

Supersonic Laminar Flow Boundary Layer Analysis

Devayani Cheruvu
Mechanical and Aerospace Engineering
Rutgers University
devayani.cheruvu@rutgers.edu

Edward Demauro, Advisor
Mechanical and Aerospace Engineering
Rutgers University
ed451@soe.rutgers.edu

Abstract

With the increase and importance of high speed aircraft, it is necessary to study the aerodynamics of various supersonic flow situations. With the hemisphere being a common protrusive geometry on many aircraft, this is a particularly useful case to study with the use of a wind tunnel. Due to Covid-19, the hemisphere study was carried out virtually using ANSYS Fluent by modeling the Emil Buehler Supersonic Wind Tunnel at Rutgers. The particular focus of the study revolved around the boundary layer profile of the hemisphere model in a laminar flow. The geometry consists of a flat plate portion as well as the hemisphere. The boundary layer over the flat plate was studied first. Using the wind tunnel conditions, the flat plate was analyzed and a velocity contour and boundary layer profile were generated. The boundary layer profile was compared with the Blasius solution, and determined to be a good representation of it. The results were as expected according to the Blasius solution.

Background

The flow over this domain is a laminar flow, meaning the fluid particles travel in smooth paths. Due to the viscosity of the flow being laminar, a boundary layer is expected to form along the floor and hemisphere. The boundary layer is fluid that essentially clings to the surface. As the height of fluid above the surface increases, the fluid speed increases until it eventually reaches the free stream velocity.

The boundary layer profile is a graph of the height in the y direction versus the ratio of the velocity in the x direction to the free stream velocity. The Blasius solution accurately depicts the boundary layer over the flat plate. The profile curves up towards 1 and forms an asymptote at 1.

