# MAE 560 – Applied CFD – Fall 2022

# Project 3 – External Flow


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## Statement of Collaboration

No collaboration.

# Task 1

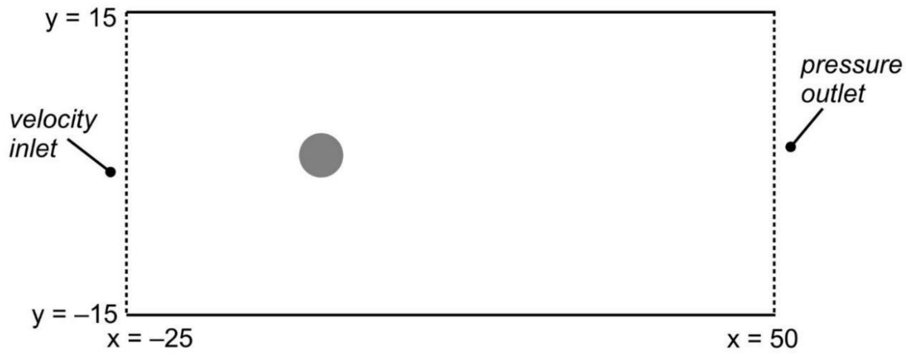


**Figure 1:** The geometry of the 2D cylinder and computational domain for Task 1a. (Not drawn to scale.) All numbers indicated in the diagram are in cm. The cylinder is centered at (0, 0), [1]

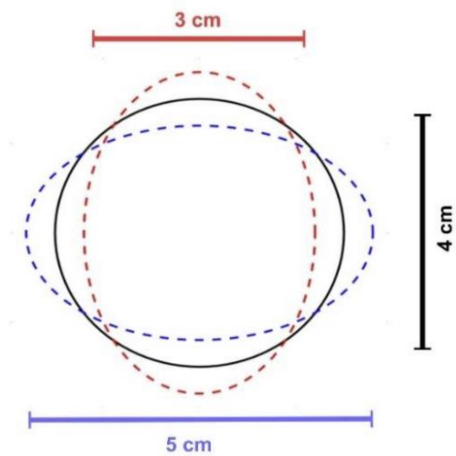


**Figure 2:** The shape of the elliptical object used in Task 1b. Black: circle from Task 1a. Red: ellipse elongated in y-direction for Run 1; Blue: ellipse elongated in x-direction for Run 2, [1]

**Objective:**

Simulate the 2D flow of diesel over different shaped beams: cylinder, and different ellipses.

**Instructions:**

a) Consider the system of a 2-D flow passing a cylinder as illustrated in Fig. 1. The 2-D cylinder, essentially a circular disk, is centered at (x, y) = (0, 0) with a diameter of 4 cm.

To perform the simulation using Ansys-Fluent, the cylinder is placed in a 2-D computational domain with its dimension (in cm) given in Fig 1. The left boundary is a velocity inlet with x-velocity set to 4 cm/s. (The x-direction is as indicated in Fig. 1.) The right boundary is a pressure outlet with zero-gauge pressure. Top and bottom are regular walls with no-slip boundary condition. The system is filled with liquid diesel ("diesel-liquid" in Fluent database) with constant density and viscosity, using the default values from Fluent database. At t = 0, the system is initialized with x-velocity = 0, y-velocity = 0, and gauge pressure = 0 within the domain. This task uses Laminar model to run a transient simulation to at least t = 1 minute.

