Lift to Drag Study Cessna 210J

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Summary

- Used a High Y+ Reynolds-Averaged Navier Stokes K-Omega Turbulence Segregated Flow Model
- Utilized a trim volume mesh with 9 prism layers to reduce memory usage
- The L/D ratio of the Cessna 210J from the study was 17. This value is far above what is expected due to modeling simplifications and the High Y+ model to stay within cell count limits.
- 14.4 million cell size is within the 10 to 15 million cell limit requirement
- Accuracy limited by mesh size requirements. Further memory allocation would allow for a higher fidelity study that will return more accurate data

Source [1]: Cessna Flyer Association

Cessna 210J

- Cessna 210 is a single-engine, six-seat plane first flown in 1957
- Cessna 210s went through many iterations and improvements throughout the production cycle from 1956 to.
- Cessna resumed propeller plane production in 1996

Source [1]: Cessna Flyer Association

CFD Workflow Outline

- Started by ensuring agreement with management on study objectives
- Imported the provided Cessna 210J model
- Split and grouped surfaces
- Created the fluid domain and defined boundary conditions and regions
- Selected physics models
- Created surface mesh and the volume mesh
- Defined convergence criteria
- Prepared post-processing scenes
- Ran analysis and documented results

Specifications

- 100 knots equivalent airspeed (168.8 ft/s)
- 5 degree angle of attack (AoA)
- Flying at sea level
- Required cell count between 10 to 15 million cells

Objectives

- Determine lift to drag ratio of the Cessna 210J
- Identify areas with energy loss to develop suggestions to decrease drag
- Determine pitching moment of the Cessna

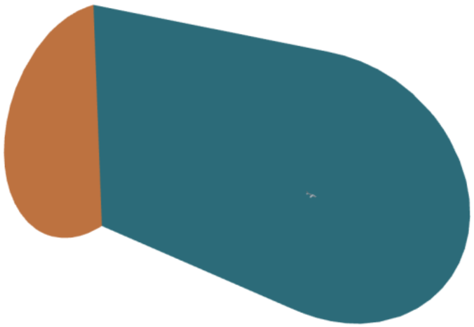
Geometry and Boundaries

Geometry Simplifications:

- Removed aircraft propeller which would results in more drag by increasing speed of air
- Removed inlets for engine cooling which resulted in a much lower drag value
- Removed landing gear, hinges, and antennas

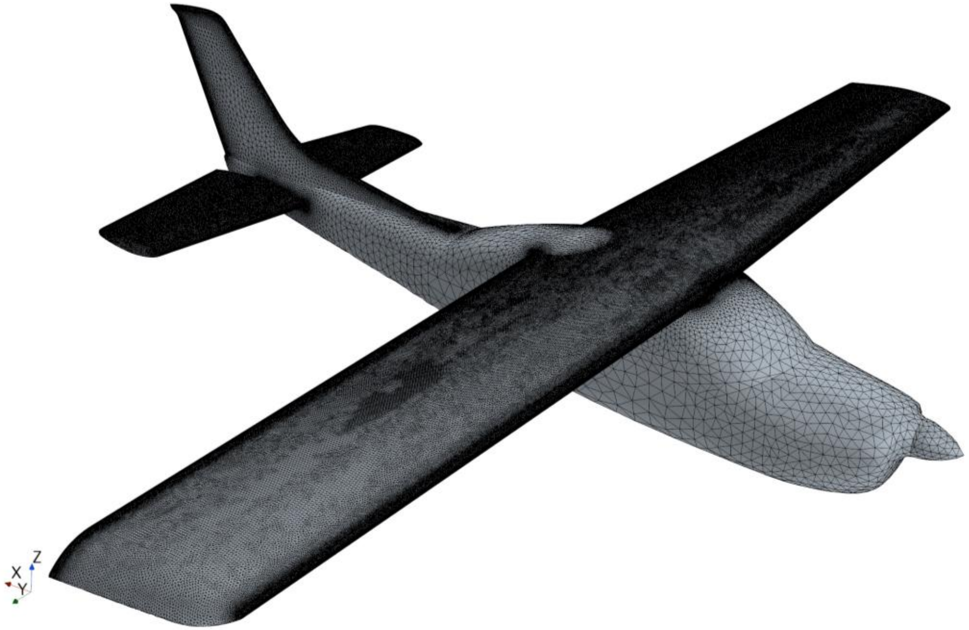
Boundaries:

