MAE 560 - Applied Computational Fluid Dynamics
Project #3
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By:
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Statement of Collaboration

Name of Collaborator: N/A	
Tasks(s)	**Contribution**
N/A	N/A

Task 1 - 2D Transient Simulation

For this task we will consider a 2-D flow passing a cylinder as illustrated in figure 1. For part a, the cylinder is circular with a diameter of 4cm. In part B, two more runs are performed but now the circular cross section is converted to an elliptical cylinder, for the first run of this task the major axis is perpendicular to the flow and for the second run the major axis is parallel to the flow. As defined by the project definition the major axis has a length of 5 cm. and 3 cm. for the minor axis. The computational domain as defined in figure 1 is 75 cm. long horizontally and 30 cm. high vertically.

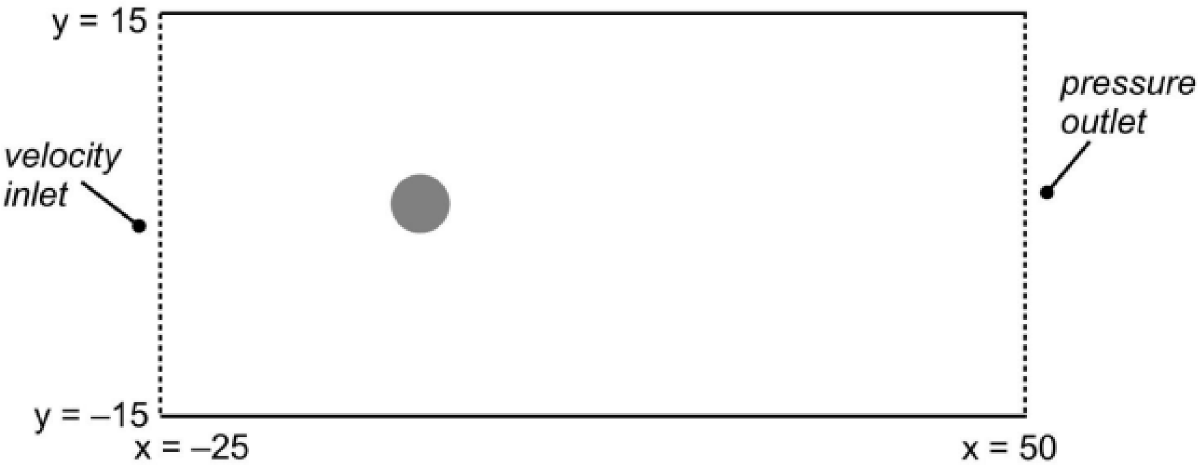

Fig. 1 - Computational Domain of task 1.

The left side of the domain is defined as a velocity inlet with x-velocity set to 2.5 cm/s and the right side is a pressure outlet with zero gauge pressure. The top and bottom are defined as walls and the system is filled with water as defined by the Fluent Database. This task was run till the simulation reached the 2 minutes mark in the transient domain.

<u>Deliverable 1:</u> An estimate of Reynolds number for this system.

The values of density and dynamic viscosity were determined from the fluent database.

$$Re = \rho * V * D/\mu$$
$$\rho = 998.2\ kg/m^3$$
$$\mu = 0.001003\ kg/(m * s)$$
$$V = 0.025\ m/s$$
$$D = 0.04\ m$$
$$Re = (998.2 * 0.025 * 0.04)/\ 0.001003$$
$$Re = 995.21$$

Deliverable 2: A description of the mesh resolution and time step size used for the simulation.

Element Size (m.)	Number of Elements
2.5e-3	35851

Table 1 - Description of mesh resolution.

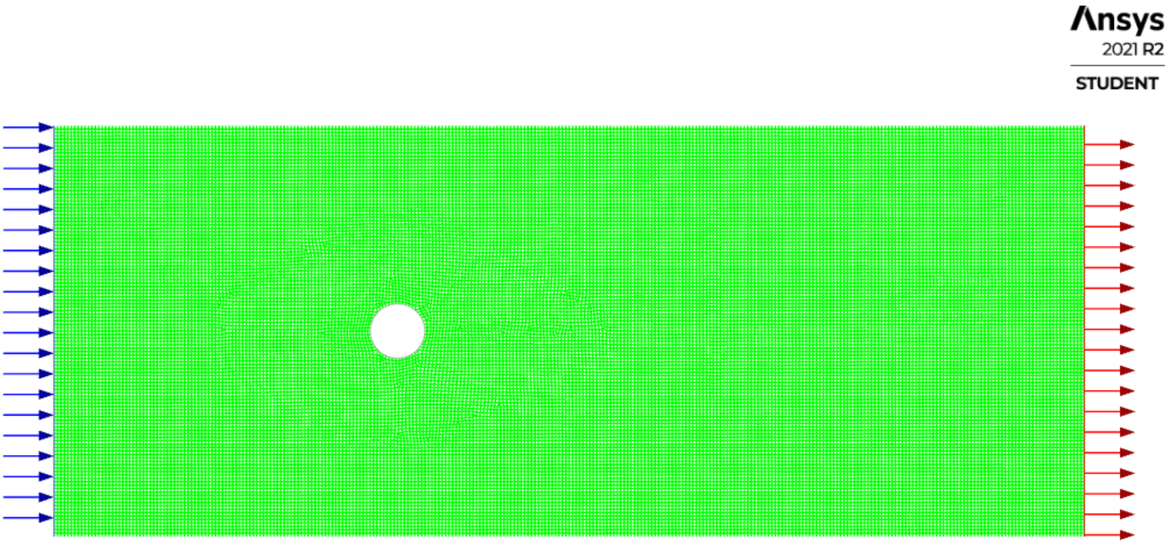

Fig. 2 - Mesh Definition.

Time Step (s)	Number of Time Steps	Max Iterations/ Time Step
0.12	1000	15

Table 2 - Transient Solution Parameters.

Deliverable 3: Contour plots of stream function and vorticity magnitude (not to be confused with velocity magnitude) at t = 2 min.

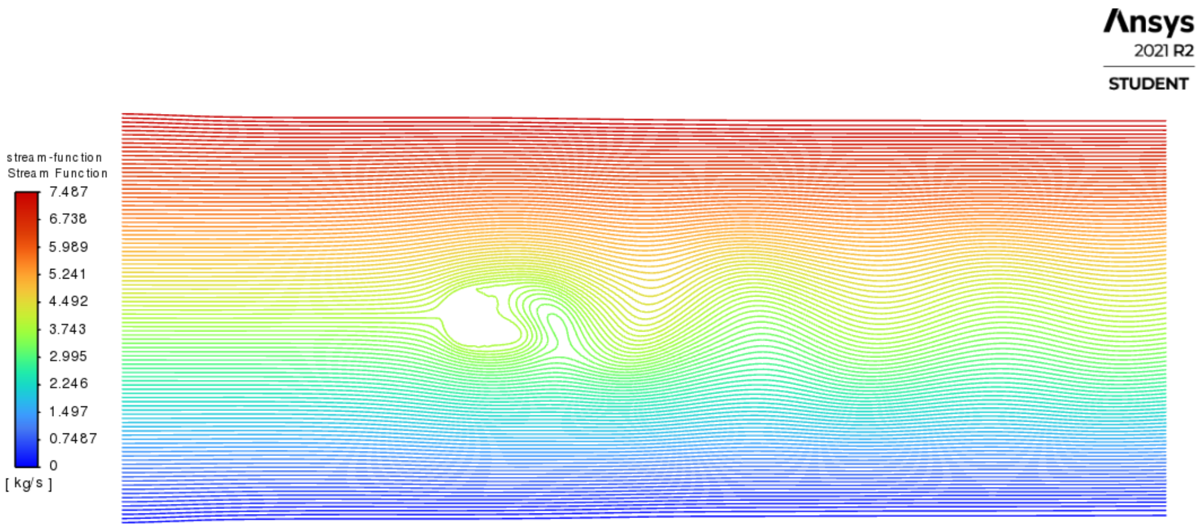

Fig. 3 - Stream Function at 2 minutes.

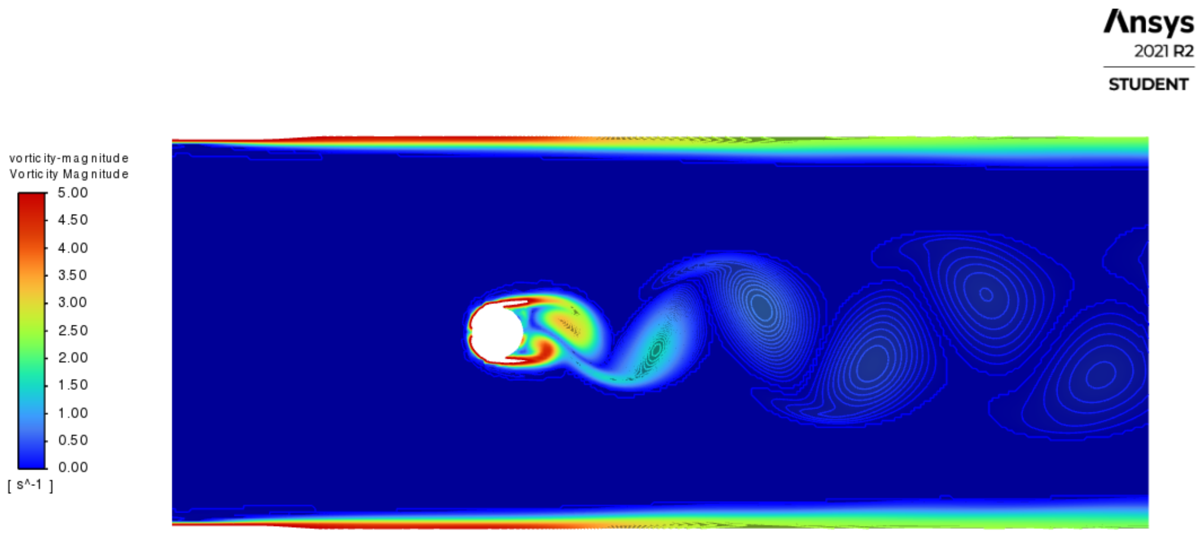

Fig. 4 - Vorticity Contour plot at 2 minutes.

