Structural design of Mini-bee

-- Final Defense --

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0. Introduction

Context

- Technoplane’s project
- VTOL-Octocopter
- Range *600km*, Vmax *300km/h*, MTOW *1.2*T

Objectives

- Design a structure layout for the Mini-Bee
- Evaluate and optimize the structure through iterations

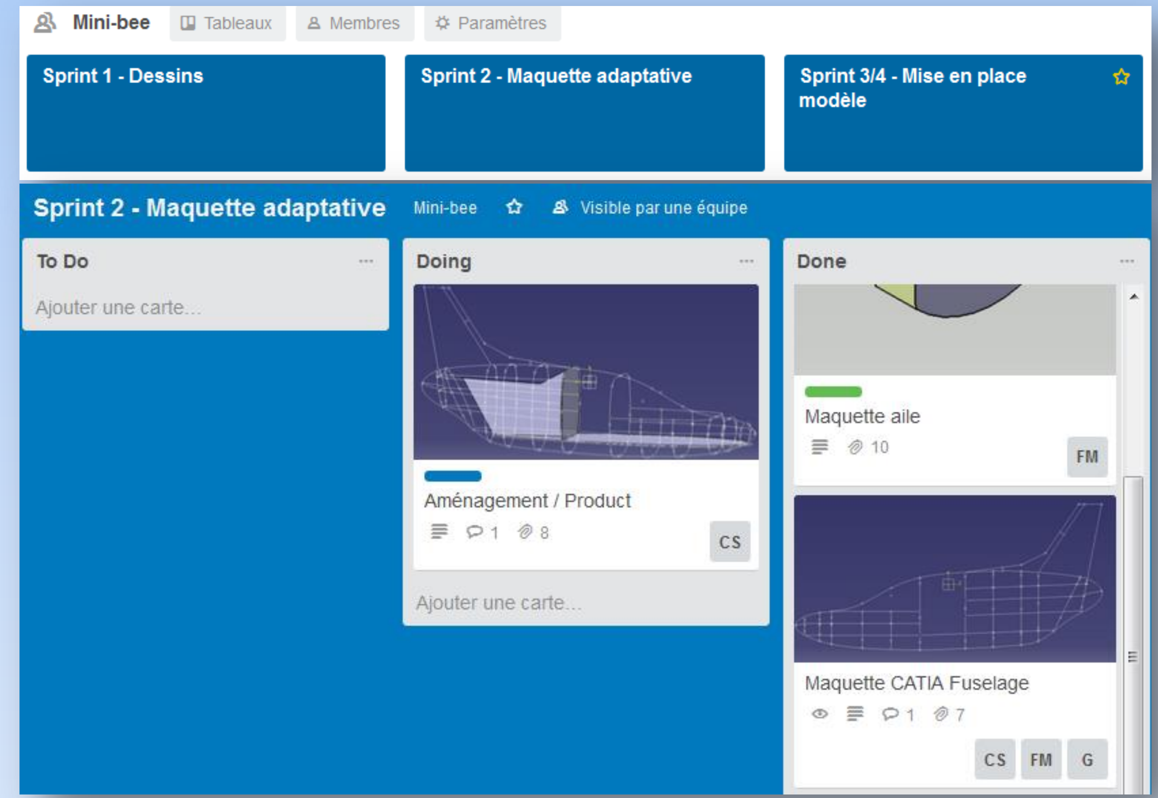
Main ideas

- Top & Down methodology
- Car industry process of development: *Design>Conception*
- Collaborative project

0. Introduction

<u>Team Management</u> – SCRUM, *Agile method of management*

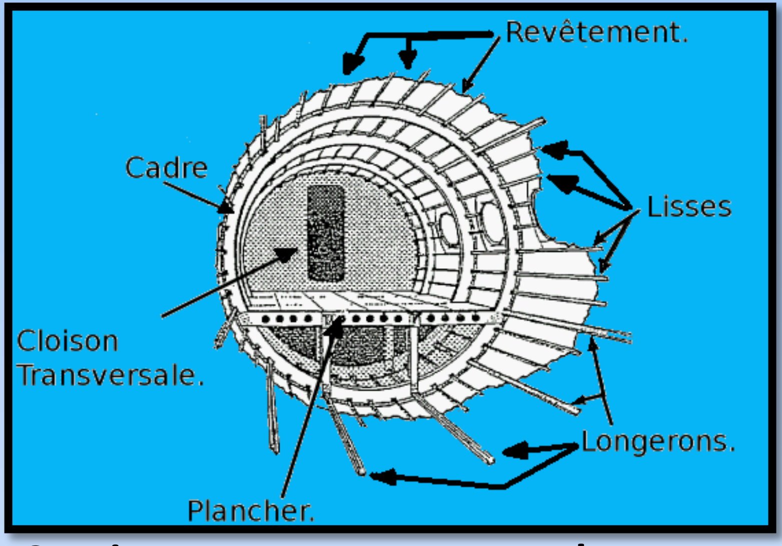
- Product backlog – *concept increment*
- Sprint backlog - *project increment*
- *Kanban* from software development filled with *userstories*
- *Scrums* on userstories



I. S1 – Structure layout and drawing

Choice of semi-monocoque layout:

Advantages:
- Good strength
- Ease of construction
- Max usable space in the fuselage
- Keep enough rigity even in case of hard damage



Semi-monocoque structure layout

Characteristics:

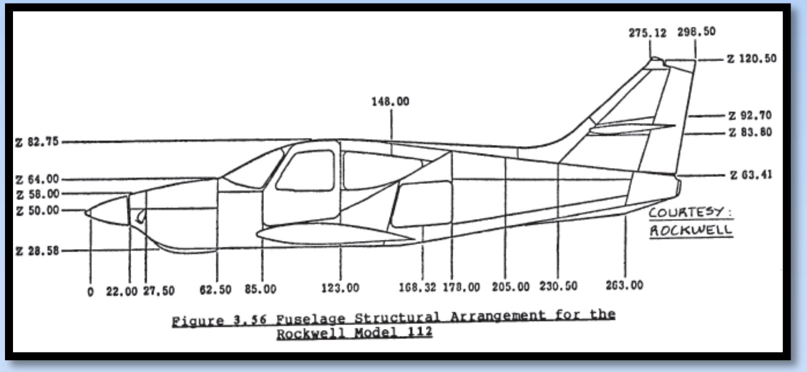
- Stringers:
  - ✓ Aluminium beams.
  - ✓ Support most of bending loads.
- Lisses:
  - ✓ Support the fuselage coating
- Frames:
  - ✓ Give its shape to the fuselage
  - ✓ Support the lisses
- Partition walls
  - ✓ Similare to frames
  - ✓ Placed where strain is the most important
- Fuselage Coating:
  - ✓ Give rigidity to the fuselage.
  - ✓ Sheet metal or Sandwich panels.
- Floor:
  - ✓ Increase rigidity.

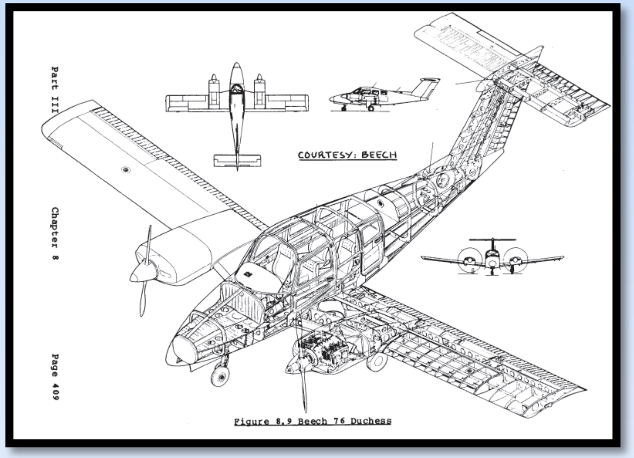
I. S1 – Structure layout and drawing

- Methodology to design the structure layout was based on top&down methodology. Thus we looked for similar models.

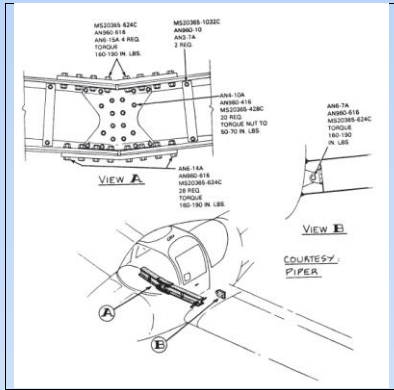
	Inches	mm
Height of frames	1,5	38,1
Frame spacing	24	609,6
Stringer spacing	10	254

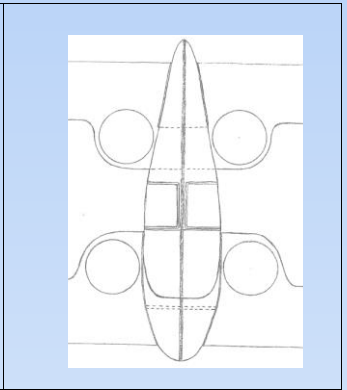
<u>**Usally used values for sizing beams**</u> (Jan Roskan, 1986)



