# Analysis of Motorsport Wing Mounting Brackets

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Applied Finite Element Analysis

5/9/25

# Purpose of Wings, and how can FEA help?

- In motorsports, cars typically have a rear wing for generating downforce. This helps the car grip the track more easily during quick turns. The wing is mounted to the car on brackets, which must be able to withstand the wing's downforce without mechanically failing.

- When designing a racecar, it is generally good practice to make weight reductions wherever possible. Reducing the car's weight improves its performance.

- This project will cover the design, and analysis of a custom wing and its mounting brackets. Multiple FEA methods will be used to simulate the behavior of the wing/brackets, optimize the mass of the geometry, and analyze potential failure conditions.

Things to Consider:

- ❑ How will the wing behave?
- ❑ What bracket material is best?
- ❑ Locate bracket's critical stress areas?
- ❑ Will the bracket fail?
- ❑ Reduce weight, without compromising functionality?

# Design and Finite Element Analysis Process

**SolidWorks**
-Design Models
-Make Iterations

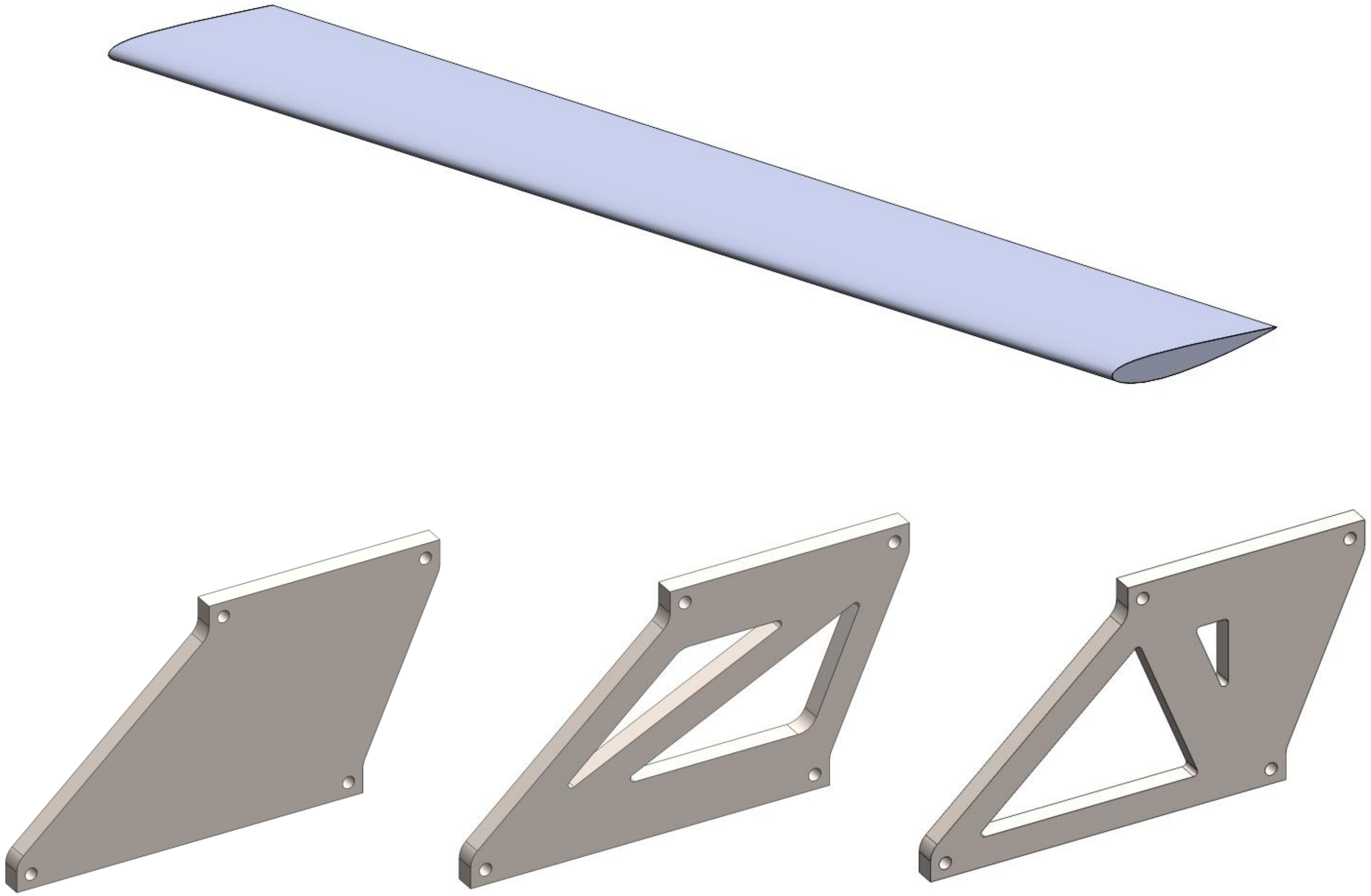
**Ansys Fluent**
-CFD Wing Analysis
-Calculate Wing Downforce (loading conditions for brackets)

**Altair Inspire**
-Analyze Bracket Stress
-Topology Optimization

**Ansys Mechanical**
-Analyze Bracket Stress
-Mesh Convergence
-Compare results of mass optimized part

**Final Results**
-Will Bracket model fail?
-Is Topology Optimization Viable?
-Validate Results

# Designing the Models (SolidWorks)



## Wing

- NACA 2412 airfoil profile
- Chord Length: 12 in
- Wingspan: 75 in
- Angle of Attack: -5 degrees
- Assumed Weightless

