X-29 CFD Study – Low Angle of Attack Subsonic Performance

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Summary

- Used a Low Y+ Reynolds-Averaged Navier Stokes K-Omega Turbulence Incompressible Segregated Flow Model
- Utilized a trim volume mesh with 17 prism layers to reduce memory usage
- The largest lift to drag ratio for the X-29 is a L/D of 10 at 6 AoA
- 19.9 million cell size is within the 15 to 20 million cell limit requirement
- Recommended location for an air data package on wing is discussed in later slides

Source [1]

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X-29

- The X-29 is a research supersonic aircraft with forward swept wings
- Forward swept wings and moveable canards allowed for greater control of the aircraft up to an angle of attack of 45 degrees
- Supercritical airfoil allowed for better performance at transonic speed

Source [2]

CFD Workflow Outline

- Started by ensuring agreement with management on CFD study objectives
- Imported the provided X-29 model
- Performed surface repairs to make model closed and manifold
- 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 alpha sweep macro and documented results

Specifications

- 150 knots equivalent airspeed (294.6 feet per second)
- Angle of attack (AoA) sweep from 0 to 10 degrees in 2 degree increments
- Flying at 10,000 feet mean sea level
- Required cell count between 15 to 20 million cells

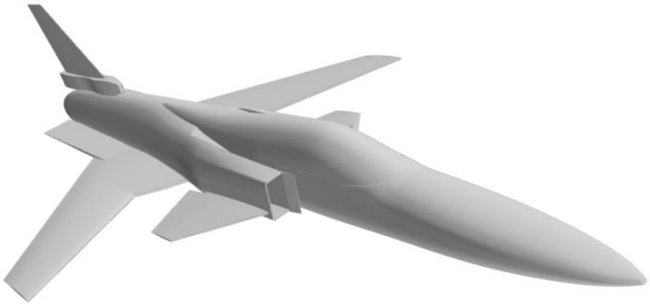
Objectives

- Determine peak L/D ratio in the AoA range
- Determine pitching moment of the X-29
- Recommend location for air-data measurement package on wing outside boundary layer and flow separation zones
- Create graphics showing primary vortex interactions and separation locations on main wing
- Develop recommendations on future CFD simulation iterations

Geometry and Boundaries

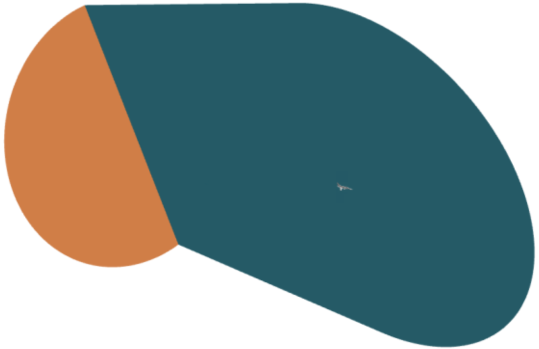
Geometry Simplifications:

- Removed antennas, hinges, and similar small protrusions
- Removed drag from intakes for engine cooling which resulted in a much lower drag value
- Can use correction factors to account for excrescence drag and engine cooling drag



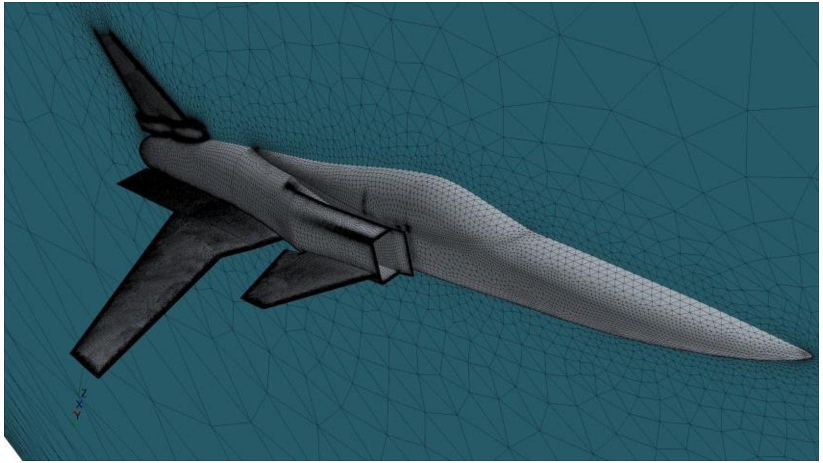
Boundaries:

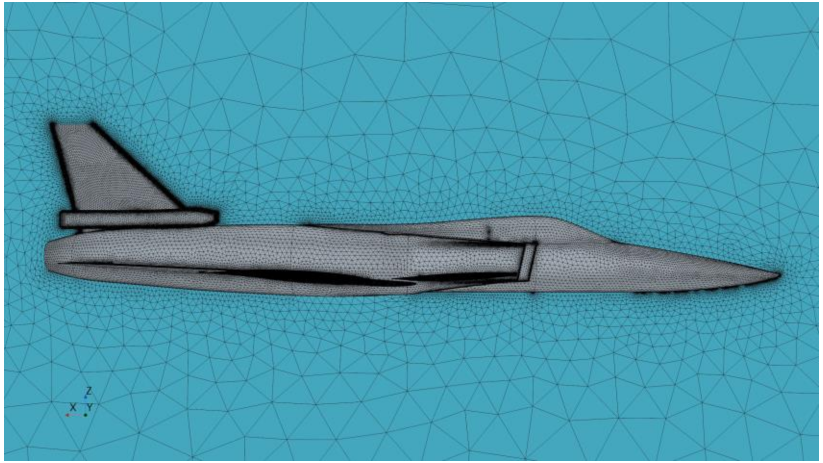
- Boundary outlet and X-29 intake set to a pressure outlet at 0 psig
- Outer surface of cylinder and sphere set to velocity inlet
- Velocity vector was split into X and Z components to account for the angle of attack
- Exhaust of X-29 set to velocity inlet at 294.6 feet per second (true airspeed)