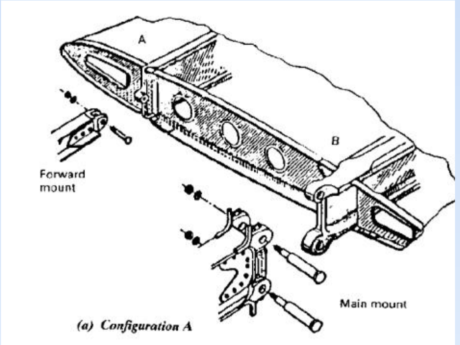


- Assembly considerations were important to take into account at the beginning





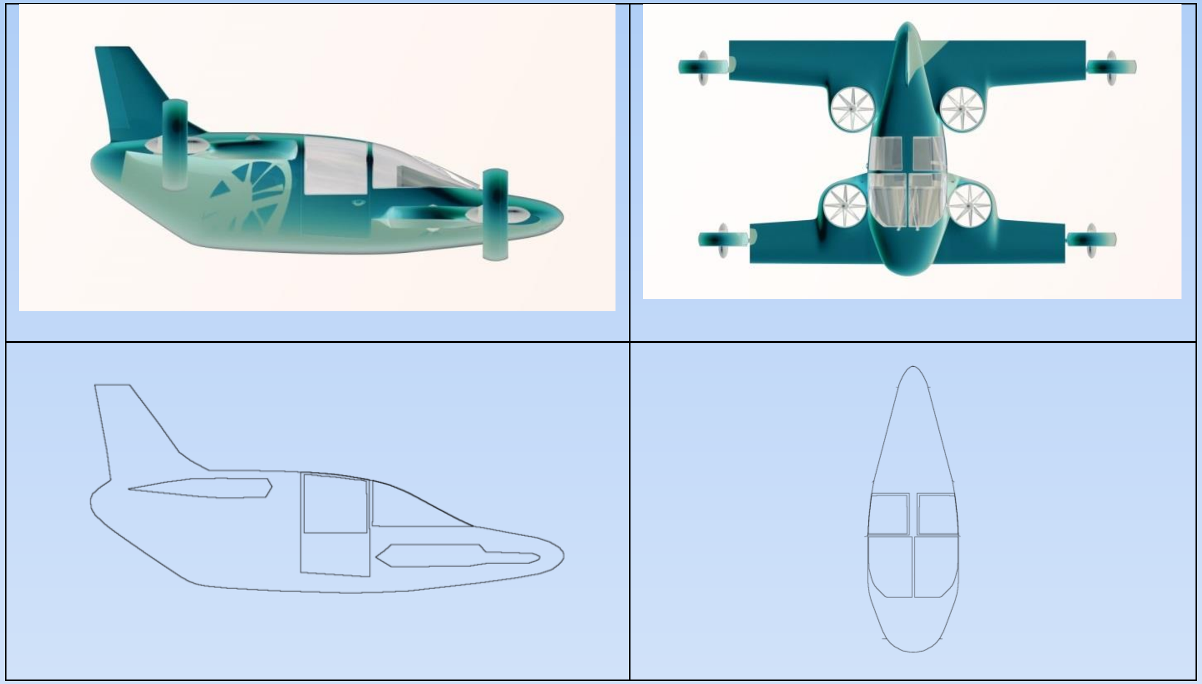
- Beam between half-wing for front wing to increase stiffness



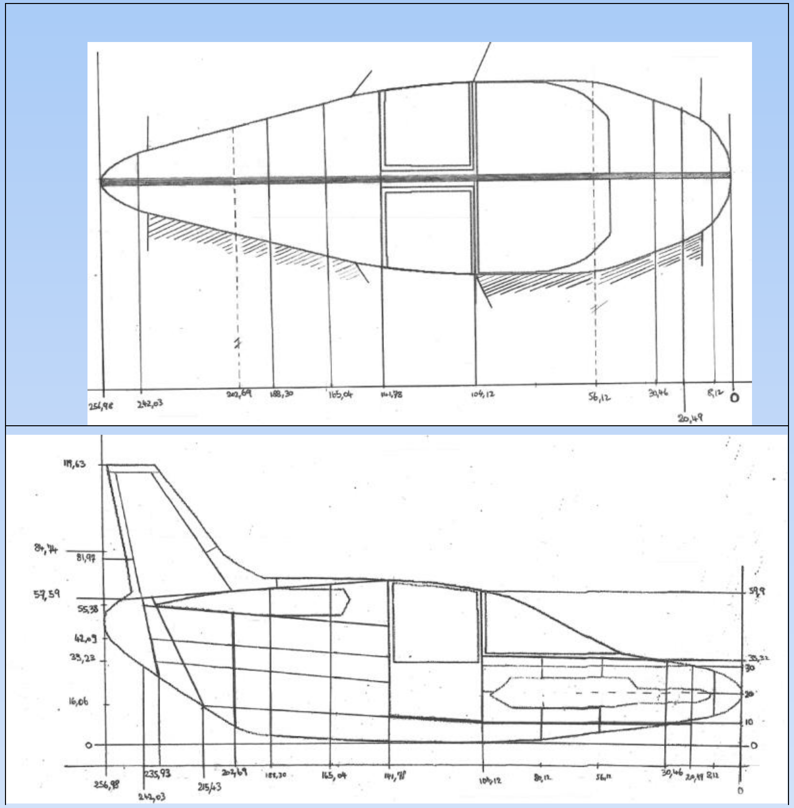
- Hinge using lugs

<u>**Hinge system for front wing**</u>

I. S1 – Structure layout and drawing



Design and contours



Drawn structure layout

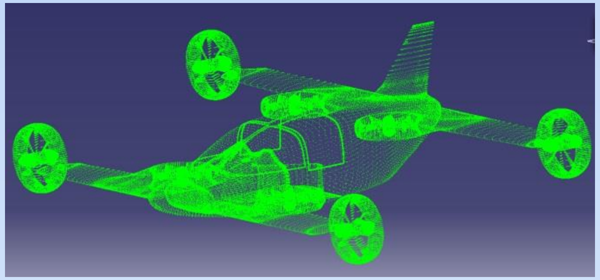
- Structure layout was drawn from doors because those have the most constraining dimensions.

→ We obtained the structure layout to compute on CAD.

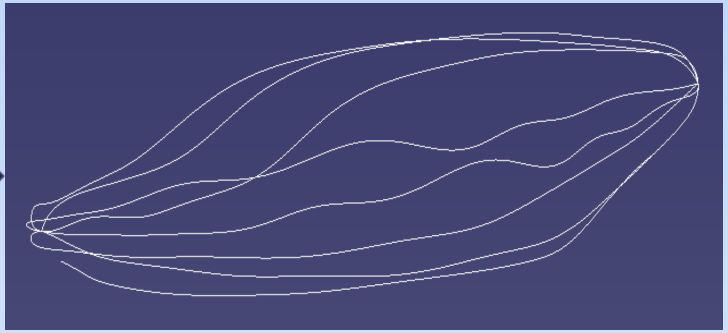
II. S2 – Adaptive CAD

- Idea was to reuse design from the designer to keep the concept.
- Thus we took the point clouds for start and create curves which would be based on the design.

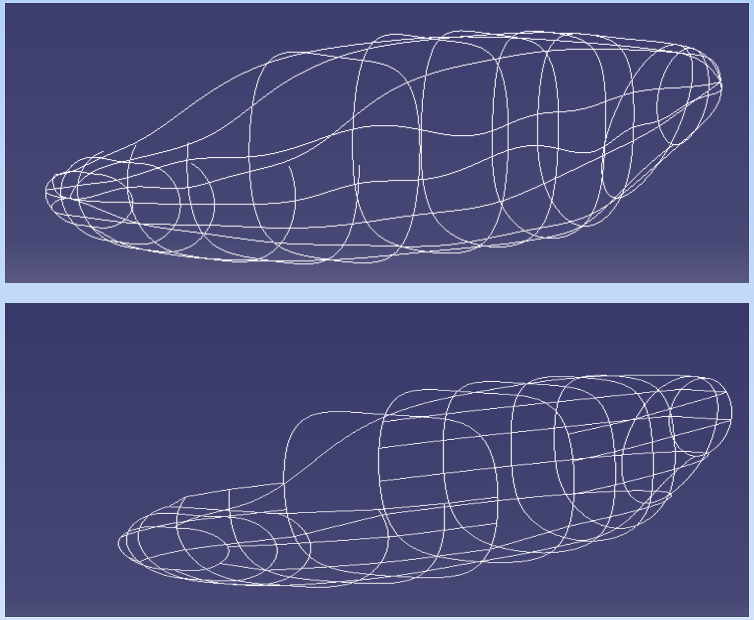
- Then with optimized copies on those curves we placed the layout in accordance with the drawings we made.



Point cloud



Generative curves of the structure



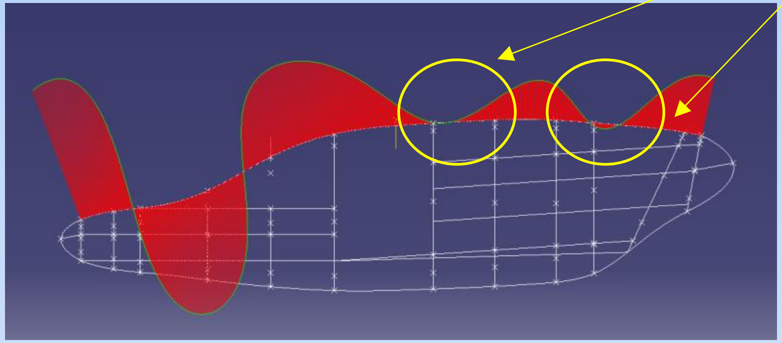
Construction of the structure layout

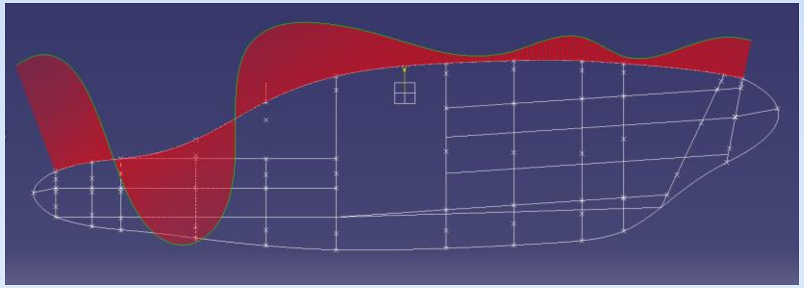
II. S2 – Adaptive CAD

- An analysis of the curves' curvature is important to prevent the structure from instability phenomenon and aerodynamic issues.