- Boundary outlet set to a pressure outlet at 0 psig
- Outer surface of cylinder and sphere set to velocity inlet
- Velocity vector was split into X and Z components to account for the angle of attack
- Central plane set to symmetry plane



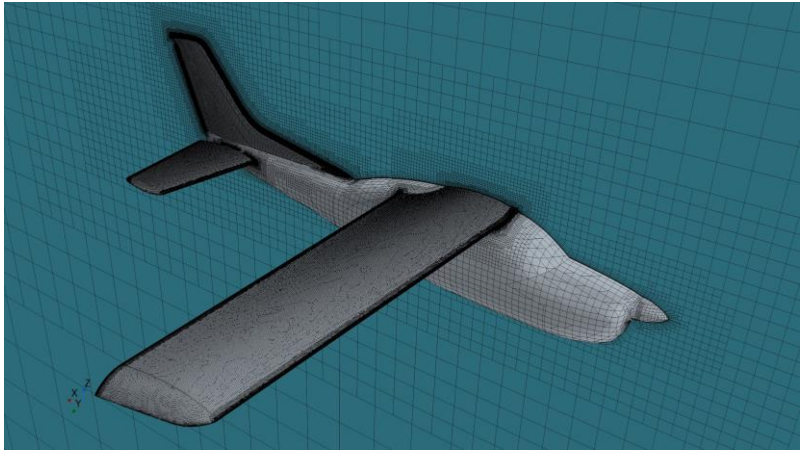
Surface Mesh

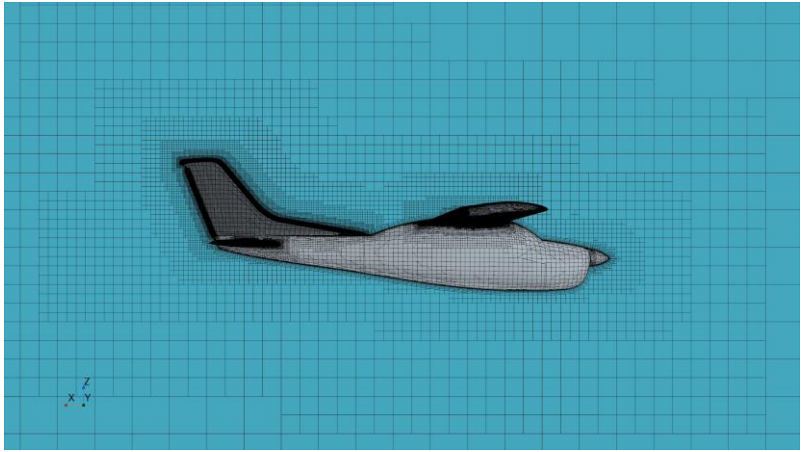
- Local refinement in areas of high gradients like the leading edge
- Fuselage goes from fine to coarse to fine to reduce cell counts in less important areas
- Refinement on wing and horizontal tail results in 100 cells across the chord
- Lifting surface trailing edges have 4 cells across their thickness
- Leading edges have similar refinement as trailing edges



Volume Mesh

- Trim mesh used to reduce computational cost
- Maximum cell size set to wingspan length of 11 meters to reduce cell count in the boundary far away from the Cessna
- Added mesh refinement at wing tips to capture vortices and separation zone behind the fuselage (refinement shown in the bottom figure)
- Created multiple iterations to stay within cell count limit while maintaining appropriate refinement





