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MSc in Aerospace Engineering

—– Computational Engineering —–
Computational Structural Analysis

TASK 02: Structural analysis of an A320 fuselage

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1 Introduction

The aim of this report is the structural study of an Airbus A320 fuselage. The study is carried out with Matlab, where some input data is already given. The analysis is performed for the following cases:

- A. Structural weight.
- B. Weight of the cabin passengers.
- C. Loads transmitted by the wings.
- D. Loads transmitted by the nose and the tail cone.
- E. Cabin pressure.

For the problem approach, first of all the problem description is defined in order to show the physical and geometrical properties of the fuselage. After that, each case is studied considering and additional case where all loads are applied simultaneously. Finally, some conclusions are presented.

2 Problem description

2.1 Physical definition

First of all, the geometry of the Airbus A320 fuselage must be defined. For that purpose, the structural elements have been divided into two sub-major groups, being beams and plates. On Figure 2.1, an scheme of the model is presented.

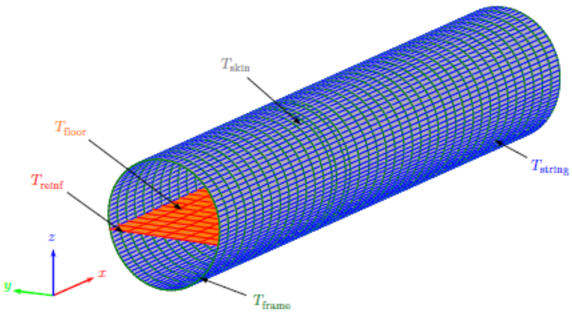

Figure 2.1: Model of the A320 fuselage.

The elements that are modelled as plates are the following:

- The outer skin elements (T_{skin}), with $h_s = 4mm$.
- The cabin floor elements (T_{floor}), with $h_s = 8mm$.

While the elements that are modelled as beams are the following:

- The frames elements (T_{frame}), with section A.
- The stringers elements (T_{string}), with section B.
- The cabin floor reinforcements elements (T_{reinf}), with section C.

As mentioned, the beams can have three different sections. These sections, are represented on Figure 2.2.

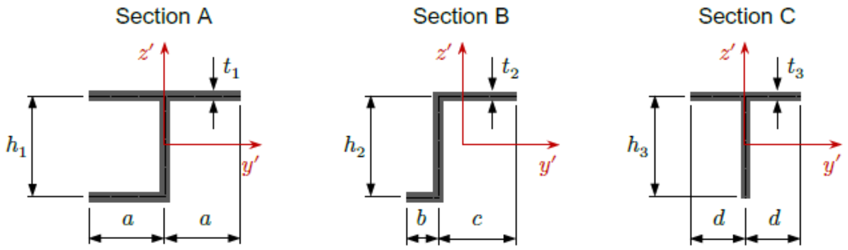

Figure 2.2: Three types of sections defined for the beams.

The beams' section geometrycal properties are defined on the following table.

Parameter	Dim. (mm)	Parameter	Dim. (mm)	Parameter	Dim. (mm)
h_1	74	h_2	24	h_3	48
t_1	2	t_2	2.5	t_3	2.2
a	20	b	18	d	22
		c	20		

Table 2.1: Beams' section parameters.

The physical properties regarding to the different components are defined on Table 2.2.

Component	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's ration
Frames Stringers	2650	70.1	0.30
Reinforcements Skin Floor	2910	76.3	0.35

Table 2.2: Material properties

Given the symmetry along the XZ plane, the analysis can be performed just for half of the structure.

2.2 Cases definition

In this section, the different cases mentioned that are analysed are defined.

2.2.1 Structural weight

The weight is considered as a distributed load:

$$\mathbf{w}_{beams,e} = \rho_{eff,e} A_e \mathbf{g}, \quad \forall e \in T_{beams} \tag{2.1}$$

$$\mathbf{w}_{plates,e} = \rho_{eff,e} h_e \mathbf{g}, \quad \forall e \in T_{plates} \tag{2.2}$$

where the effective density $(\rho_{eff,e})$ is defined as:

$$\rho_{eff,e} = \rho_e \hat{\rho} \tag{2.3}$$

where,

$$\hat{\rho} = \frac{M_s - M_{beams} - M_{plates}}{V_{beams} + V_{plates}} \tag{2.4}$$

where $M_s = 22900kg$ and

$$V_{beams} = 2 \sum_{e \in T_{beams}} A_e l_e; \quad V_{plates} = 2 \sum_{e \in T_{plates}} 4 a_e b_e h_e \tag{2.5}$$

$$M_{beams} = 2 \sum_{e \in T_{beams}} \rho_e A_e l_e; M_{plates} = 2 \sum_{e \in T_{plates}} 4 \rho_e a_e b_e h_e \tag{2.6}$$

The factor of two is used in order to take into account the other half of the fuselage.