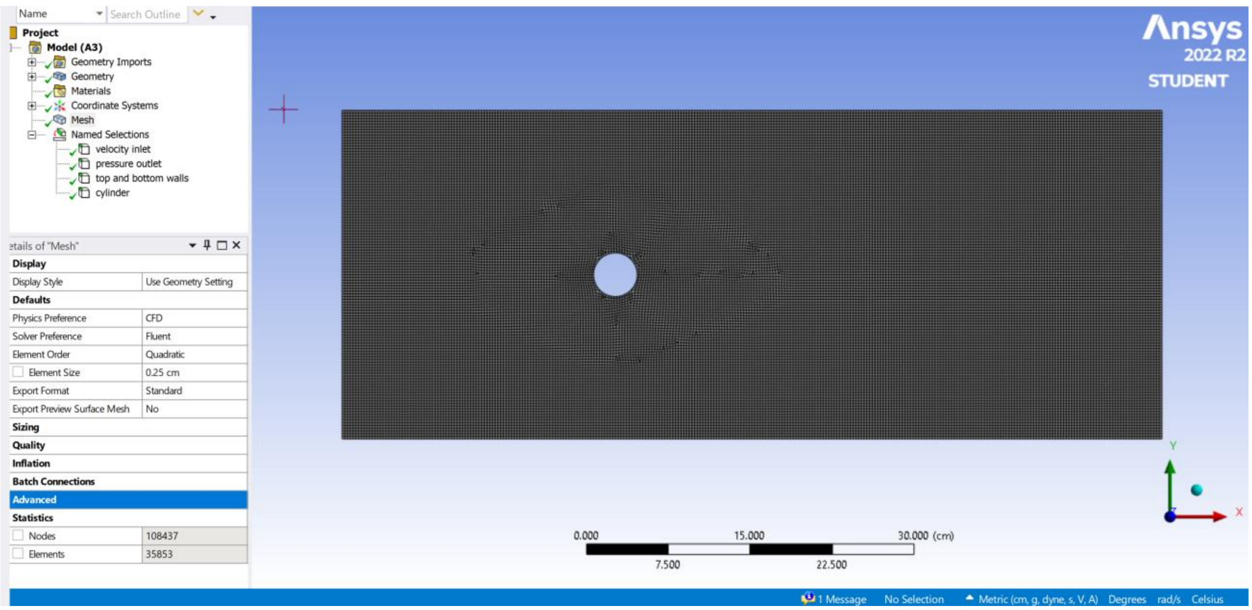


**Figure 3:** Mesh of Task 1 a) with the circular cylinder

b) Use the same setting as (a) to perform two additional simulations with elliptical instead of circular cylinders. Run 1 uses an ellipse elongated in y-direction, with the lengths of its major and minor axes 5 cm and 3 cm (the major axis is parallel to y-axis), as illustrated by the red dashed curve in Fig. 2. Run 2 uses an ellipse elongated in x-direction, with the lengths of its major and minor axes 5 cm and 3 cm, as illustrated by the blue dashed curve in Fig. 2.

