# Turbulent Boundary Layer CFD

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## Introduction

In every aerodynamic design, skin friction drag on the boundary layer of the surface needs to be taken into account. The neglect of this could cause a significant error in drag and lead to a faulty design. The aerodynamics of skin friction drag can be assessed using computational fluid dynamics (CFD). CFD is a method that uses numerical algorithms to solve and analyze fluid flow, which can then be used to predict physical flow. This study analyzed skin friction drag caused by a small geometric change on a surface using the commercial software ANSYS Fluent. This software offers a widely tested shear stress transport (SST) turbulence model. Fluent combines the SST model with other turbulence modeling innovations for maximum accuracy in wall shear, which corresponds directly to skin friction drag.

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho U_\infty^2}$$

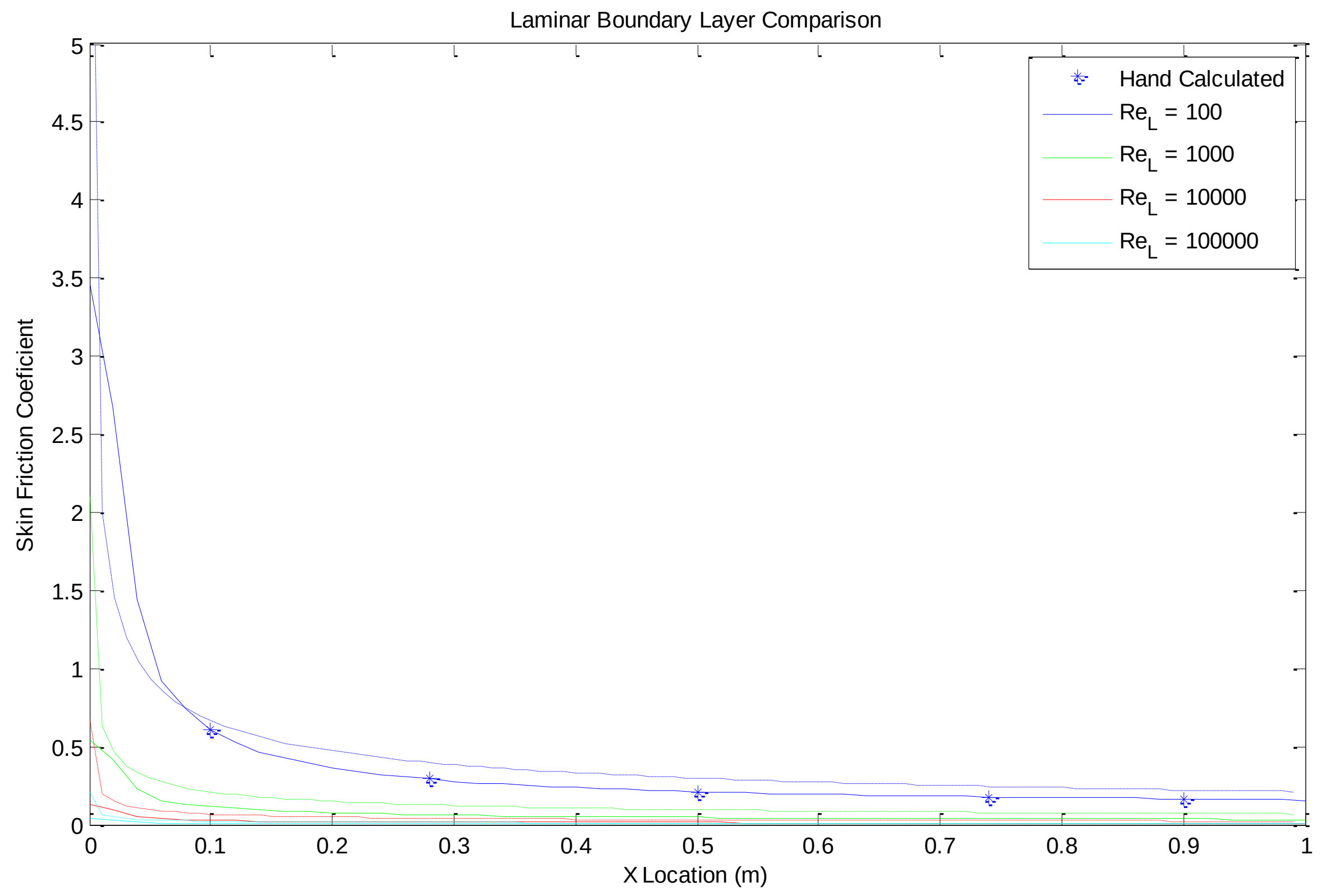
## Verification

To make sure ANSYS Fluent was providing accurate results, a test geometry consisting of a flat plate with a laminar boundary layer was first used. The velocity profiles computed were compared with the Blasius solution by converting the computed results into the similarity variables $\eta$ and $u$*. The local skin friction coefficients computed were then compared with a laminar correlation.