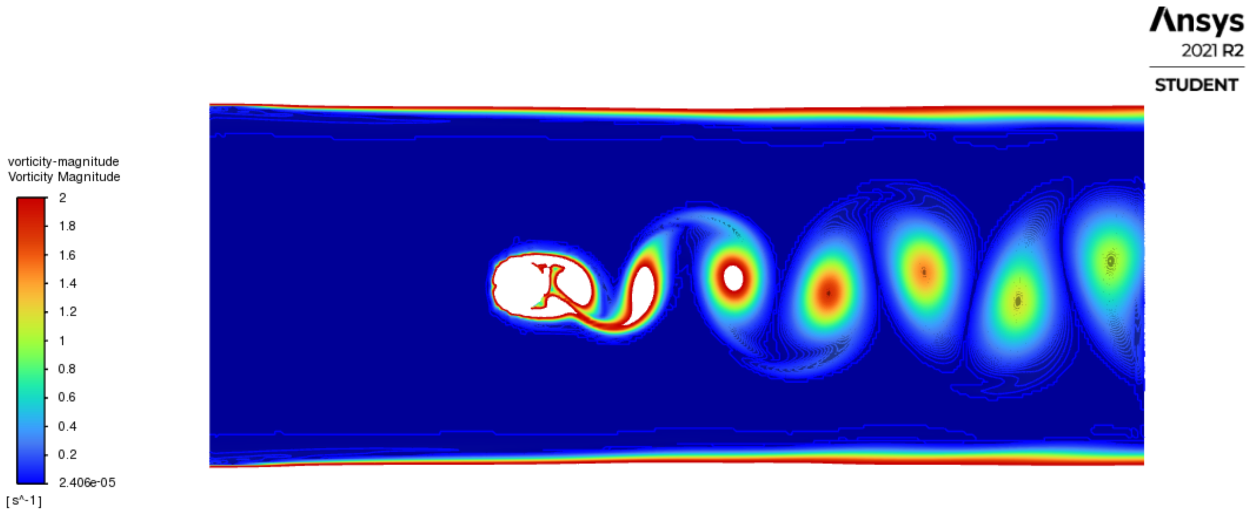

Fig. 4.1 - Vorticity Contour plot at 2 minutes (Refined Axis)

<u>Deliverable 4:</u> A plot of the lift force (that fluid exerts on the cylinder) as a function of time from t = 0 to t = 2 min.

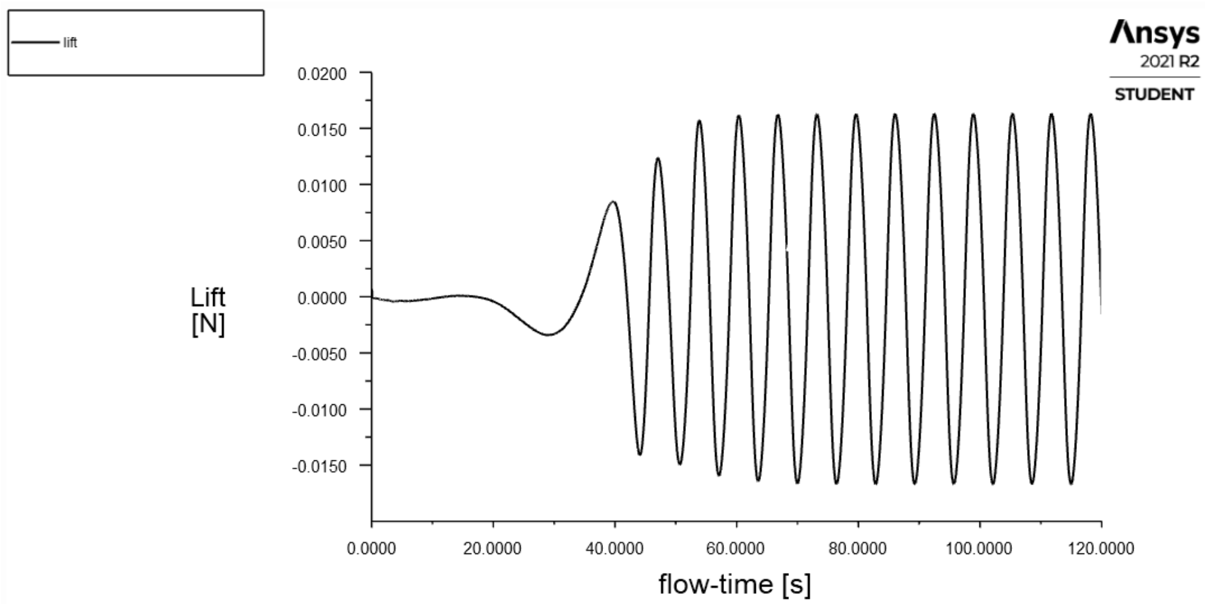

Fig. 5 - Lift Force plot vs. Flow time

Figure 5 shows the plot of lift force over the two simulated minutes. As predicted by the contour plots and the line plot the lift force is unsteady. The estimated amplitude of the lift force is close to **0.017 Newtons** and a period of **7 seconds**.

For the next part of the task, the elongated elliptical cross-sections were analyzed.

Deliverable 5: For each of Run 1 and Run 2, a plot of the lift force as a function of time from t = 0 to t = 2 min. From the plot, estimates of the amplitude and period of oscillation of the lift force.

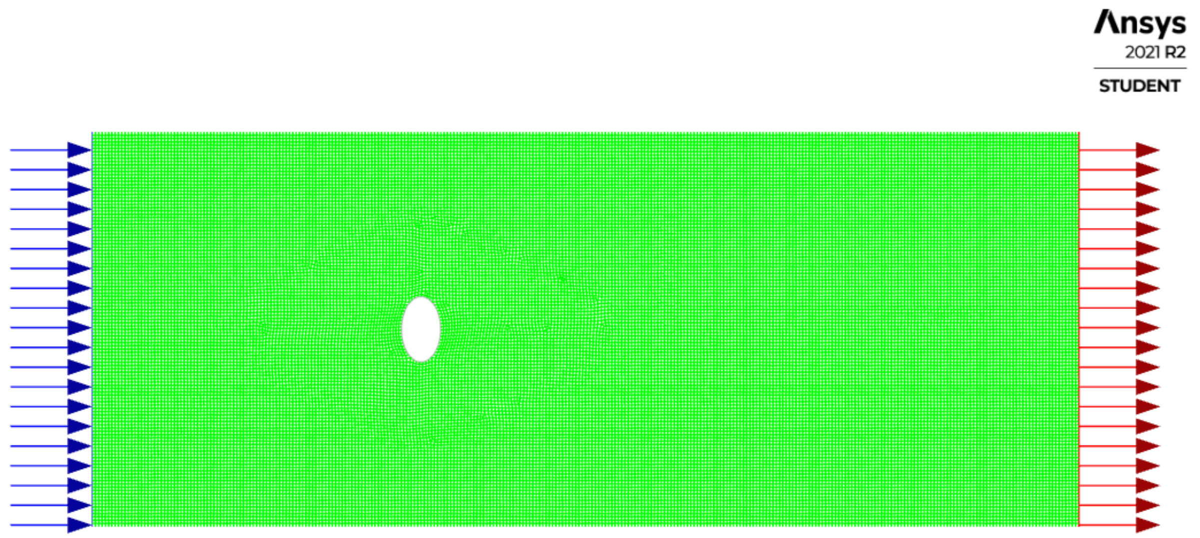

Fig. 6 - Setup for Cylinder perpendicular to air flow.