2.2.2 Weight of the cabin passengers

The cabin passenger's weight is considered as a distributed load on the floor plates:

$$\mathbf{w}_{p,e} = \frac{M_p}{S_{floor}} \mathbf{g}, \quad \forall e \in T_{floor} \tag{2.7}$$

where $M_p = 13500kg$ and

$$S_{floor} = 2 \sum_{e \in T_{floor}} 4 a_e b_e \tag{2.8}$$

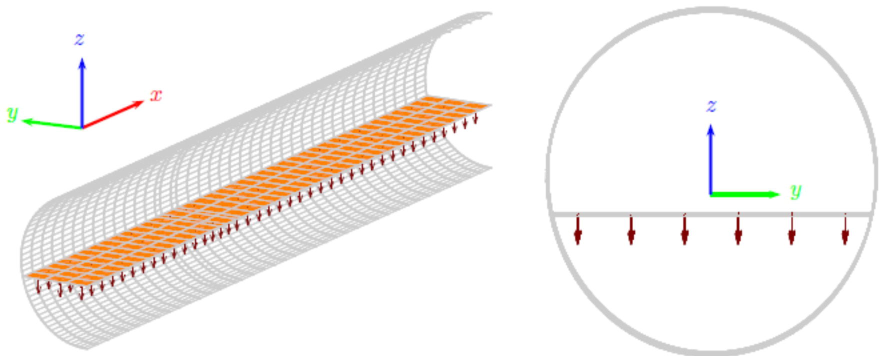

Figure 2.3: Weight of the cabin passengers representation.

2.2.3 Loads transmitted by the wing

The front and rear spars of the A320 aircraft are attached to the selected frames' elements, T_{front} and T_{rear}, respectively. Assuming the wing's system reaction forces and moments at the joint are given by:

$$\mathbf{F}_f = \begin{bmatrix} 78.94 \\ 72.22 \\ -71.07 \end{bmatrix} kN; \quad \mathbf{F}_r = \begin{bmatrix} 17.18 \\ -72.22 \\ -25.47 \end{bmatrix} kN \tag{2.9}$$

$$\mathbf{M}_f = \begin{bmatrix} -349.08 \\ 194.87 \\ -86.29 \end{bmatrix} kN \cdot m; \quad \mathbf{M}_r = \begin{bmatrix} -203.2 \\ 83.85 \\ -91.93 \end{bmatrix} kN \cdot m \tag{2.10}$$

The force applied by the wing to the fuselage is considered as an equivalent uniformly distributed load over each frame segment:

$$\mathbf{q}_{front,e} = -\frac{\mathbf{F}_f}{l_{front}}, \quad \forall e \in T_{front}; \quad l_{front} = \sum_{e \in T_{front}} l_e \tag{2.11}$$

$$\mathbf{q}_{rear,e} = -\frac{\mathbf{F}_r}{l_{rear}}, \quad \forall e \in T_{rear}; \quad l_{rear} = \sum_{e \in T_{rear}} l_e \tag{2.12}$$

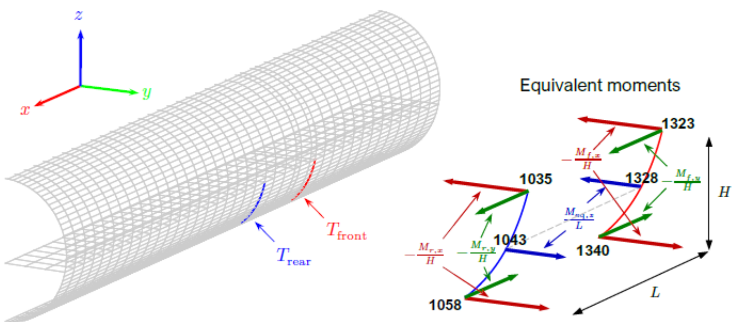

Figure 2.4: Loads transmitted by the wing representation.