Surface Mesh

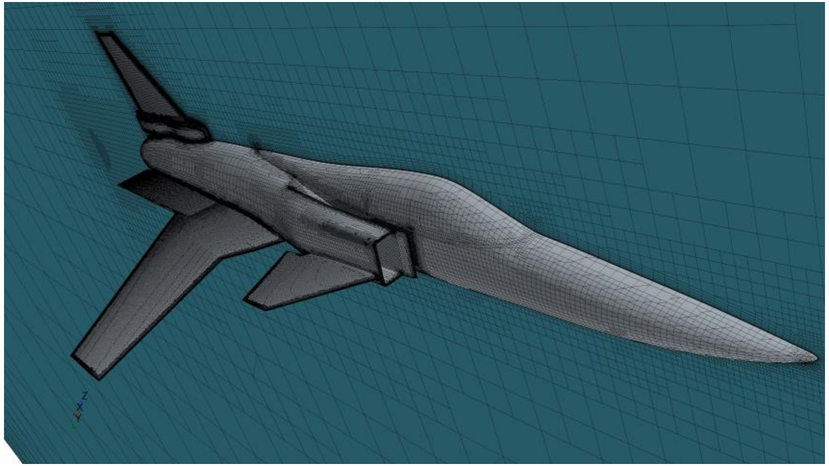
- Local refinement in areas of high gradients like leading edges
- Refinement on wing and canard result in 100 cells across the average chord
- Lifting surface trailing edges have 4 cells across their thickness to account for gradient
- Leading edges have similar refinement as trailing edges

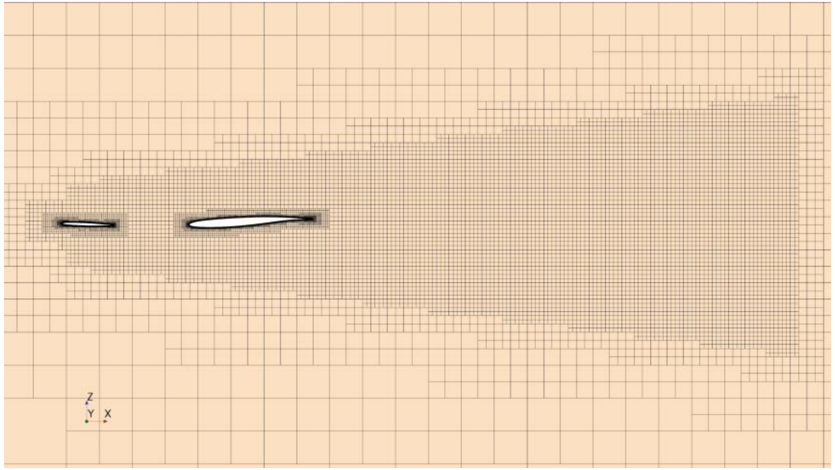


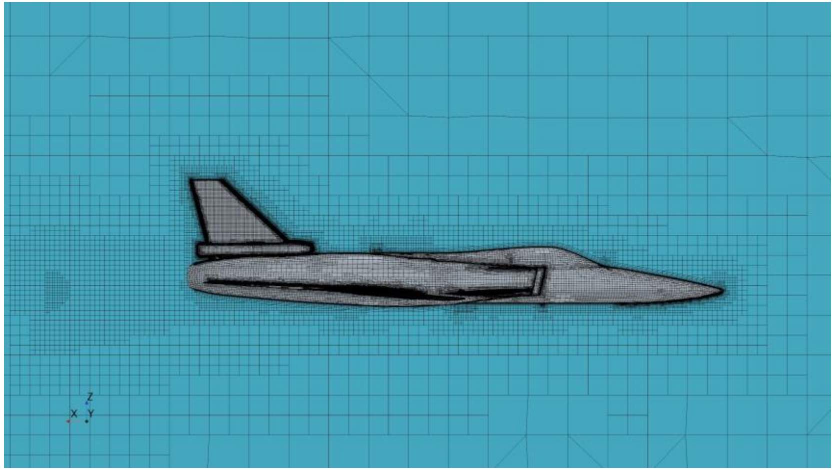


Volume Mesh

- Trim mesh used to reduce computational cost
- 19.9 million cells in the volume mesh
- Added mesh refinement at wing and canard tips to capture vortices and at separation zone behind the fuselage