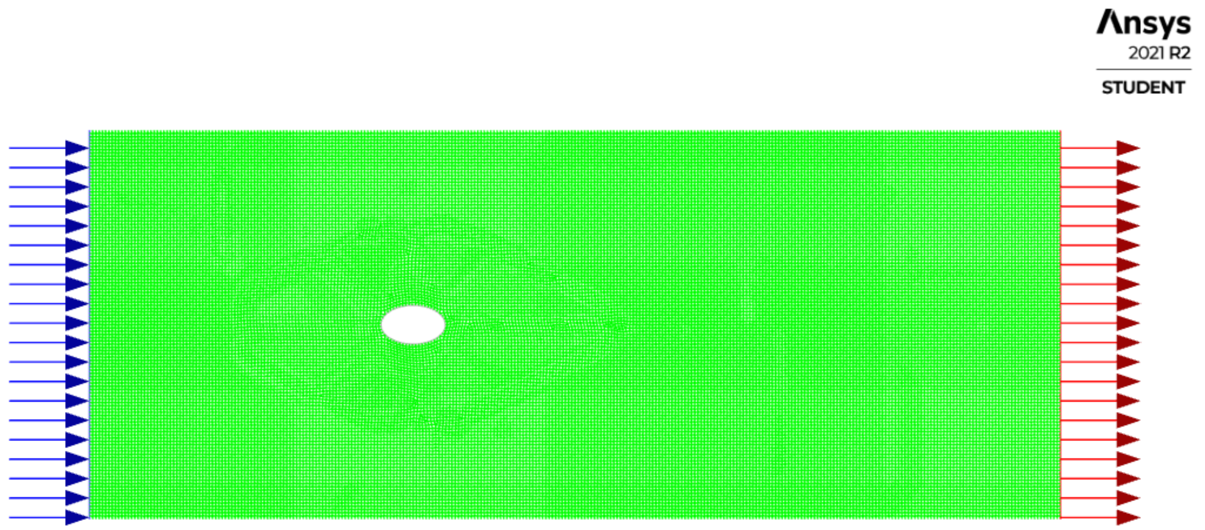

Fig. 7 - Setup for Cylinder parallel to air flow.

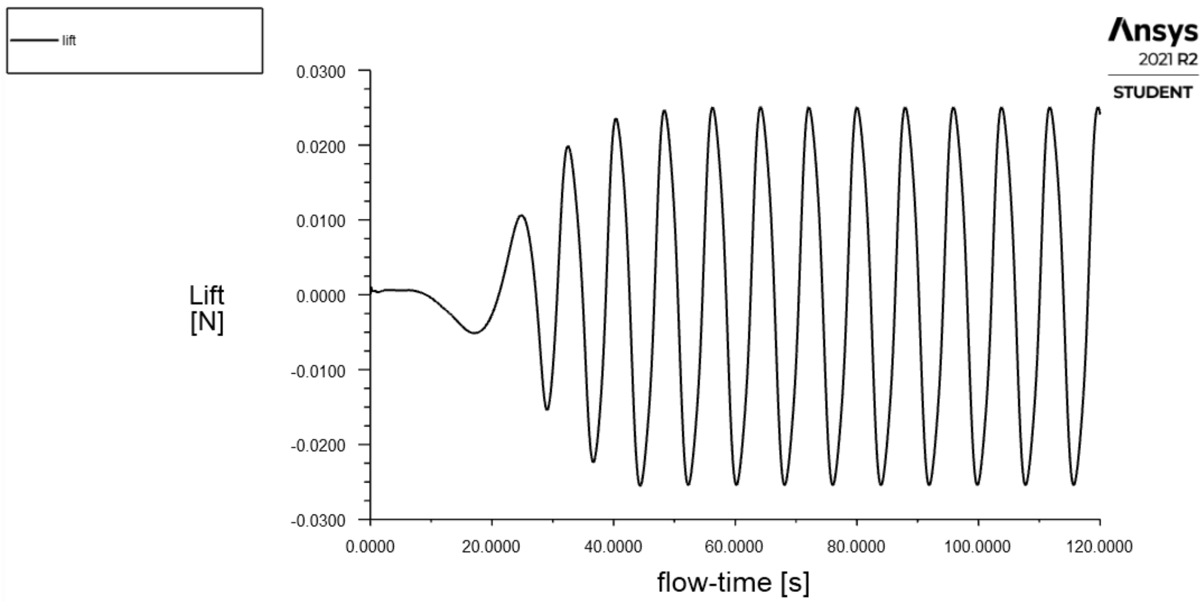

Fig. 8 - Lift force for the major axis perpendicular to air flow.

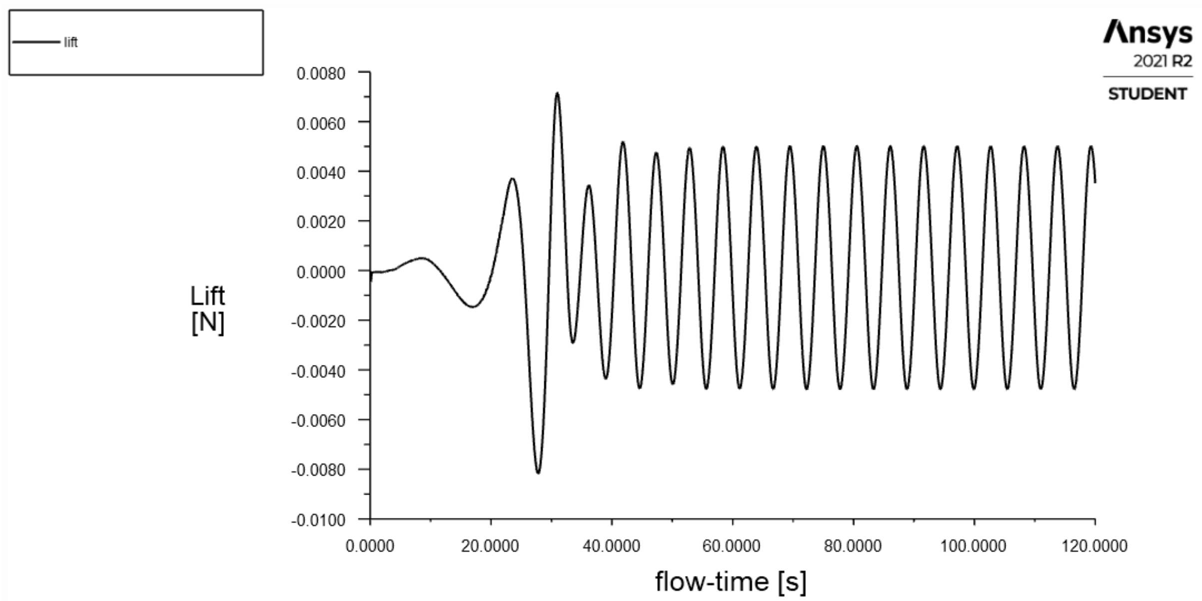

Fig. 9 - Lift Force for the major axis parallel to air flow.

	Run 1 (Circular)	Run 2 (y-elongated)	Run 3 (x-elongated)
Amplitude (N)	0.017	0.027	0.006
Period (Sec.)	7	7.5	6

Table 3 - Amplitude and Period of simulations (approximate values)

From the results we can conclude that the amplitude and period increases when the cylinder is elongated in the Y-direction and it decreases when it is elongated across the x-direction.

Task 2 - Flying Saucer Simulation

For this task the aerodynamics of a 3D flying saucer in a cylindrical virtual wind tunnel will be tested. The wind tunnel has a velocity inlet and a pressure outlet as shown in figure 10. The radius is dimensioned at 60 cm. and the length is 200 cm. The system is filled with air whose values are approximately similar to the middle troposphere. The inlet velocity was set to an axially-symmetric parabolic profile for the x-velocity, given by:

$$u = 60(1 - (r/0.6)^2)[m/s]$$

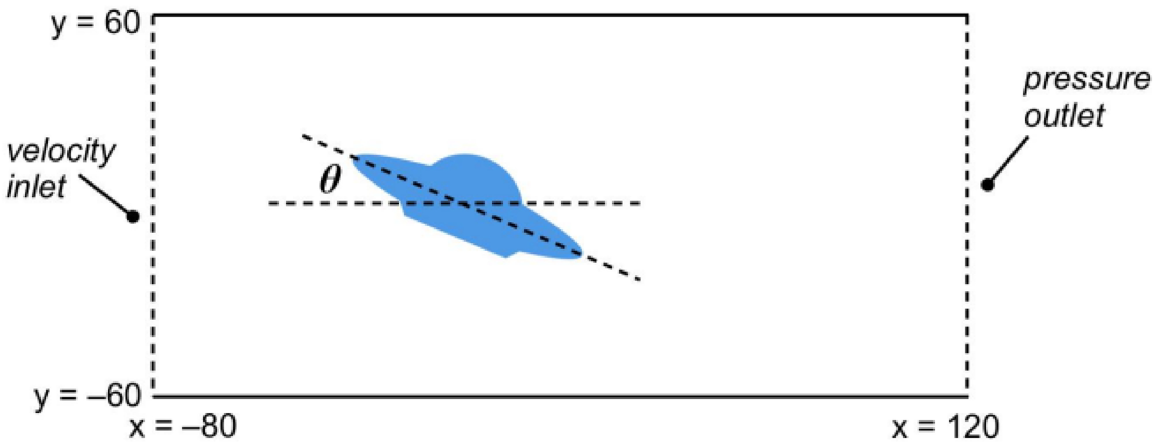

Fig. 10 - Computational Domain of task 2.

All simulations used a turbulence k-epsilon model, and seek steady state. Three runs were performed with a tilt angle of 0, 16 and 32 degrees.

<u>Deliverable 6:</u> A plot of the mesh along the plane of symmetry for the case with θ = 32°.