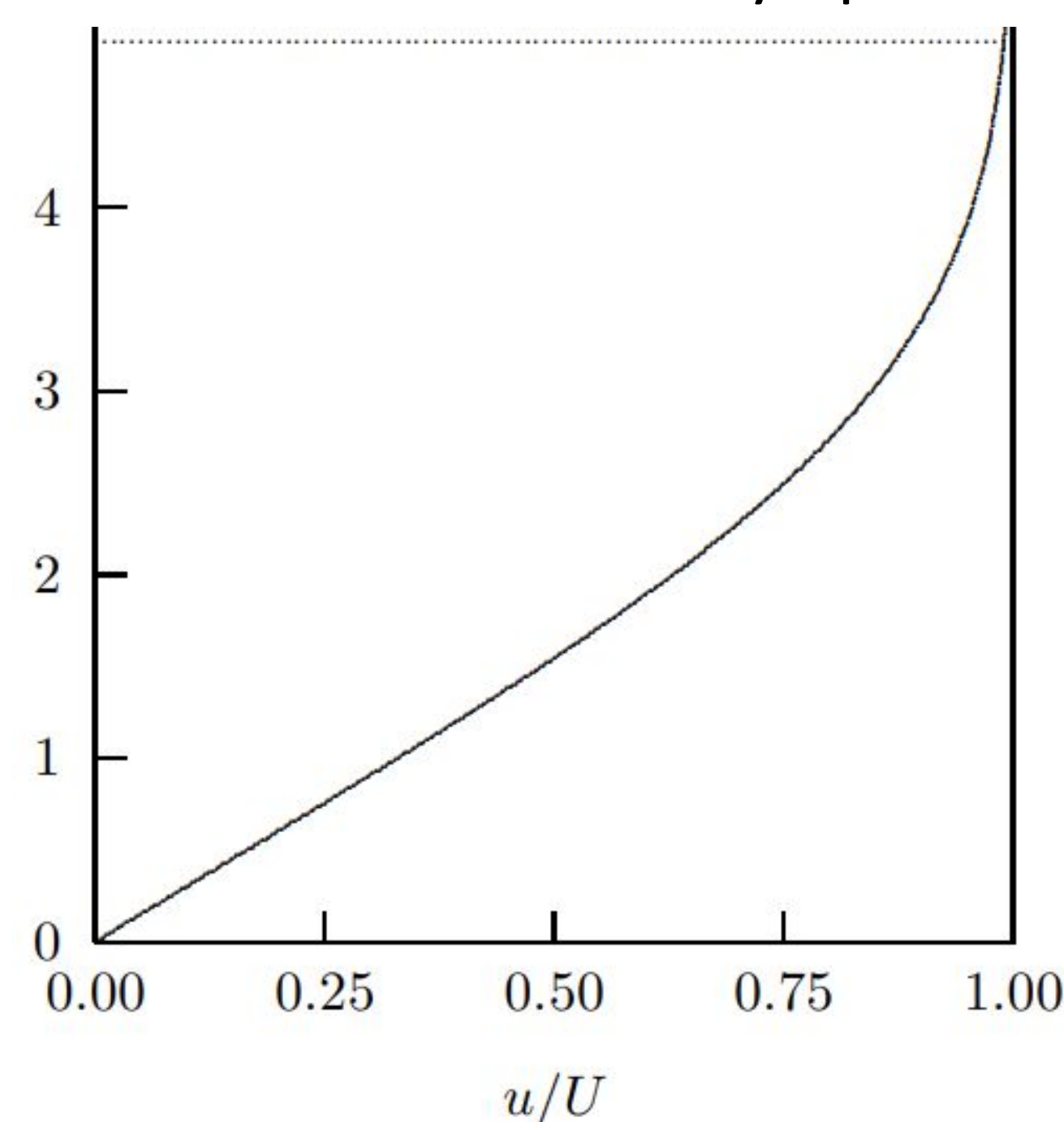


Figure 1: Blasius solution graph

In order to arrive at a boundary layer result using ANSYS Fluent, there are multiple steps: creating the geometry, mesh, and inputting a physics setup for the solution. First, a 2D geometry was created; a 0.1m by 0.1m square was chosen to model the flat plate portion that comes before the hemisphere.

The meshing was done in such a way that there was a high concentration of cells that bordered the floor. To achieve this, the inflation setting was used along the floor with 35 layers, a growth rate of 1.2, and a total boundary layer thickness of .016m. These values represent the actual flow behavior in the supersonic wind tunnel. The size of each element cell was set to .0009m to give the mesh further refinement.

Methods and Materials

For the physics setup of the problem, a pressure-based solver was chosen. The top and left edges were given the boundary conditions of a velocity inlet. Both were set to 626.3 m/s, which corresponds to Mach 3.4, the speed of free stream in wind tunnel. The right edge was given the boundary condition of a pressure outlet. The fluid of the entire domain was set to air, and viscosity set to laminar. Through these steps, a solution was converged, therefore allowing a boundary layer profile and a velocity contour to be created.