The moment applied by the wing to the fuselage is accounted for by an equivalent system of point loads, as shown on Figure 2.4, where $H = z_{1323} - z_{1340}$, and $L = x_{1043} - x_{1328}$. The equivalent moment around z-axis is given by:

$$M_{eq,z} = -(M_{f,z} + M_{r,z}) - (M_{f,y} + M_{r,y})\frac{W}{H}; \quad W = y_{1323} - y_{1340} \tag{2.13}$$

2.2.4 Loads transmitted by the nose and the tail cone

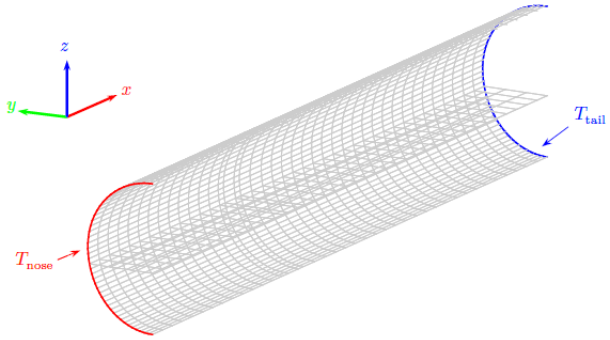

Figure 2.5: Loads transmitted by the nose and the tail cone representation.

The drag of the aircraft's nose is applied on the first frame elements, T_{nose}, as a uniformly distributed load:

$$\mathbf{q}_{nose,e} = \frac{1}{l_{nose}} \begin{bmatrix} D_{nose} \\ 0 \\ 0 \end{bmatrix}, \forall e \in T_{nose} \tag{2.14}$$

where,

$$l_{nose} = 2 \sum_{e \in T_{nose}} l_e \tag{2.15}$$

$$D_{nose} = \frac{1}{2} \rho V^2 S C_D \tag{2.16}$$

with $\rho = 1.225 kg/m^3$, $V = 210\ m/s$, $C_D = 0.39$ and $S = 12.84\ m^2$.

The lift and drag caused by the aircraft's tail is applied on the last frame elements, T_{tail}, as a uniformly distributed load:

$$\mathbf{q}_{tail,e} = \frac{1}{l_{tail}} \begin{bmatrix} D_{tail} \\ 0 \\ L_{tail} \end{bmatrix}, \forall e \in T_{tail} \tag{2.17}$$

where $L_{tail} = 164.01 kN$ and $D_{tail} = 56.98 kN$ and

$$l_{tail} = 2 \sum_{e \in T_{tail}} l_e \tag{2.18}$$

2.2.5 Cabin pressure

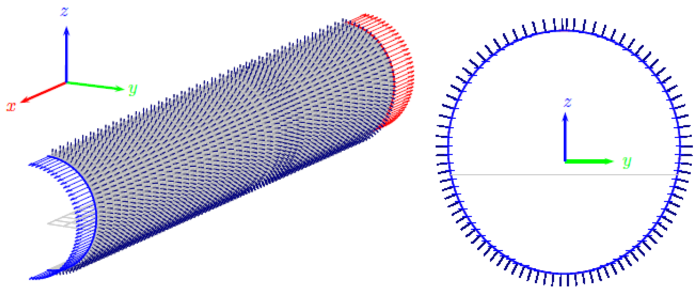

Figure 2.6: Cabin pressure representation.

The cabin pressurization is considered as a differential pressure load applied normal to the skin elements:

$$\mathbf{P}_{skin,e} = (p_{in} - p_{out})\mathbf{n}_e, \quad \forall e \in T_{skin} \tag{2.19}$$

where $p_{in} = 78191.21Pa$, $p_{out} = 22632.06Pa$ and $\mathbf{n}_e$ is the unit normal to the element surface.

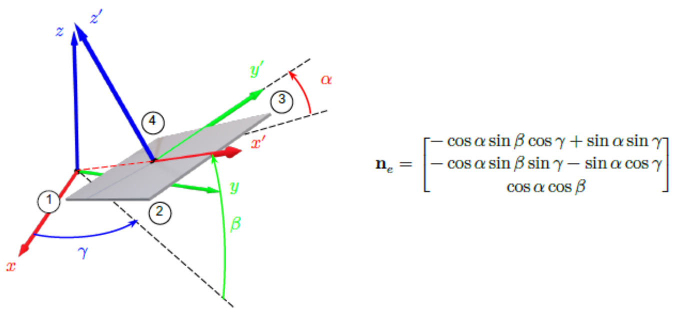

Figure 2.7: Normal vector representation.

Moreover, the equivalent axial stress produced by the same differential pressure on the x-direction is considered as a distributed load on the first and last frames elements:

$$\mathbf{p}_{nose,e} = \frac{1}{l_{nose}} \begin{bmatrix} -(p_{in} - p_{out})S \\ 0 \\ 0 \end{bmatrix}, \forall e \in T_{nose} \tag{2.20}$$

$$\mathbf{p}_{tail,e} = \frac{1}{l_{tail}} \begin{bmatrix} (p_{in} - p_{out})S \\ 0 \\ 0 \end{bmatrix}, \forall e \in T_{tail} \tag{2.21}$$

where $S = 12.84m^2$.