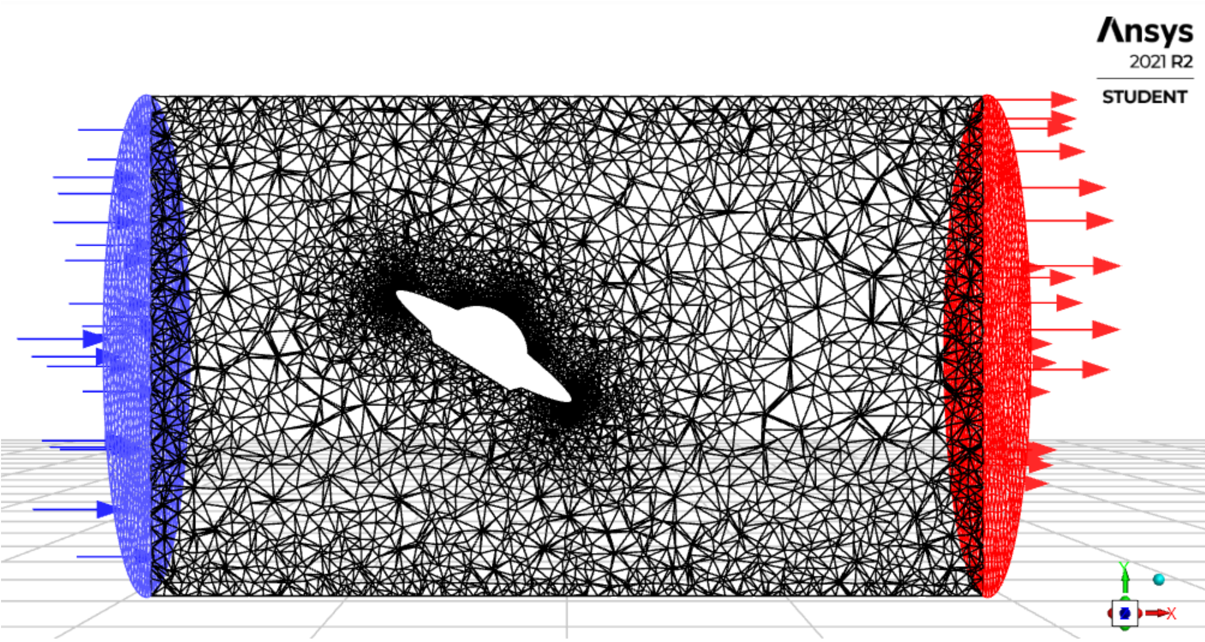

Fig. 11 - Mesh along the plane of symmetry.

Element Size (m.)	Number of Elements
4e-2	489297

Table 4 - Description of mesh resolution.

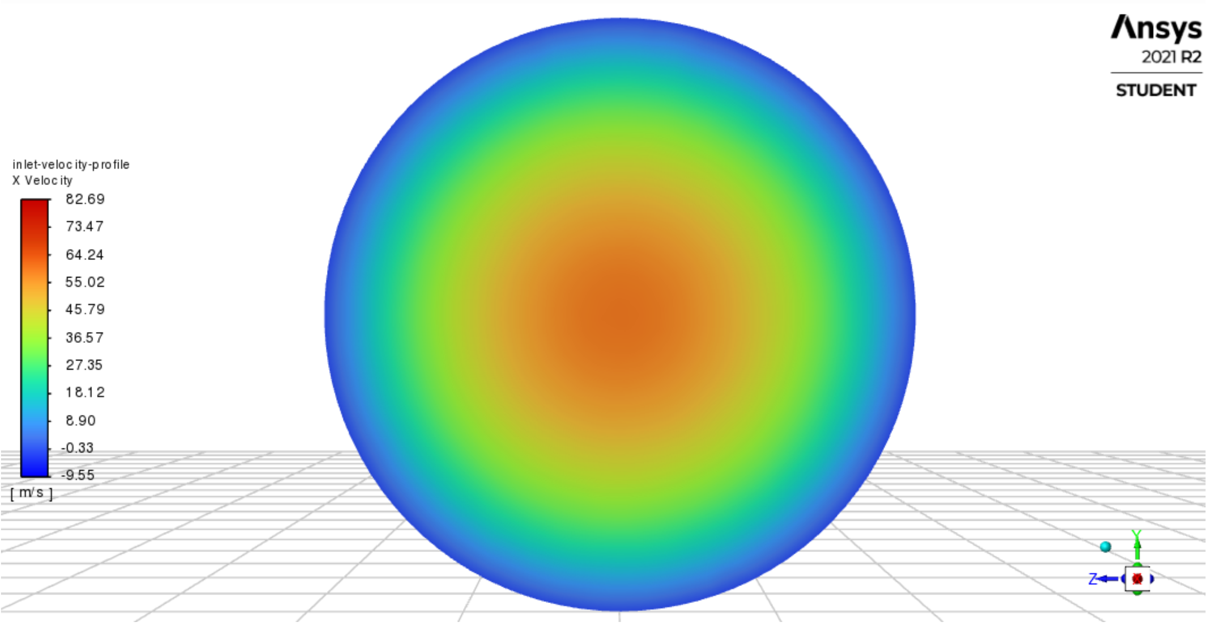

Fig. 12 - Inlet Velocity Profile.

<u>Deliverable 7:</u> Contour plots of x-velocity on the plane of symmetry for the three cases with θ = 0°, 16°, and 32°.

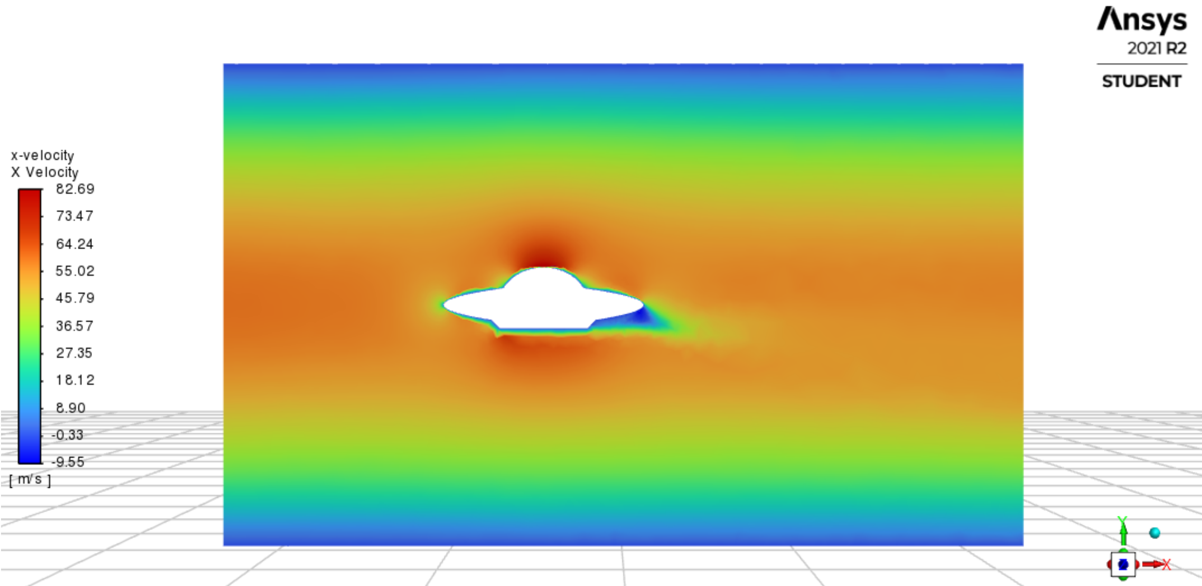

Fig. 13 - X velocity at 0 degrees.

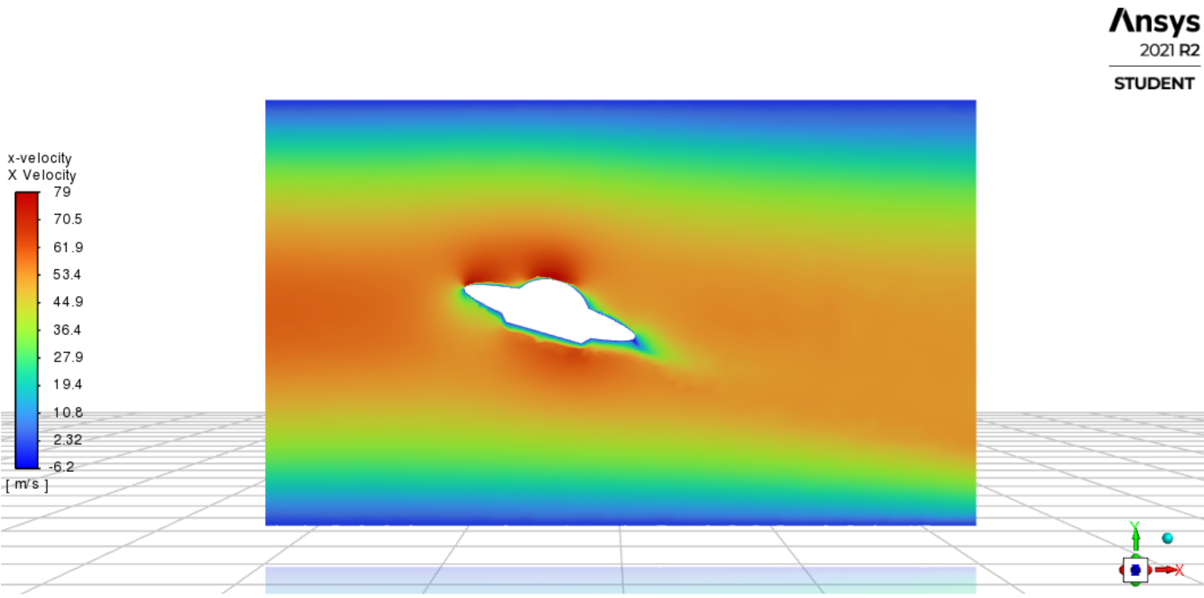

Fig. 14 - X velocity at 16 degrees.