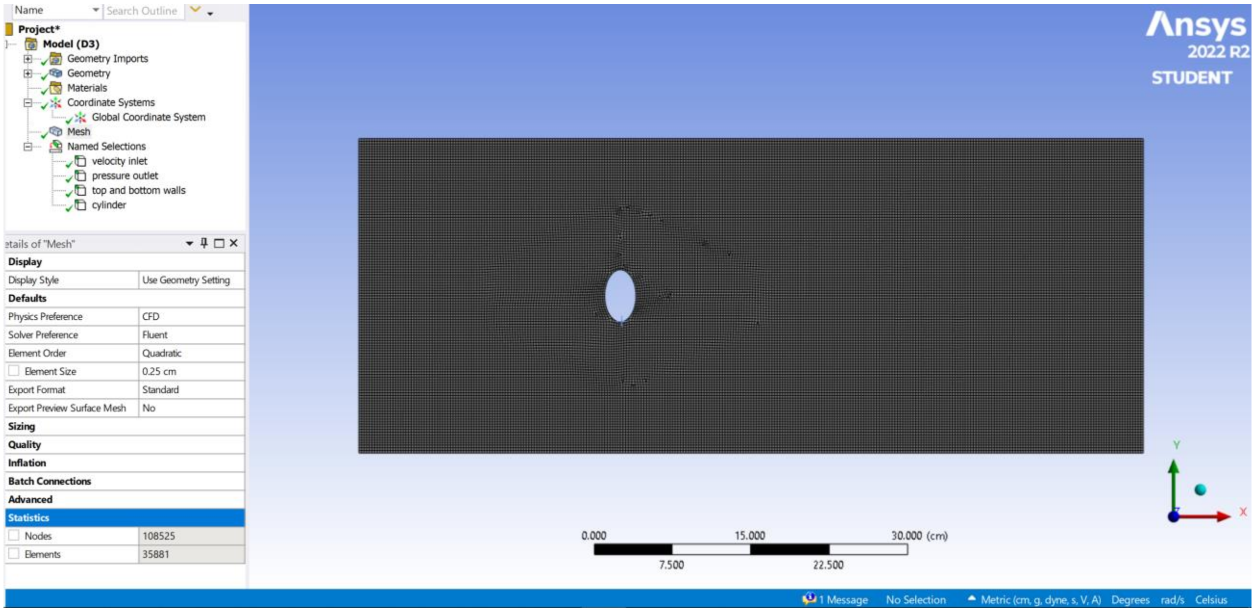

**Figure 4:** Mesh of Task 1 b) with the run 1 of the elliptical cylinder

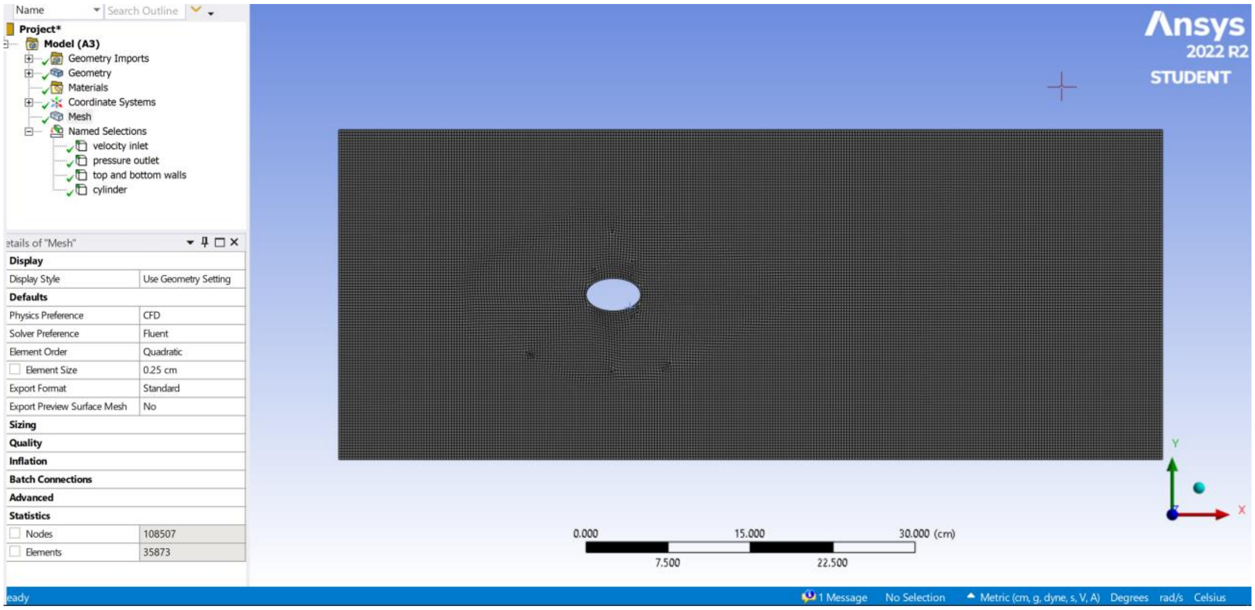

**Figure 5:** Mesh of Task 1 b) with the run 2 of the elliptical cylinder

**(D1)**

For all runs, a mesh element size of 0.25 cm was chosen, a step size of 0.025s, and the standard 20 maximum number of iterations per time step. The Reynold’s number was calculated to be:

$$Re = \frac{UL}{\nu} = \frac{UL\rho}{\mu} = \frac{\left(0.04\frac{m}{s}\right)(0.04m)\left(730\frac{kg}{m^3}\right)}{0.0024\frac{kg}{m\,s}}$$