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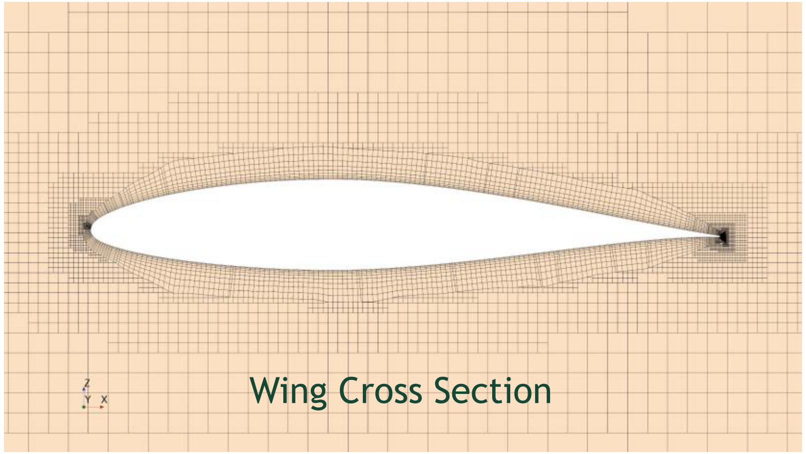
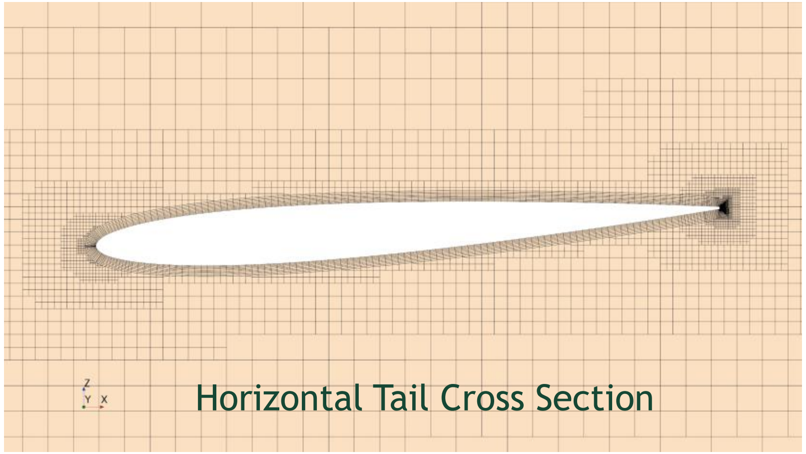
Prism Layers

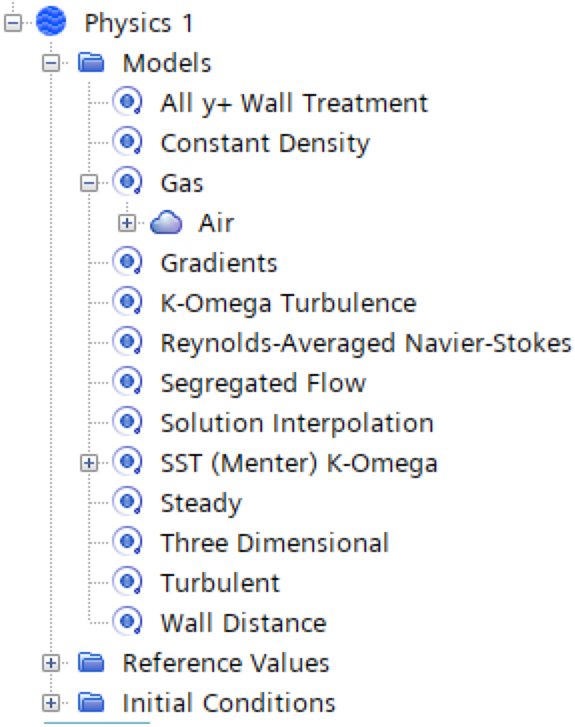
- Initially started with 24 prism layers and a low Y+ to get best drag force estimate
- This resulted in 25+ million cells
- Switched to 9 prism layers and High Y+ to fit within cell count requirements
- Results in drag values not being accurate because separation is not accurately captured by simulation
- Prism layer total size set to the turbulent boundary layer thickness of each region