For the 32 degrees simulation it is important to mention that it was noticed that initialization affects the final steady lift and drag. So for this case two simulations were run, one initialized with hybrid initialization which yields the same outcome as doing standard initialization with x velocity equal to 0 m/s and one with standard initialization and initial x velocity of 30 m/s.

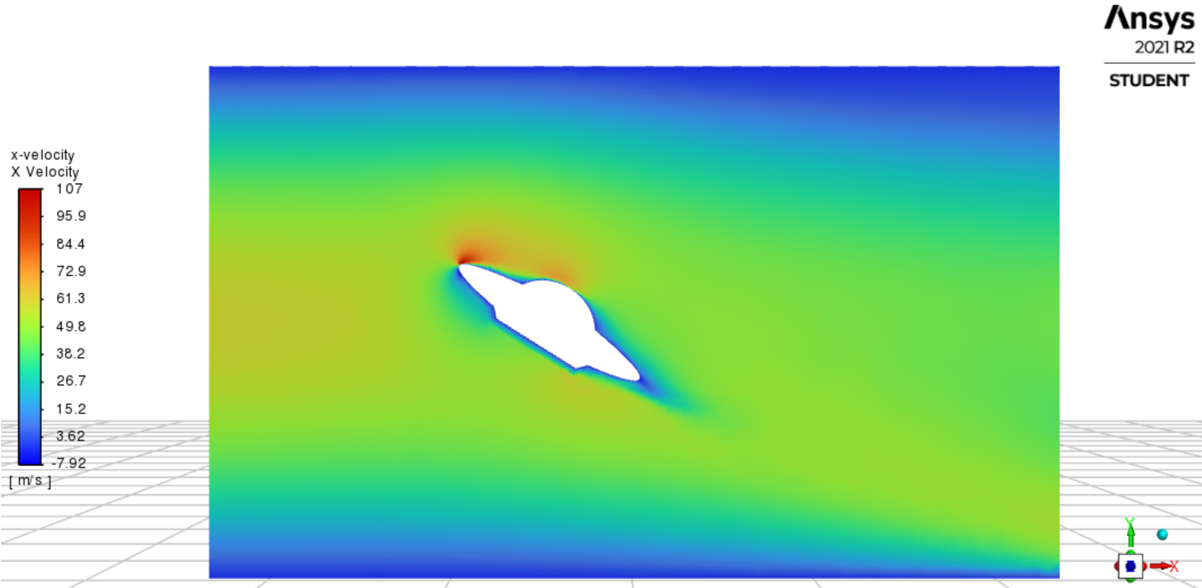

Fig. 15 - X velocity at 32 degrees - Hybrid Initialization.

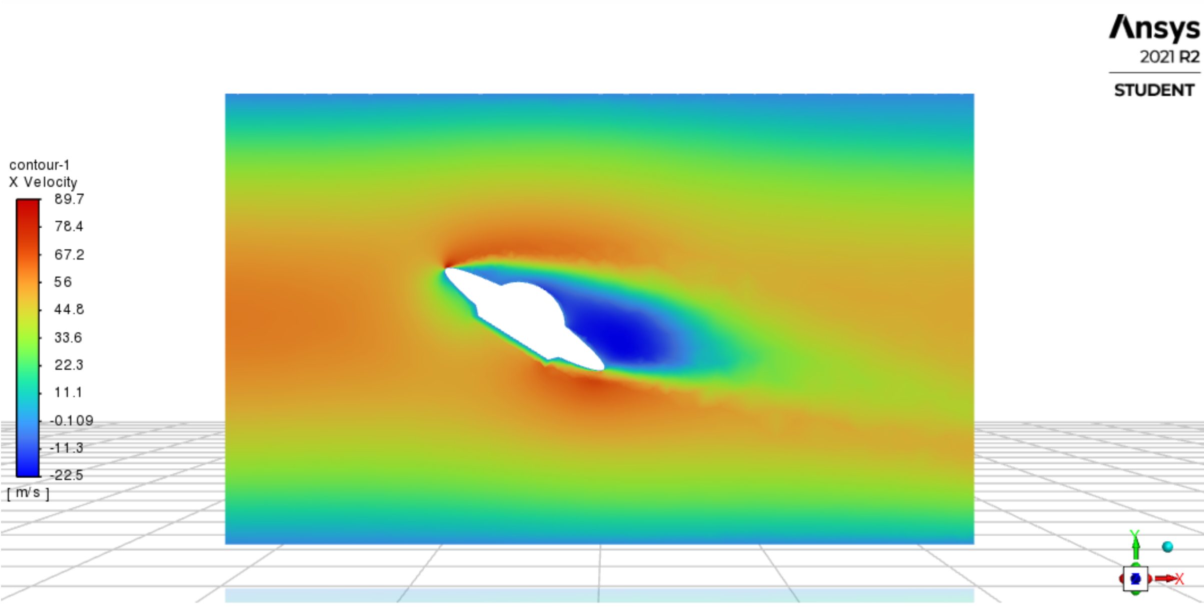

Fig. 15.1 - X Velocity at 32 degrees - Standard Initialization Xvel. = 30m/s

<u>Deliverable 8:</u> The values of lift force and drag force (that fluid exerts on the flying saucer) as a function of the tilt angle.

	Lift Force (N)	**Drag Force (N)**
0 Degrees	11.51	7.26
16 Degrees	69.48	18.96

32 Degrees	Hybrid Init.	150.48	63.76
	Standard Init.	48.5	49.23

Table 5 - Lift and Drag force for task 2.

Task 3 - 3D flow over a Pentagon-Shaped Building

In this task, the flow over a pentagon-shaped building was simulated in a virtual wind tunnel. The building geometry and computational domain is demonstrated in figure 16. The building is 2.5 meters tall and each side of the pentagon is 1 meter long. The left and right opening are set as velocity inlet and pressure outlet for run 1 and as pressure outlet and velocity inlet for run 2 respectively. The tunnel is filled with air with constant density and viscosity. The inlet velocity is set to a uniform 60 m/s.

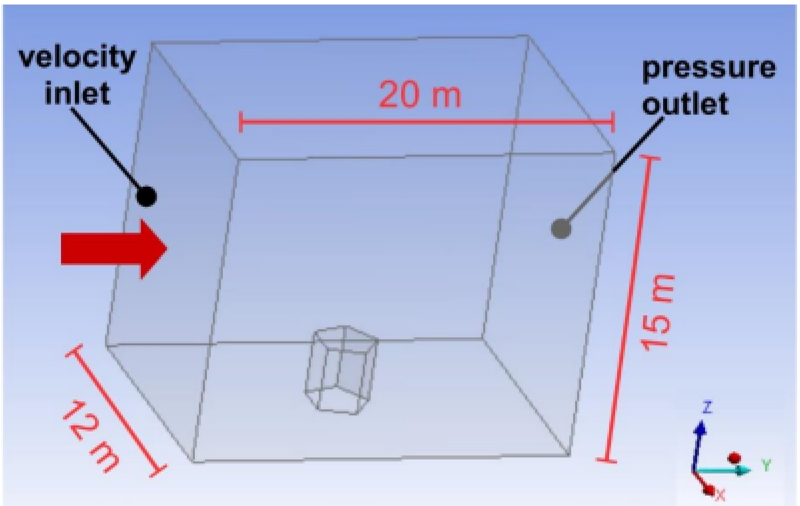

Fig. 16 - Computational domain and geometry.

Deliverable 9: For each of Run1 and Run 2, contour plots of static pressure and y-velocity on the horizontal plane with z = 1.25 m.

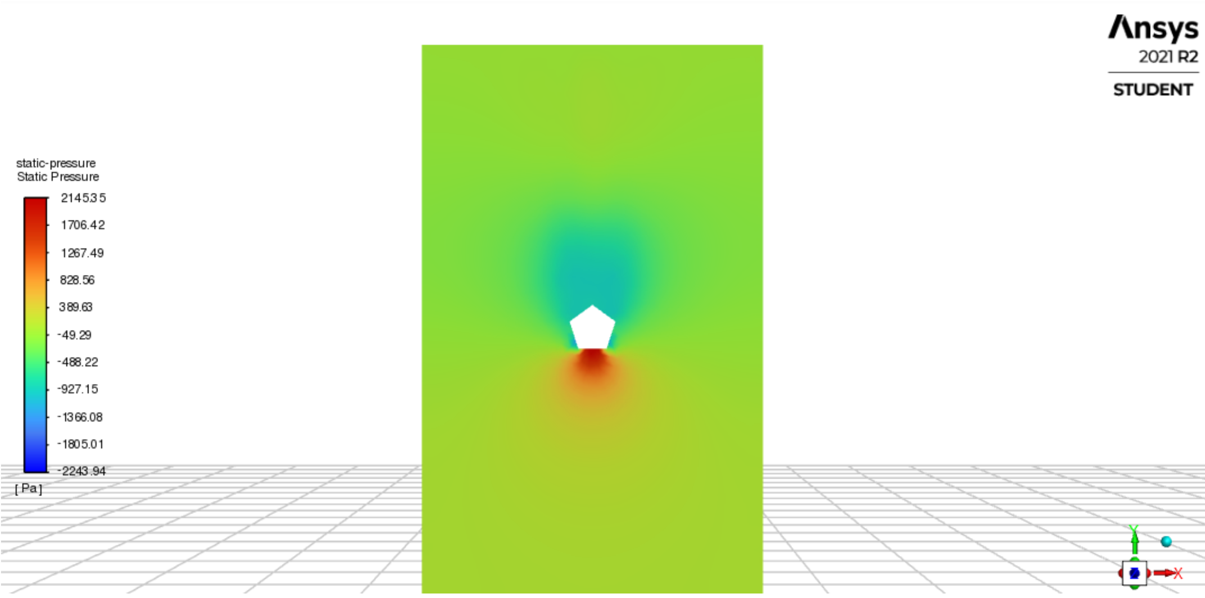

Fig. 17 - Static Pressure plot for Run 1.

