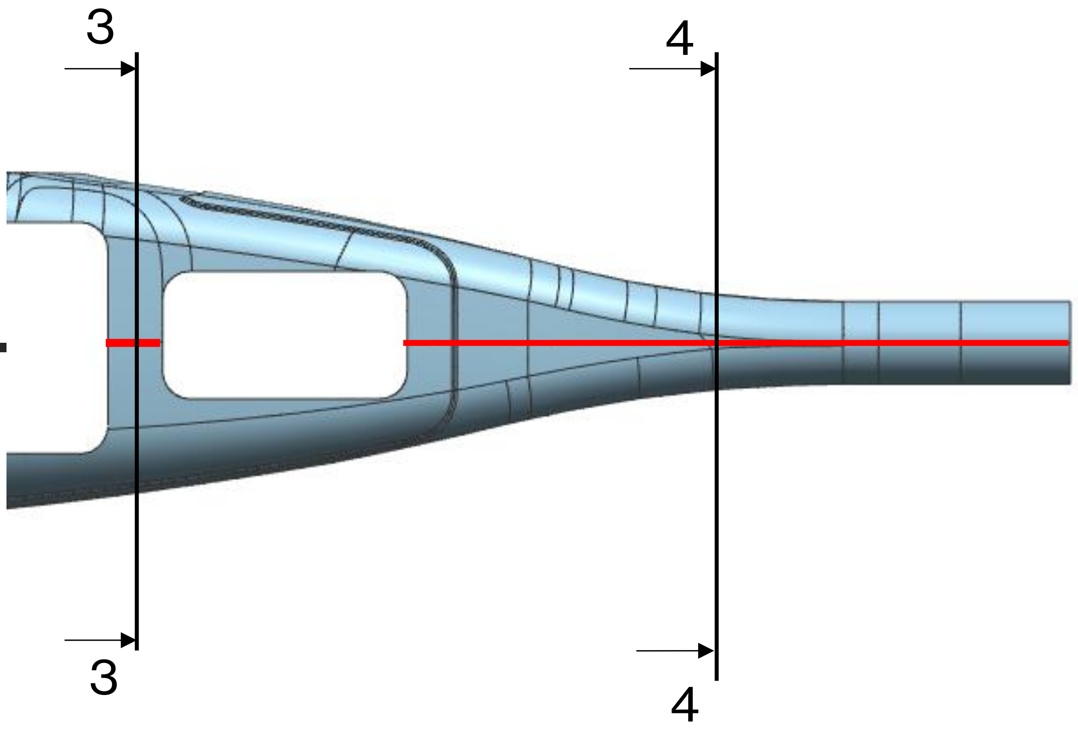




SCALATURE - OFFSET

Sezione 3





LAMINATION

First, we applied the filler and sanded the mould to remove any imperfections. Next, we applied the release agent and pore filler. Before proceeding with the laminating sequence, we carried out reinforcement operations, which involved placing strips of material inside the edges of the models. The mould was laminated to obtain two half moulds, ‘TOP’ and ‘BOTTOM’. Once the sequence was complete, the final bag was made, taking particular care in its preparation as it would have to withstand the autoclave curing cycle.

LAMINATION

In the post-curing phase, the moulds were extracted and finished by removing any excess material. Sanding was also carried out to prepare the surface for the actual lamination of the component, mainly to remove any release agent residue. After completing this phase, we treated the moulds by applying the release agent. Once the mould treatment phase was complete, we were able to proceed with the lamination. Lamination was carried out using open moulds, i.e. keeping the TOP and BOTTOM moulds separate. The two parts were then assembled before firing, taking into account the appropriate overlap between the skins. In fact, the TOP mould will have positive offsets and the BOTTOM mould will have negative offsets. This is necessary because when the two half-moulds close, the skins will have a slight margin to overlap.

LAMINATION

After finishing laminating both moulds, the design is joined and placed in an autoclave.

The final bag is made very carefully, paying particular attention to avoiding the formation of bridges that could cause the bags to explode.