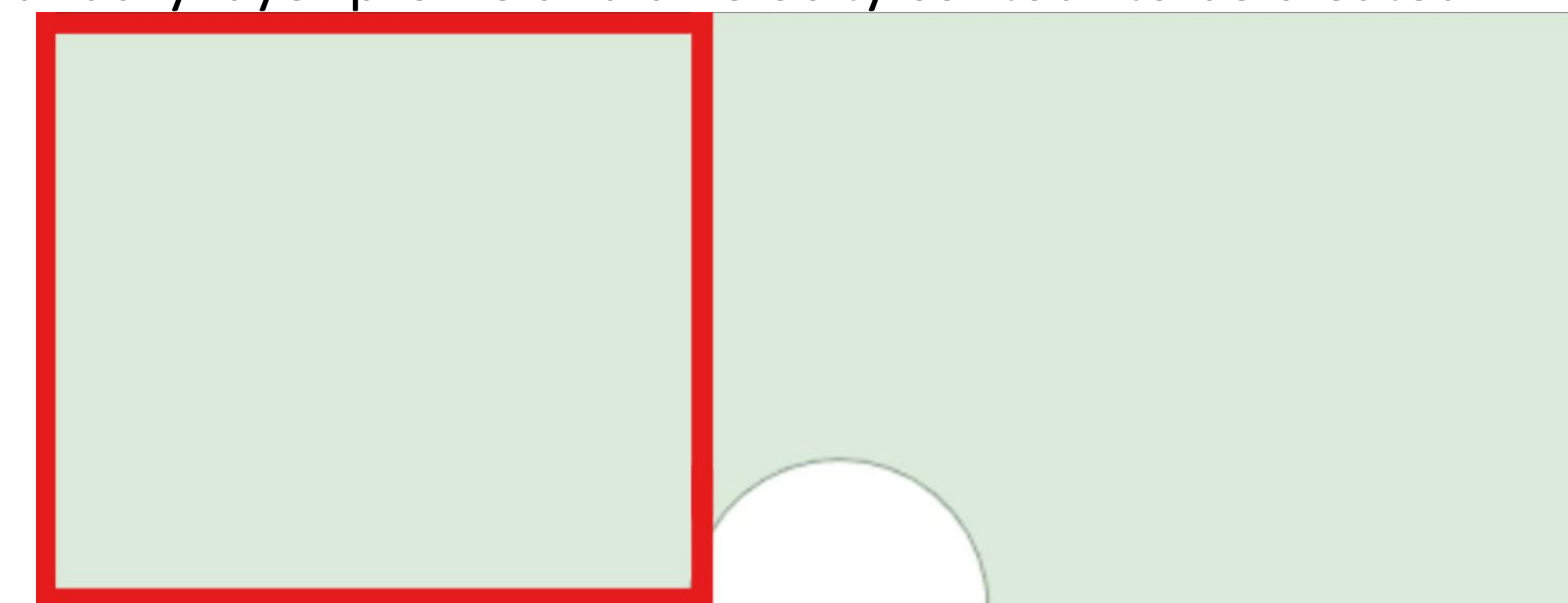


Figure 2: Full hemisphere geometry with flat plate portion outlined

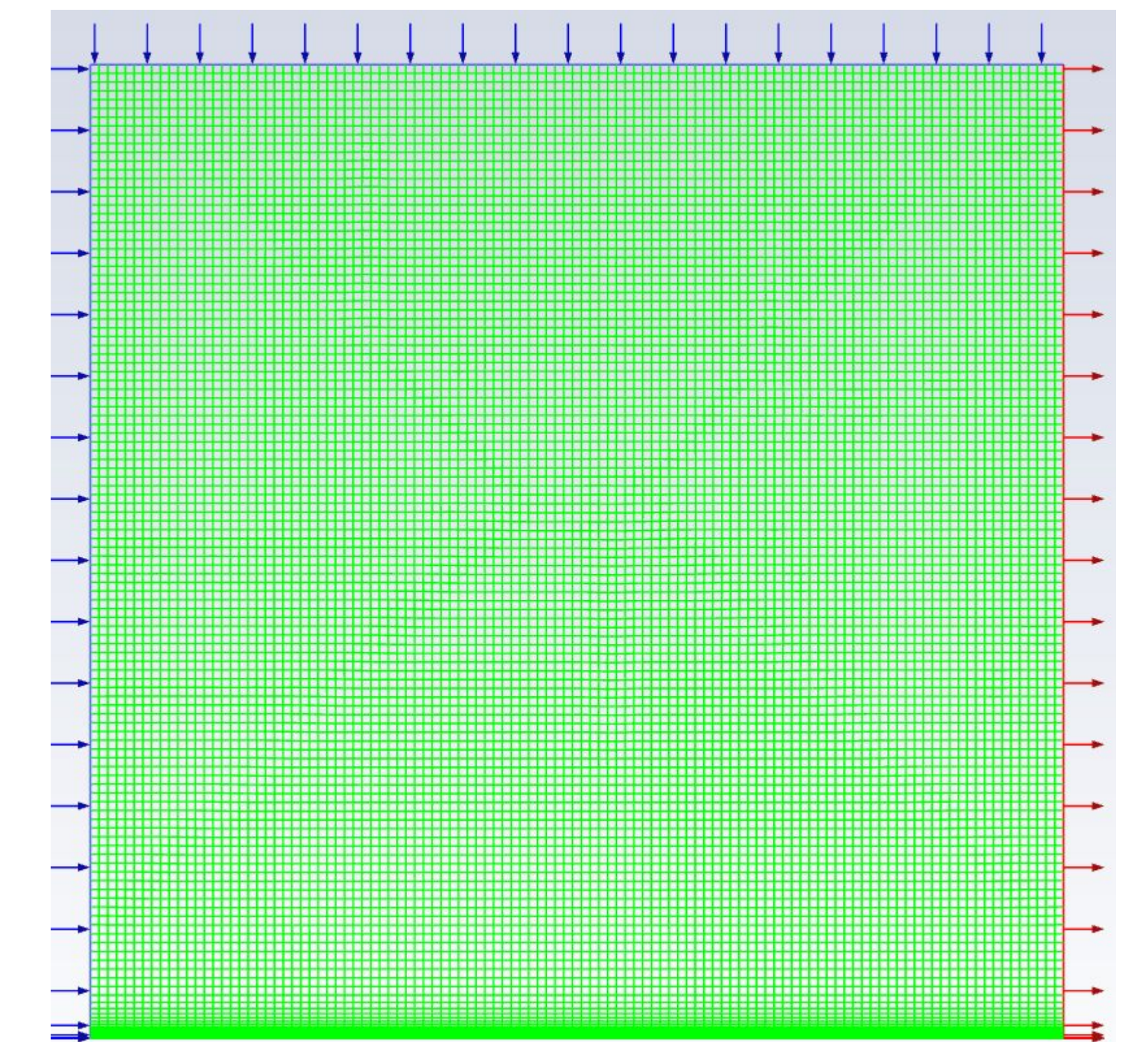


Figure 3: Mesh of flat plate with blue arrows representing velocity inlets and red arrows representing pressure outlet