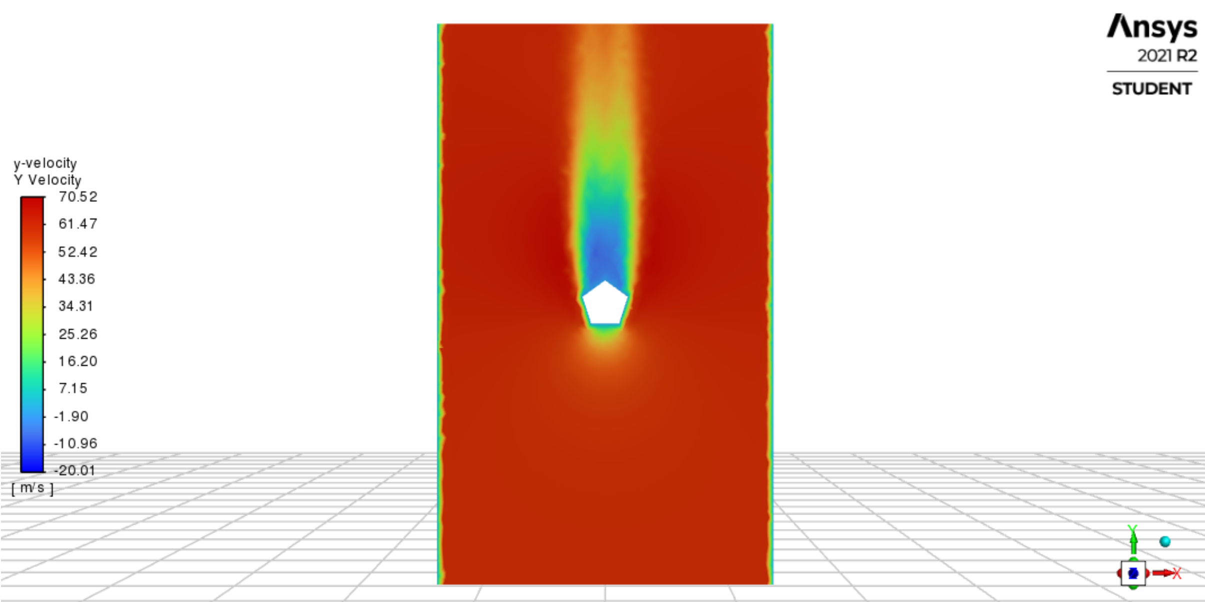

Fig. 18 - Y-Velocity plot for Run 1.

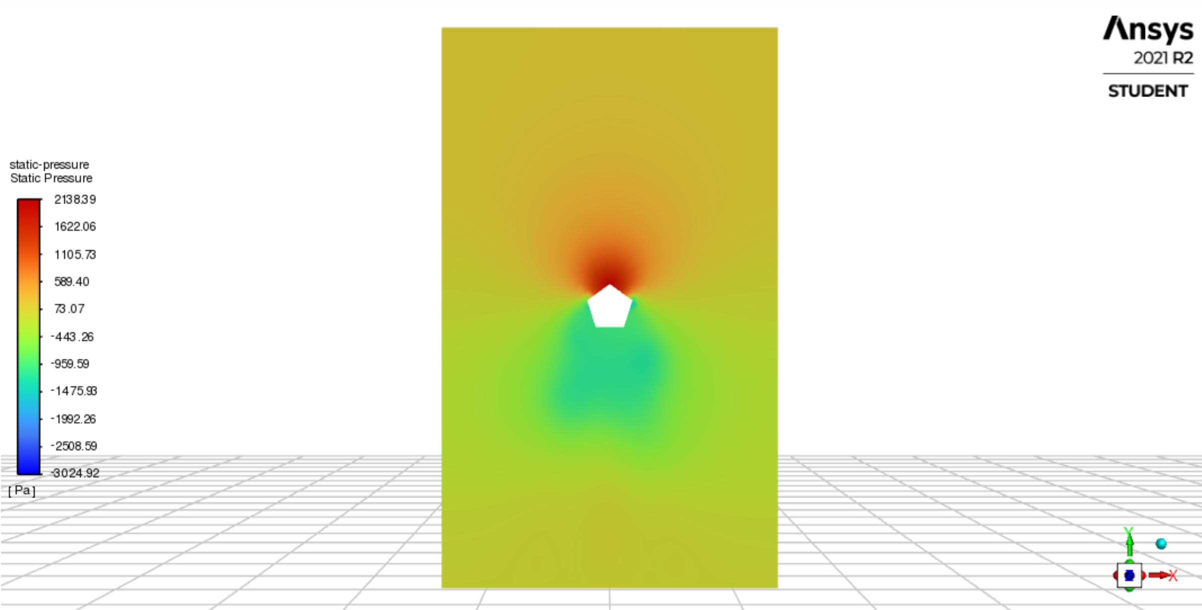

Fig. 19 - Static Pressure plot for Run 2.

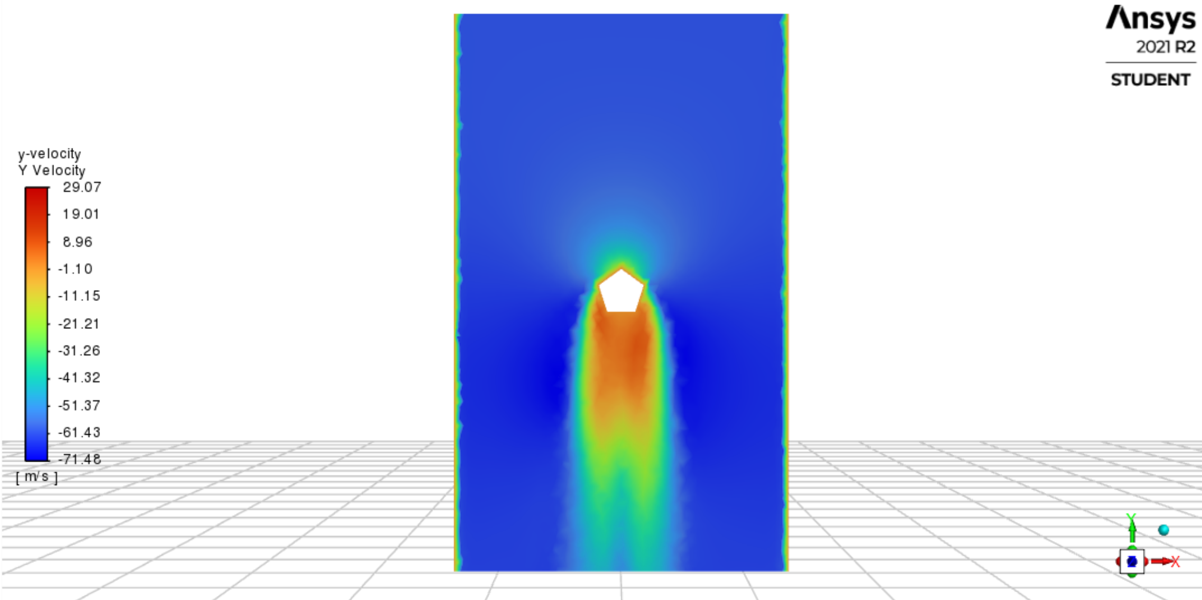

Fig. 20 - Y-Velocity plot for Run 2.
(Note the velocity is negative in this case due to the nature of the simulation)

<u>**Deliverable 10:**</u> For both runs, the values of total drag force (that fluid exerts on the building) and the individual contributions to the drag force from the pressure and viscous terms.

	Total Drag (N)	Pressure Term of Drag (N)	Viscous Term of Drag (N)
Run 1 (Flat Face)	6300.48	6281.96	18.52
Run 2 (Pointy)	9183.65	9179.13	4.52

Table 6 - Drag Terms.

Task 4 - Asymmetric forms of Cylinder.

In the 3rd video from lecture 21, it was mentioned that some asymmetric forms of cylinders are unstable, in that a flow passing the cylinder induces a large-amplitude response so as to damage the structure.using the setup from task 1, a transient simulation was runned but with an asymmetric shape. The goal is to demonstrate that a large-amplitude response in the lift as shown in the video can be produced by the numerical simulation.