3 Results

On this section, the different results obtained for each case are presented and discussed.

3.1 Structural weight

On this case, the load is the weight of the whole structure (Ms = 22900 kg). To do so, the computation for the effective density needs to be one so it is possible to compute the equivalent weight of each element.

As explained before, loads are duplicated taking into account the symmetry of the structure.

On the other hand, additional degrees of freedom must be fixed as noted in the statement of the problem. Some nodes must be restricted in the x-direction and z-direction in order to avoid rigid body modes.

In this case the selected nodes correspond to a node in the maximum value of x (it is to be said the front) and the minimum value of z (the bottom of the fuselage) = Node 260. As well as the minimum value of x (it is to be said the rear) and the minimum value of z (the bottom of the fuselage) = Node 1968.

On this case, the Von Mises distribution and displacements are presented. As it can be seen on both figures, the fixed nodes don't displace. The rest of the domain however, suffers a downwards displacement on Z axis. The maximum value is slightly higher than 5 cm, obtained along the X axis in the center of the fuselage. Regarding Figure 3.1, representing the Von Mises distribution, it can be stated that the highest values are obtained where the nodes were fixed. On real case, it would be expected to obtain these maximum values on the landing gears on ground, being the zone which withstands the whole weight.

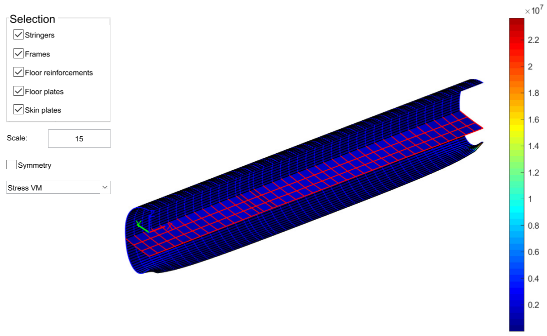

Figure 3.1: Case A. Von Mises Distribution with a scale of 15.

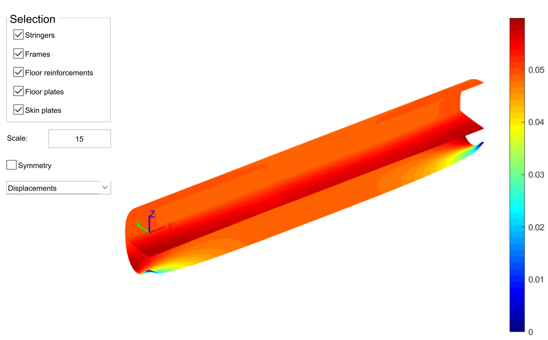

Figure 3.2: Case A. Displacements with a scale of 15.

3.2 Weight of the cabin passengers

For this second case, as it was explained on the problem description the passengers weight ($M_p = 13500kg$) is studied. The associated weight is distributed along the plates on the floor, where passengers are standing. For this case, two nodes have been fixed to avoid rigid modes. Both have been fixed on the X and Z direction, and these nodes are the 125 and 1947. These two nodes are the ones which unify the floor with the fuselage at both extremes of the fuselage.

As occurred on the previous case, the major Von Misses stress is found around the fixed nodes (Figure 3.3). Regarding to the displacements, it can be observed on Figure 3.4 how does the floor bend due to the passengers weight. The major values are obtained along the centerline of the fuselage, X axis, with maximum values of about 18mm. On the contrary, there is no effect in terms of displacement on the part which is not the floor.

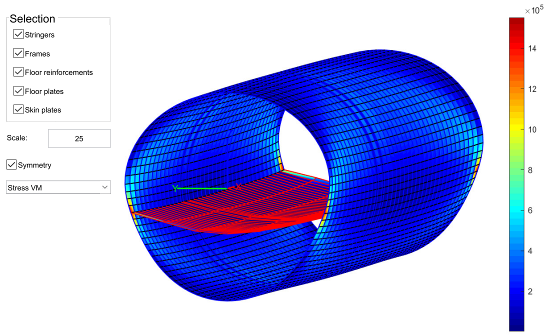

Figure 3.3: Case B. Von Mises Distribution with a scale of 25.