$$\eta = y\sqrt{\frac{U_\infty \rho}{x\mu}}$$

$$u^* = \frac{u}{U_\infty}$$

$$C_{f_x} = \frac{0.664}{\sqrt{\mathrm{Re}_x}}$$

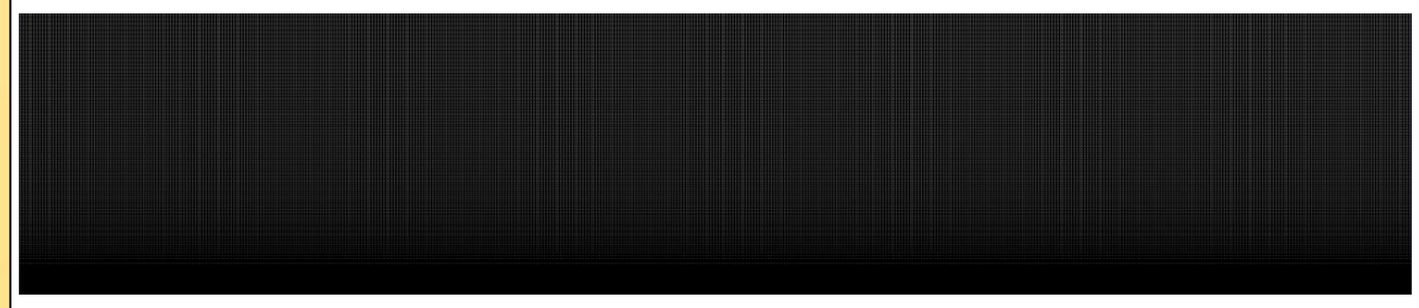


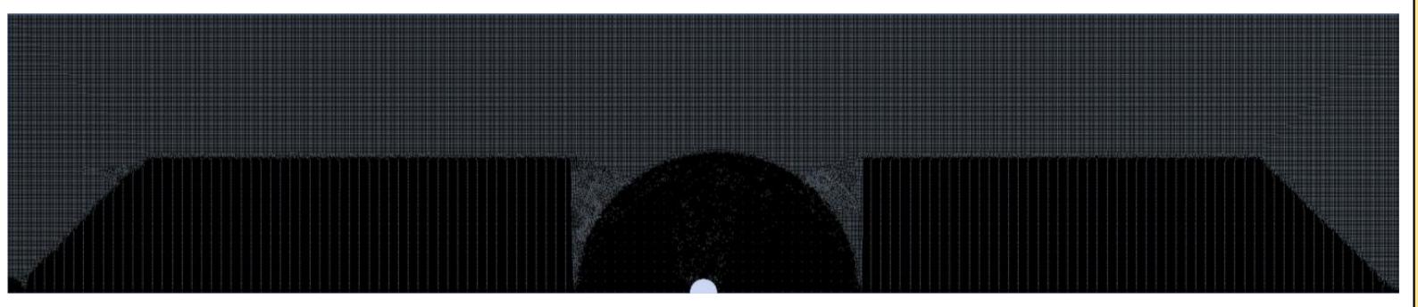
Once the laminar case was verified, the turbulent k-omega SST model was compared with turbulent skin friction coefficient correlations. The turbulent skin friction correlations used are Prandtl (1927) and Grandville (1977).

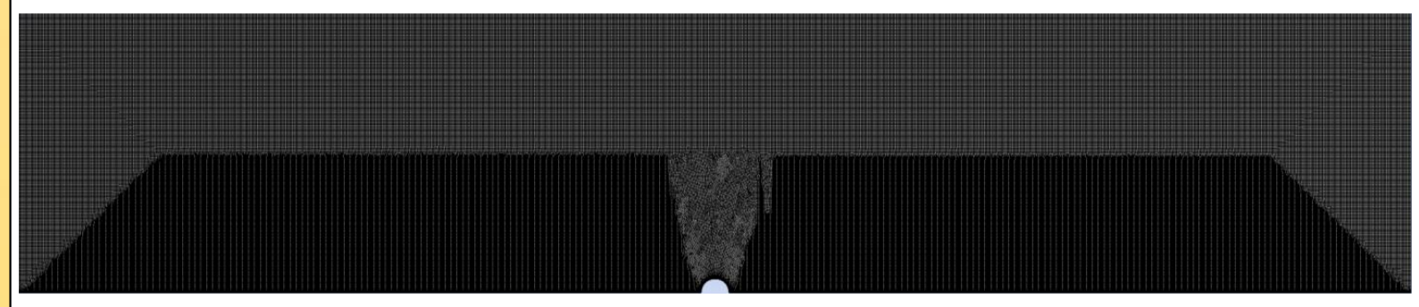
$$C_{f_x} = \frac{0.074}{\mathrm{Re}_x^{0.2}} \qquad C_{f_x} = \frac{0.0776}{\left(\log_{10}(\mathrm{Re}_x) - 1.88\right)^2} + \frac{60}{\mathrm{Re}_x}$$

## Setup

The two dimensional inflow conditions and geometry were set so that the flow would reach equilibrium before it arrived at the cylinder. The inflow conditions used during the turbulent cases are: fluid density 1.00 kg/m$^3$, dynamic viscosity 0.0001 N·s/m$^2$, temperature 288.16 K, and ratio of specific heats 1.4. The fluid geometry was a horizontal 100 m by vertical 20 m space above a flat plate with the center of a 1 m radius cylinder located at 50 m. The inflow velocities used were 10 m/s, 100 m/s, and 300 m/s. To make sure the skin friction coefficient extracted reached a mesh independent solution, three different meshes were used for the cylinder and compared with a flat plate.