$$\boxed{Re = 486.7}$$

**(D2)**

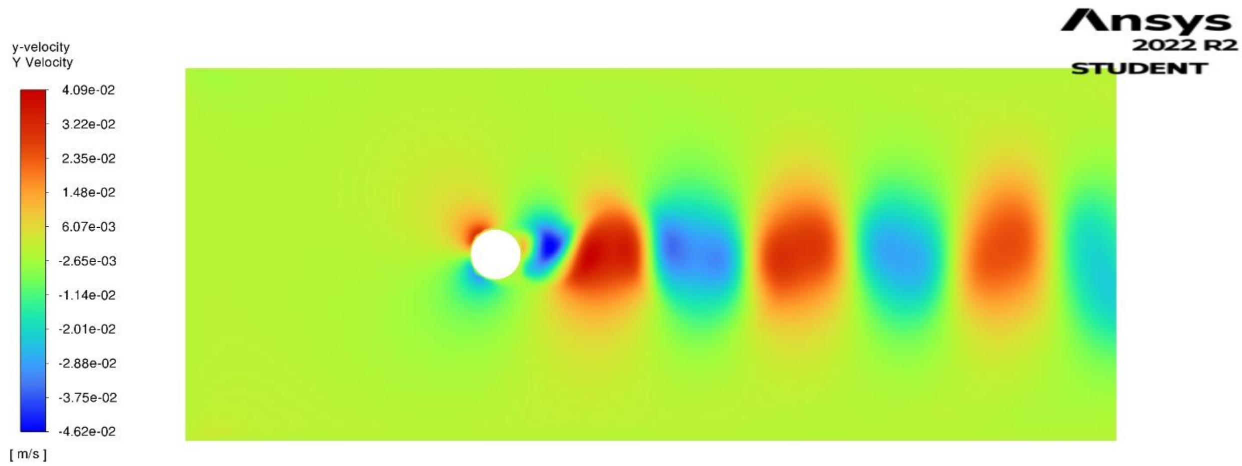


**Figure 6:** Contour plot of y-velocity of liquid diesel over the circular cylinder at t = 1 min (D2)

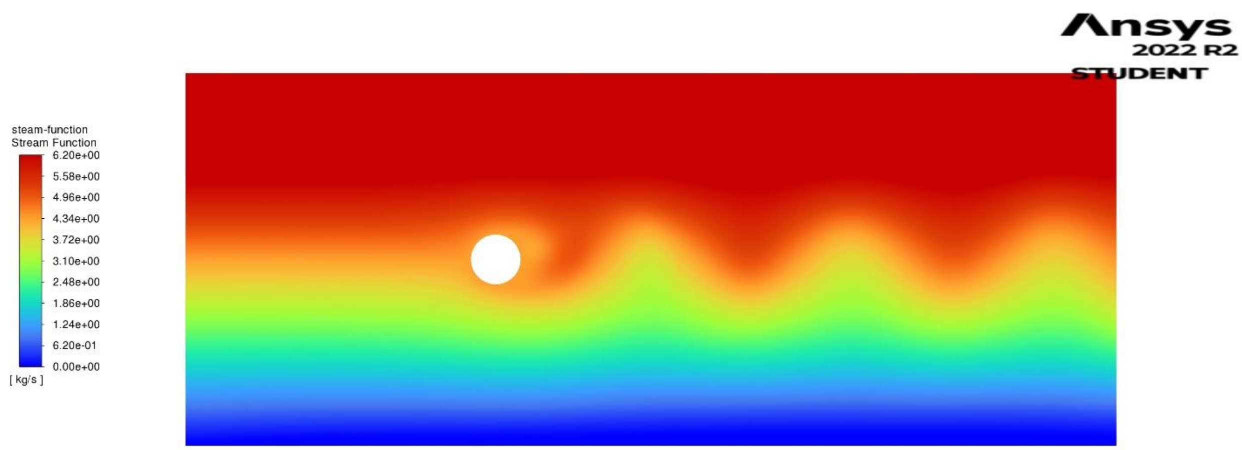


**Figure 7:** Contour plot of the stream function of liquid diesel over the circular cylinder at t = 1 min (D2)

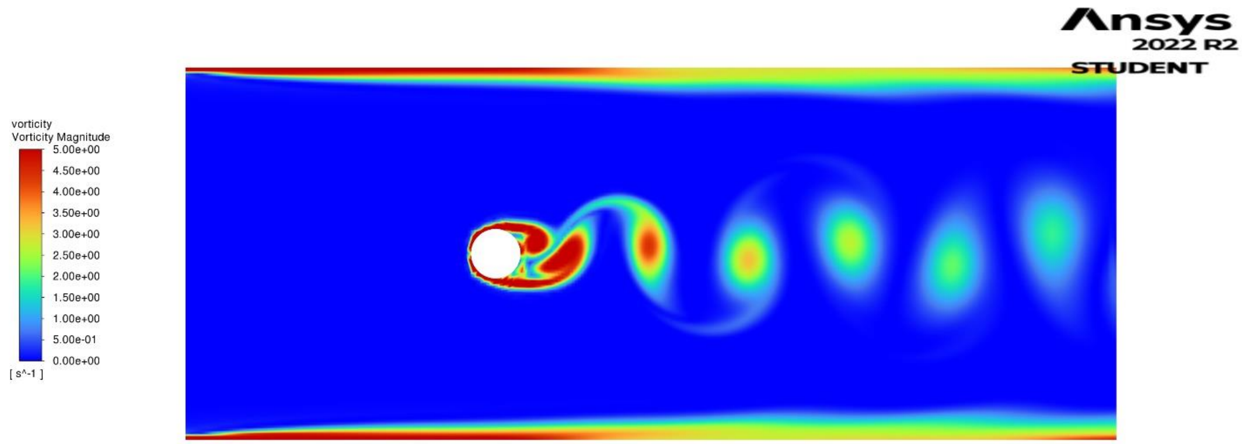


**Figure 8:** Contour plot of the vorticity magnitude of liquid diesel