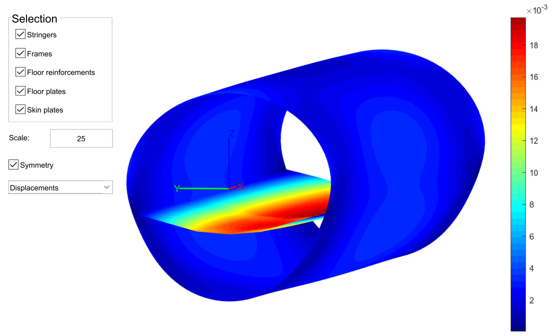

Figure 3.4: Case B. Displacements with a scale of 25.

3.3 Loads transmitted by the wings

This case corresponds to the effect of the wings on the structure, as mentioned on the problem descriptions the reaction forces and moment are prescribed on the rear and front spars. The fixed nodes to avoid rigid modes are the same as on case A.

On the contrary to the other two previous cases, the displacement is upwards on the Z direction. Moreover, on this case there is Von Mises stress on other zones rather than surroundings of the fixed nodes. As it can be observed on Figure 3.5, the highest values of stress are obtained on the front and rear spars corresponding to where the wings are attached. On the front spar a maximum stress of 30 MPa is obtained, whereas on the rear a maximum stress of 12.5 MPa is achieved. On the other hand, the other zones of highest values of stress is on the fixed nodes.

Regarding to the displacements, all the fuselage is displaced except for the fixed nodes, as expected. The highest values of displacements are obtained under the zone where the wings are attached, on the lowest part, where a maximum displacement of 7 mm is achieved (Figure 3.6.

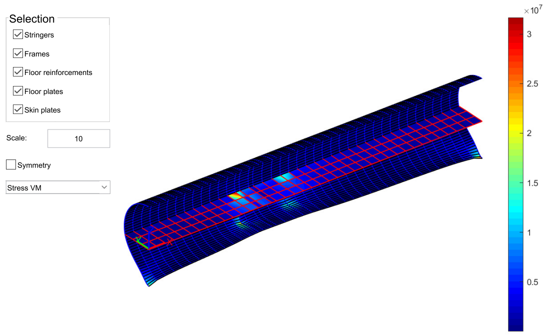

Figure 3.5: Case C. Von Mises Distribution with a scale of 10.

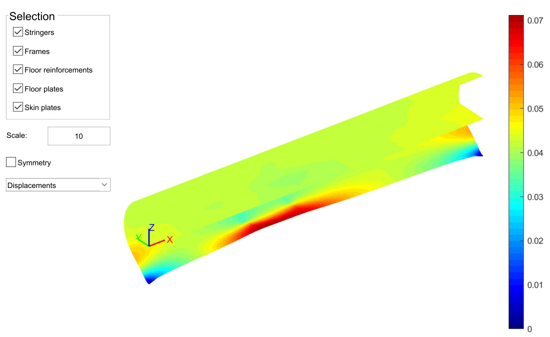

Figure 3.6: Case C. Displacements with a scale of 10.

3.4 Loads transmitted by the nose and the tail cone

The fourth case correspond to the study of the loads transmitted by the nose and tail cone. As mentioned on the problem description, the nose generates drag and the tail generates both drag and lift and these values are known. The fixed nodes and their respective DOF fixed are the same as in case A.

For the Von Mises distribution it can be observed that there is the maximum affectation on the zones near the fixed nodes, with a peak of 18 MPa. On the other zones, the affect of this stress is very low with values lower than 5 MPa (Figure 3.7). On the other hand, the displacements obtained on Figure 3.8 shows how the displacements increase along the X axis, obtaining the minimum values on the front and the maximum on the rear. For this case, the displacement is along Z axis upwards, due to the effect of the lift, with a maximum value of 7 cm.

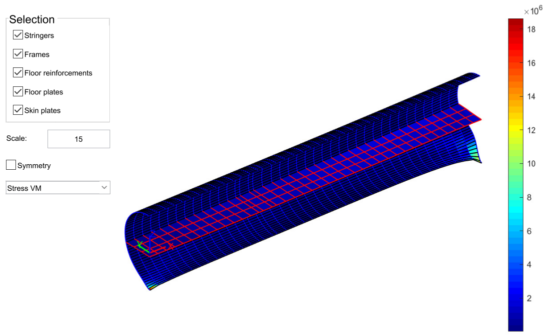

Figure 3.7: Case D. Von Mises Distribution with a scale of 15.