Flat Plate Mesh – 258600 Elements

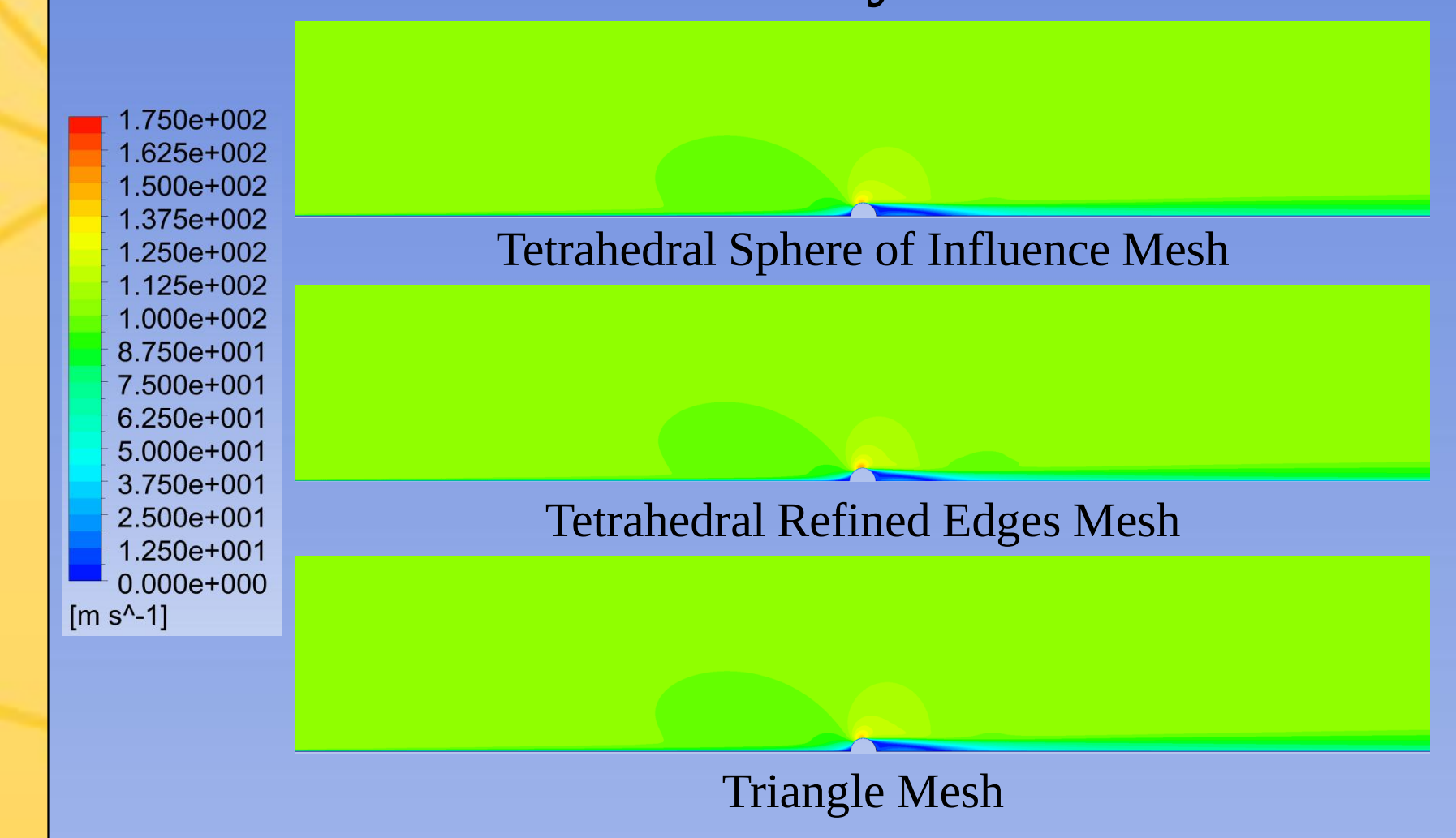

Tetrahedral SOI Mesh – 321463 Elements


Tetrahedral RE Mesh – 296513 Elements


Triangle Mesh – 453613 Elements

## Results

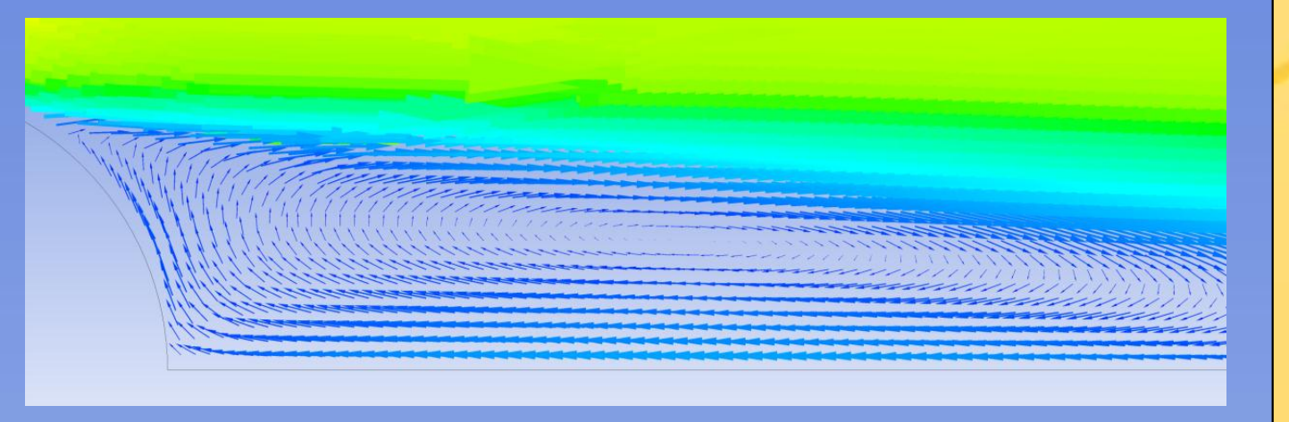
### Total Velocity at 100 m/s



Tetrahedral Sphere of Influence Mesh

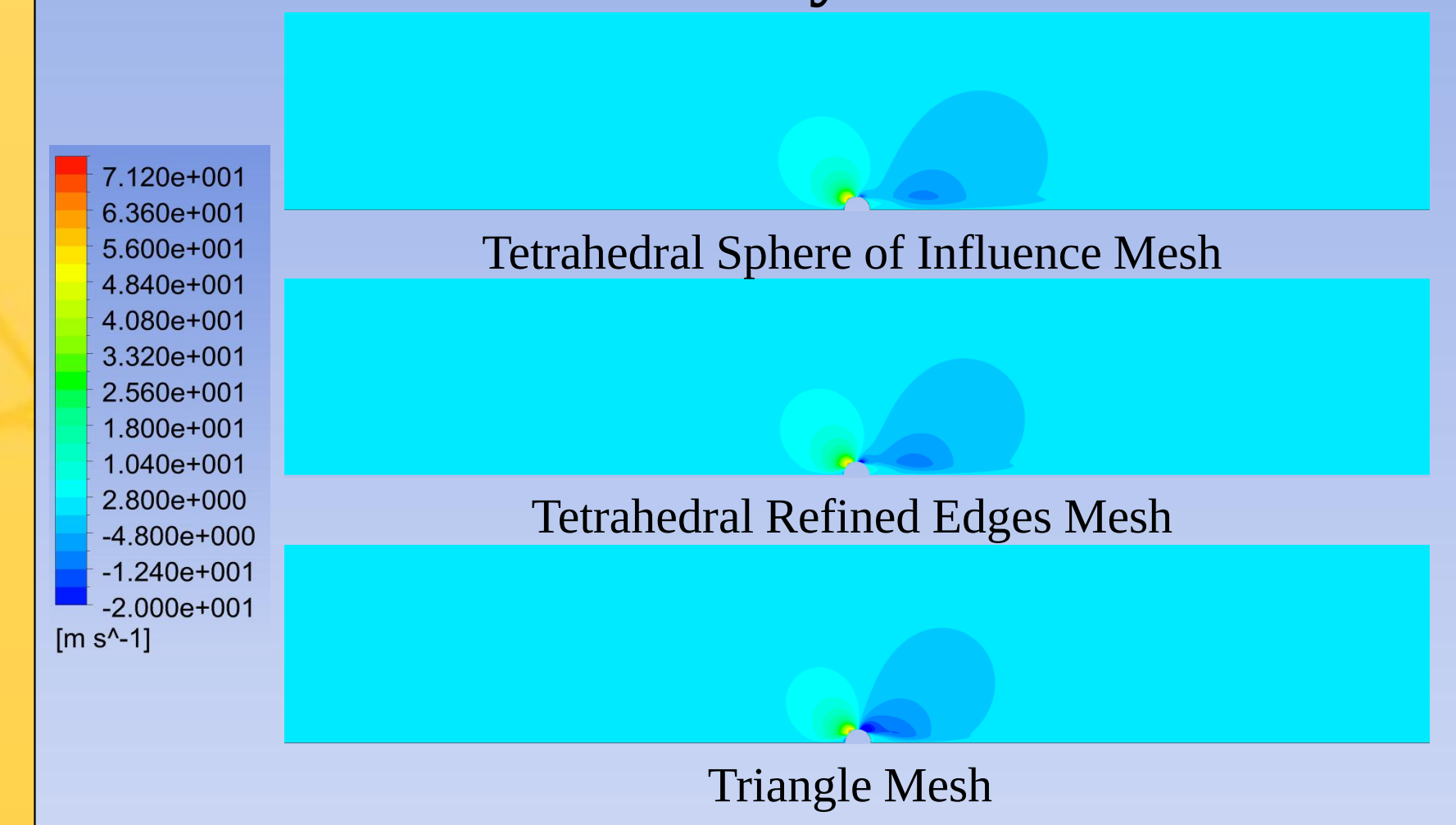
Tetrahedral Refined Edges Mesh

Triangle Mesh



| Quantity | Mesh - Free Stream Velocity | Min | Max |
|---|---|---|---|
| Total Velocity [m/s] | Tetrahedron SOI -100 m/s | 0 | 150.1 |
| | Tetrahedron RE -100 m/s | 0 | 144.3 |
| | Triangle -100 m/s | 0 | 162.4 |
| Y Velocity [m/s] | Tetrahedron SOI -100 m/s | -26.46 | 65.06 |
| | Tetrahedron RE -100 m/s | -17.81 | 66.37 |
| | Triangle -100 m/s | -42.69 | 65.04 |
| Pressure [Pa] | Tetrahedron SOI -100 m/s | -9165 | 1846 |
| | Tetrahedron RE -100 m/s | -8327 | 2299 |
| | Triangle -100 m/s | -11070 | 1703 |