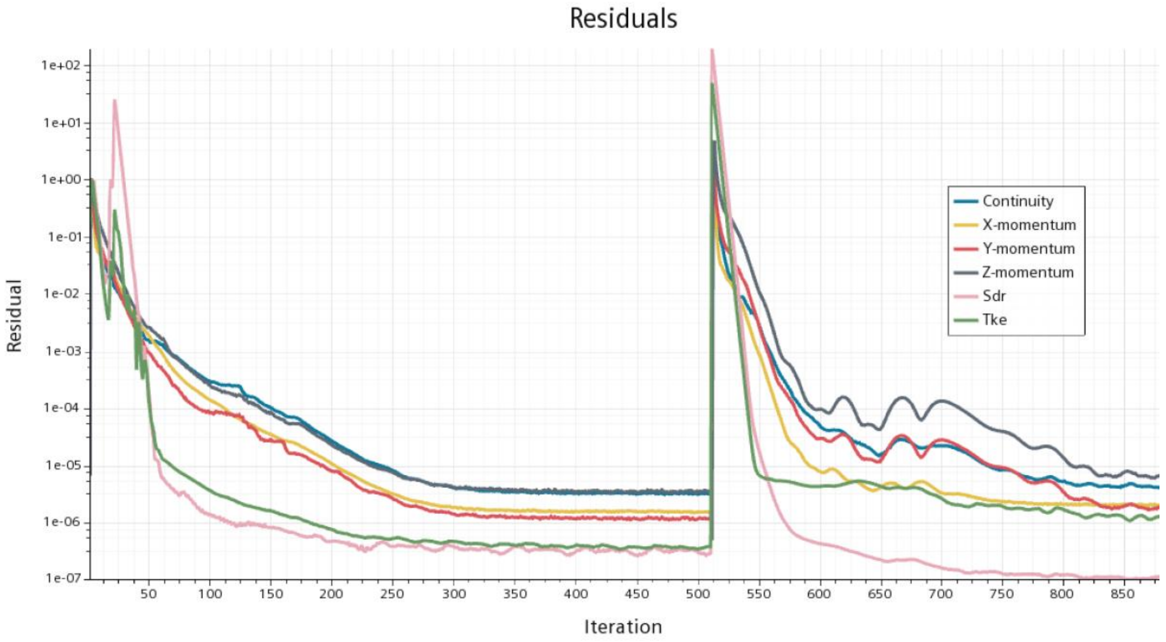
Physics Models

- Used a Reynolds-Averaged Navier Stokes K-Omega Turbulence Model
- Selected an incompressible Segregated Flow model to decrease solving time
- Segregated flow is appropriate for Mach numbers < 0.3
- Modeled the system as steady and three dimensional
- These are standard industry models for external aerodynamics simulations
- Set initial conditions to the boundary conditions