over the circular cylinder at t = 1 min (D2)

**(D3)**

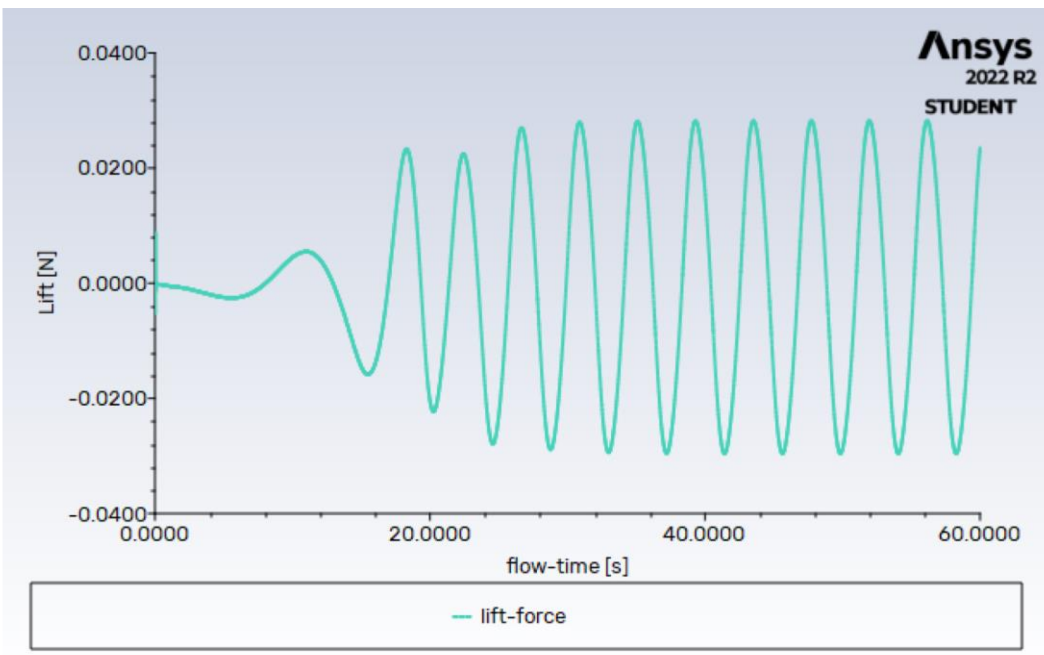


**Figure 9: P**lot of the lift force (N) on the circular cylinder vs. time (s) from t = 0s to 1 min (D3)

**(D4)**

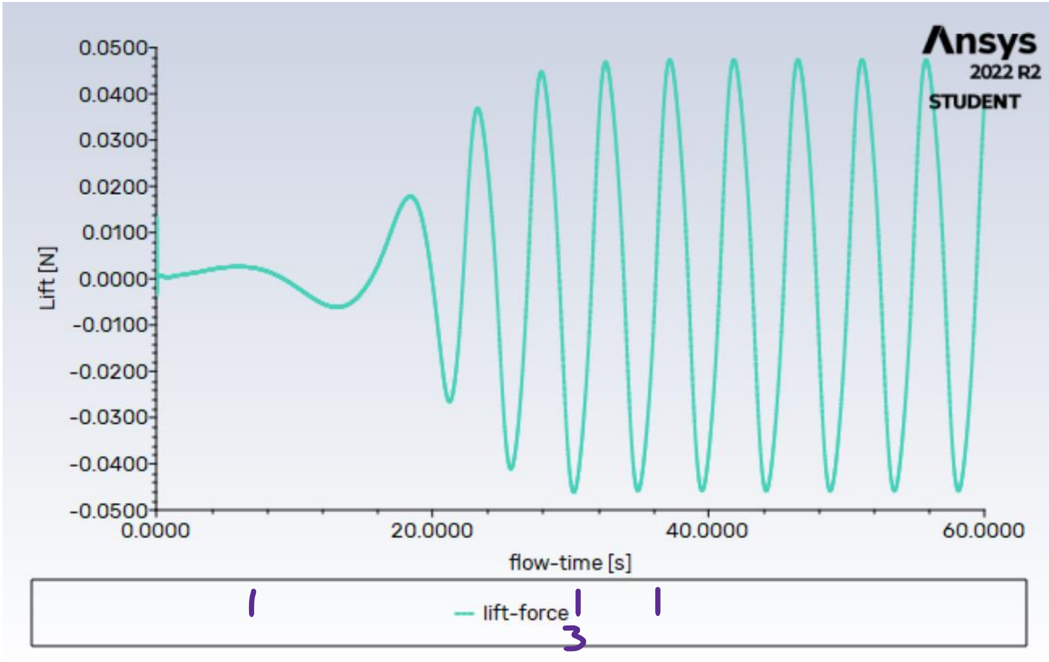


**Figure 10: P**lot of the lift force (N) on the elliptical cylinder (Run 1) vs. time (s) from t = 0s to 1 min (D4)

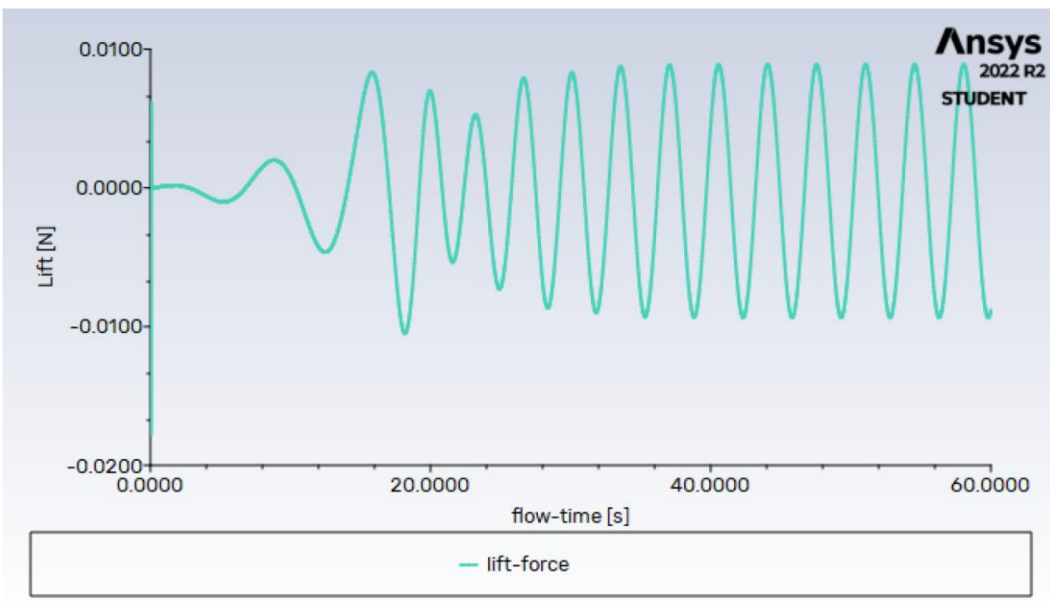


**Figure 11: P**lot of the lift force (N) on the elliptical cylinder (Run 2) cylinder vs time (s) from t = 0s to 1 min (D4)

**Table 1:** Estimates of the amplitude and period of oscillation of the lift force

| **Cylinder Shape** | **Amplitude (N)** | **Period (s)** |
|---|---|---|
| Circular | $\frac{0.0287-(-0.0299)}{2} = 0.0293$ | 4.2 |
| Elliptical, Run 1 | $\frac{0.0481-(-0.0461)}{2} = 0.0471$ | 3.6 |
| Elliptical, Run 2 | $\frac{0.009-(-0.0095)}{2} = 0.00925$ | 3.5 |