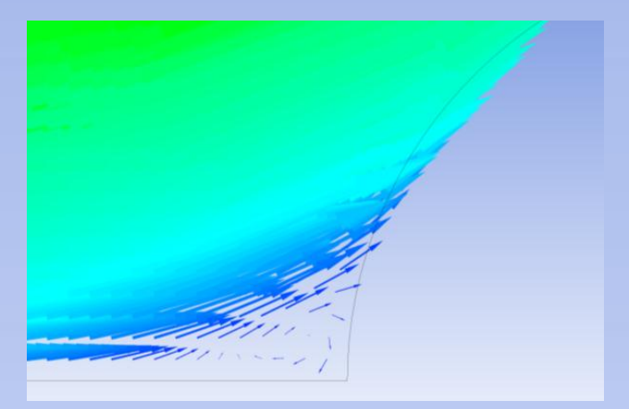
### Y Velocity at 100 m/s



Tetrahedral Sphere of Influence Mesh

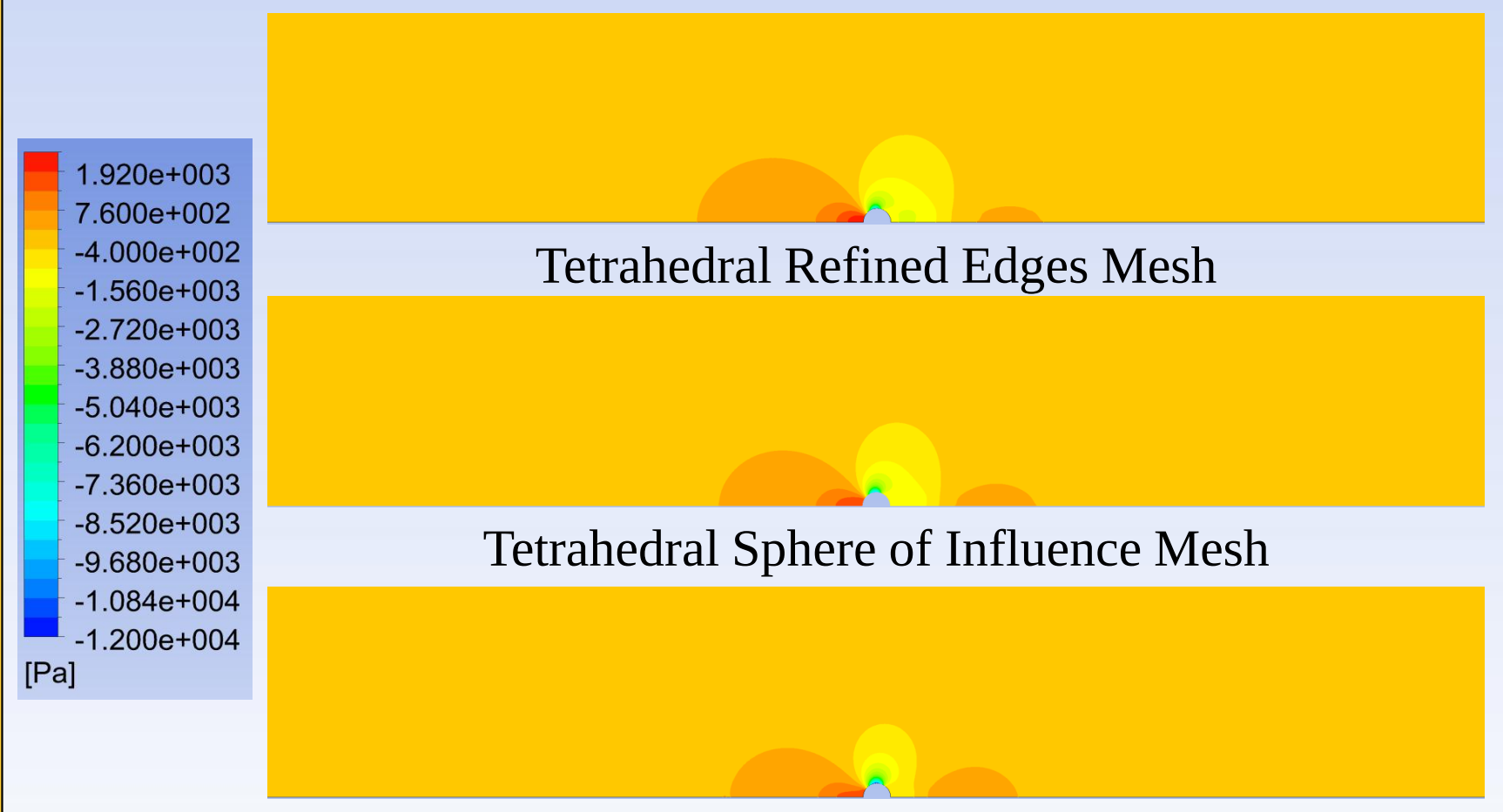
Tetrahedral Refined Edges Mesh

Triangle Mesh



| Quantity | Mesh - Free Stream Velocity | Min | Max |
|---|---|---|---|
| Total Velocity [m/s] | Tetrahedron SOI -10 m/s | 0 | 14.25 |
| | Tetrahedron SOI -100 m/s | 0 | 150.1 |
| | Tetrahedron SOI -300 m/s | 0 | 440.5 |
| Y Velocity [m/s] | Tetrahedron SOI -10 m/s | -1.616 | 6.523 |
| | Tetrahedron SOI -100 m/s | -26.46 | 65.06 |
| | Tetrahedron SOI -300 m/s | -56.45 | 204.9 |
| Pressure [Pa] | Tetrahedron SOI -10 m/s | -79.53 | 22.48 |
| | Tetrahedron SOI -100 m/s | -9164 | 1846 |
| | Tetrahedron SOI -300 m/s | -77460 | 22080 |