## Brackets

- Thickness: 0.5 in
- Material: Steel Alloy
    - Elastic Modulus: 210 GPa
    - Poisson’s Ratio: 0.28
    - Density: 7700 kg/m^3
    - Yield Strength: 250 MPa

# Determining Downforce (Ansys Fluent, CFD)

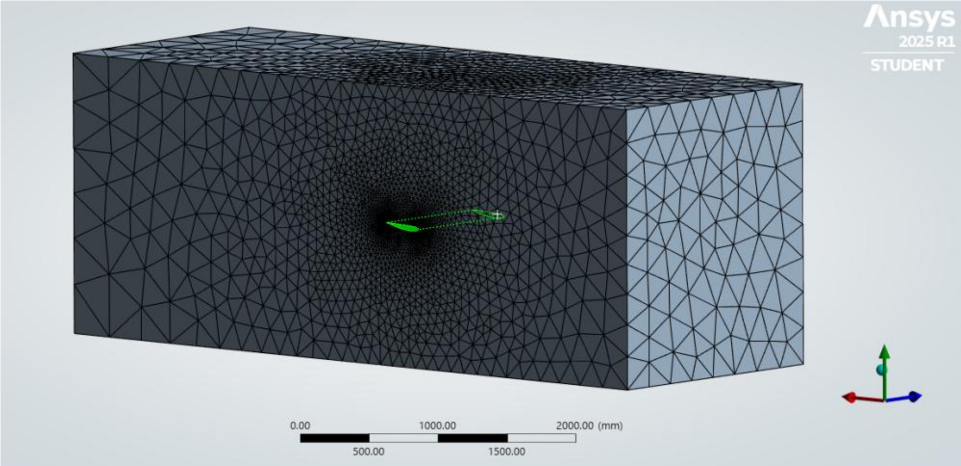



Figure 1. Mesh of Fluid Domain

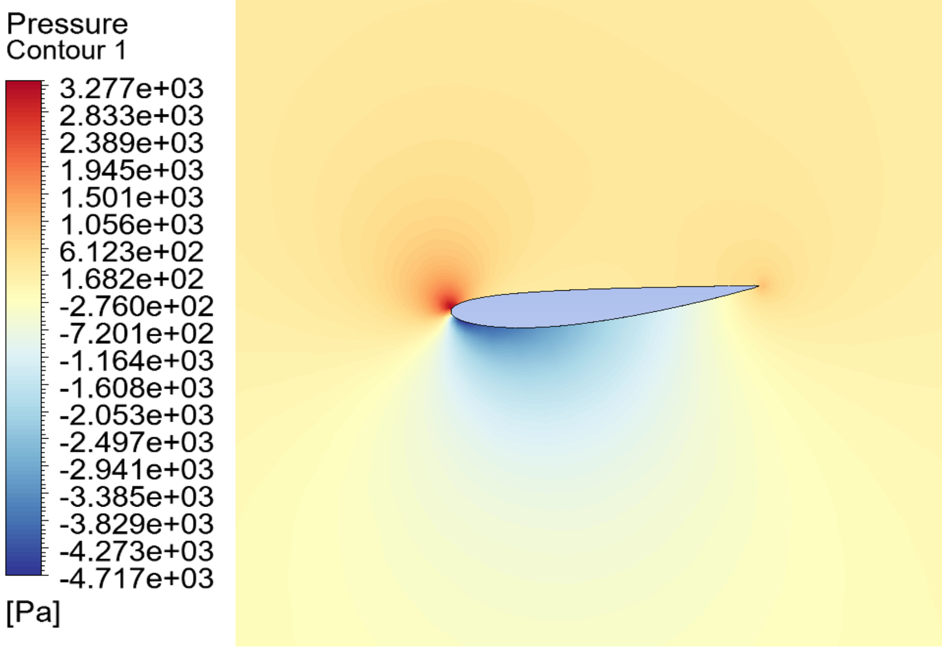



Figure 2. Airfoil Pressure Distribution

Ansys Fluent was used to determine the downforce generated by the wing. When solving for lift, a negative result indicates that it is downforce. The two mounting brackets must be able to bear this load. The **mesh surrounding the wing is denser** for a more accurate pressure distribution.

## Boundary Conditions

- **Midplane Symmetry**, to simplify the model
- **Walls**, to define fluid domain
- **Inlet** and **Outlet**, to define fluid flow direction