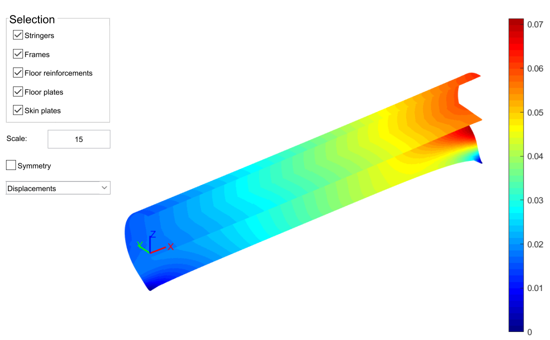

Figure 3.8: Case D. Displacements with a scale of 15.

3.5 Cabin pressure

The last load case account for the cabin pressurization. The values of the pressure inside and outside the fuselage are described on the problem description. Also, the equivalent stress produced by the same differential pressure is computed for the first and last frame. For this case, the fixed node is the 925 on Z-direction, which is a node in the center of the fuselage.

For the cabin pressure, the hydrostatic stress is studied instead of the Von Mises stress. The main reason to do so, is because the pressurization exerts a normal force on the plates, which can be expressed more clearly with the hydrostatic stress. As it can be observed on Figure 3.9, the maximum values of stress are obtained on the upper part of the airframe, with a maximum value of 1 MPa. On the other hand, the lower values are obtained on the attachment of the wings and on the plates on the rear and front. As expected, the major stress are all over the airframe. Regarding to the displacements, observed on Figure 3.10, the maximum values are obtained on the lowest part of the fuselage, and then they decrease while increasing Z.

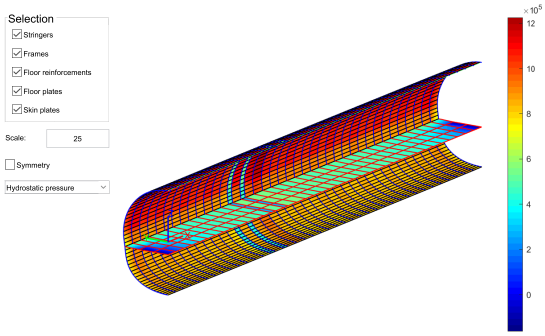

Figure 3.9: Case E. Hydrostatic stress with a scale of 25.

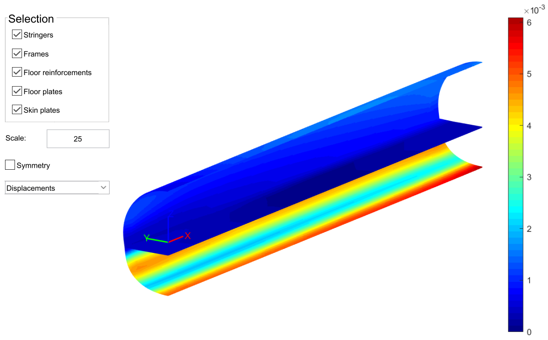

Figure 3.10: Case E. Displacements with a scale of 25.

3.6 All loads

Finally, all loads are studied simultaneously. The fixed nodes for this case are nodes 125 and 1947 on X and Z direction.

Regarding to the displacements, on the front part there is a major displacement on the Z axis downwards, on the contrary on the rear part the displacement is upwards but lower values (Figure 3.12). This is due to the fact that the lift on the rear is compensated by the weight of the passengers. Regarding to the Von Mises stress, plotted on Figure 3.11, it is observed how the wing loads represents the highest values of stress, being the predominant force in comparison to the other cases. A stress of 30 MPa is obtained on the front attachment and 12.5 MPa on the rear.

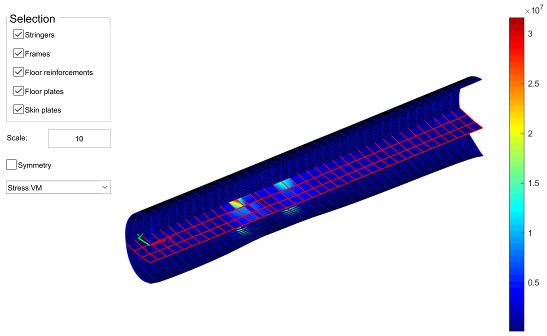

Figure 3.11: All loads. Von Mises Distribution with a scale of 20.

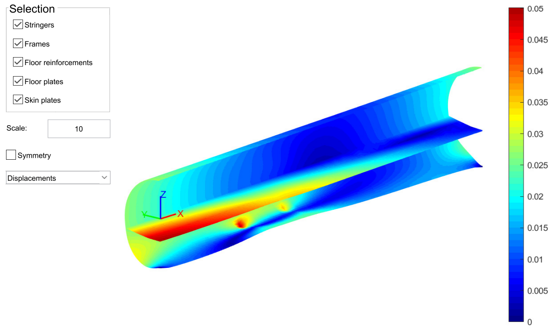

Figure 3.12: All loads. Displacements with a scale of 20.