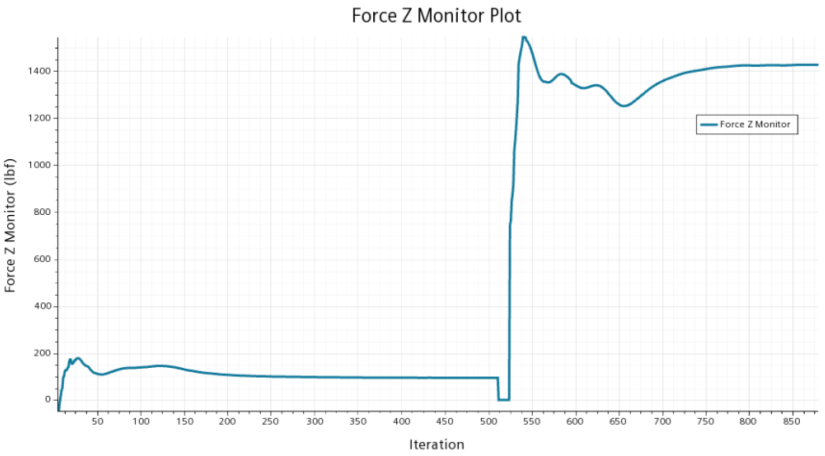
Convergence

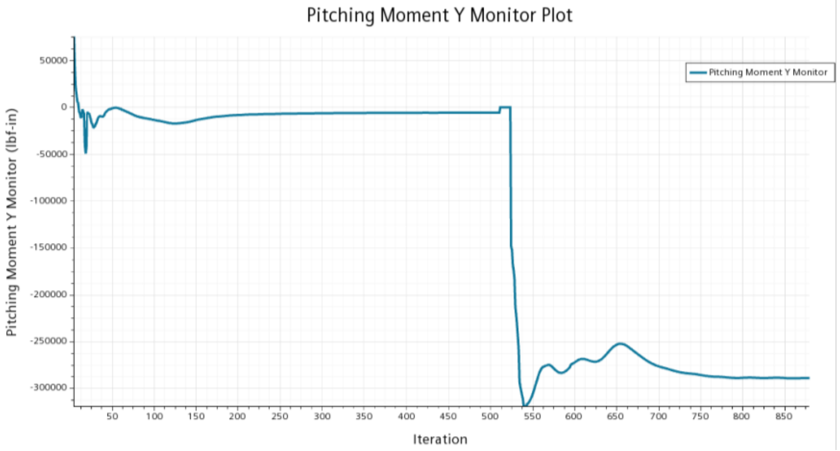
- Convergence criteria of 3% asymptotic convergence of engineering parameters of interest for 100 iterations
- Engineering parameters of interest were X direction force, Z direction force and pitching moment
- Residuals dropped by multiple orders of magnitude
- First solution was incorrect due to a boundary condition error, and next revision converged after 390 more iterations
- Final solution converged after 891 iterations

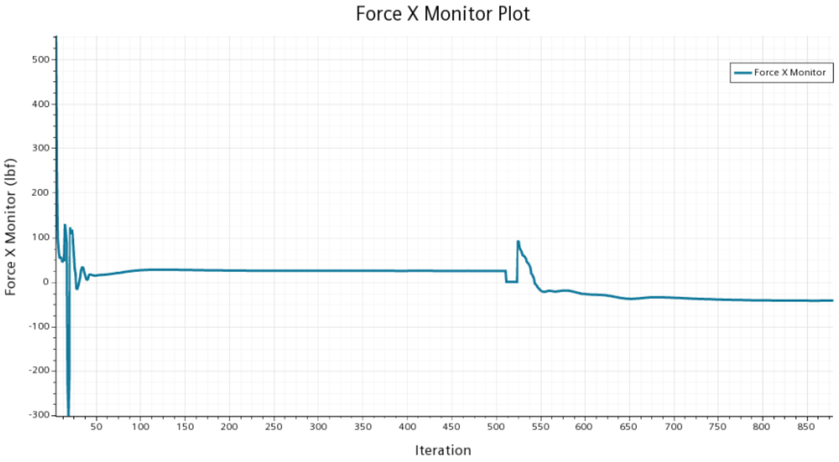


Parameter Convergence

- On the second revision of the boundary conditions, the solution converged after 390 iterations