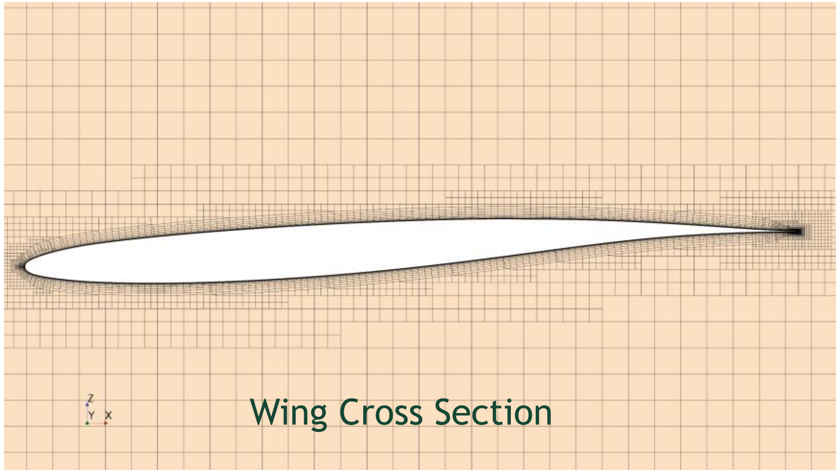




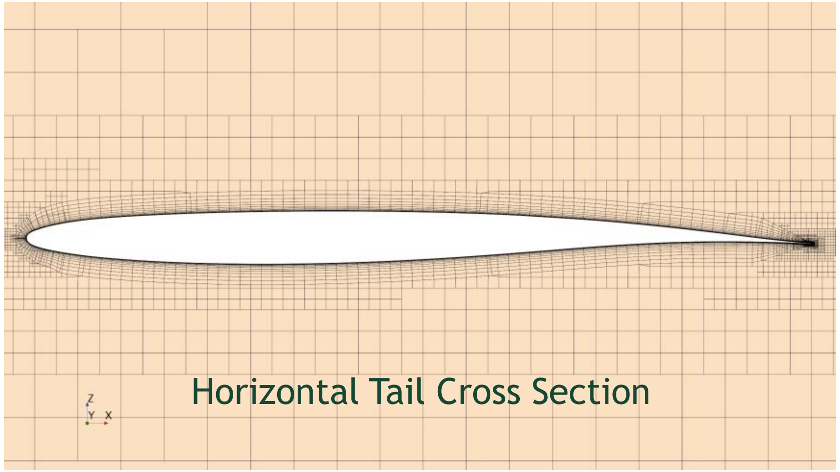


Prism Layers

- Used 17 prism layers fit within cell count requirements
- Future iterations of study with a larger cell count allowance would allow for more prism layers which would increase accuracy
- Prism layer total size set to the turbulent boundary layer thickness of each region
- Average Y+ across the X-29 was 3



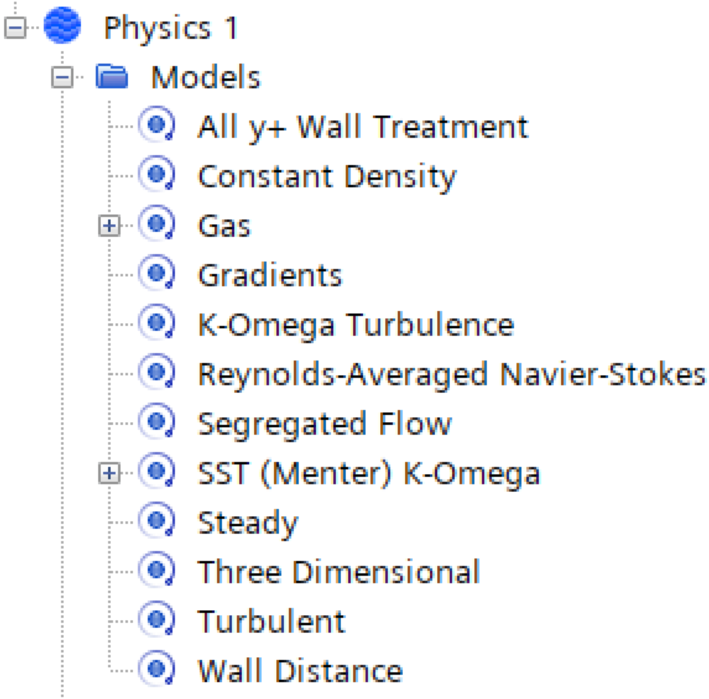
Wing Cross Section



Horizontal Tail Cross Section

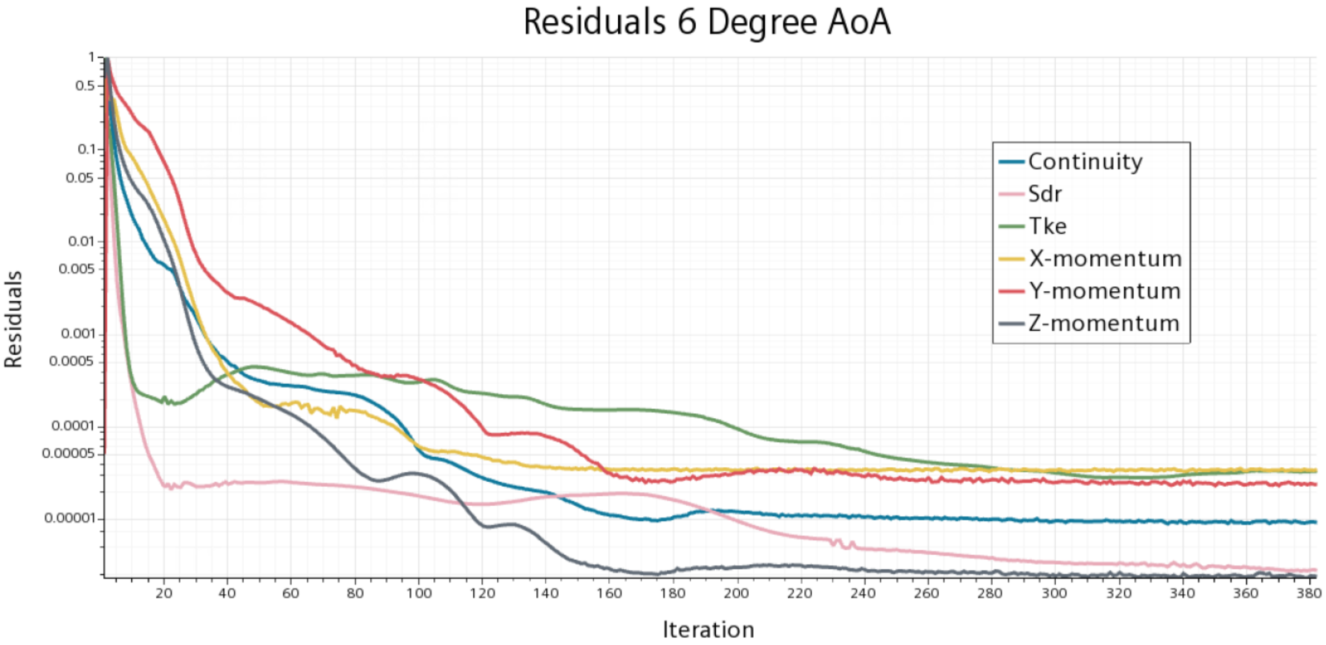
Physics Models

- Used a Reynolds-Averaged Navier Stokes Incompressible Segregated Flow K-Omega Turbulence Model
- Mach number is 0.27 which is near the recommended limit of 0.30 for incompressible segregated flow
- Incompressible segregated flow models were used to save time for the first pass of the CFD study
- Modeled the system as steady and three dimensional
- These are standard industry models for external aerodynamics simulations
- Set initial conditions to the boundary conditions