# Task 2

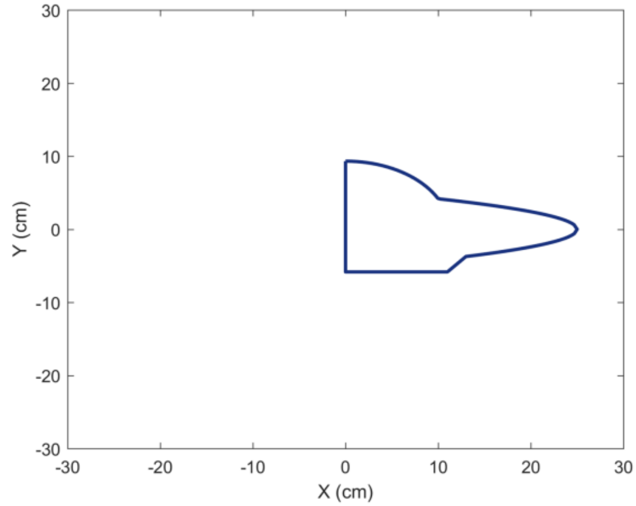


**Figure 12:** The profile of the "half 2D flying saucer". The detailed data is in flyingsaucer2DH.txt [1]

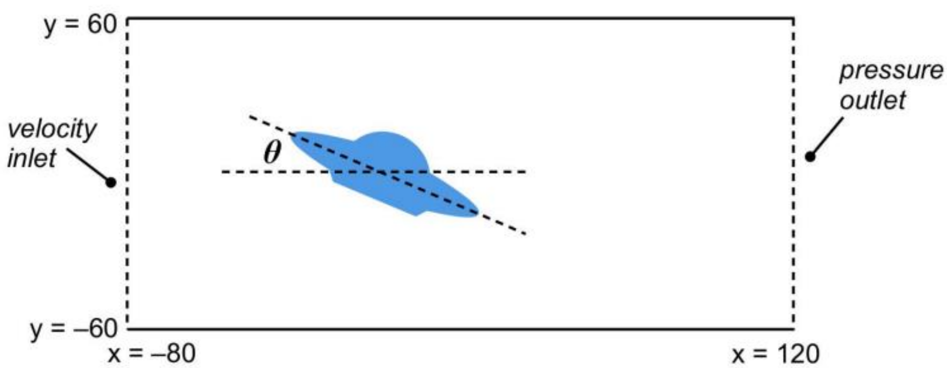


**Figure 13:** The dimension (in cm) of the cylindrical virtual wind tunnel along its plane of symmetry, and the definition of the tilt angle, [1]

**Objective:**

Test the aerodynamics of a 3D flying saucer in a cylindrical virtual wind tunnel.

**Instructions:**

- It has a velocity inlet and a pressure outlet. The boundary condition for the wall of the cylinder is wall with zero shear stress. The surface of the flying saucer is a regular wall with no-slip boundary condition. The detailed dimensions (in cm) of the system are given in Fig. 13. (For clarity, we show only the cross section along the plane of symmetry. The system is fully 3-D.) The radius and length of the cylindrical tube are 60 cm and 200 cm, respectively. The precise x and y coordinates of the corner points are given in Fig. 13. (The flying saucer is placed closer to the inlet than the outlet.) A tilt angle, θ, is defined in Fig. 13. It is the angle of rotation of the 3-D object using the z-axis as the axis of rotation. The system is filled with air with a constant density of 0.35 $kg\ m^{-3}$ and constant dynamic viscosity of $1.5\ \times\ 10^{-5}\ N\ s\ m^{-2}$ . [These values represent the condition of the atmosphere at approximately the top of troposphere (~ 10 km altitude).] For all simulations in this task, the inlet velocity is set to an axially symmetric parabolic profile for the x-velocity given by

$$u\ =\ 90\ (1\ -\ \left(\frac{r}{R}\right)^2)\ m\ s^{-1}\ ,$$

- where $r\ =\ \sqrt{y^2\ +\ z^2}$ is the radial distance from the center of the circular opening of the inlet, and R = 60 cm is the radius of that circular opening. With this setup, u reaches the maximum of 90 m/s at r = 0, and minimum of 0 at the wall where r = R. All simulations use turbulence k-omega model (with the default setting) and seek steady solution. Perform three runs with the tilt angle set to θ = 0°, 25°, and 50°.