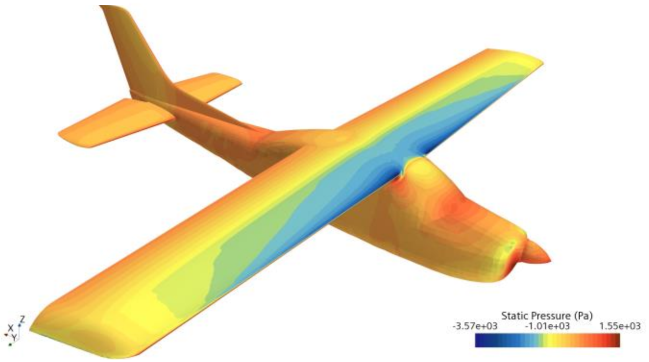






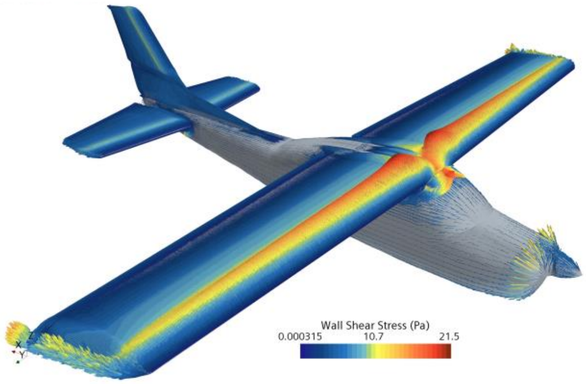
Surface Pressure

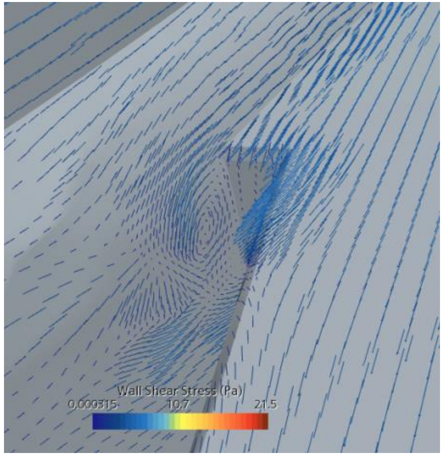
- The figure shows low-pressure zones on the top and front of the wings near the fuselage
- High pressure zones on bottom surface of wings, generating a large lifting force
- Expected static pressure distribution for 5 degree AoA
- The uniform pressure distribution on top of the wing tips shows the winglets are successfully reducing induced drag



Wall Shear Stress

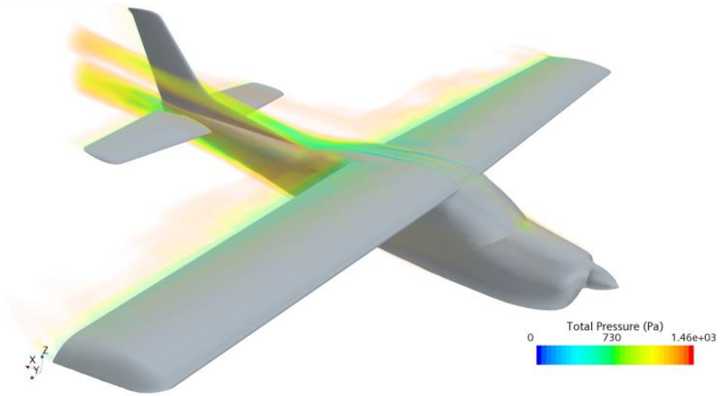
- Areas of largest wall shear stress correspond with the low-pressure areas from the static distribution plot
- Shows that fluid is accelerating over the top surface in the front of wing
- The area between the horizontal tail and the fuselage has recirculation due rapid area change
- This recirculation can be easily visualized with the wall shear stress velocity vectors
- Further mesh refinement would allow for better visualization of boundary layer separation

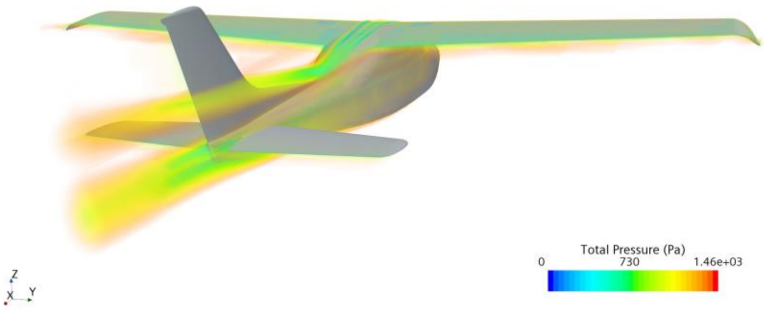




Total Pressure

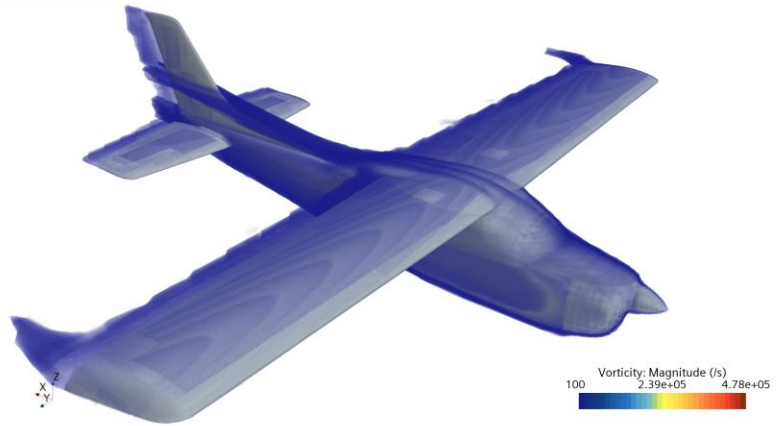
- Scene shows total pressure values that are 90% the dynamic pressure value (1623 Pa) or less
- Areas with low pressure behind illustrate there is energy loss due to separation, which increases drag
- Further mesh size allowance would allow for further refinement in areas with separation