## Assumptions

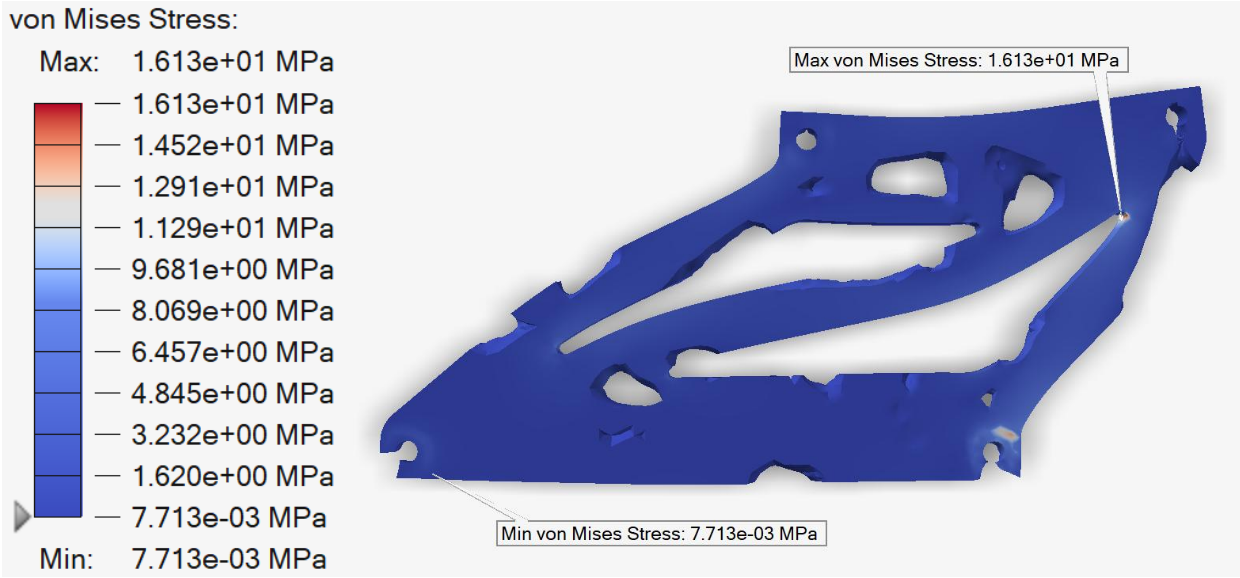
- Freestream velocity: 82 m/s (maximum speed of Porsche 911 GT3 RS)
- Steady State
- Working Fluid: Dry Air at STP
  - ρ = 1.225 kg/m^3

## Results

- Experimental Lift: **-1331.436 N**
- Experimental Drag: **66.6746 N**
- Experimental Lift Coefficient: **-0.56**
  - $L = C_L \frac{1}{2} \rho V^2 A$

The pressure distribution shown in Figure 2 shows high-pressure zones on top of the leading edge, and in the wake. There is a low-pressure zone underneath the wing, which is consistent with the characteristics of wings meant for downforce.

# Preliminary Bracket Analysis (Altair Inspire)


The initial bracket design was simulated in Altair Inspire using **-665.718 N** of downforce as previously determined. The full calculated downforce needs to be divided by 2, since it is distributed it between both brackets. Since CFD was ran on half the wing, -665.718 is actually the value that Ansys Fluent originally yielded. After, topology optimization was performed to identify areas where weight reductions could be made.

## Stress Analysis

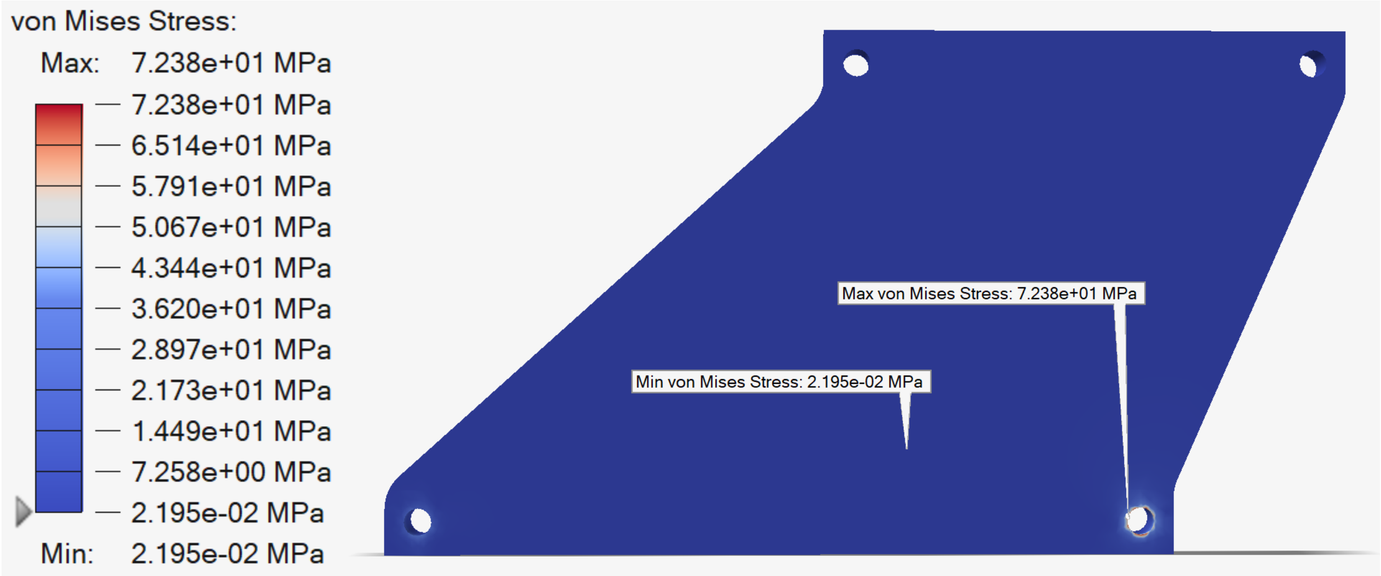
- Boundary Conditions
  - Force of -665.718 N applied to top face
  - Pinned supports at bottom holes
  - Nut and Bolt Fasteners at all holes
- Maximum Von Mises Stress: **15.82 MPa**