Results

The boundary layer profile created from the flat plate represents the expected results based on the Blasius solution. As mentioned in the background section, the Blasius solution graph shows the boundary layer thickness versus the ratio of the velocity at a certain point within the boundary layer to the free stream velocity. In the graph, the asymptote begins around the expected location, along $x = 1$. Each curve corresponds with a different x value on the flat plate domain: .025m, .05m, .075m, and .1m. Also as supported by the Blasius solution, as the x value on the domain increases, so does the boundary layer thickness. Each curve has higher boundary layer (y axis) values than the previous, just as expected. The velocity contour is a visual representation of the change in velocity within the boundary layer.

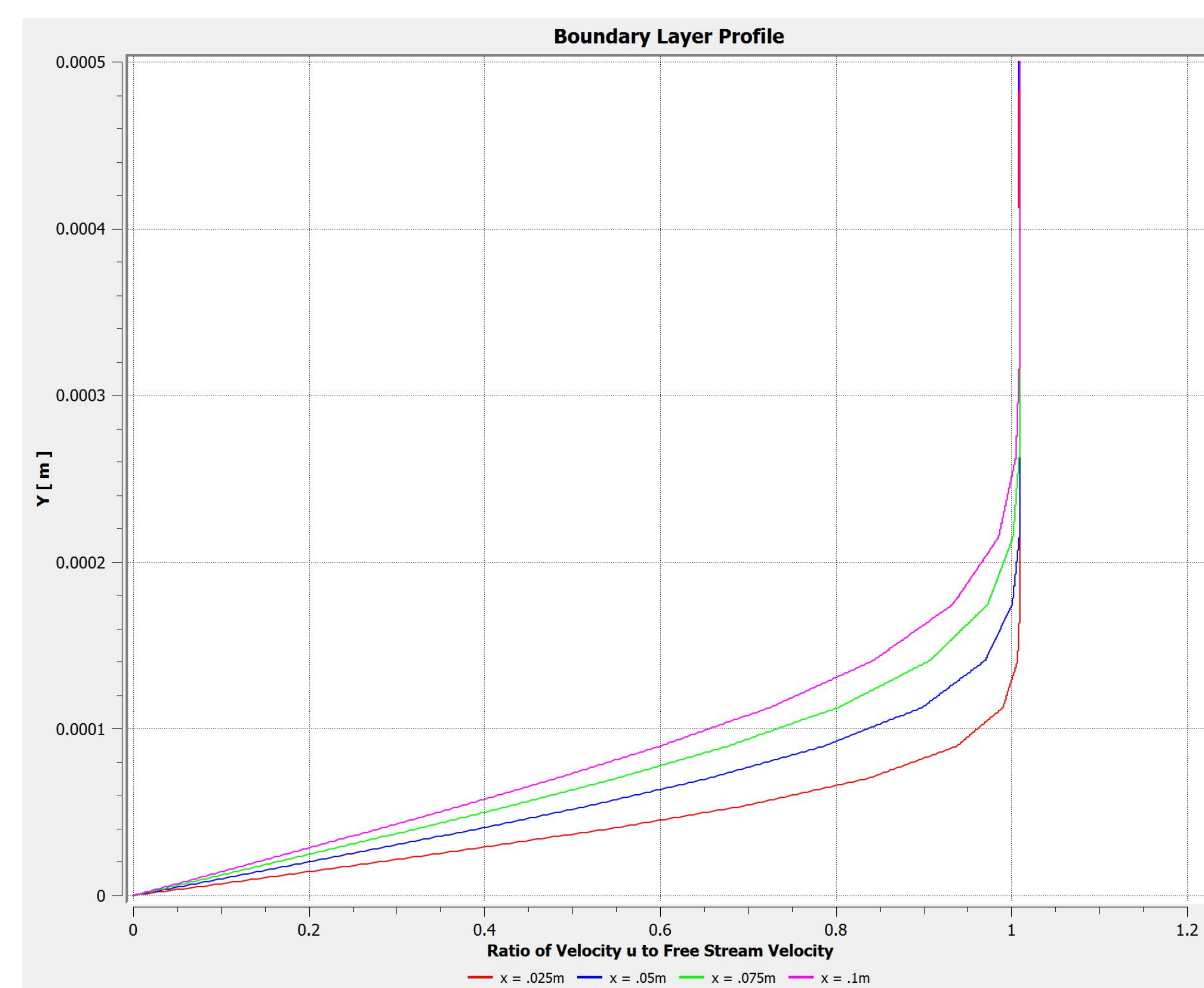


Figure 4: Flat plate boundary layer profile

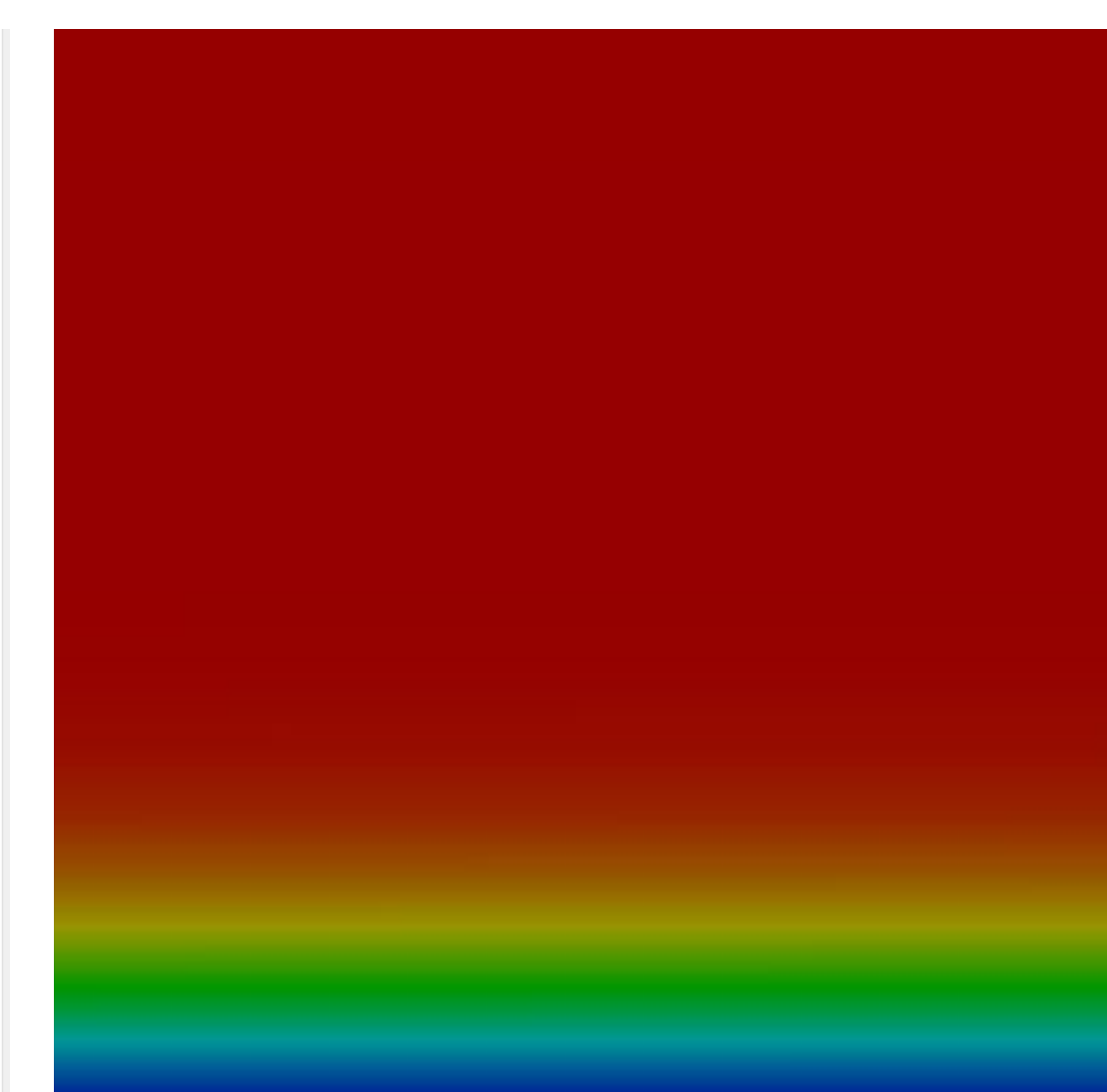


Figure 5: Velocity contour close-up of flat plate

Future Direction

The next steps involve resolving a boundary layer over the hemisphere itself. The results will be confirmed for accuracy using the boundary layer profile and comparing to the Blasius solution again.

References

- Principles of Fluid Dynamics: Blasius solution. Retrieved from <http://www.fluidynamics.it/capitoli/blas.pdf>.
- Bhaskaran, Rajesh (2020). Flat Plate Boundary Layer. Retrieved from <https://confluence.cornell.edu/pages/viewpage.action?pageId=90737911>.



RUTGERS