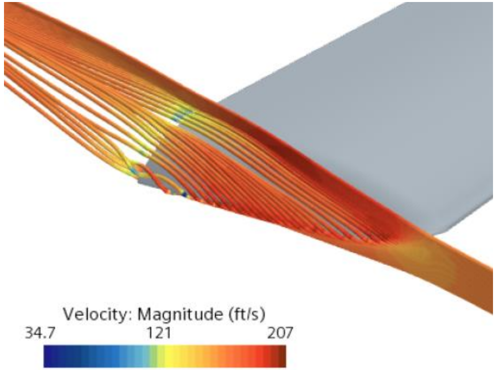




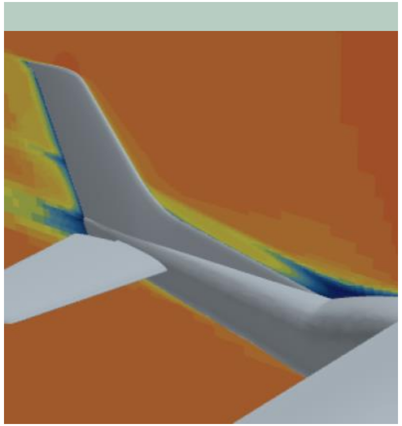
Vortices

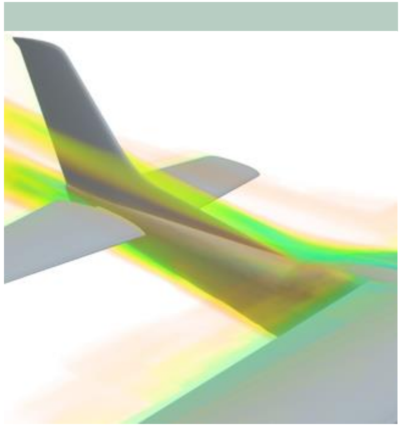
- Separation behind fuselage is also illustrated in the vorticity magnitude plot
- Additional volume mesh refinement at wing tips to better capture vortices
- With a larger mesh size allowance, further refinement at wing tips and between fuselage and the vertical tail would be added
- The streamline plot shows the vortex created at the wing tips
- The vortex is smaller than expected, illustrating that further wing tip refinement is necessary

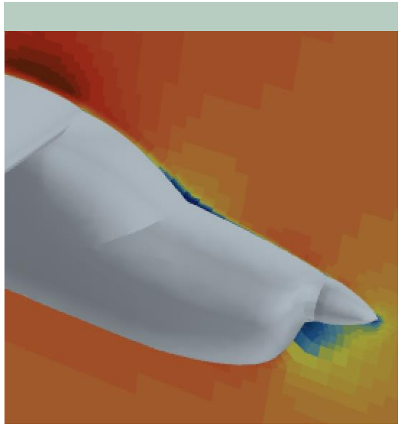


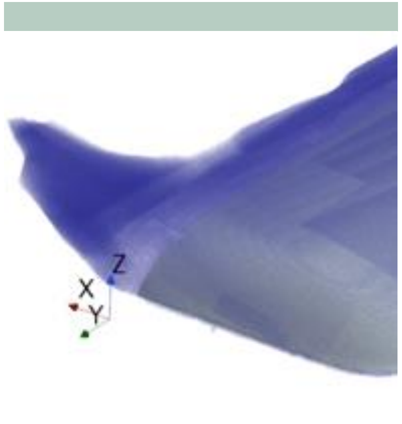


Areas of High Drag









- A more gradual reduction in curvature for the back of the fuselage would result in less boundary layer separation, which is visualized in the two left figures
- Similarly, a more gradual increase in curvature for the front of the fuselage would remove the recirculation zone shown in the third figure
- Adding fairings would reduce induced drag further. More analysis should be done to find viability of fairings