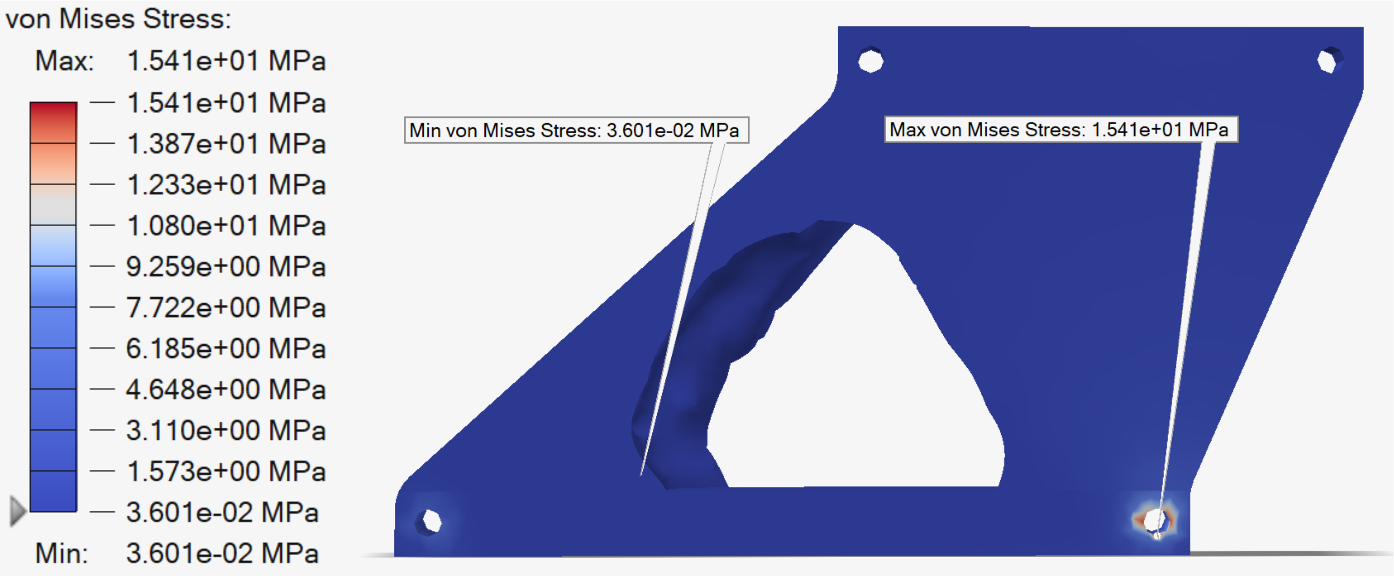
## Topology Optimized Analysis

- Target Mass Reduction: **25%**
- Maximum Stress Increase: **~2%**

The bracket was able to carry the load from the wing without permanent deformation. The maximum Von Mises stress was **15.82 MPa**, which does not exceed the yield strength of **250 MPa**.
However, performing topology optimization removed material erratically from lots of areas. This made it unclear where weight reductions should ideally be made, and whether topology optimization was beneficial or not.

# Topology Optimization (Altair Inspire)




A second approach was taken by filling in the extruded cuts on the initial model, then re-running the optimization process, to observe where Altair would choose to remove material from.

**Loads**

- -665.718 N load applied at top face

**Boundary Conditions**

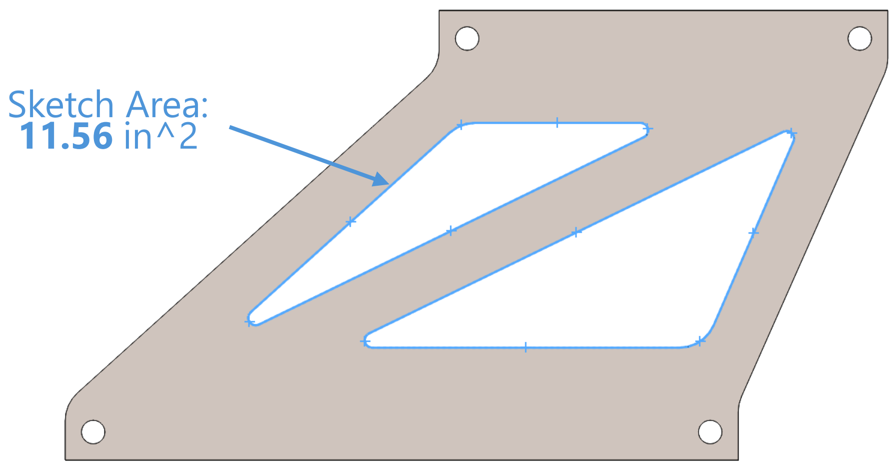
- Plane Symmetry
- Pinned Supports at bottom holes
- Nut & Bolt Fasteners on top holes

**Table 1. Topology Optimization Results**

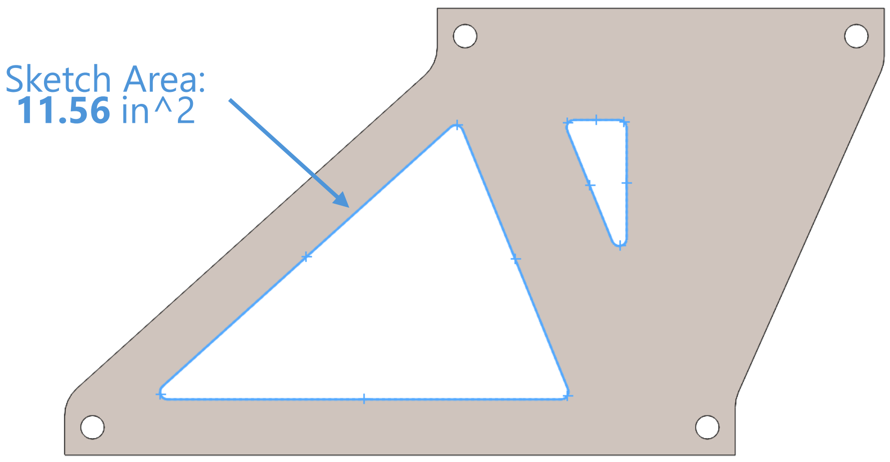
| Model | Mass (kg) | Max von Mises Stress (MPa) |
|---|---|---|
| Initial | 2.32 | 72.38 |
| Optimized | 1.64 | 15.41 |
| % Difference | -30% | -78.69% (???) |