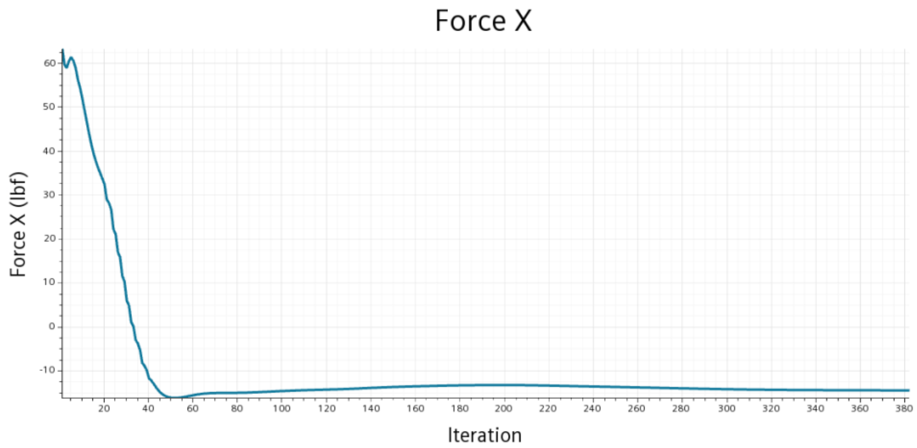
Convergence

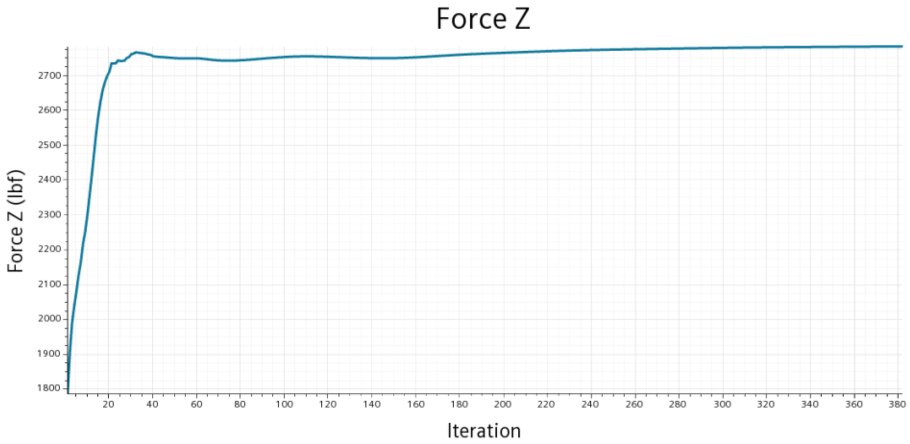
- Convergence criteria of 3% asymptotic convergence of engineering parameters of interest for 100 iterations
- Engineering parameters of interest were X direction force, Z direction force and pitching moment
- Residuals dropped by multiple orders of magnitude
- All simulations converged after less than 400 iterations

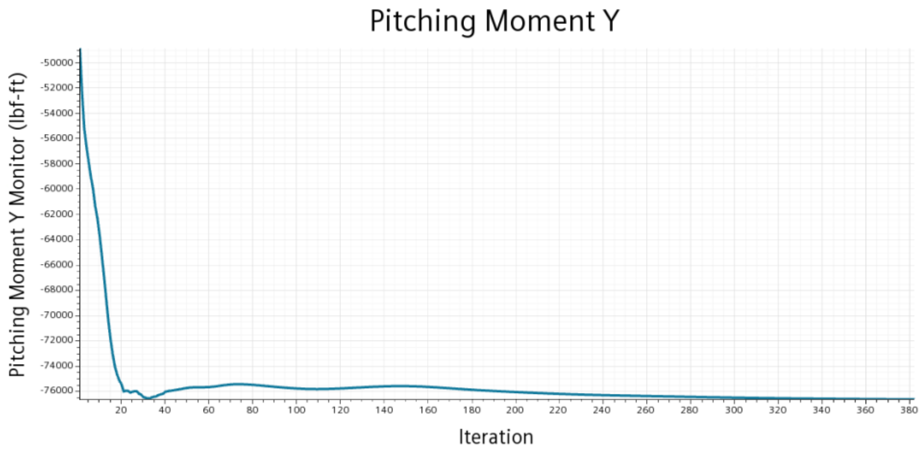


Parameter Convergence

- Plots show the convergence of the engineer parameters of interest at a 6 degree angle of attack