Parameter Values

- An L/D value of 17 is a high estimate of the lift to drag ratio for a Cessna at a 5 degree AoA
- The estimate is very high because the drag force is low due to geometry simplifications, mainly due to not modeling the air used to cool the engine
- Pitching moment is with reference to the origin of the study [0, 0,0], which is in front of and below the Cessna
- Future iterations will place the reference point to the centroid of the Cessna
- Force and moment values doubled to account for use of a symmetry plane

Parameter	Value	Units
L/D	17	Not Applicable
Pitching Moment	-48220	Lbf-feet
Lift Force	2850	Lbf
Drag Force	166	Lbf

Next Steps

- Use correction factors to account for the geometry simplifications which will increase the drag force and return a more accurate L/D ratio
- Accuracy of solution limited by mesh size limit because 9 prism cells do not adequately capture all details of separation, which is integral for drag and developing drag reduction recommendations
- Requesting increased memory allocation to allow for a maximum mesh size of 30 million cells
- This would allow for a Low Y+ CFD study with at least 24 prism layers which will return a more accurate lift to drag ratio and increase overall simulation fidelity
- Will also allow for further volume mesh refinement in areas of high gradient such as the separation zone behind the fuselage and at the wing tips

Additional Slides

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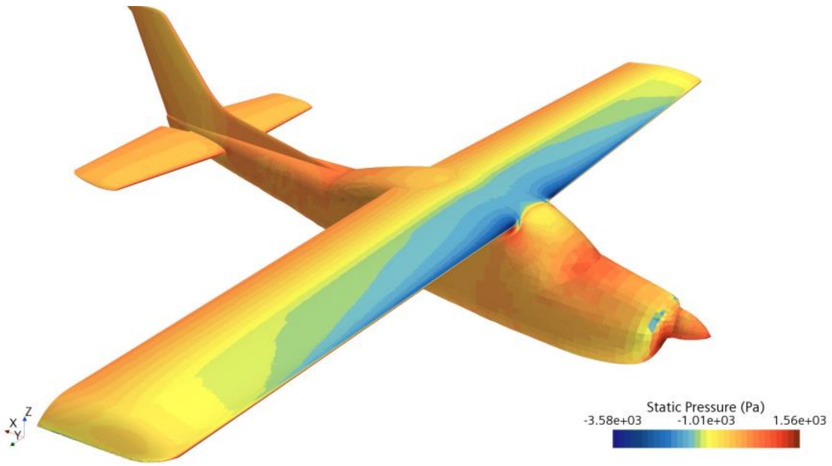
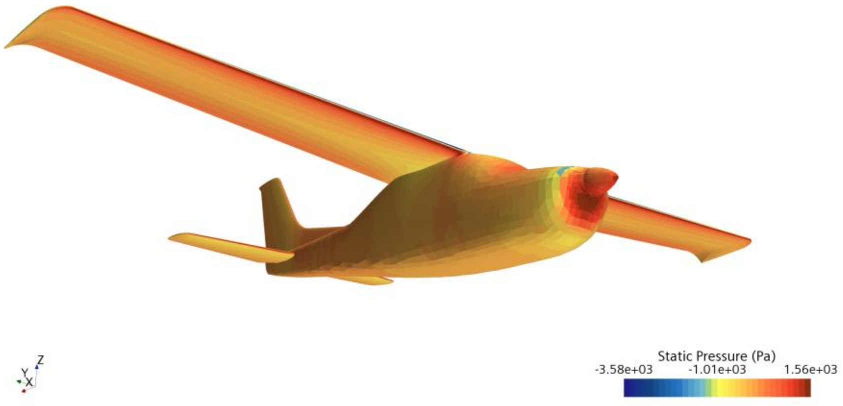
Citations

[1] Ells, Steve. “Cessna 210 Centurion.” *Cessna Flyer Association*, www.cessnaflyer.org/cessna-singles/cessna-210.html. Accessed 9 Nov. 2023.

Static Pressure Distribution not Blended





- This shows there is acceptable refinement across the plane surface
- Would add further refinement at front of the fuselage in later iterations with larger cell count