Structures

# Task 1







Figure - Cross Sectional Properties & Example of discretised section

Above are the graphs showing the cross-sectional properties along the span of the wing for the initial set of design variables, as well as a graphical example of the discretization. As shown, the cross section is split into 4 elements for the wing box, and then each stringer is represented by one element each. The decision was made not to discretize into even more elements, as testing showed that increasing this had a minimal effect on results, due to the relatively simple geometry. We can see the general trend of the values of the cross-sectional properties, decreasing as we move outboard along the wing which is what we would expect due to the dimensions of the wing box decreasing as we move outboard, as well as the thickness of the web, skin and stringers.

# Task 2





Figure - Internal Shear and bending moments

The internal shear and bending moments were calculated for the whole span of the beam for both the load cases given, -1g and 2.5g. For the internal shear forces, this was done by integrating the loads along the span, for multiple fictitious cuts along the wing, in order to give a distribution of the shear forces along the span. This was then simply integrated in a similar process (using MATLABs trapz function) to work out the distribution of the bending moment along the span. As seen in the results, we can see that there is a maximum of both near the root of the wing, with it decreasing to 0 at the tip, this is true for both load cases.

# Task 3



Figure - Example of Axial Stress Distribution



Figure - Variation of Maximum and Minimum Axial Stress

The first figure shows the axial stress variation of the 1st rib under the negative 1g load case, with the variation of the Y of the cross section. There is maximum magnitude stress at the top and bottom surfaces of the wing, with the bottom surface being in compression (negative stress) and the top surface in tension. We can also observe zero axial stress at the neutral axis, y = 0. The second figure shows the variation of the maximum and minimum axial stress along the span of the wing. We can see that this is symmetrical, ie the maximum is just equal and opposite to its minimum counterpart. This reflects what we would expect as the cross section is symmetrical about y = 0.

# Task 4



Figure - Initial Condition Failure indices

The above graph shows the failure indices represented in a graphical form, where a positive value implies a failure in that condition. This is the graph for the initial set of design variables. With the initial set of variables, the only mode of failure, when not accounting for shear, is the buckling of the top and bottom stiffened panels. These fail up to 8 meters along the span. The Stringers buckling failure condition is also close to failure with a small margin , but the rest of the failure modes have a good amount of margin to failure.

# Task 5



Figure - Point Load Equivalents for FEA model

The first step in the FE wing model was to break up the wing (modelled as a beam) in the spanwise direction into multiple nodes. For our analysis, this was 50 nodes from root to tip, hence dividing the beam into 49 elements. For the purposes of this analysis, as we are only interested in the deflection of the wing in the y direction, we modelled the wing in 2D as a beam. Therefore, we used the stiffness matrix for a 2D beam, and since all the nodes were in line with each other, the rotational matrix was not needed. The next step was to model the distributed load given, into an approximate representation using point loads. This is shown in the figure above. The displacement solution, and gradient of the displacement was then calculated and is shown in Figure 7.



Figure - Wing Deflection and Gradient

# Task 6

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Skin Thickness (root) | Skin Thickness (tip) | Web Thickness (root) | Web Thickness (tip) | Stringer Height (root) | Stringer Height  (tip) | Stringer Thickness (root) | Stringer Thickness (tip) | Number of Stringers |
| 0.0026091 | 0.0010001 | 0.0010001 | 0.0010002 | 0.060669 | 0.02789 | 0.004552 | 0.0008698 | 12 |

Table – Optimised design variables

The optimisation was carried out utilizing MATLAB’s fmincon, which is a built-in gradient-based optimisation function. The variables passed into the optimiser are shown above, except for the number of stringers. Due to stringers needing to be an integer (i.e., cannot be decimal) this was handled by carrying out multiple optimisations for stringers from a range of 4, up to 20 and the design with the smallest wing mass was chosen. Figure 8 shows the new designs failure indices.



Figure - Failure indices of optimised design

As we can see in figure 8, the failure indices are all negative so unlike the initial variables this design does not fail, but generally the design is a lot closer to the failure condition then with the initial conditions. Therefore, this provides the absolute minimum values before failure, for actual design it would be best to implement a safety margin.

# Task 7

The shear stress within the cross sections was found by using shear flow. This was done by assuming that the hollow rectangular beam (wing box) could be modelled as a thin wall structure. The shear flow of each sub section of the beam was found, and then the shear stress in each of these sections was found by dividing through by the thickness. The stringers were not considered when calculating the shear flow as under thing wall assumptions, the stringers only carry axial loads. This resulted in the distribution in figure 9.



Figure - Example of Shear Stress Distribution of cross section

This shows the distribution starting from an arc length of 0, at the middle of the top skin, and increasing until the middle of the bottom skin. As we can see, there is maximum shear stress along the middle of the right surface, which corresponds to being inline with the neutral axis which is what is expected. This distribution would be mirrored on the opposite side.

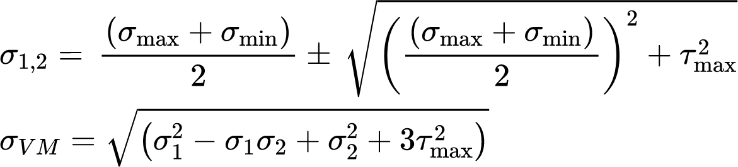


Figure - Maximum and Minimum Shear Stress Distribution

Figure 10 shows the minimum and maximum shear stress along the span. We can see for both load cases, the maximum occurs around 8 meters along the span for the initial design variables.

# Task 8

The failure criteria chosen to reflect a combined axial and shear failure case was the von mises failure criteria. This was chosen as von mises is suitable for ductile materials, which aluminium is, as well as the loading being gradual rather than sudden. The formula used to calculate the condition is shown below. Failure was determined if the von mises stress exceeded the materials yield strength. As seen in figure 11, the initial design does not fail the von mises criteria.



Equation - Von Mises Equations



Figure - Von Mises Failure Indices for Initial Design

# Task 9

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Skin Thickness (root) | Skin Thickness (tip) | Web Thickness (root) | Web Thickness (tip) | Stringer Height (root) | Stringer Height  (tip) | Stringer Thickness (root) | Stringer Thickness (tip) | Number of Stringers |
| **0.0037639** | **0.0028986** | **0.001** | **0.001** | **0.063734** | **0.037802** | **0.005238** | **0.00099801** | 9 |

Table - Optimised Variables including Shear conditions.



Figure - Failure indices for 2.5g load, optimised design

Figure 12 shows the failure indices for the 2.5g load case, including the von mises condition. As expect, all of them remain negative (no failure) however are close to failure, this is due to no safety margin being implemented as part of the design process. The mass calculated is