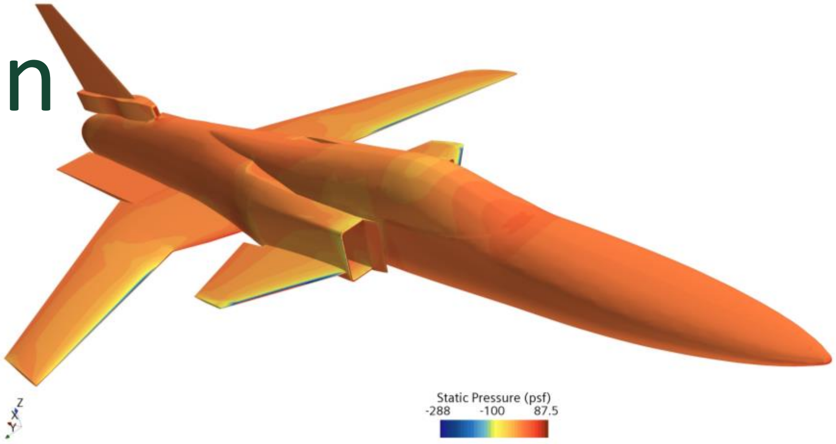


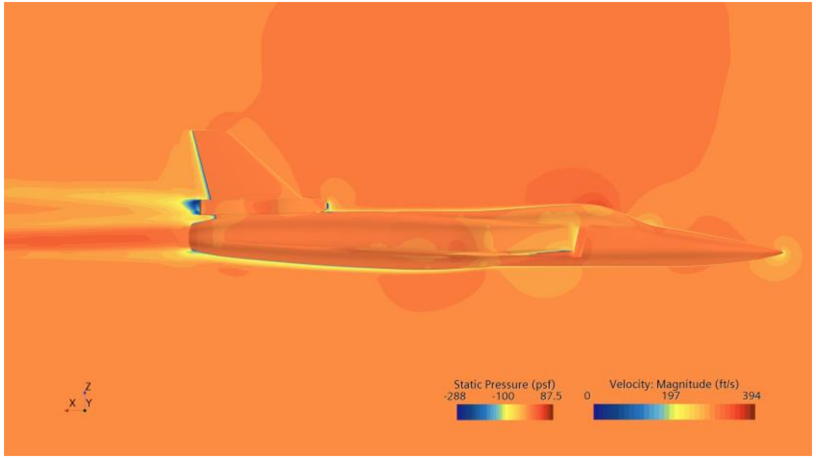


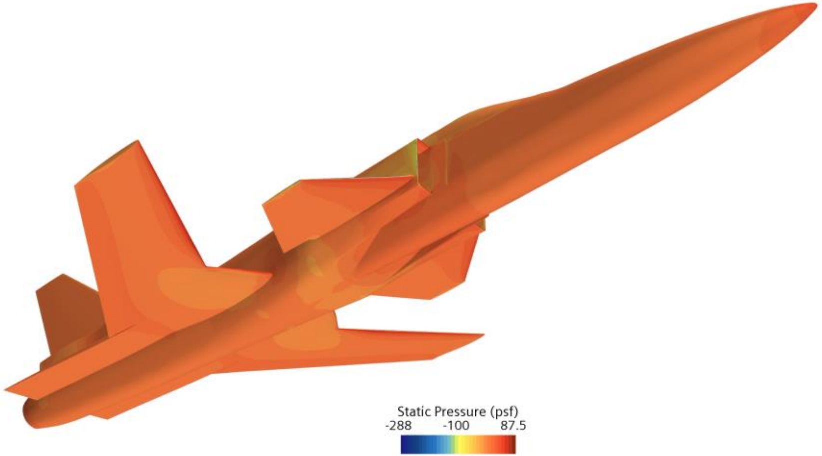


Pressure Distribution

- Expected pressure and velocity distribution for 6 degree angle of attack with relatively high L/D
- Large static pressure at spin chute leading edge shows area with large contribution to drag

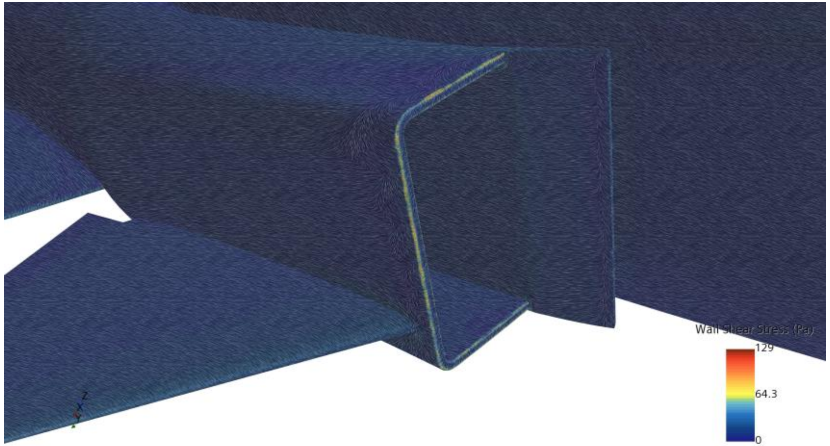


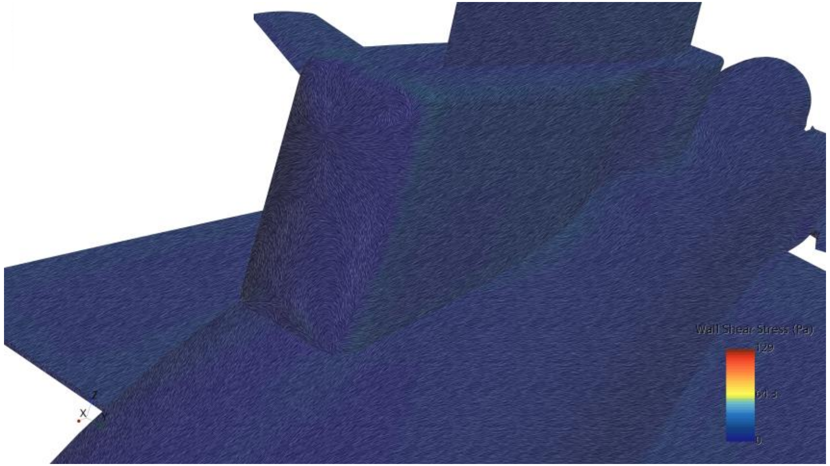




Recirculation Zones

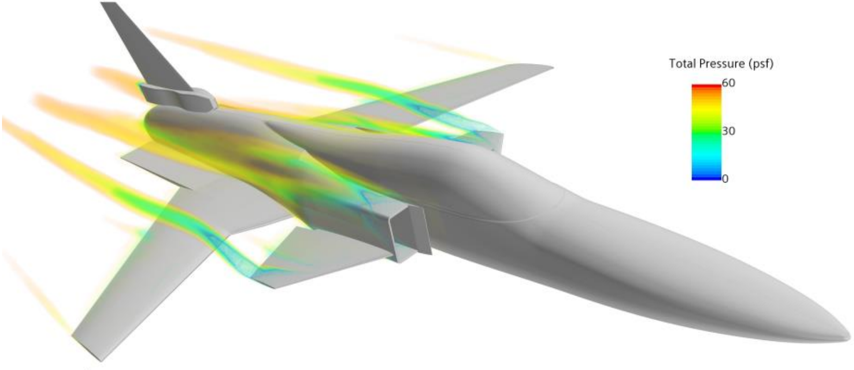
- Wall shear stress plots at 0 AoA shows shear stress velocity vectors circulating in some areas
- Large amount of separation at the front on the intake
- If optimizing aircraft for subsonic speed at low angles of attack, changes to intake lip geometry would be beneficial
- Large amount of recirculation at the back of the spin chute
- Extending the spin chute with amore streamlined shape would reduce recirculation and energy loss