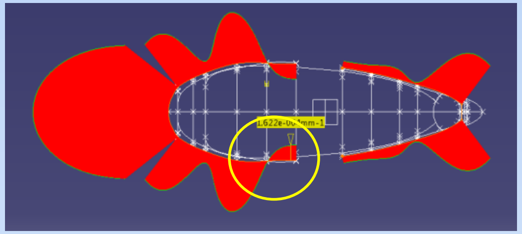
Inflexion point on the stringer

Example: 1) Top stringer

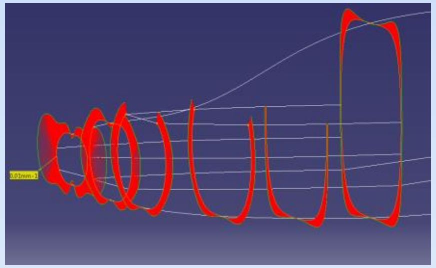




Example: 2)Side stringer



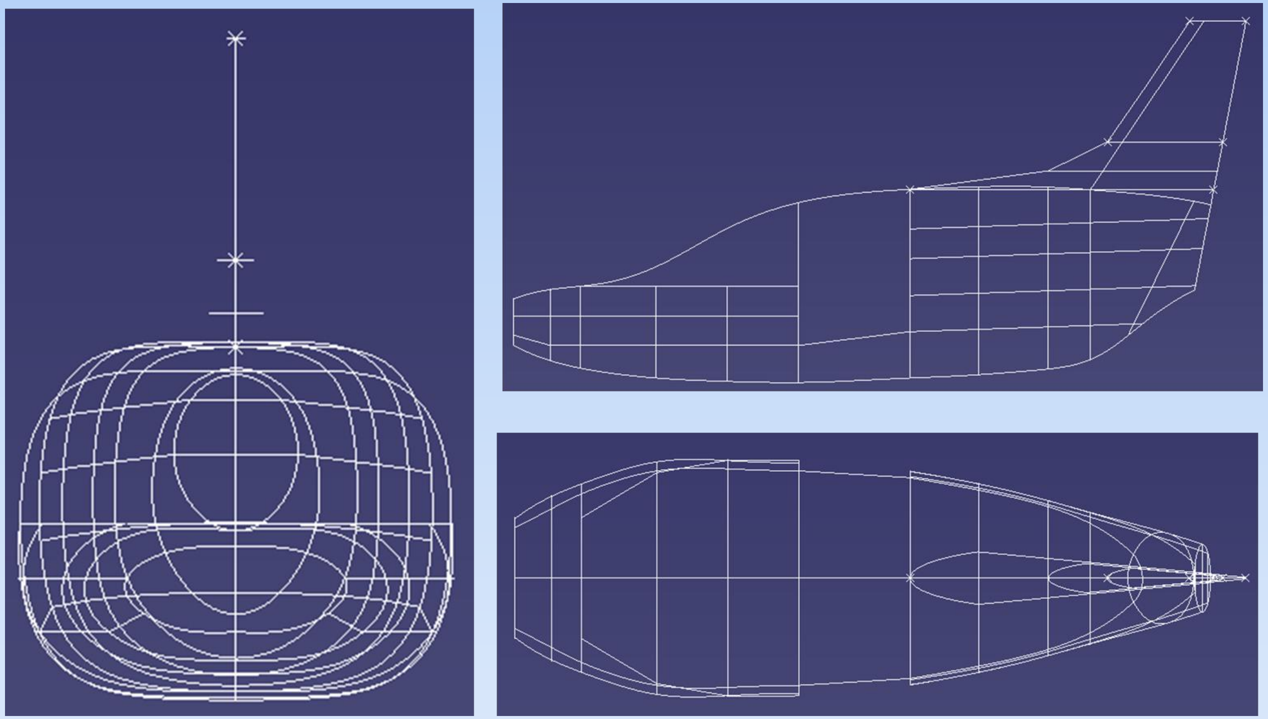
Example: 3) Structure's frame



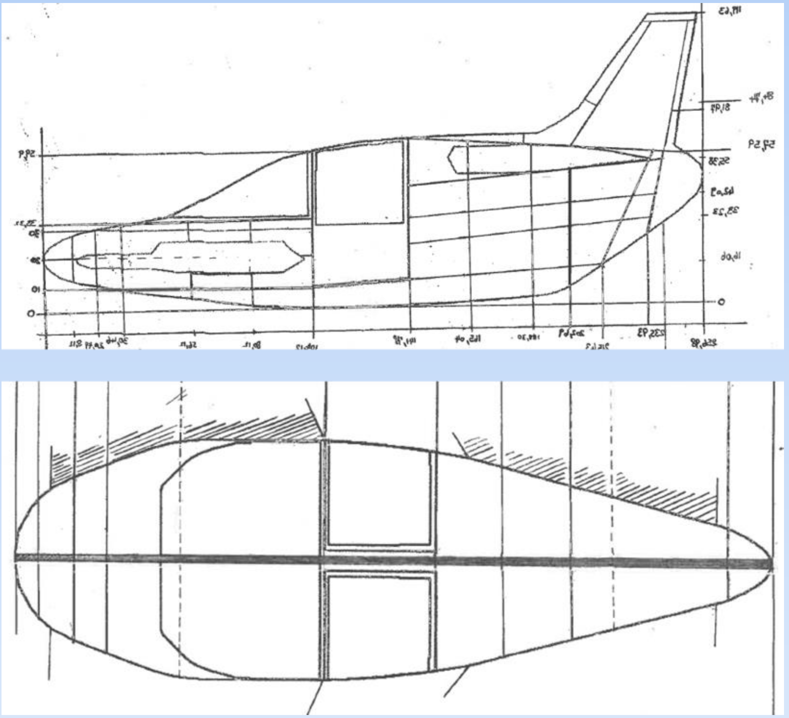
→ We were able to produce a first CAD structure layout and correct it before numerical analysis

II. S2 – Adaptive CAD

- We did create a CAD model that match our structure layout.
- CAD with wires will be usefull to compute consistent-numerical-models faster than solid models.



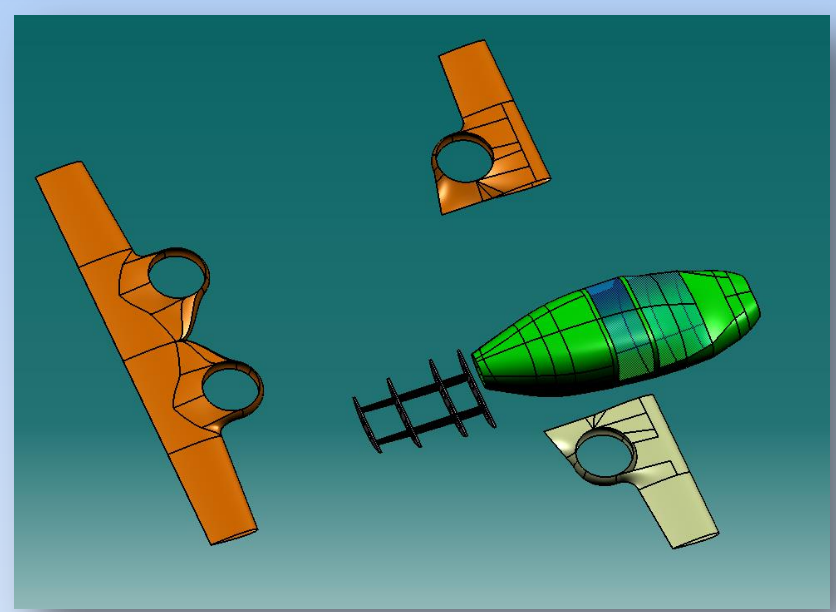
CAD structure layout



Drawn structure layout

Conception de la structure de l'aéronef Mini-Bee

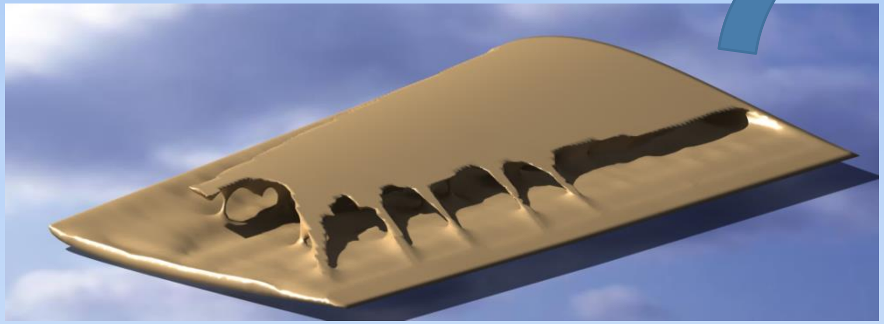
I. S1 – Structure layout and drawing
II. S2 – Adaptive CAD
III. S3 / S4 Numerical models and analysis
   1. Wing conception
   2. Fuselage – Structure
   3. Fuselage – Crash test
   4. FSI – Fluid-Structure Interaction



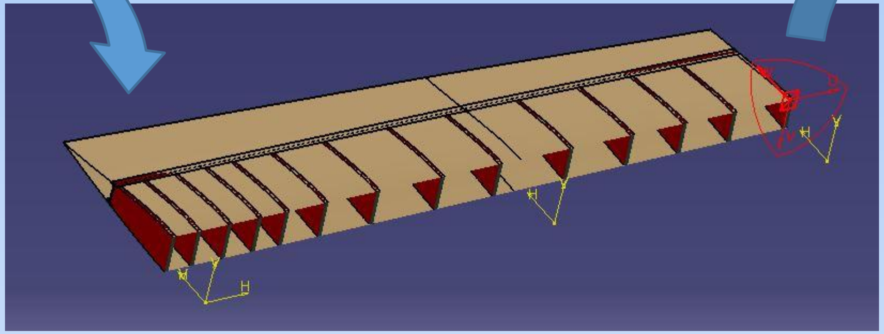
Exploded view of the simulated parts

I. S1 – Structure layout and drawing
II. S2 – Adaptive CAD
III. S3 / S4 Numerical models and analysis
   1. Wing conception
   2. Fuselage – Structure
   3. Fuselage – Crash test
   4. FSI – Fluid-Structure Interaction

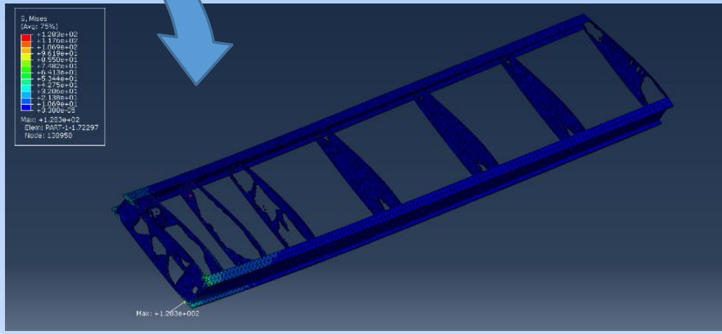
III. 1. Wing conception



First wing optimization



Conception within results of first optimization



Results of Second optimization

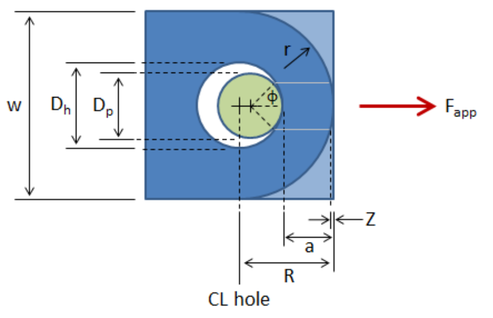
- **Assumptions:**
- Lift force applied on the wings
- At the fixtions ALL DOF=0