<u>Run 1:</u>

For this run an asymmetric rectangle was sketched with similar dimensions as the circular cross-section. For this case the surface area of the domain is 2238.6 cm^2 and the circular cross section is 2237.4 cm^2 which means that they almost have the same cross-sectional area.

<u>Deliverable 11:</u> A plot of the geometry of your design of the asymmetric cylinder

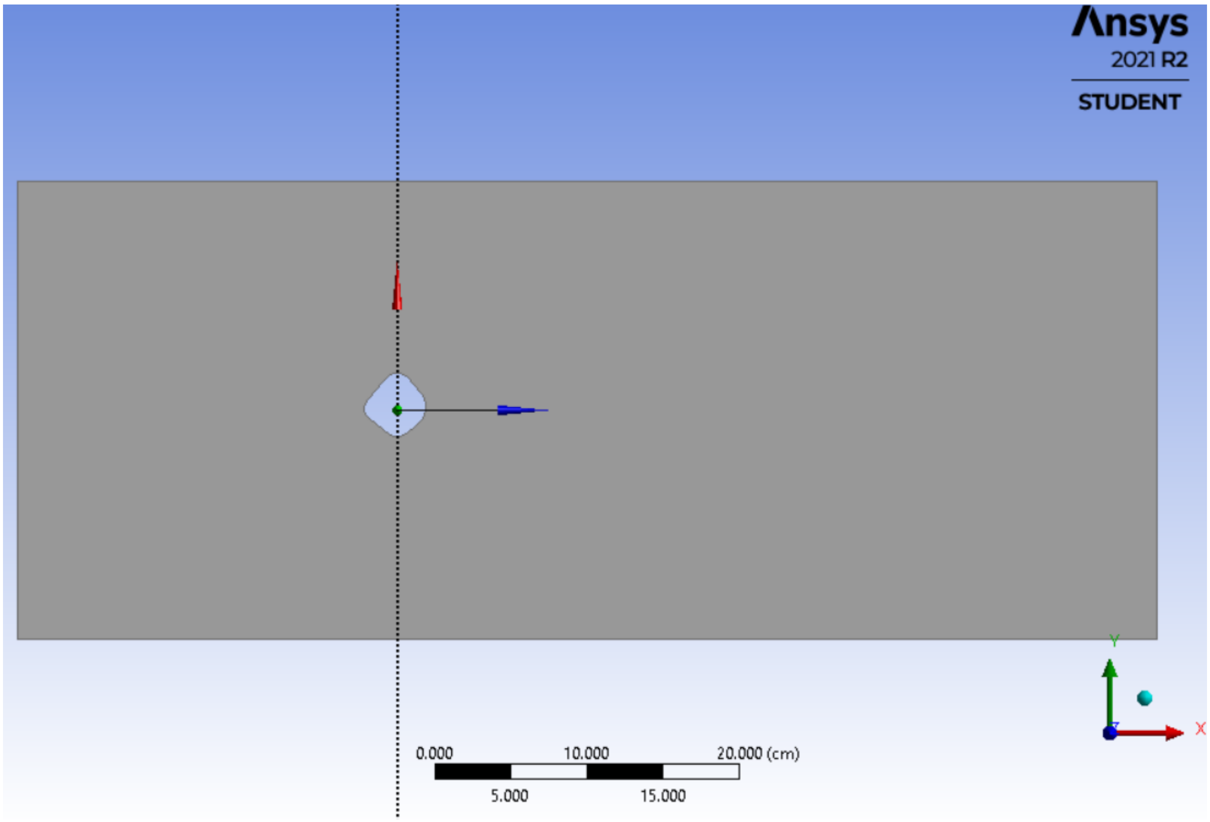

Fig. 21 - Geometry of Asymmetric Cylinder for run 1.

Deliverable 12: A plot of lift force vs. time from the transient simulation, similar to deliverable (D4) of Task 1a.

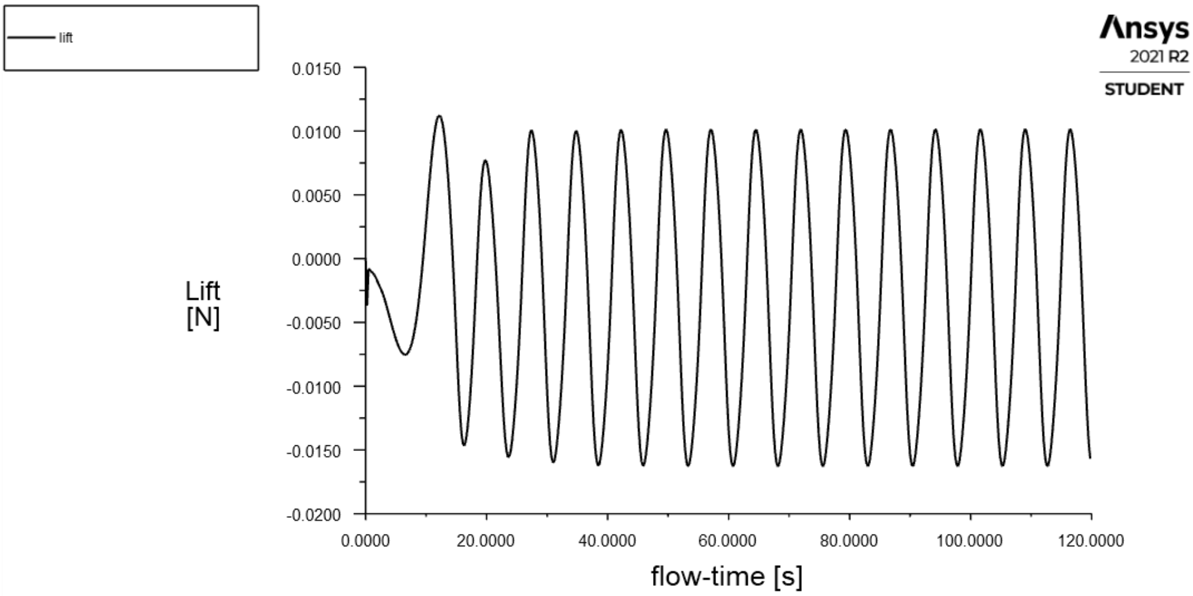

Fig. 22 - Plot of Lift force vs. time for run 1.

Run 2:

For this run an half moon shape was sketched with similar dimensions as the circular cross-section. For this case the surface area of the domain is 2233.4 cm^2 and the circular cross section is 2237.4 cm^2 which means that they almost have the same cross-sectional area.

Deliverable 11: A plot of the geometry of your design of the asymmetric cylinder

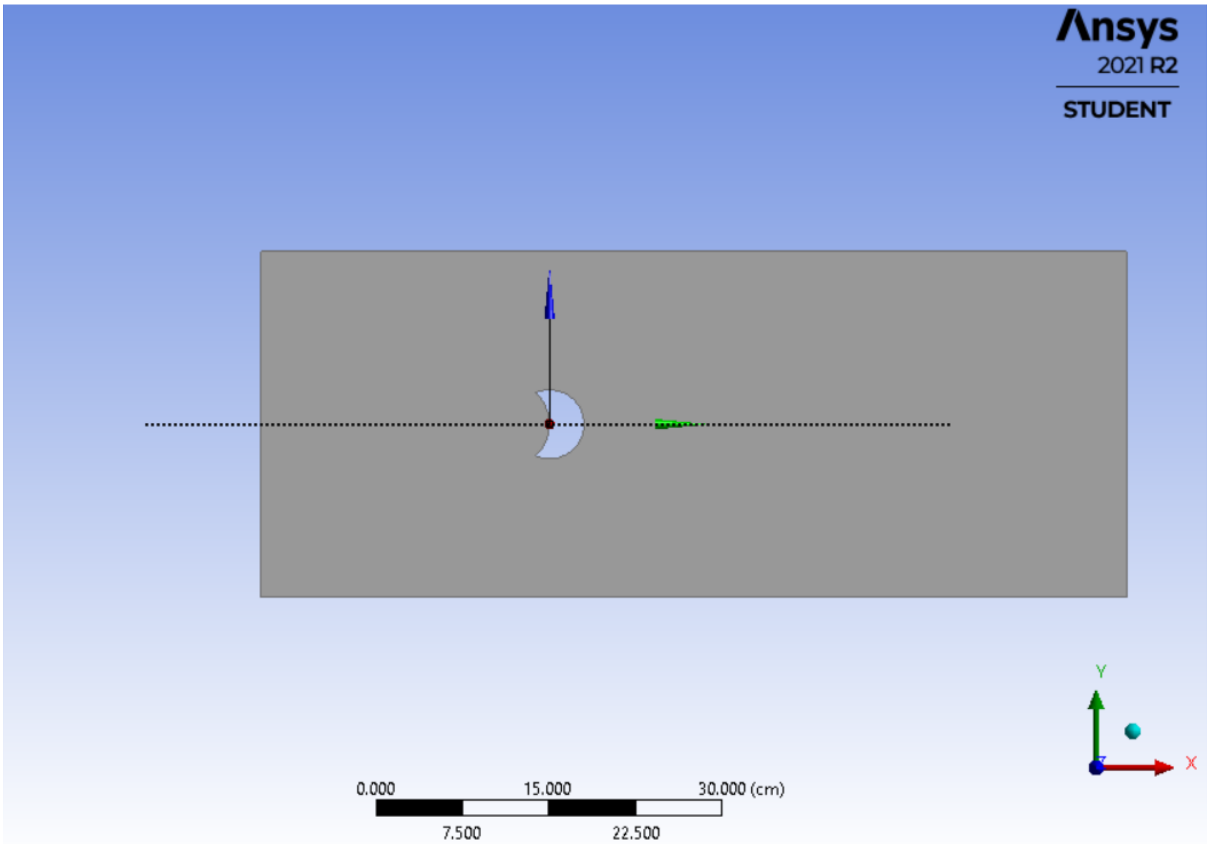

Fig. 23 - Geometry of Asymmetric Cylinder for run 2.