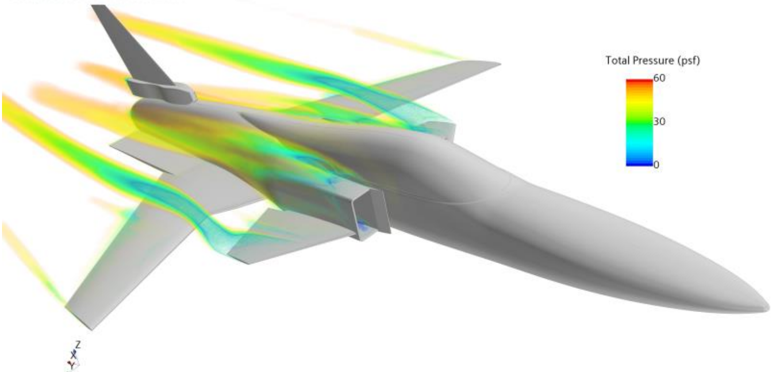


Total Pressure

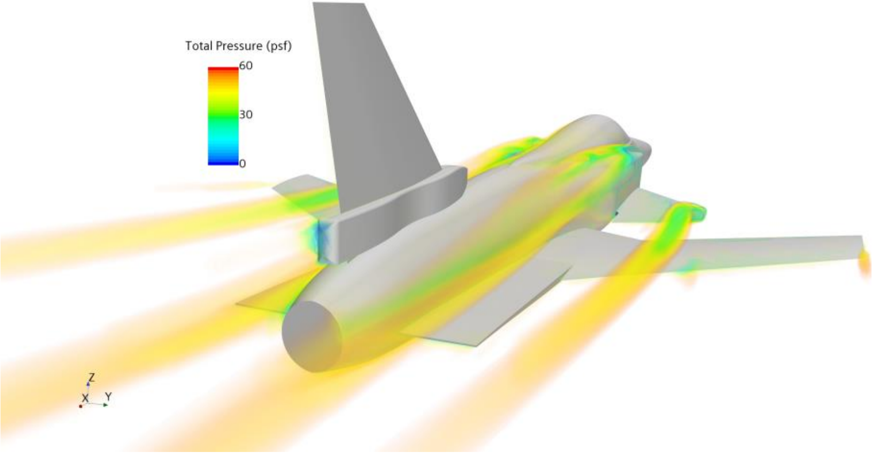
- Areas with low pressure behind illustrate there is energy loss
- Energy loss at back of spin chute and at the air intake illustrated by low pressure regions