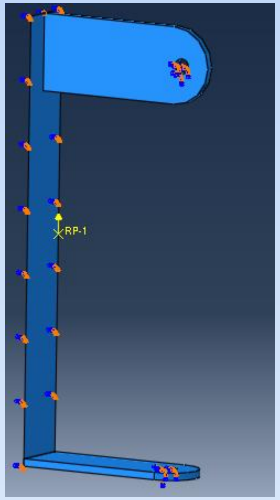
- **Results:**
- Far from boundary conditions Stress Von Mises < 100MPa

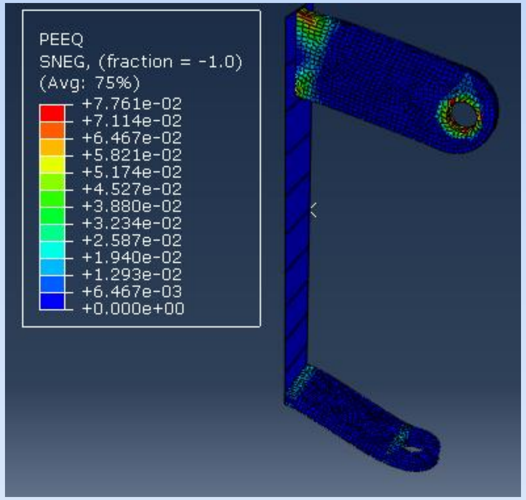
- **Optimization validated**

III. 1. Wing conception

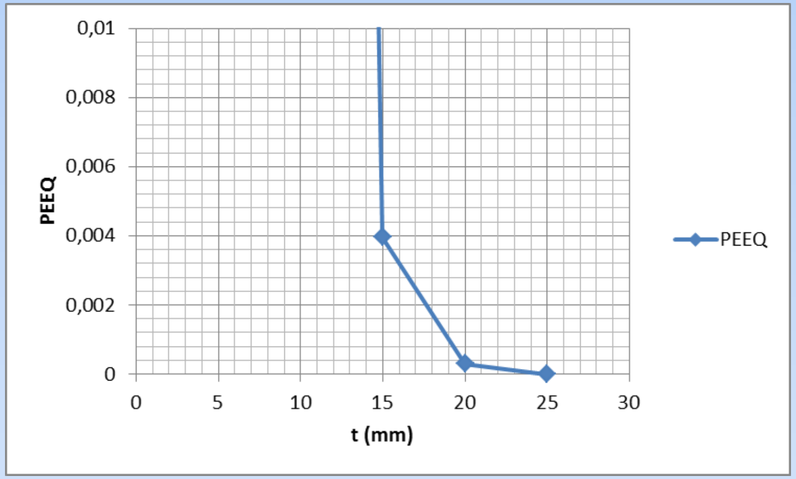
- Parametric CAD was created to perform the different steps ofur design of experiments.
- Solid numerical model with vertical loading of *1500N* to simulate lift of the wing







Loads and BC of lug part and Results on plasticity deformation

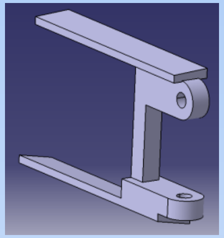


Result of study on plastic deformation for different thickness

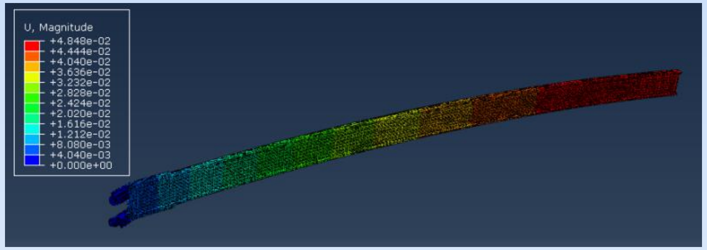
→ Considering a conventionnal plastic deformation we can size the lug with depth of $20mm$

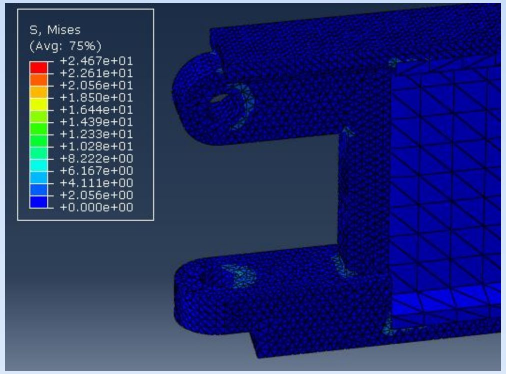
III. 1. Wing conception

- Complete design of the lug part for further evaluation



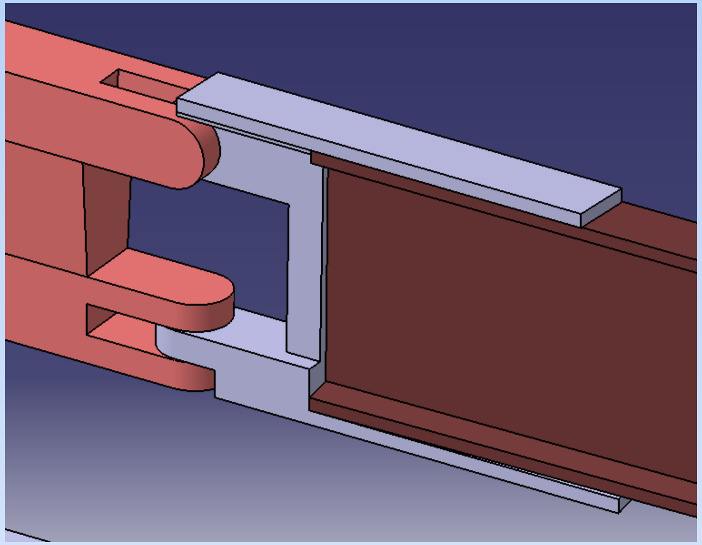
- Simulation with solid element
- Lift load on wing’s longeron and boundary condition of symmetry
- Boundary condition on bolts’ positions





Results of the whole hinge part’s simulation

- Design of the centrale beam for stiffness and fixation to the fuselage

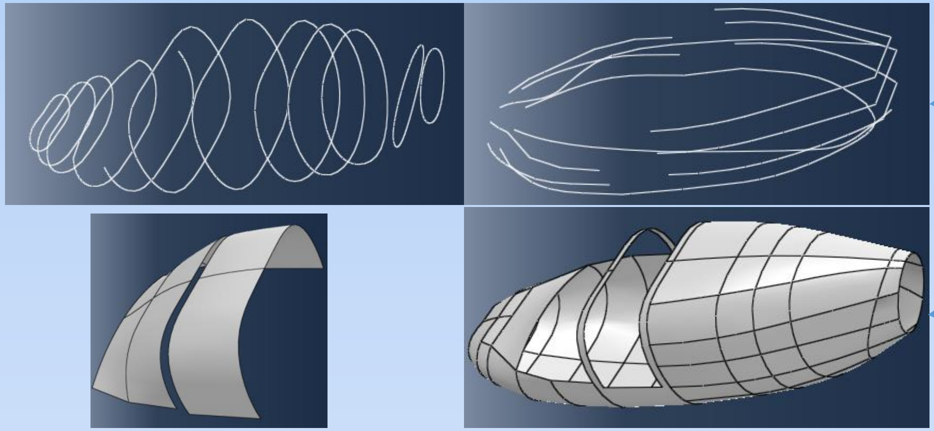


CAD of hinge and its central beam

TECHNOPLANE
AERONAUTICAL INNOVATION

III. 2. Fuselage – Structure

- Need to produce a numerical model to evaluate our structure resistance to static loading and structure stability to buckling.



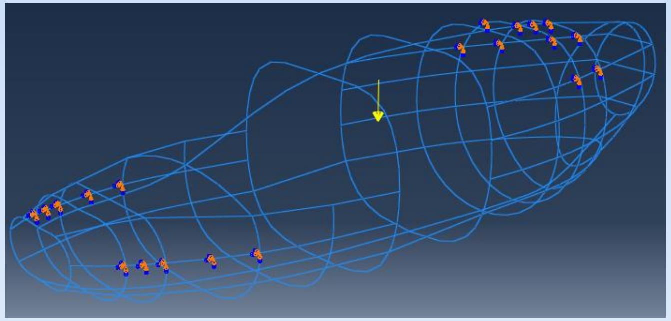
Al6061 beams

Al6061 shell

PMMA – *transparent polycabornate*

- Mass of the system was simulated with an inertial mass placed on the down-stringers where the floor will be placed.
- Connection between the beams was simulated using joint-connectors be consistent with beam-column model.

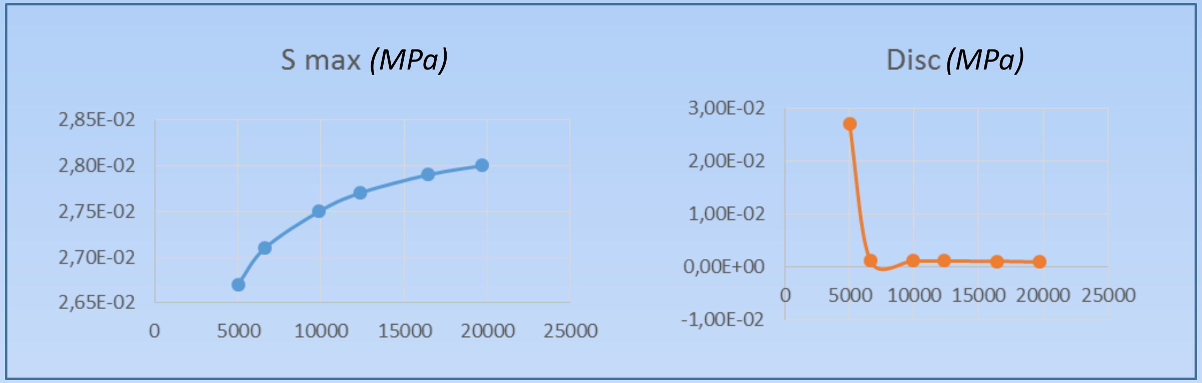
- Step of simulation was using a boudary condition on the wings’ connection.
- Body force equivalent to $3\vec{g}$ was applied.