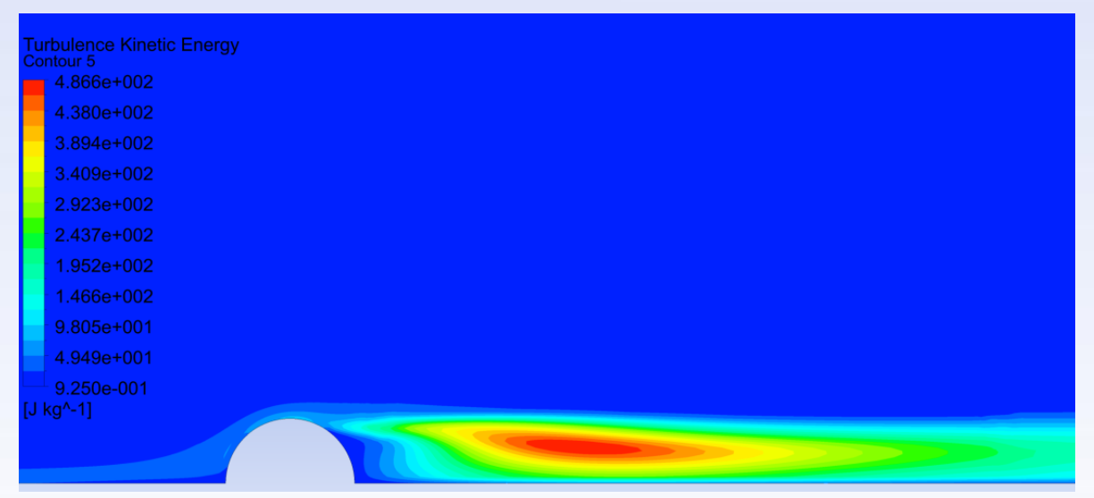
### Pressure at 100 m/s



Tetrahedral Refined Edges Mesh

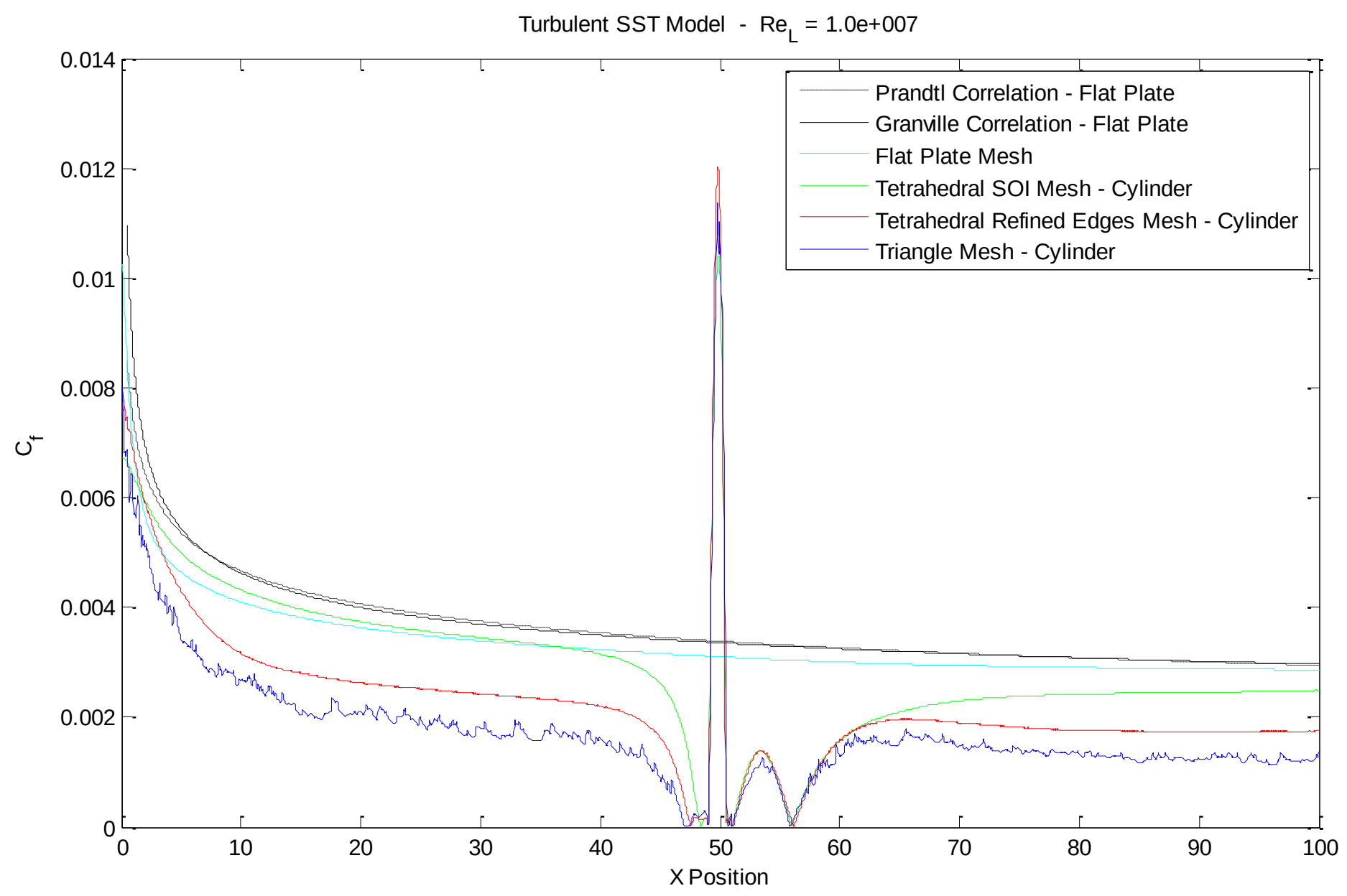
Tetrahedral Sphere of Influence Mesh

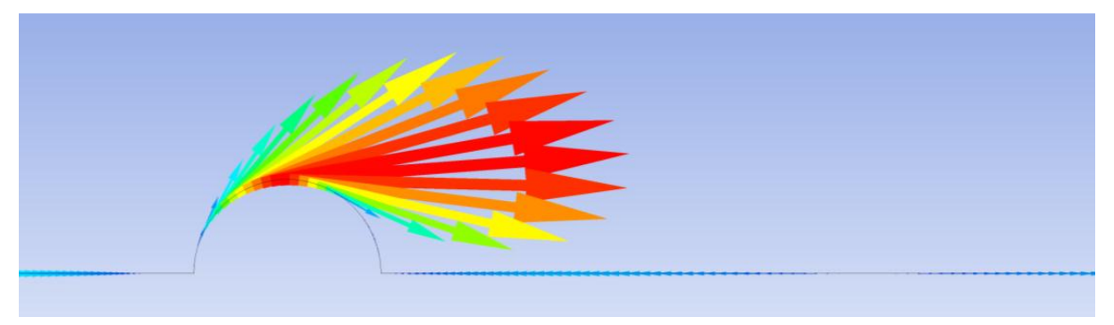
Triangle Mesh

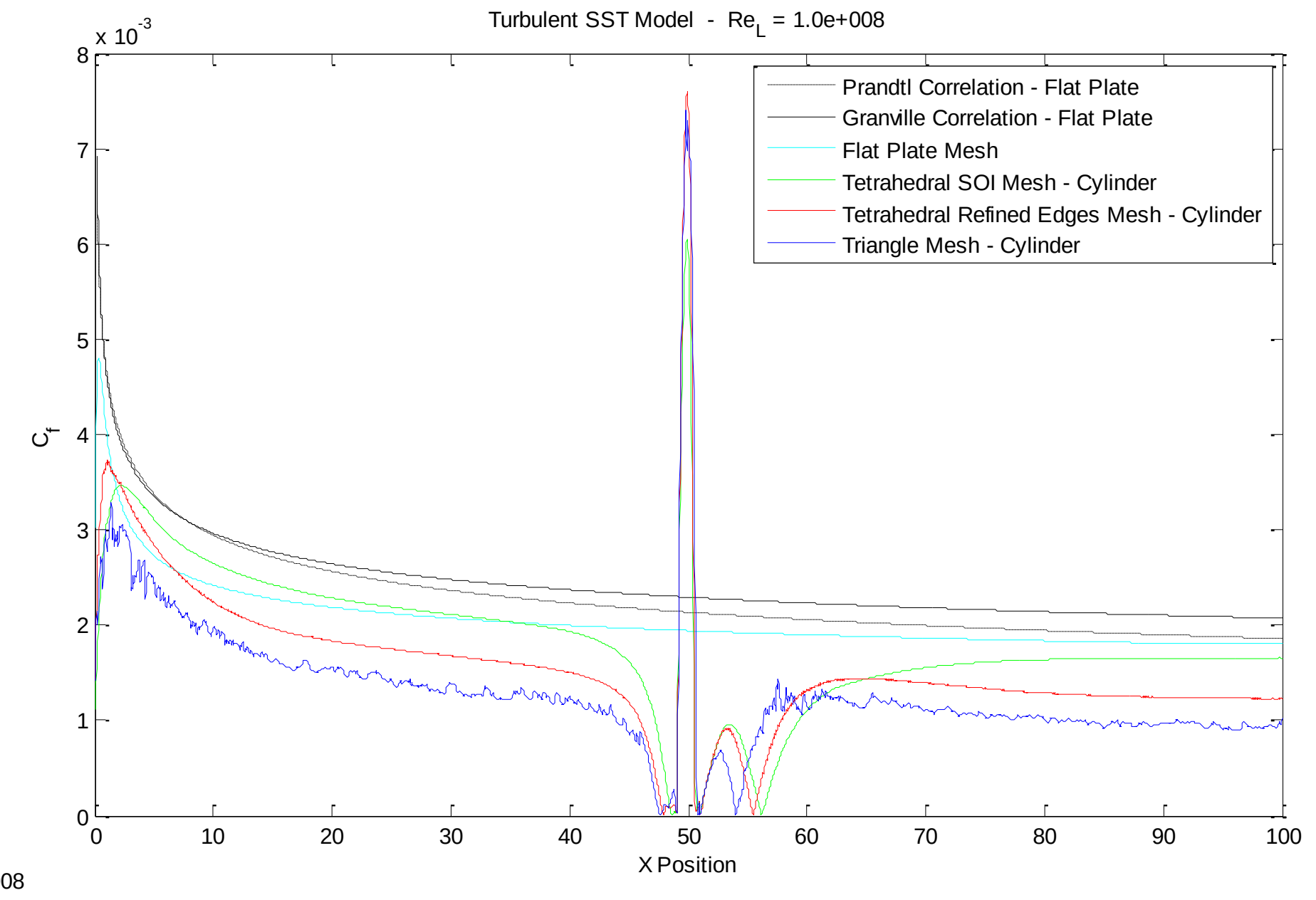


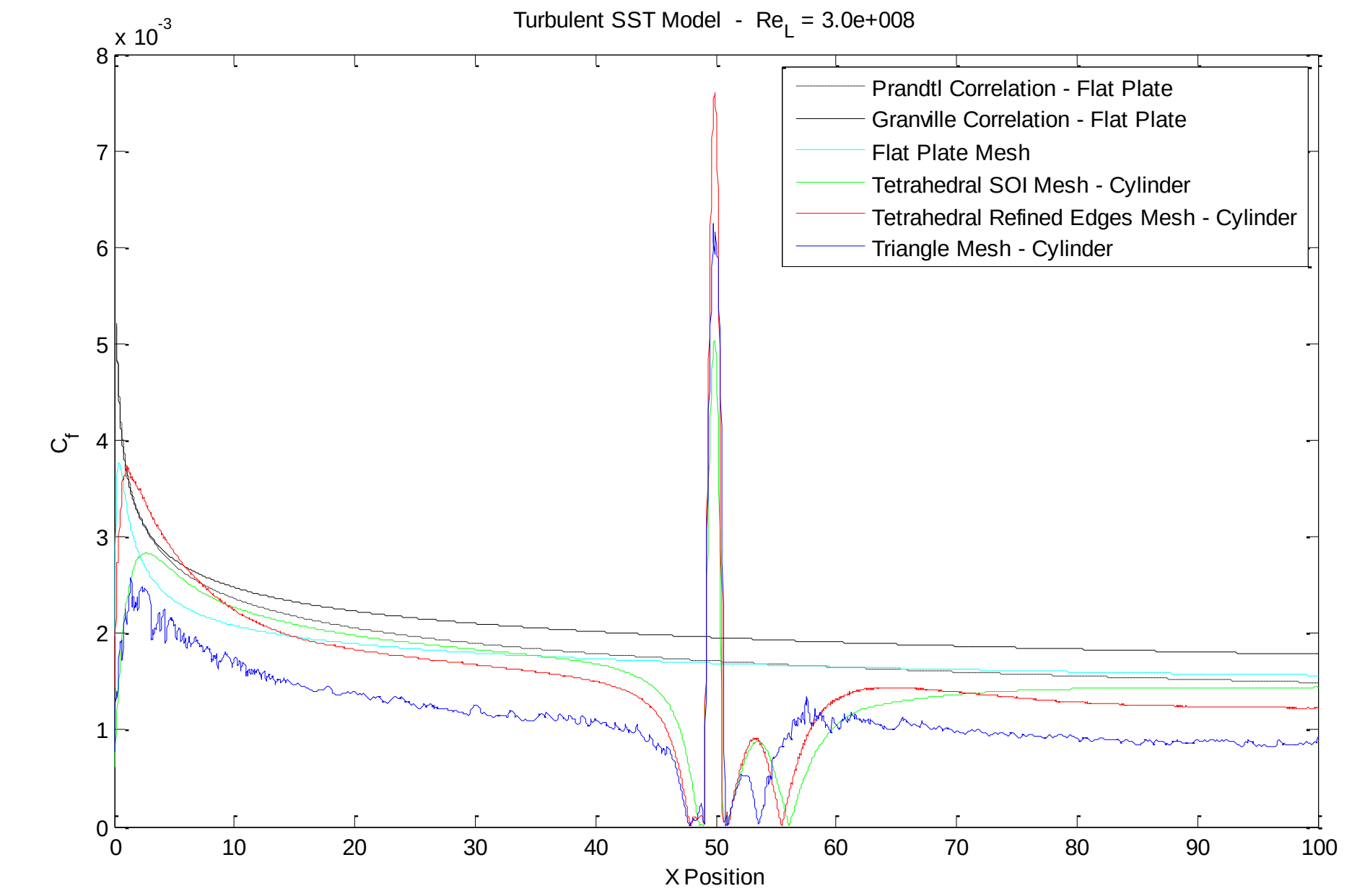
## Results

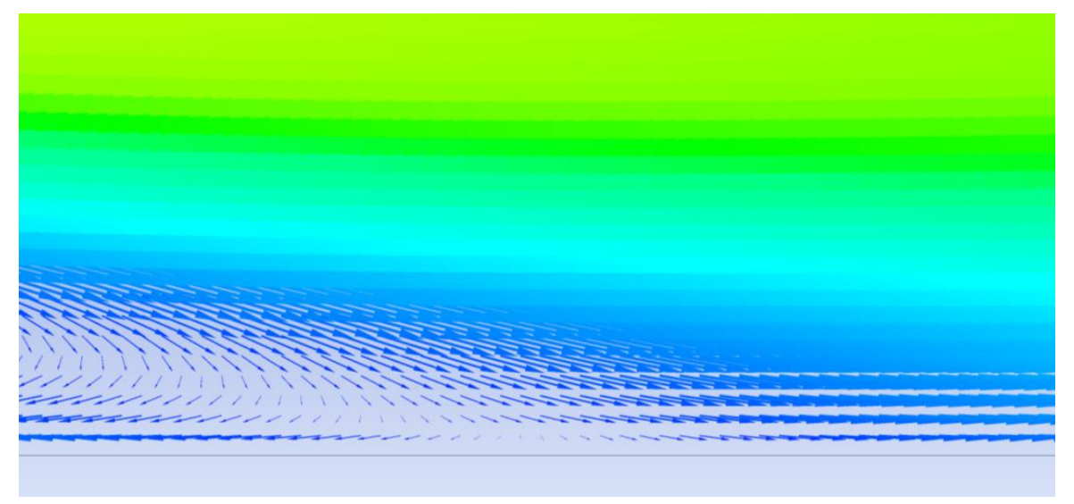
The local skin friction coefficient was extracted for each velocity and mesh. These were then compared to turbulent correlations.











## Conclusion

CFD is able to predict physical flows when applied correctly. Because of the number of elements needed for this analysis, this study pushed the limits of the software version and computational power available. This project provided a deeper understanding of turbulence CFD modeling that allowed for the prediction of the local skin friction coefficient for different flows for a single surface geometry. Because the local skin friction coefficient for each mesh produced significantly variable results, further analysis needs to be completed to find a mesh independent solution. This requires finer mesh resolution and more computational power. Further analysis with more complicated surface geometries will provide engineers with a more thorough understanding of fluid surface interactions and its effects on skin friction drag. This information can then be used to optimize aerodynamic surfaces.

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