6 Degree AoA

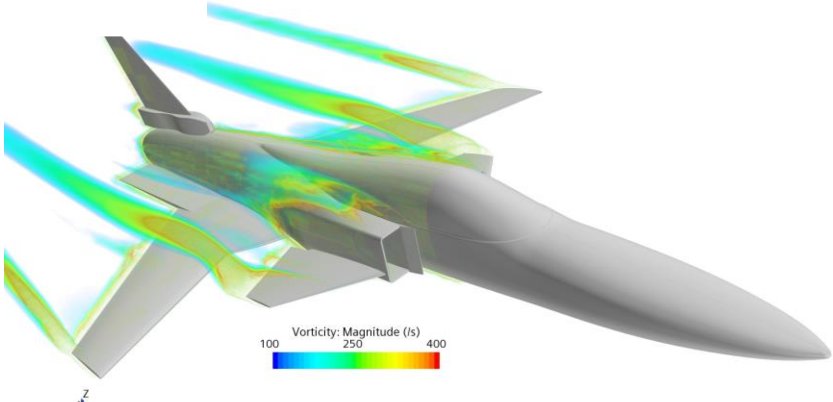


10 Degree AoA

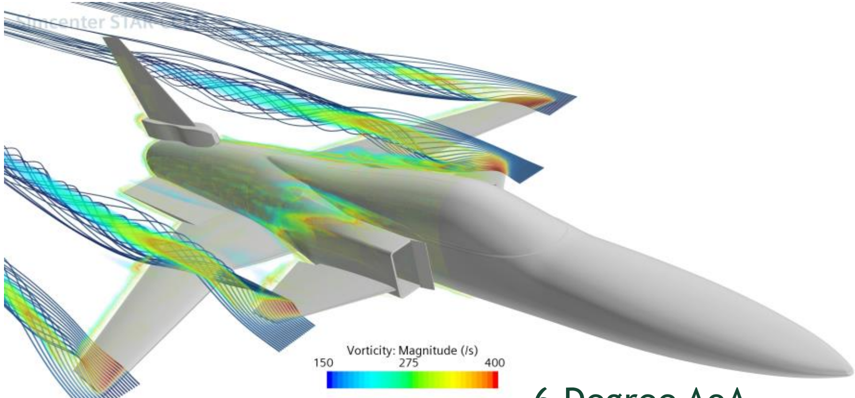


Vortex Locations

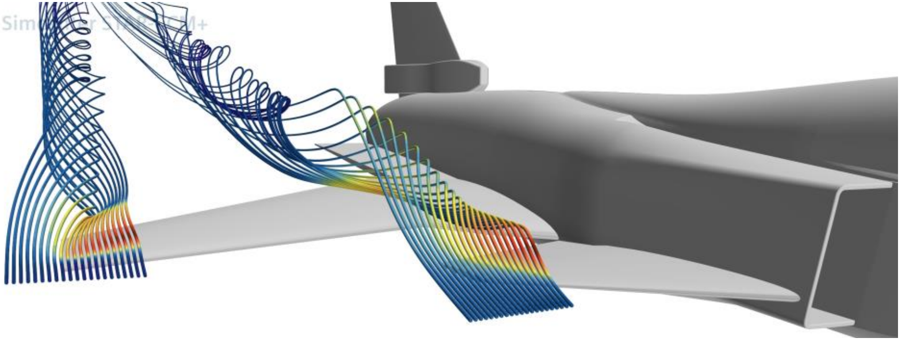
- Large amount of vorticity at canard and wing tips shown by streamlines and resampled volume
- More vorticity at larger angle of attack



10 Degree AoA



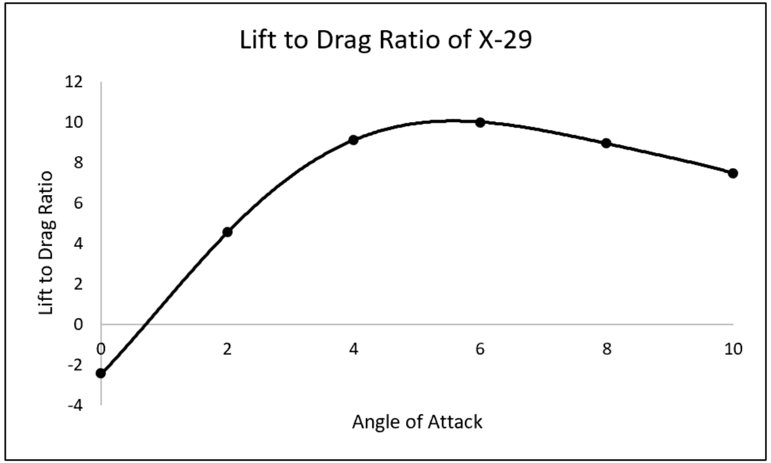
6 Degree AoA



Lift to Drag Ratios

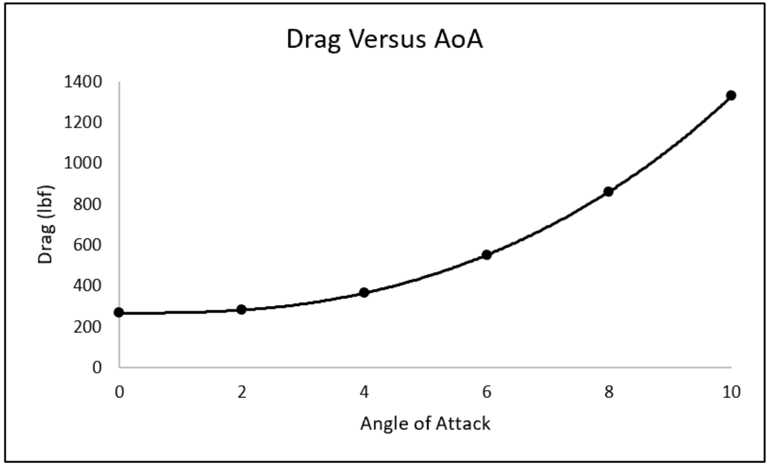
- Values at 294.6 feet per second at 10,000 feet mean sea level
- Pitching moment is with reference to the origin of the study [0, 0, 0]
- Force values doubled to account for symmetry plane
- L/D values are overestimates as excrescence and engine cooling drag not accounted for
- Negative lift at 0 AoA due to negative incidence of the wing

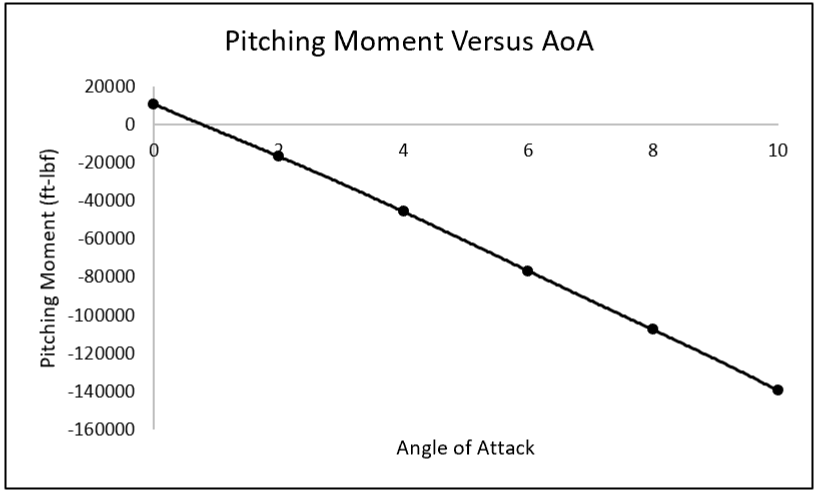
AoA	Pitching Moment (ft lbf)	Lift (lbf)	Drag (lbf)	L/D
0	10877	-658	268	-2
2	-16572	1293	283	5
4	-45589	3345	366	9
6	-76672	5539	553	10
8	-107484	7719	863	9
10	-139480	9948	1330	7