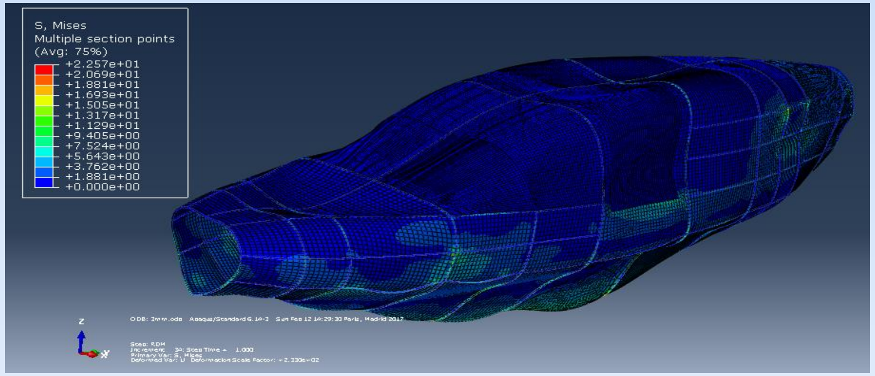
<u>Loads and BC of the structure validation model</u>

III. 2. Fuselage – Structure

- Mesh was decided from a convergency study on beams.

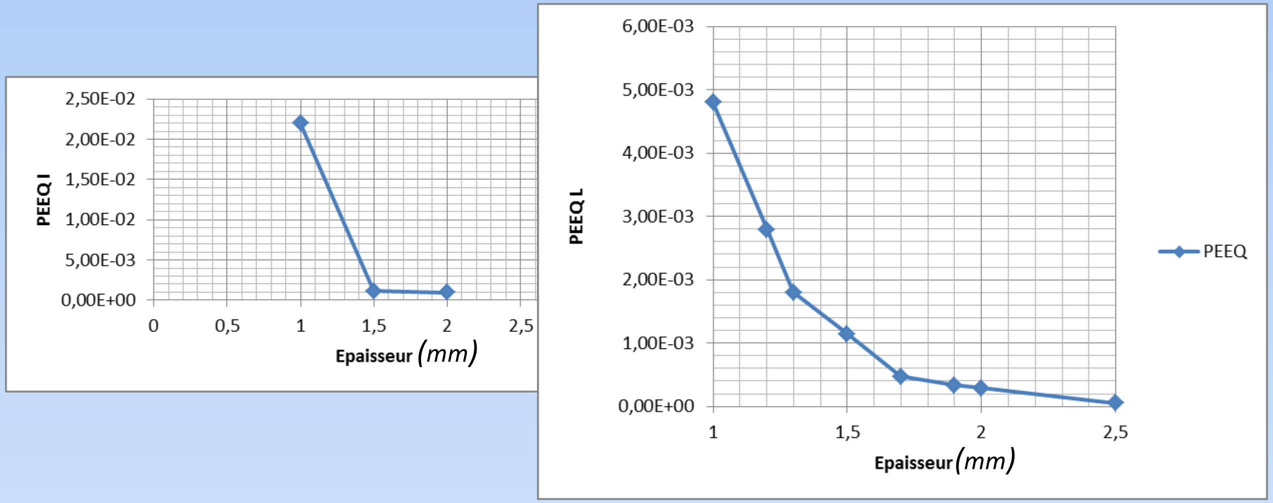


	Element type	Approx. size
Stringers	B31	30
Coating	S4R	30
Glass parts	S4R	30



Structure layout’s resistance validation

- Then we studied influence of stringers-frames depth according to what it is used in aircrafts similar to the Mini-bee.
- 0,2% of plastic deformation was accepted.



Plastic deformation for the different beams of the DOE

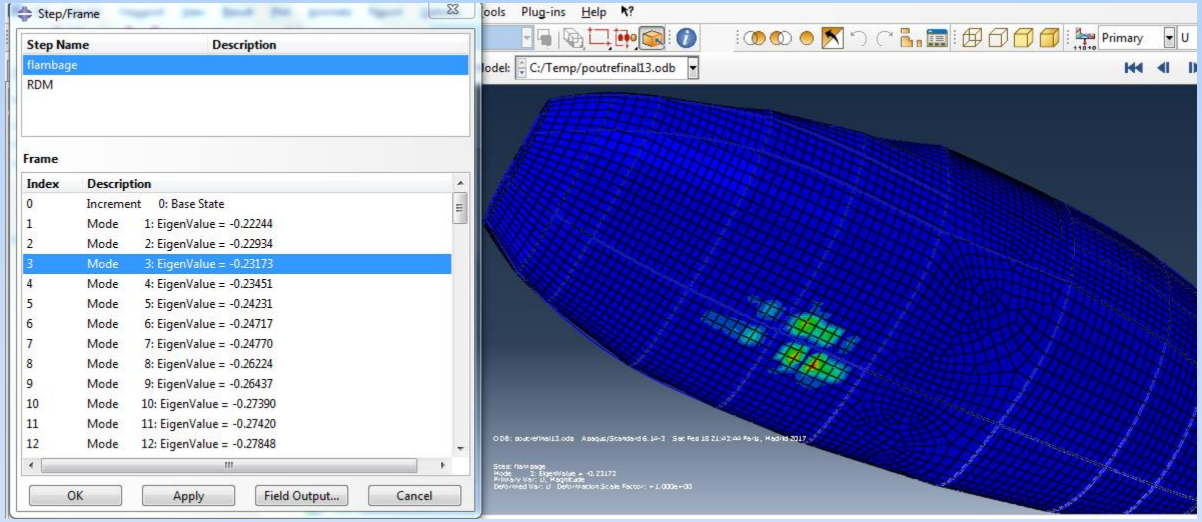
→ For a coating of 0,5mm of depth:

- I beams of 1,5mm could be used → $93,7kg$
- L beams of 1,3mm could be used → $82kg$

TECHNOPLANE
AERONAUTICAL INNOVATION

III. 2. Fuselage – Structure

- Also we needed to check buckling.
- Considering our numerical model, only subspace algorithm could be used.



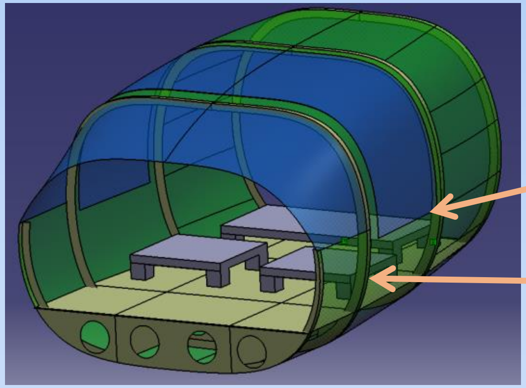
Buckling validation

- The algorithm only found negative modes beetween 20% and 115% of the simulated loading ($3\vec{g}$) → min for buckling is -$3000N$
- It could only appear if the plane was on the ground and totally empty. Or the floor-strut will increase stiffness in this area.

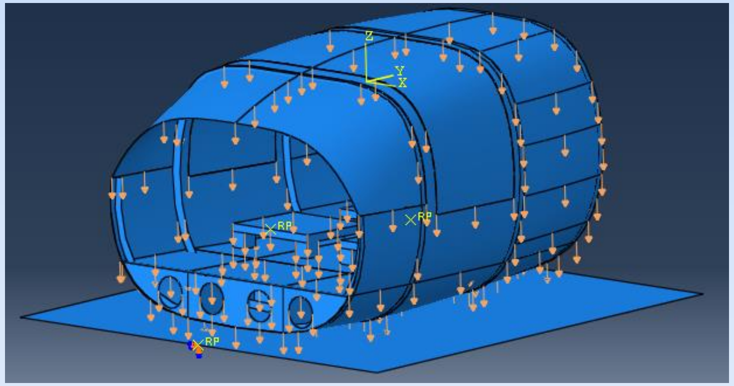
→ Structure layout is validated and optimized.

III. 3. Fuselage – Crash test

- Other consideration is to protect passengers during a crash.



CAD model used for crashworthiness

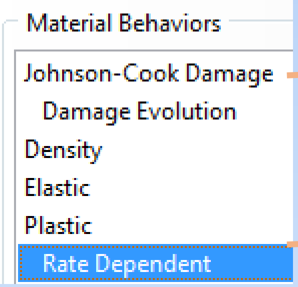


Loads and BCs on crash model

- All parts are imported as shell elements.
- Ground and « gauging blocks » are rigid parts with inertia mass.
- Material are the same but

→ plastic behavior is considered using Johnson-Cook model because of the speed-of-deformation-dependency not negligible here.