# Improved Bracket Design

**Bracket 1**




**Bracket 2**



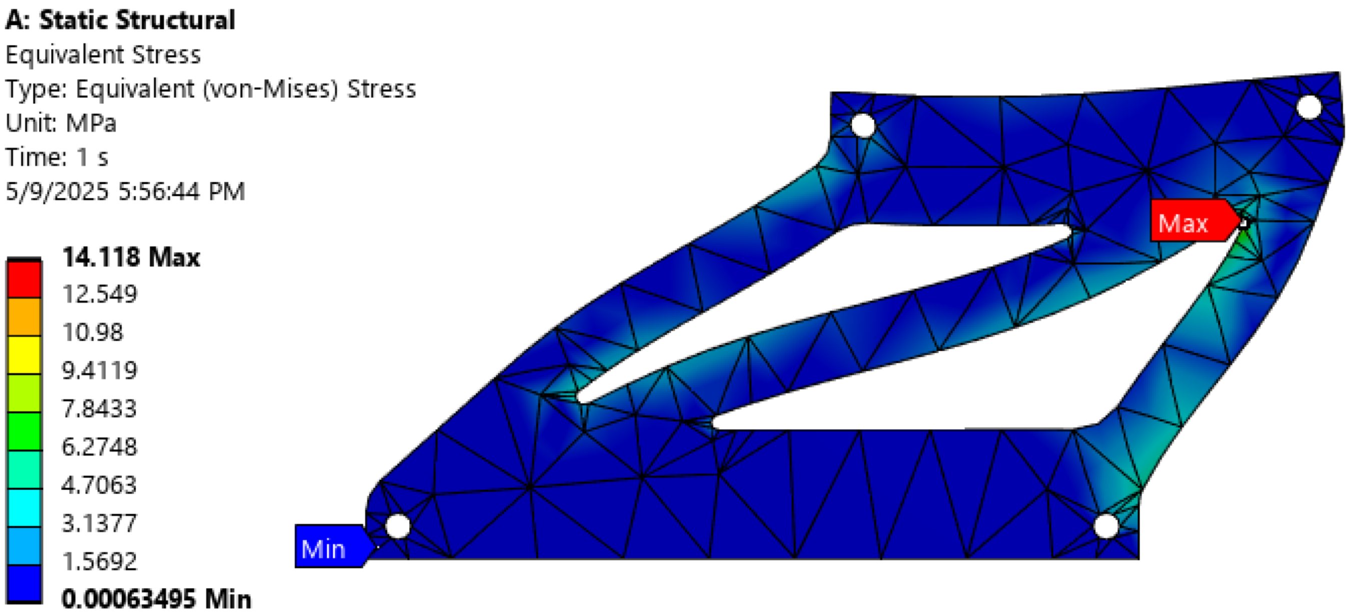

By using the information from the Altair simulations, the geometry of the bracket could be improved.

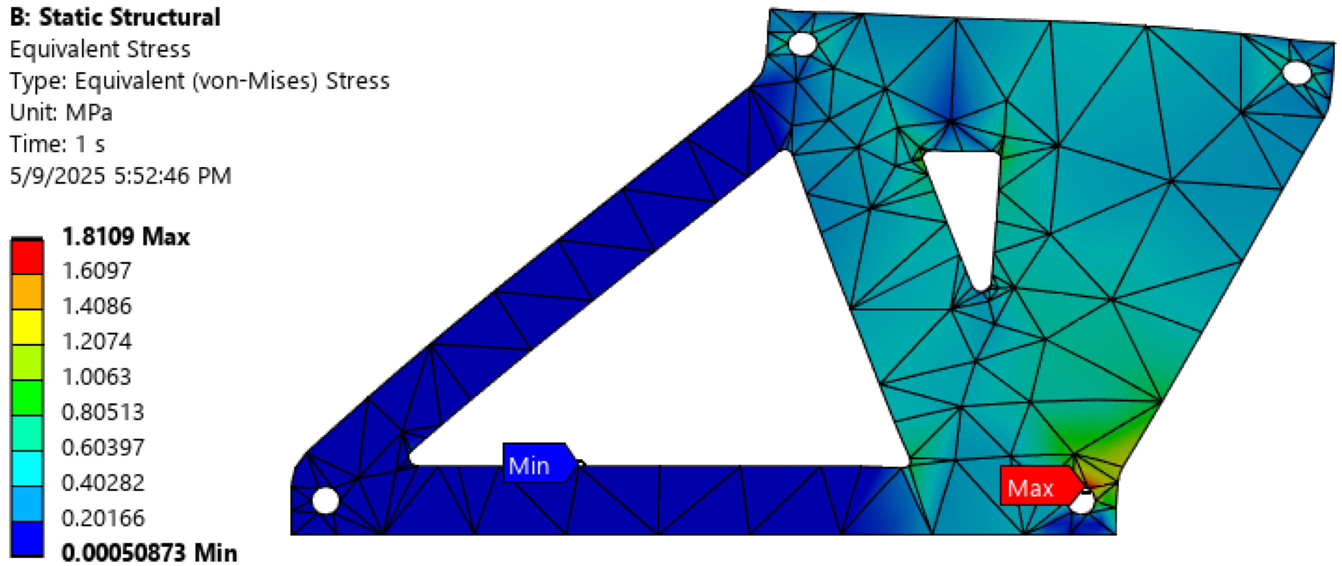
- Static Analysis
  - Highest stress on the bottom right hole of the bracket, so surrounding area needs to be thicker.
- Topology Optimization
  - Primarily removed material from front of bracket

A second iteration of the bracket was created with an emphasis on strengthening the back of the bracket.