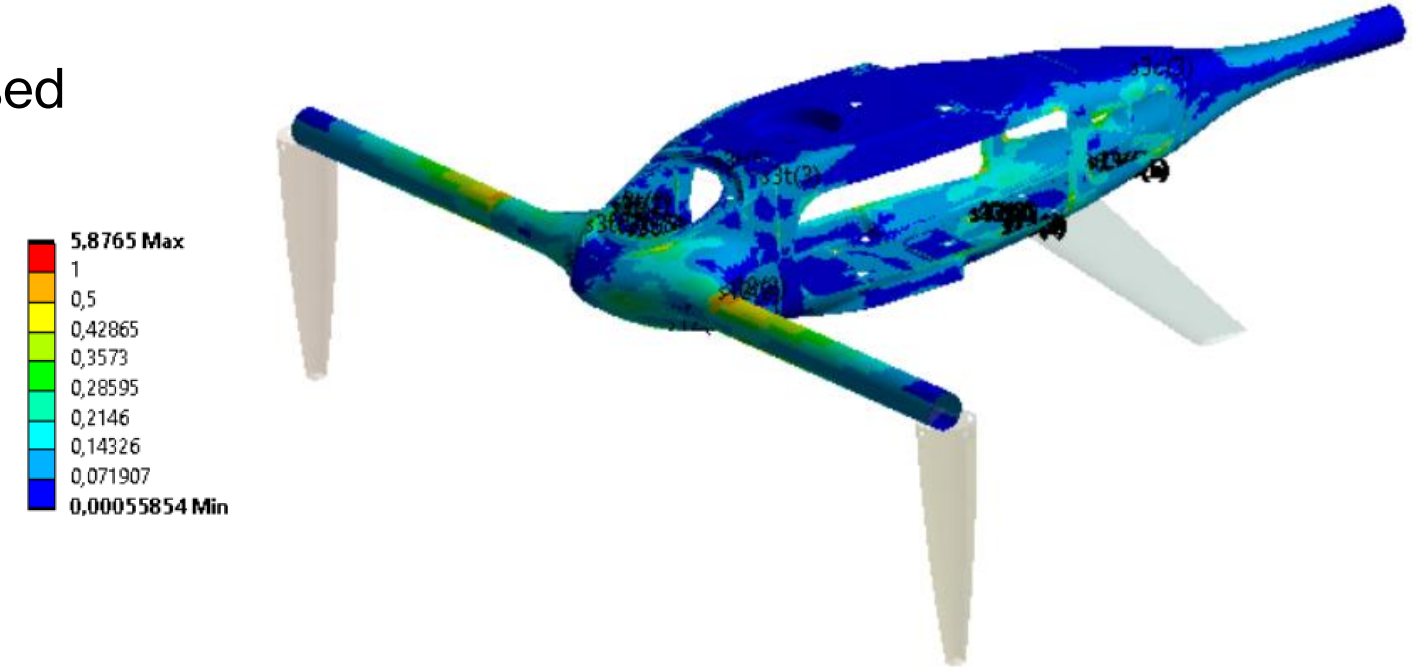
At the end of the cycle, the bag is opened and the product is removed from the mould, then the finishing process is completed.