→ Johnson-Cook damage considered also.



$$D = \sum \frac{\Delta\varepsilon}{\varepsilon_f}$$

$$\sigma = [A + B\varepsilon^n][1 + C\ln\dot{\varepsilon}^*]$$

- Step and mesh could only be base on explicit library to be consistent.
- Launch at $6 - 9$ and $12m/s$ on a step then desactivated for the impact step.
- Calculation made on calculation server using 1CPU/1 domain

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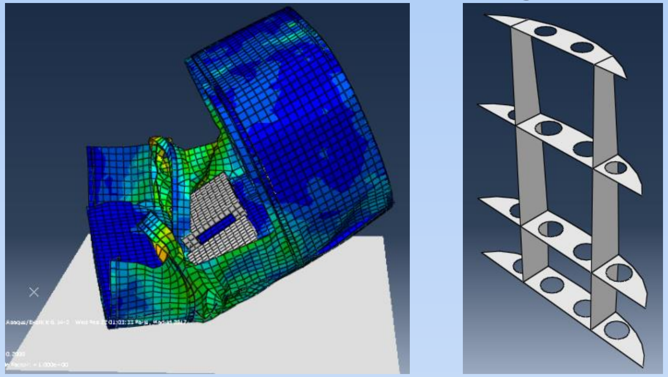
III. 3. Fuselage – Crash test

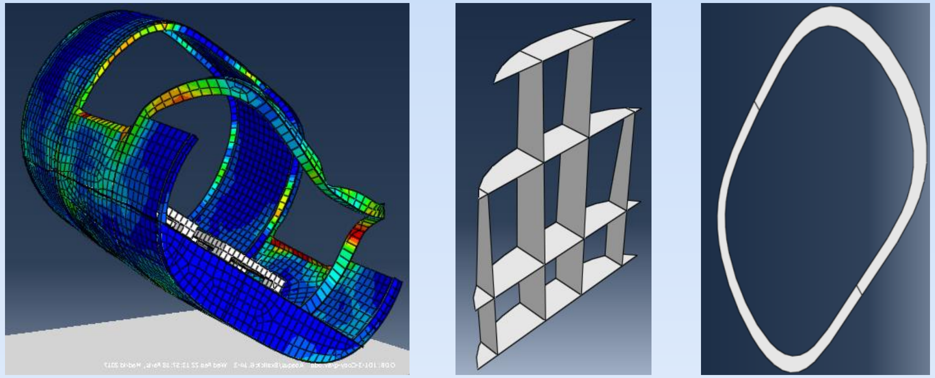
- Before the analysis of acceleration and energy absorption

→ are the deformations dangerous for passengers?



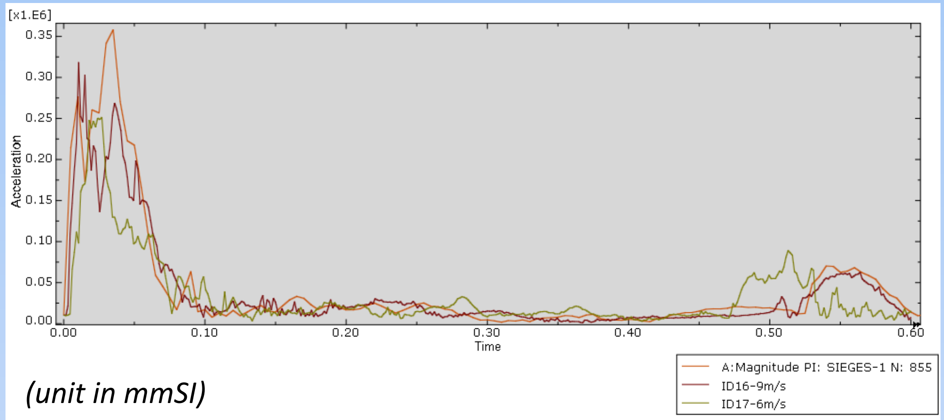
Frame of the impact – First strut design

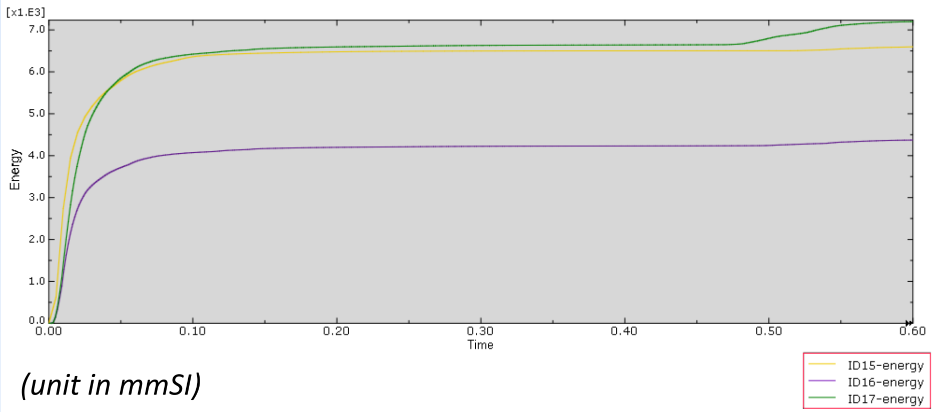
- New design to prevent collapse of the strut, with reinforced frame in the cockpit.

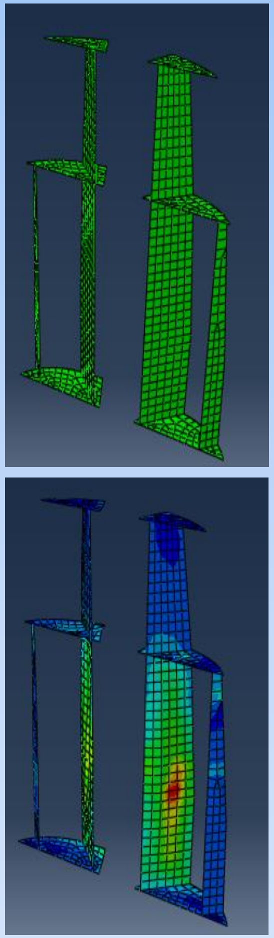


Frame of the impact – corrected strut and structure frame for stiffness

- Last design that absorbs the impact





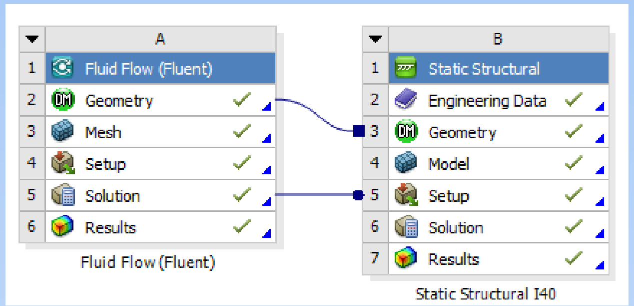


Energy dissipation

Accelerations on seats:

- ID15 – 12m/s → $35\vec{g}$
- ID16 – 9m/s → $33\vec{g}$
- ID17 – 6m/s → $25\vec{g}$

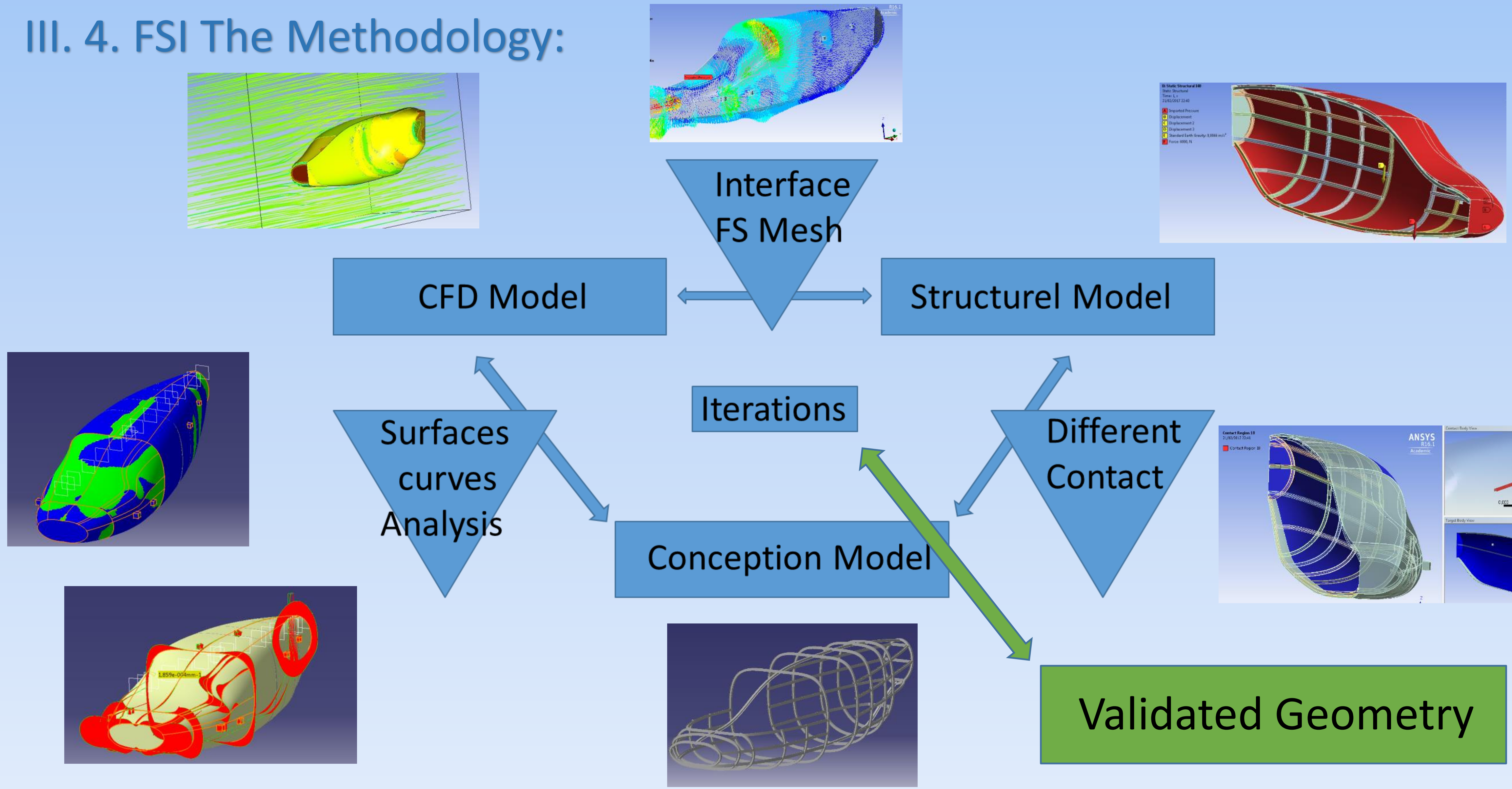
III. 4. FSI The Method



- **Advantages:**
- Interaction between fluid and structurel model = Coupling Navier stockes and structural equations
- A continuous pressure field on the skin of the plane
- More Accurate results than those obtained with a simple model

- **Disadvantages:**
- Takes much more time than the simple model
- Needs powerful machines