- The sketch areas of both iterations are equal to ensure the cut sections have equal volume, even though the shapes are different.
- 11.56 $in^2$ times the bracket thickness of 0.5” is 5.78 $in^3$, or 9.47e-5 $m^3$. Multiplied by the steel’s density of 7700 $kg/m^3$, and the mass of the cutout is **0.73 kg**

# Static Structural Analysis (Ansys Mechanical)




After improving the design of the bracket, a more thorough structural analysis was performed using Ansys Mechanical to compare the functionality of both candidates.

## Assumptions

- 2D displacement in XY plane

## Loads

- **-665.718 N** applied to **top face**

## Boundary Conditions

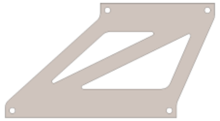
- Cylindrical Support: Bottom holes
- Fixed Support: Bottom face
- Displacement Constraint:
  - Front/Back faces, restrict translation along Z axis

## Mesh Settings

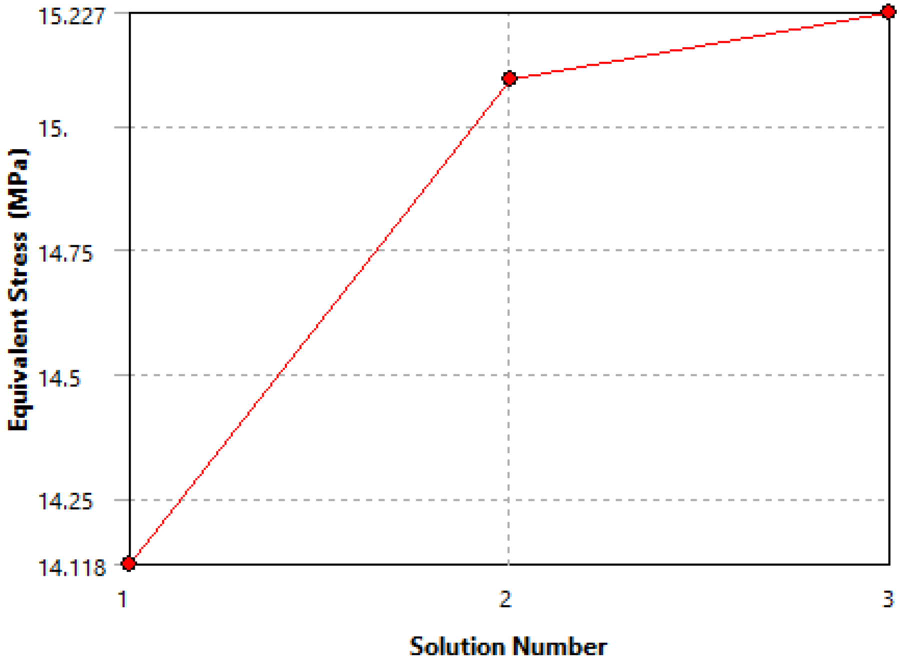
- Element Type: Tetrahedral
  - Faster solving time, and easier to locally refine for mesh convergence
- Mesh Density: Automatic, Resolution 1

The contour plot for Bracket 1 has a much more uniform stress distribution, which would typically be more ideal. However, its maximum stress is much higher, nearly 8 times greater than Bracket 2. It also has more areas of localized high stress. Bracket 2 appears to carry the load much more efficiently, with the right half of the model primarily bearing the stress. This behavior was expected from the results of the topology optimization.

# Mesh Convergence (Max Von Mises Stress)

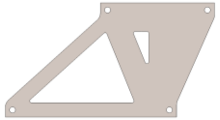


## BRACKET 1

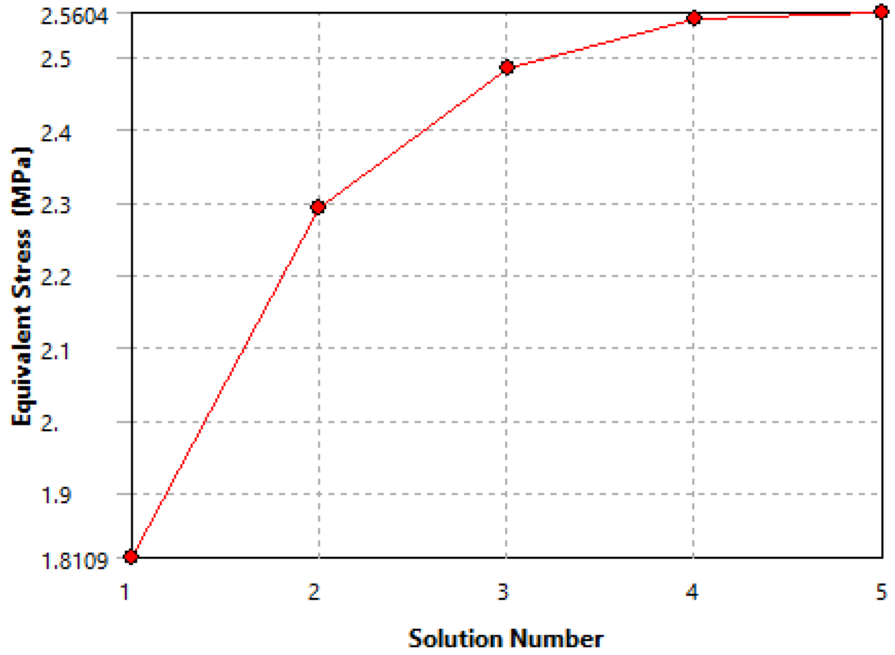



| | Equivalent Stress (MPa) | Change (%) | Nodes | Elements |
|---|---|---|---|---|
| 1 | 14.118 | | 1849 | 799 |
| 2 | 15.092 | 6.6739 | 2956 | 1444 |
| 3 | 15.227 | 0.89196 | 10357 | 6315 |