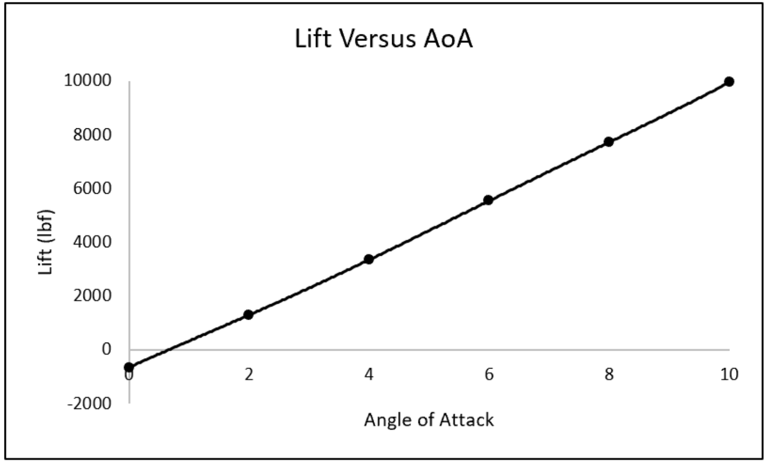


Parameter Plots

- Plots show parameters of interest from the angle of attack study

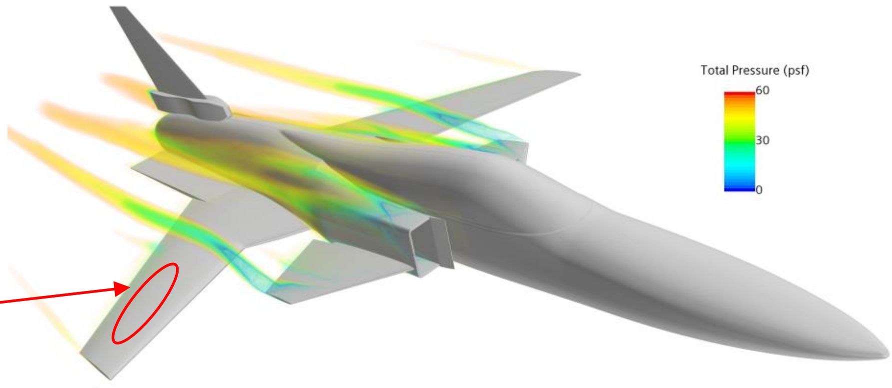


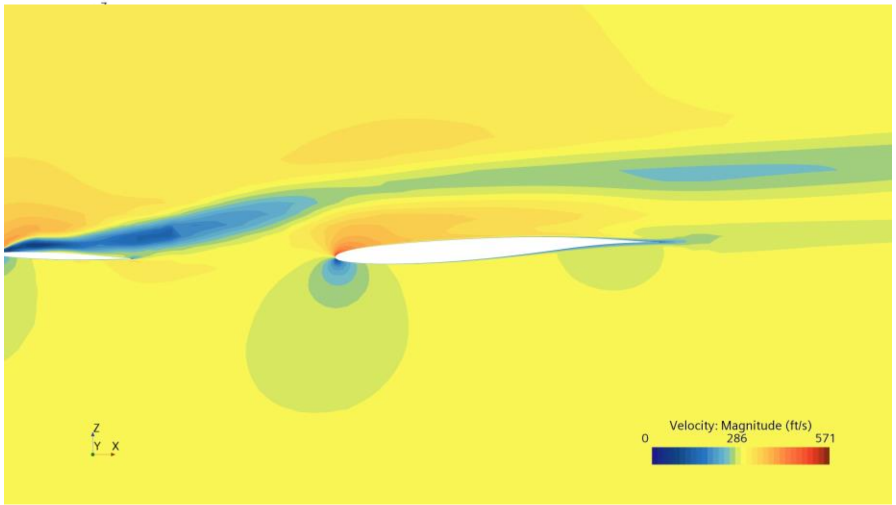




Air Data Measurement Package

- Recommended locations circled in the top figure
- Place away from wing tips and canard to avoid vortices
- Place away from the intake to avoid any separation
- Height of sensor input should be one inch from the wing or greater to get data out of boundary layer





Next Steps

- Using correction factors to account for the geometry simplifications which will increase the drag force
- Utilizing more memory would allow for more prism layers and additional refinement of fuselage wake, wing tips, and canard tips
- Adding volume mesh refinement at strake tips and wake to capture vortex
- Refining surface and volume mesh at areas with large gradients and areas found to be noncritical
- Using ideal gas and coupled flow physics models to reduce number of simplifications

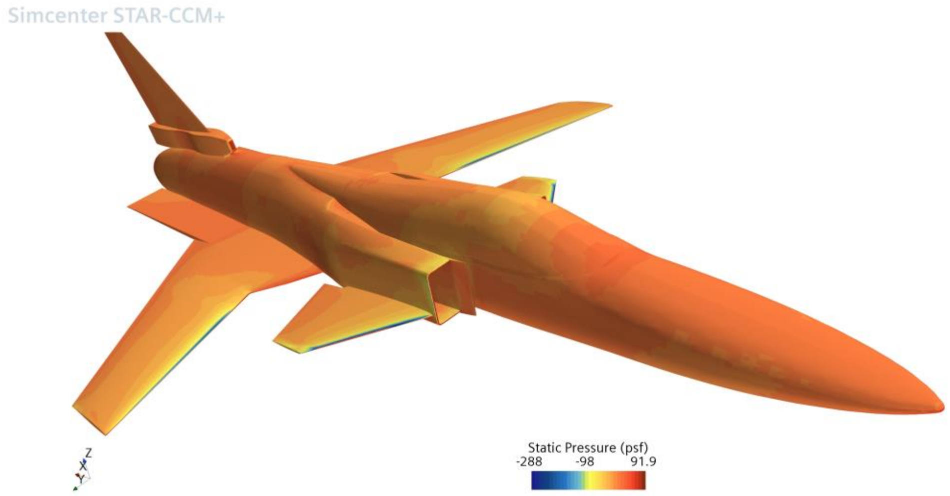
Additional Slides

Citations

[1] https://test-planes.fandom.com/wiki/Grumman_X-29

[2] https://www.nasa.gov/aeronautics/aircraft/x-29-demonstrator/

Static Pressure Distribution not Blended



- This shows there is acceptable refinement across the plane surface
- Would add some fuselage refinement with a larger memory allowance