Deliverable 12: A plot of lift force vs. time from the transient simulation, similar to deliverable (D4) of Task 1a.

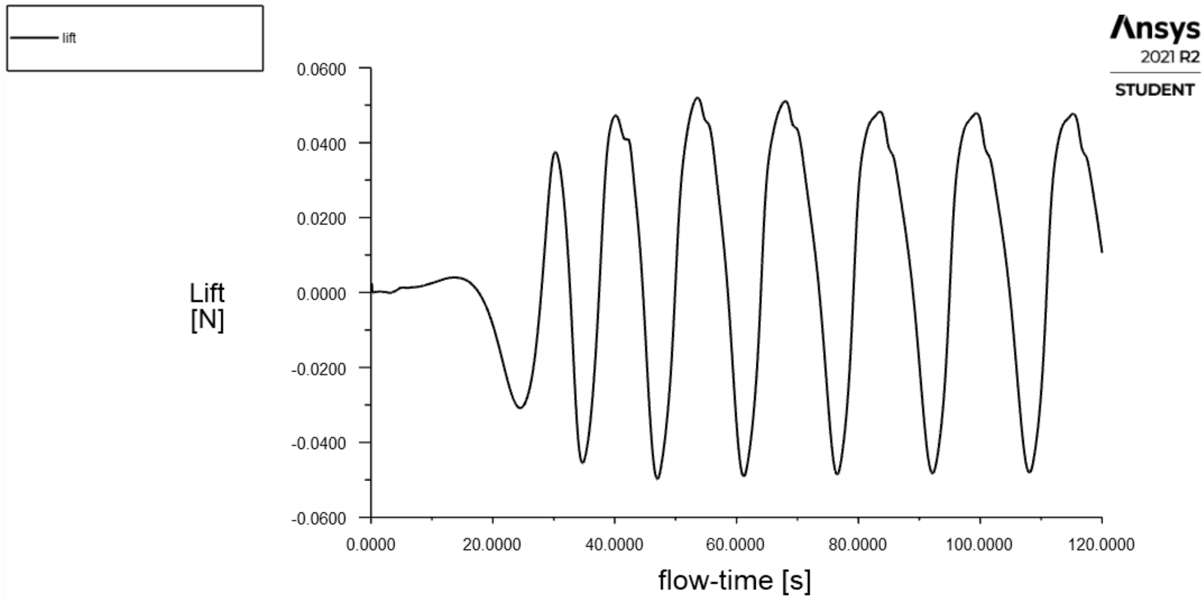

Fig. 24 - Plot of Lift force vs. time for run 2.

Run 3:

This run is to simulate the tacoma bridge collapse and understand how lift was affecting the structure overall. For this run the surface area of the new geometry is 2238.2 cm^2 which means it is similar to the circular cross section of 2238.6 cm^2.

Deliverable 11: A plot of the geometry of your design of the asymmetric cylinder

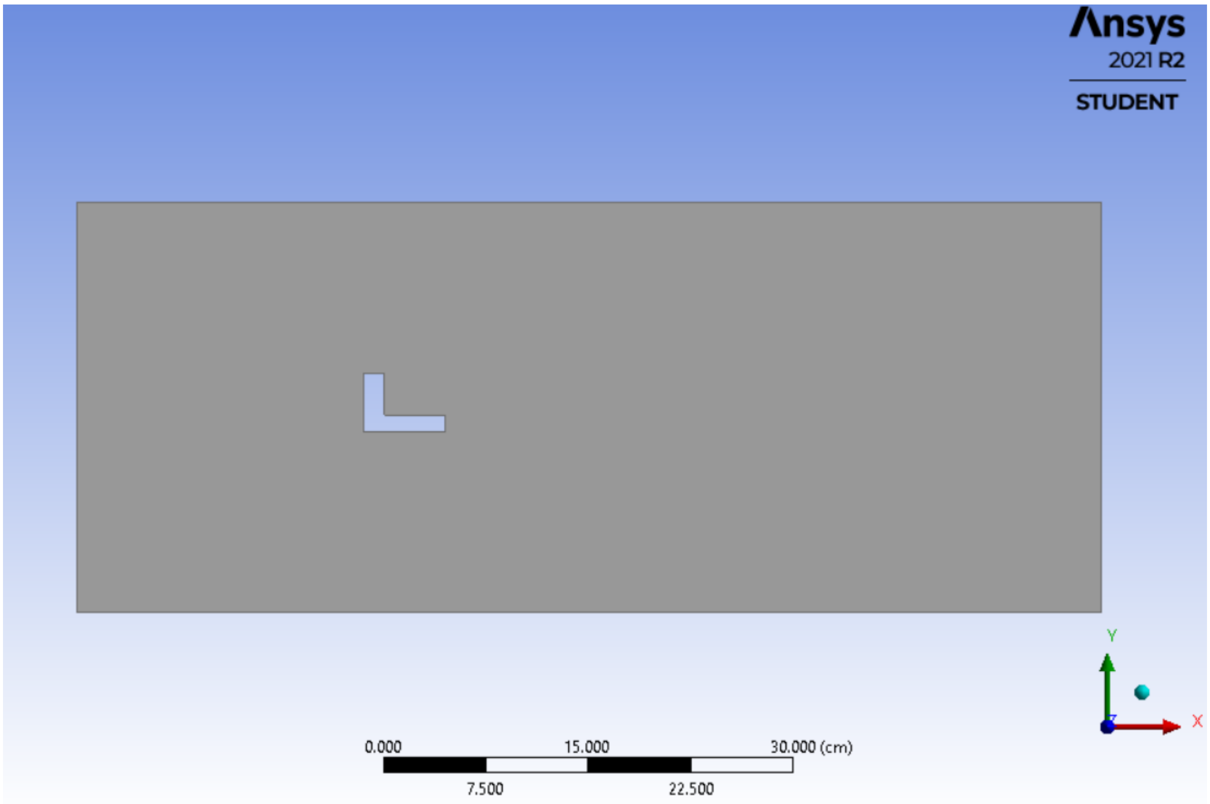

Fig. 23 - Geometry of Asymmetric Cylinder for run 3.

<u>Deliverable 12:</u> A plot of lift force vs. time from the transient simulation, similar to deliverable (D4) of Task 1a.

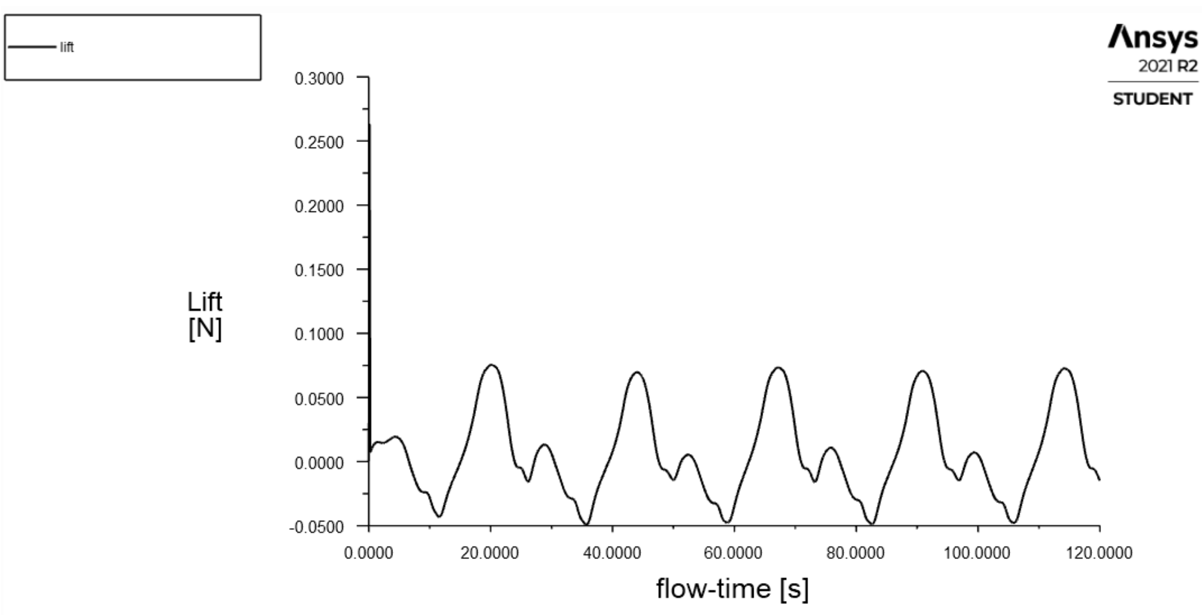

Fig. 24 - Plot of Lift force vs. time for run 3.