- Allowable Change: **1%**
- Converges At: **6315 Elements**



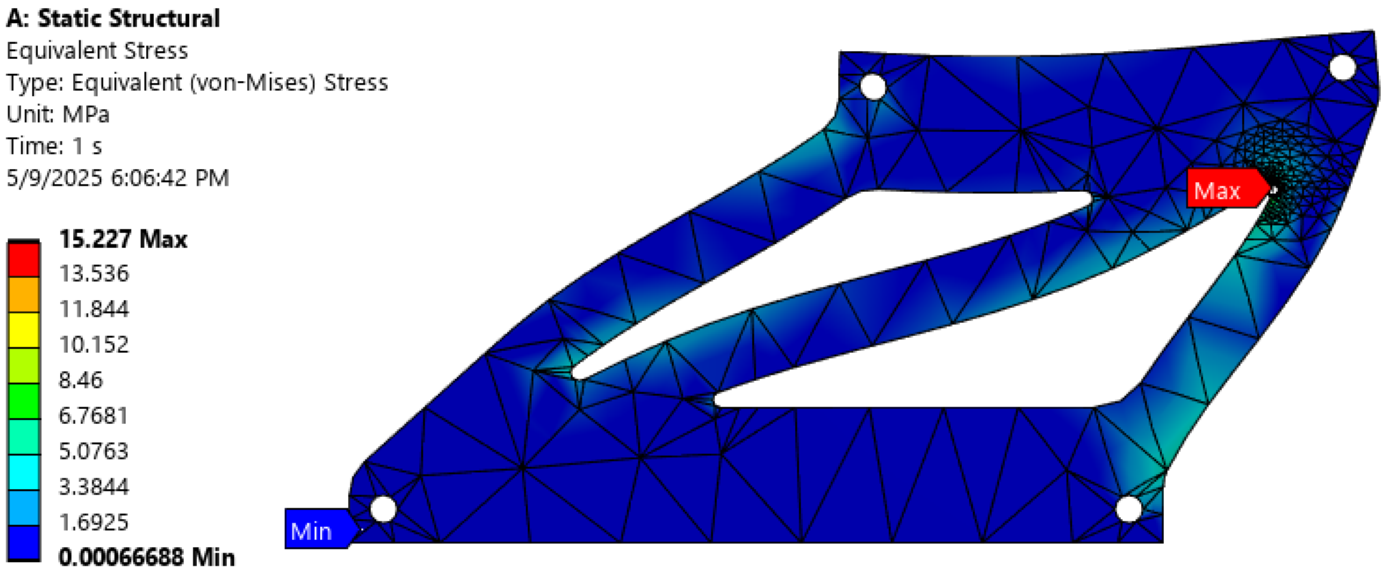
## BRACKET 2

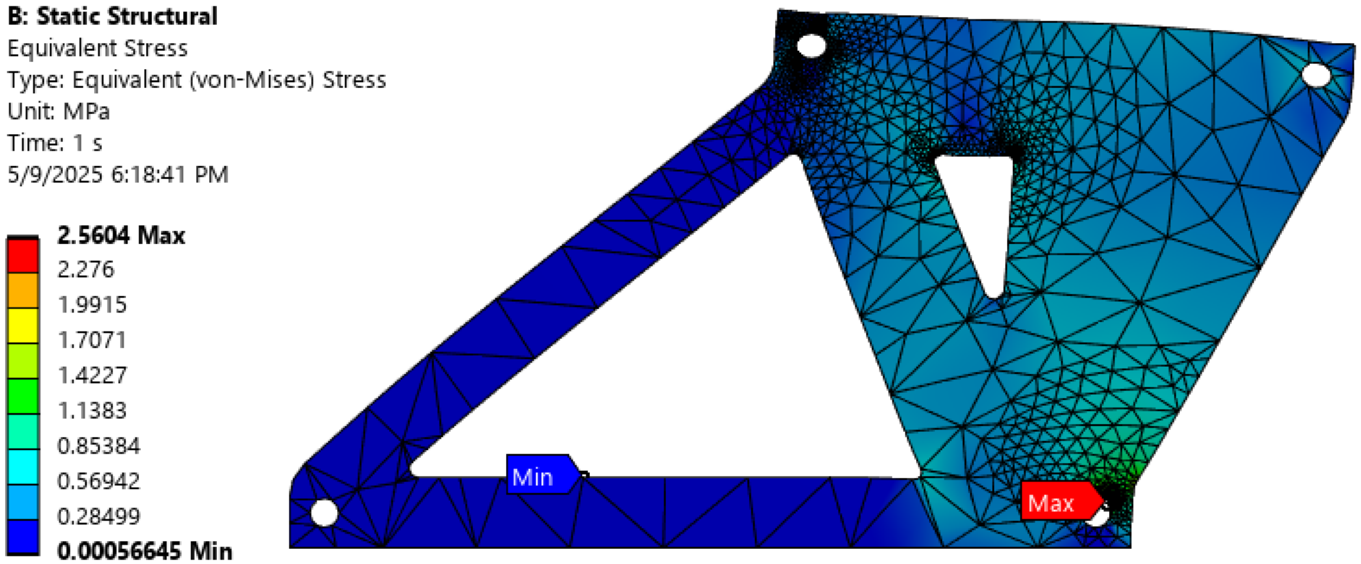



| | Equivalent Stress (MPa) | Change (%) | Nodes | Elements |
|---|---|---|---|---|
| 1 | 1.8109 | | 1994 | 891 |
| 2 | 2.2926 | 23.479 | 5642 | 3097 |
| 3 | 2.4838 | 8.003 | 21639 | 13860 |
| 4 | 2.553 | 2.7496 | 47183 | 31664 |
| 5 | 2.5604 | 0.28877 | 107397 | 74220 |

- Allowable Change: **1%**
- Converges At: **74220 Elements**

# Structural Analysis with Mesh Convergence



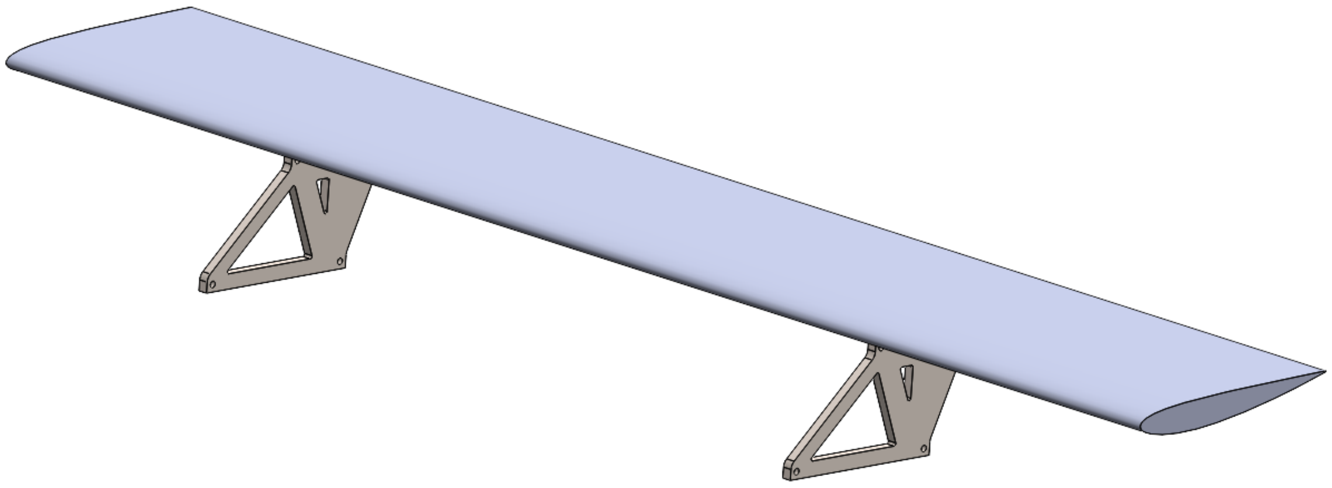

After mesh convergence, the mesh became much denser in the critical areas of the models. This helped improve the accuracy of the stress calculations for the areas with localized high stress.

Ultimately, **Bracket 2** is the superior choice to use for mounting the wing. It can bear the weight of the downforce much more efficiently, while removing the same amount of material as Bracket 1. It has a **Factor of Safety of 97.6** for its maximum Von Mises stress, which is nearly 6 times greater than Bracket 1.

**Table 2. Stress Analysis w/ Mesh Convergence**

| Bracket | Max Von Mises Stress (Mpa) | Yield Strength (Mpa) | FoS |
|---|---|---|---|
| 1 | 15.227 | 250 | 16.4 |
| **2** | **2.5604** | **250** | **97.6** |

# Final Results



Full Wing Assembly

## Wing Characteristics

| | |
|---|---|
| **Downforce** | -1331.436 N |
| **Drag** | 66.6746 N |
| **Lift Coefficient** | -0.56 |

## Bracket #2

| | |
|---|---|
| **Maximum Von Mises Stress** | 2.5604 MPa |
| **Factor of Safety** | 97.6 |