On the other hand, the following plots show the color plot of the internal distribution of the following parameters for the frames and the stringers:

- Axial force (Figure 3.13)
- Shear force in the local y' direction (Figure 3.14)
- Shear force in the local z' direction (Figure 3.15)
- Torsional moment (Figure 3.16)
- Bending moment in the local y' direction (Figure 3.17)
- Bending moment in the local z' direction (Figure 3.18)

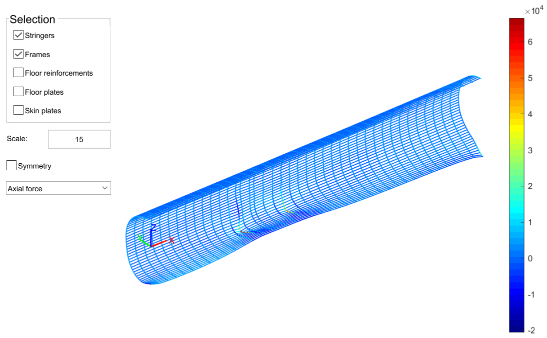

Figure 3.13: All loads. Axial Force for frames and stringers with a scale of 15.

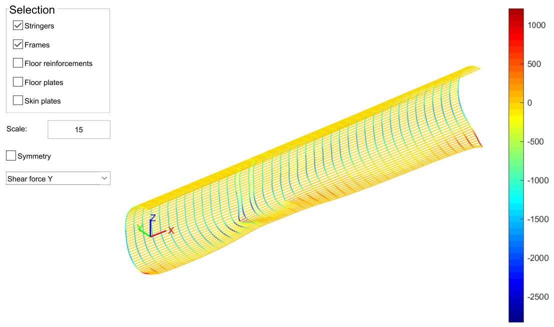

Figure 3.14: All loads. Shear Force y-direction for frames and stringers with a scale of 15.

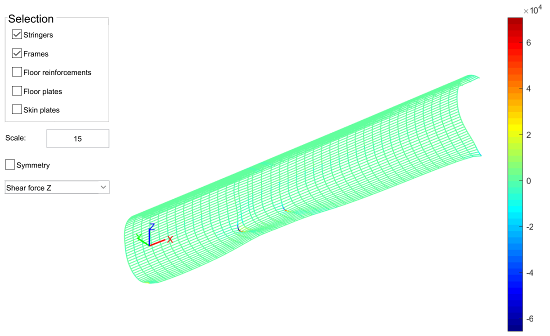

Figure 3.15: All loads. Shear Fore z-direction for frames and stringers with a scale of 15.

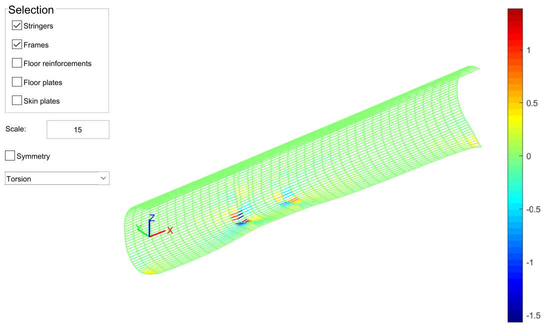

Figure 3.16: All loads. Torsion loads for frames and stringers with a scale of 15.

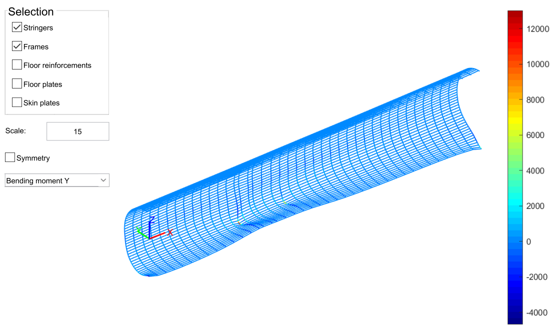

Figure 3.17: All loads. Bending Moment y-direction for frames and stringers with a scale of 15.

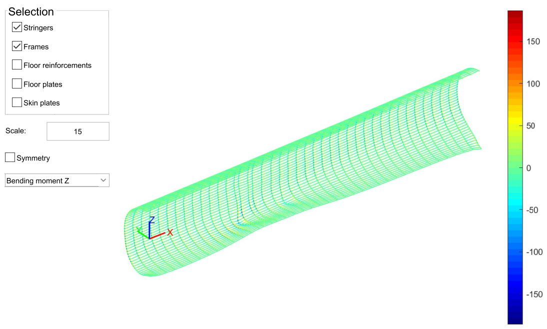

Figure 3.18: All loads. Bending Moment z-direction for frames and stringers with a scale of 15.