III. 4. FSI The Methodology:



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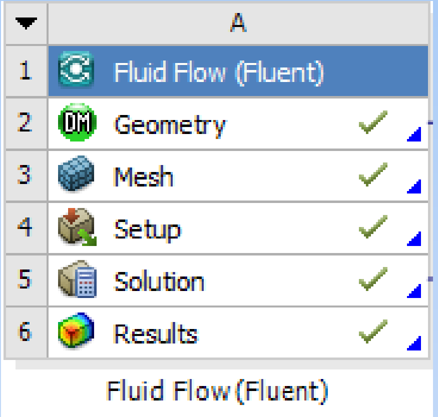
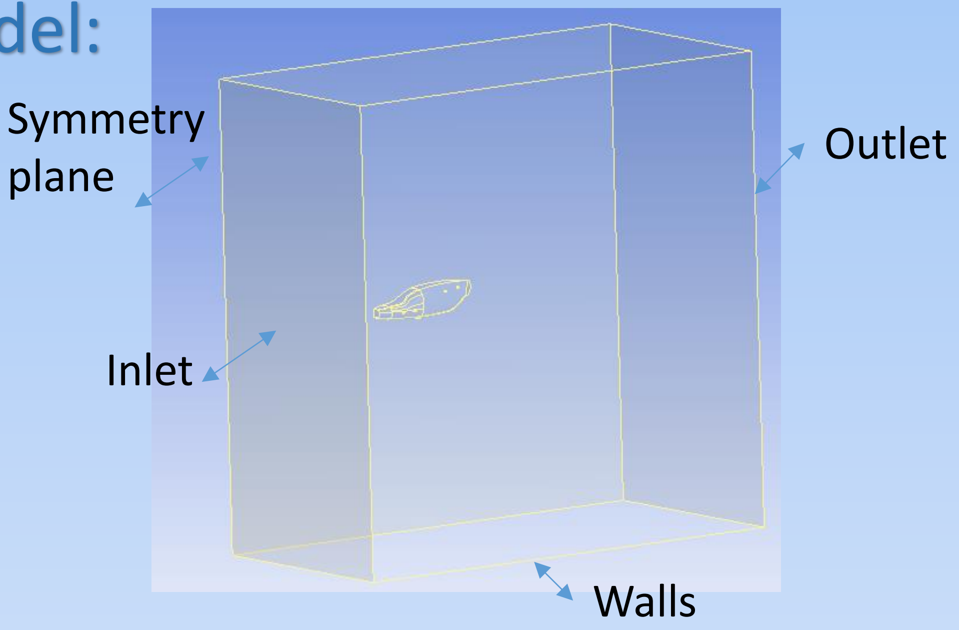
III. 4. CFD Model:





<u>Setup configuration:</u>

- Model Pressure Based
- K-Epsilon model
- Newtonian Fluid
- Steady time
- Advanced size functions

Inlet velocity 84 m/s → Field pressure on the skin plane

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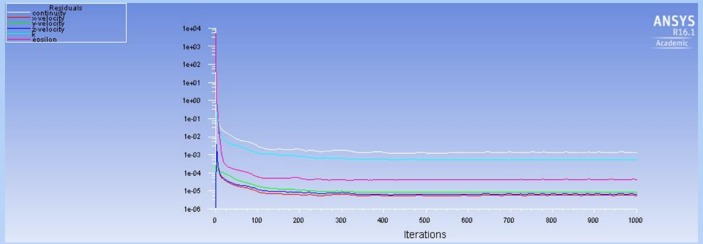
III. 4 Optimization of results: Convergence study on the mesh

	Dimensions									
Box (mm)3	20*20*20	20*20*20	20*20*20	20*20*20	20*20*20	20*20*20	25*25*25	25*25*25	25*25*25	30*30*30
Element size(mm)	20	30	25	20	20	15	18	25	25	18
Inflation(mm)	5	5	5	3	2	5	2	3	2	2
Drag Force(N)	881,3	834,95	873,09	915,2	910,6	832,52	832,04	837,21	829,5	832,9

design of experiments for mesh convergence



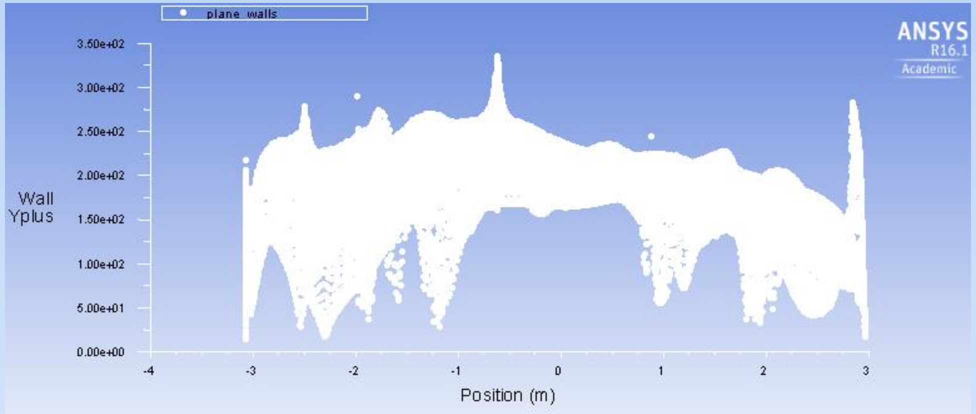
Convergence Residuals

```
Forces - Direction Vector (0 1 0)
                          Forces (n)
Zone                      Pressure        Viscous         Total
plane_walls               680.54652       151.50111       832.04764
------------------------- --------------- --------------- ---------------
Net                       680.54652       151.50111       832.04764
```

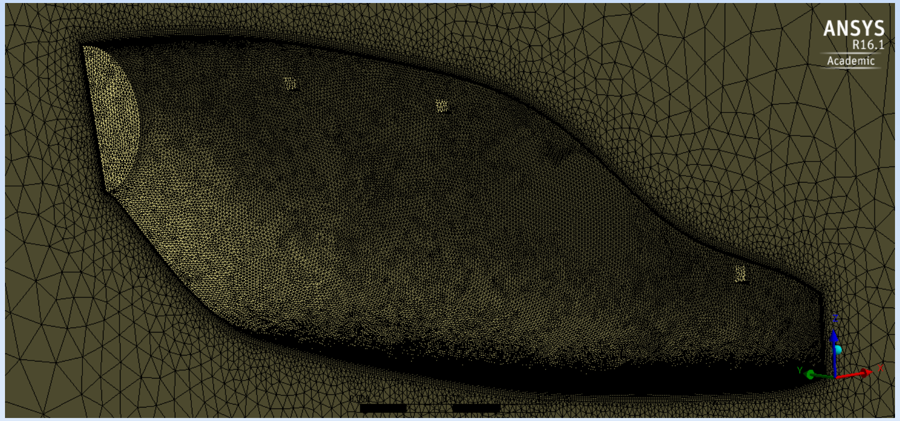
Drag force results

```
      Mass Flow Rate                  (kg/s)
-------------------- --------------------
               inlet            32156.251
              outlet           -32156.251
    ---------------- --------------------
                 Net      -0.00043122162
```