LAMINATION

RESULTS ACHIEVED

- Final fuselage mass → 0,624 kg
- Surface area of prepreg to be used

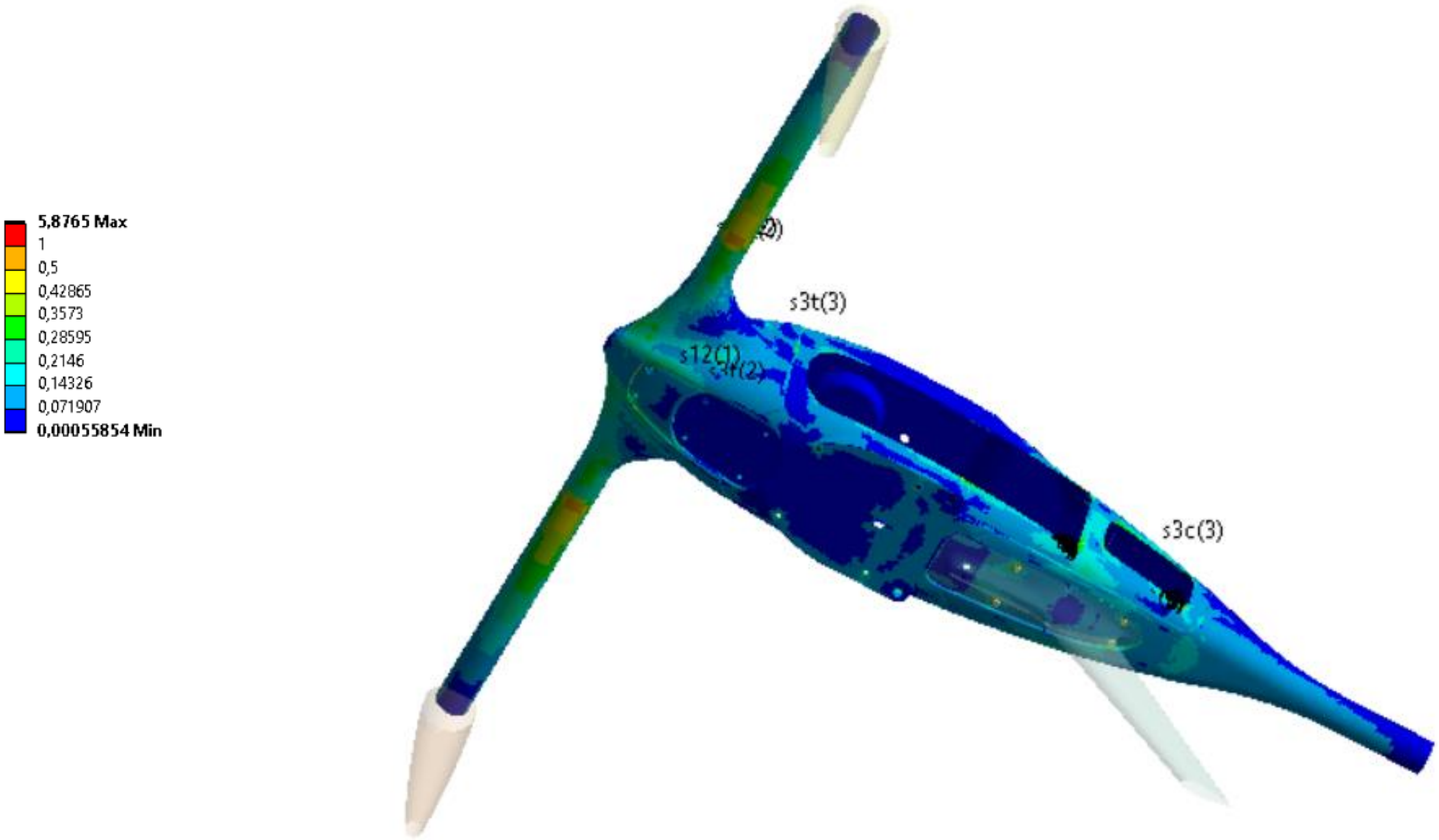
Materiale	Superficie [m²]
T300 200g	0,97
T700 380g	0,29
T700 630g	0,08



- Safety Factor

Test	ISF - Tsai Wu	Average ISF Tsai Wu	ISF - Max Stress	Average ISF Max Stress	Max Load
Impatto	< 0,45 (puntualità a 2,80)	0,116	< 0,50 (puntualità a 3,00)	0,103	a = 40g
Bolt pretension	< 0,40 (puntualità a 5,99)	0,120	< 0,40 (puntualità a 5,90)	0,106	a = 40g

RESULTS ACHIEVED



ESTIMATED PROCESSING TIME

- Lamination Moulds

Processes	Necessary Time [days]
Gluing	0,5
Anealing	0,5
Filling and sanding	1,5
Pore fillers and release agents	0,5
Mould lamination	1
Bag	0,5
Opening, finishing and mould gap	1
TOTAL	**5,5**

- Fuselage Lamination

Processes	Necessary Time [days]
Release Agent and Ply Preparation	0,5
Lamination	0,5
Bag	0,5
Opening and finishing	0,5
TOTAL	**2**

LABORATORIO DI MATERIALI COMPOSITI M A.A. 2022/23

GRUPPO 1 - PARTECIPANTI

Manuel Zambonelli manuel.zambonelli@studio.unibo.it

Alessandro Pisegna alessandro.pisegna@studio.unibo.it

Giovanni Zizzo giovanni.zizzo@studio.unibo.it

Lorenzo Bevegni lorenzo.bevegni@studio.unibo.it

Michele Furno michele.furno@studio.unibo.it

Idalgo De Maria idalgo.demaria@studio.unibo.it

Alessandro Acuna alessan.acunaguardia@studio.unibo.it

Nicola Stefano Ciancia nicola.ciancia@studio.unibo.it

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