As expected in Figure 3.13, the only beams that work under axial stress conditions are those close to the wings attachments, for the others a null axial force is obtained. Those frames that join the wing spars with the fuselage work under tensile stress, whereas the adjacent are working under compression stress.

Regarding to the shear stress on Y, on Figure 3.14, it is observed that on stringers the value is null. However, for the stringers is where the maximum values are obtained. On the rear and front part of the fuselage work under tensile stress, mainly due to the drag effect. On the other hand, wing frames work under compression shear stress. Considering the shear force on Z, Figure 3.15, it is observed that on all beams it is null except for the attachment of the wings to the fuselage. These values are obtained due to the reaction forces and moments from the wing to the fuselage.

On Figure 3.16, the torsion moment is represented. As it can be observed the values are really low, existing only on the attachment of the wing and on fixed nodes. On Figure 3.17, the bending moment is represented on Y-direction, on all the air frame the values are zero except for the wing attachment, where on the front one a maximum of 12.000 Nm moment is obtained. On the same way, on the bending moment on Z-direction the maximum values are obtained on the same area however in this case with much lower values.

3.7 Assessment with only plates

Finally, an analysis is carried out just taking into consideration only plate elements stiffness matrix for all loads. It is an interesting study because it clarifies the importance of the beam elements on the fuselage.

On Figure 3.20, the displacements with no scale are obtained. The results are alarming due to the fact that the structure is completely collapsed. Displacements of more than 1 meter are obtained in the centerline of the X axis, which is unacceptable. Regarding to the Von Mises distribution stress, almost the double of stress is obtained on the attachment of the wing of the fuselage, obtained values of almost 60 MPa when on the case with all loads for beams and plates values of 30 MPa were obtained. For these reasons, the importance of the beam elements for absorbing all forces is remarked.

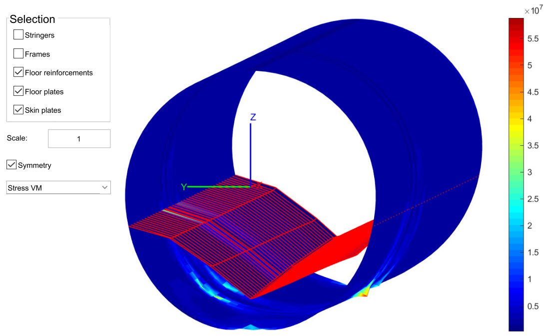

Figure 3.19: All loads. Von Mises Distribution for only plates.

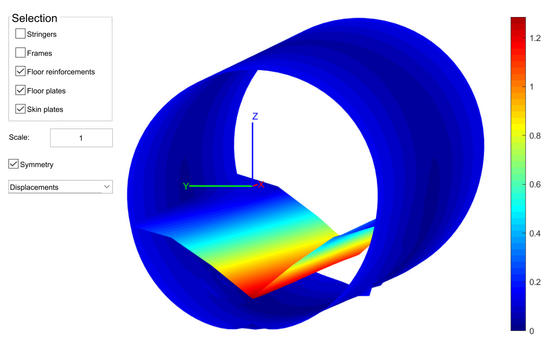

Figure 3.20: All loads. Displacements for only plates.

4 Conclusions

On this report, an analysis has been performed for all the loading cases given. Each case has been studied individually and the affectation to each of the fuselage parts has been studied. For all of them, displacements and Von Mises stress distribution have been studied and discussed, and for case E hydrostatic stress has been analysed as well. All results are considered satisfactory, the forces, moments and displacements behaviour were the ones that were expected.

After having studied all cases individually, all loads have been computed simultaneously. The results have been the ones that were predicted, were major forces are obtained on the attachment to the wings. It was predictable because when studying them individually, with case C major values of stress where obtained. For all loads computation, axial, shear torsional and bending moments has been studied for frames and stringers. The results were solid and demonstrated low values for almost all the air frame except for this critical area of the wing attachment.

Finally, in order to demonstrate the importance of beams the beams on the fuselage a simulation has been carried out just considering the plate element stiffness matrix. The results were redundant, showing a collapse on the structure. With this study then, how do beams absorb forces is shown.

To conclude, a deep analysis on an Airbus A320 fuselage has been carried out. The results are considered satisfactory and it shows how each loading affects to it.