| **Weight Reduced** | 0.73 kg per bracket |

# Potential Improvements

- Since the Factor of Safety for the brackets ended up being much higher than necessary for this application, further weight reductions can certainly be made. Some methods besides topology optimization that could be explored are:
    - Try alternative materials
    - Make the brackets thinner

- It may be worth it to perform further CFD simulations on a full assembly of the wing – or the brackets individually – in order to reduce the drag.

- Generative Design could be a useful approach to use for designing the brackets.

# Conclusion

## Applications of FEA

Finite Element Analysis was a crucial factor in choosing a design for the wing mounting brackets. **Bracket #2**'s design was chosen due to its superior ability to carry the applied loading condition. Predicting the behavior of the brackets would not have been possible without FEA simulations.

- **CFD** - Determined the behavior of the wing, and the downforce it generated.
- **Topology Optimization** - Identified key areas where material could be removed without sacrificing functionality.
- **Structural Analysis** – Predicted the behavior of the mounting bracket, calculated the stresses exerted on the solid model, and revealed which designs were better suited for the application.

## Viability of Topology Optimization

- Great for reducing the weight of parts, but generates complex geometry that is difficult to manufacture using traditional methods.
- Sometimes it is better to identify areas where weight can be reduced, then iterate the designs manually to retain manufacturability.