Mass flow verification



Y Plus verification 30<y<350



Mesh adapted

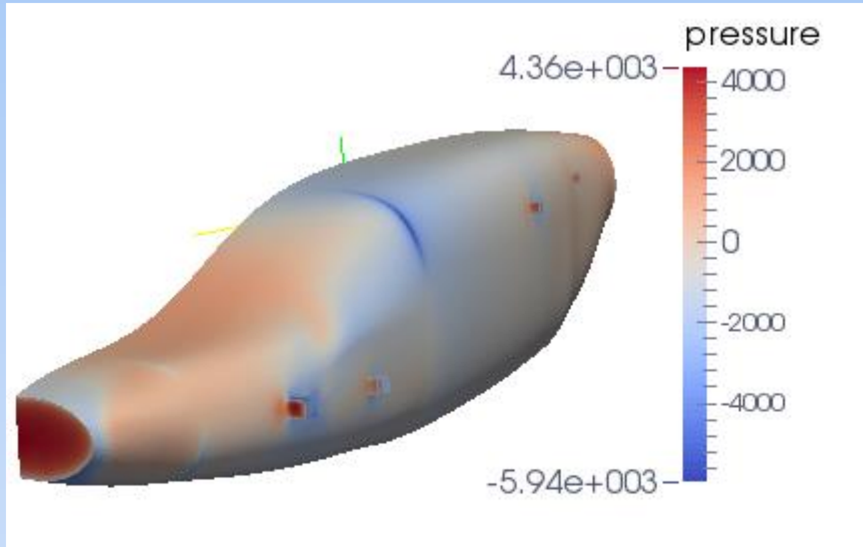
Final mesh choosen: Box =25*25*25 mm^3

Tet element size=18 mm

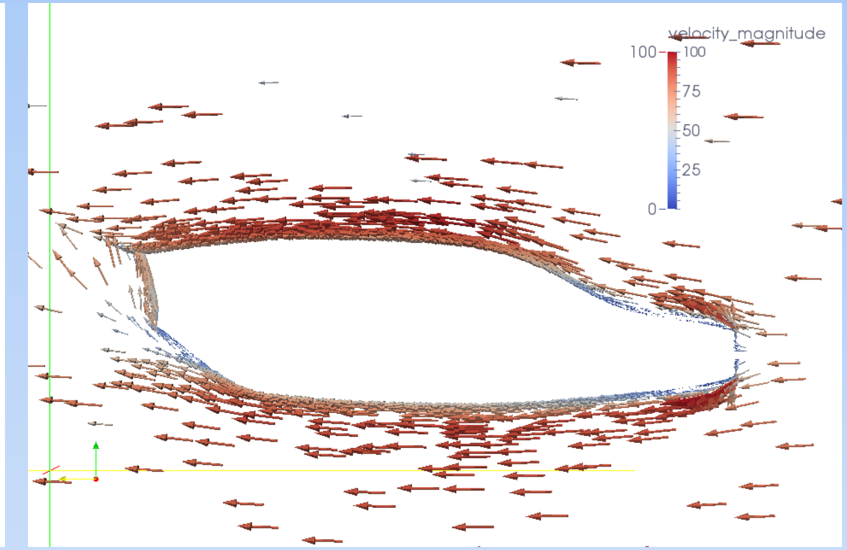
Inflation=2 mm

Conception de la structure de l'aéronef Mini-Bee

III. 4.CFD Results and analysis:

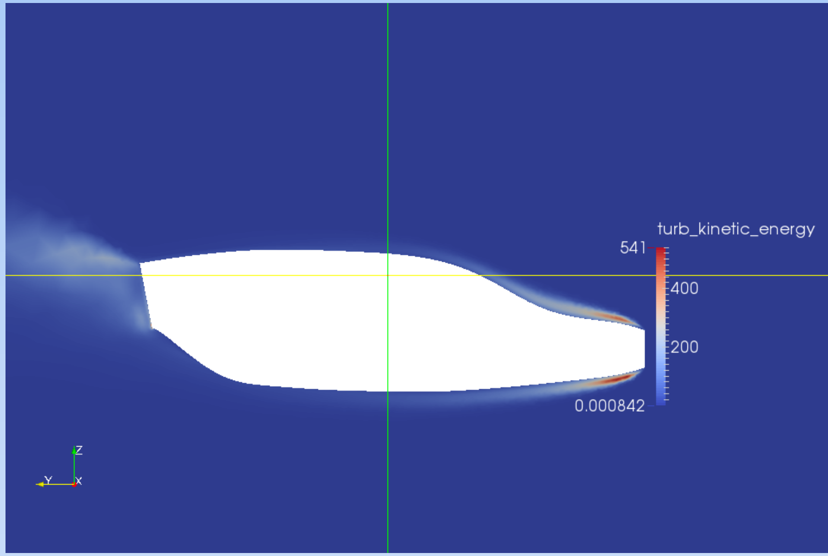


Skin plane pressure



Velocity arround the plane

At 300 km/h



Turbulent kinetic energy

Bernoulli conditions:

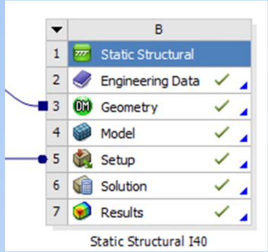
- Incompressible
- Steady time
- Inviscid

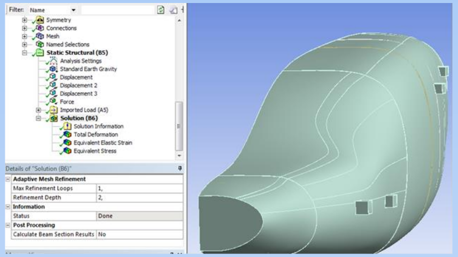
Along a streamline → $P_s + \frac{\rho V^2}{2} + \rho g z = Cte$

The shape of the plane is validated for the aerodynamics requirements → Geometry ready for the structural validation

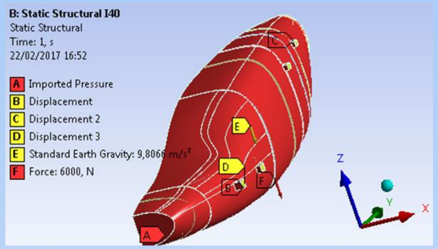
Conception de la structure de l'aéronef Mini-Bee

III. Structural model: Steady time

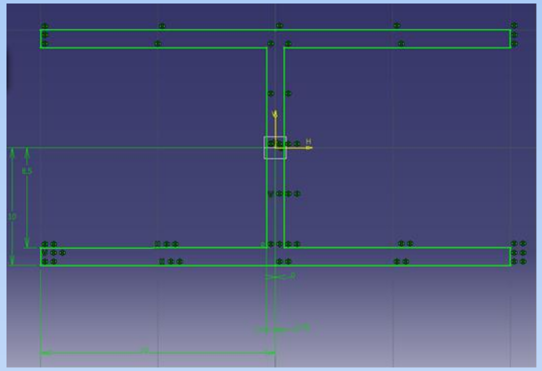




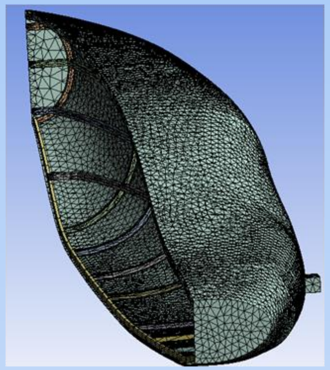
Mechanical interface



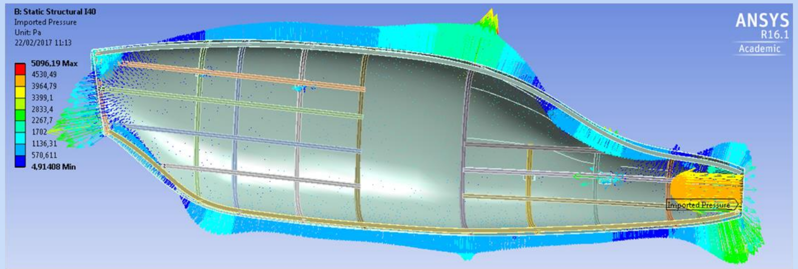
Limits conditions

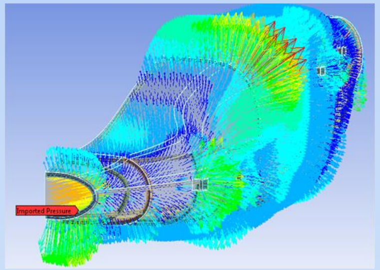


Dimensions Beam choosen
I 40 *20*1,5



Mesh choosen
- Solid187
- Conta174
- Surf 154
- Tet 3mm





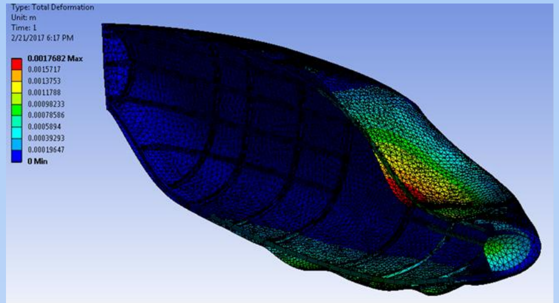
Field Pressure imported

- **Assupmtions of the problem:**
- Displacement DOF z =0 (on wings fixations)//Lift
- Displacement DOF y=0 (on wings fixations) //Force engine
- Displacement DOF x=0 (on wings fixations)// Delete the last DOF
- Field Gravity
- -6000N // 600 Kg imported on the plane
- Pressure field on the skin // Effect of the velocity on the fuselage
- Material used Aluminium

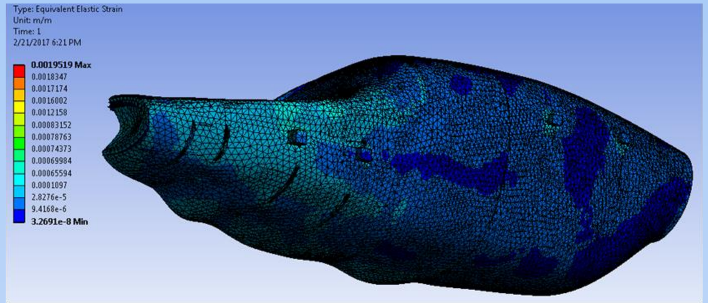
Problem well posed

Conception de la structure de l’aéronef Mini-Bee

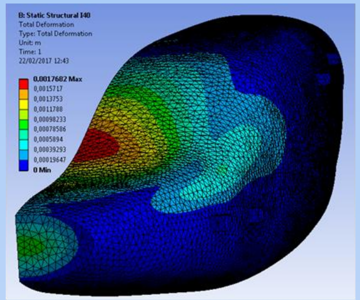
III. 4.Structurel model: Results



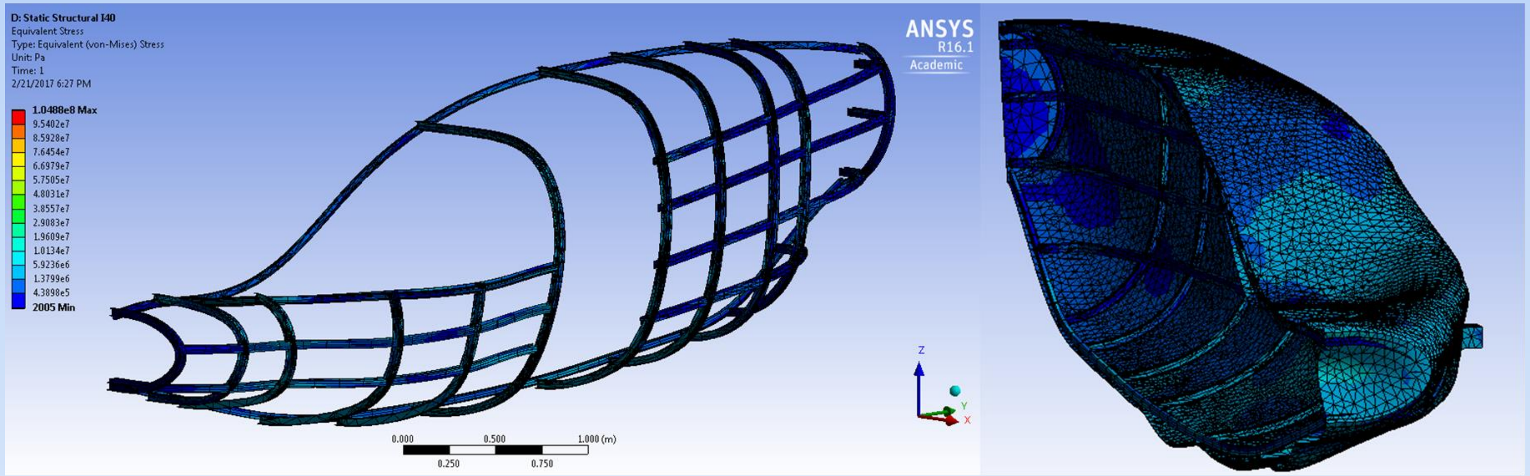
Total deformation



Equivalent Elastic Strain



Total deformation (true scale)



Equivalent Von Mises Stress

- **Results:**
- Max deformation 1,7mm
- Max strain 0,0019
- Max Stress 104 Mpa < Re

Beam I 40*20*1,5 mm^3
Skin thickness 3,5 mm

→

FSI Method validated through consistency again
Fuselage resistance validated with a weight of 191,57 Kg

Structural design of Mini-bee

-- Final Defense --

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