**Notes:**

- All simulations were run for 20 iterations.

**(D5)**

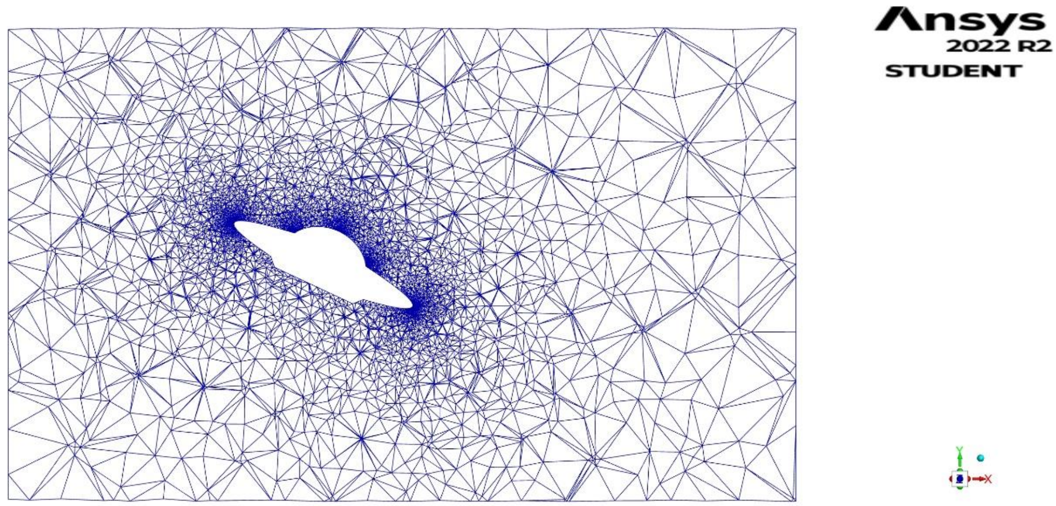


**Figure 14:** Plot of the mesh along the plane of symmetry for the case with θ = 25° [D5]

**(D6)**

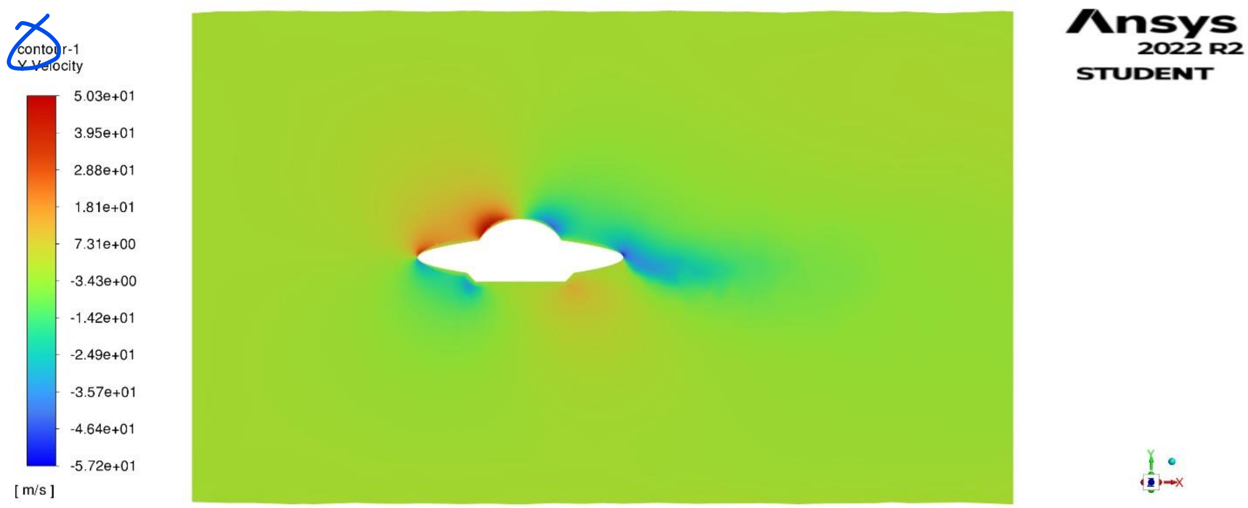


**Figure 15:** Contour plot of x-velocity on the plane of symmetry for the three cases with θ = 0° [D6]

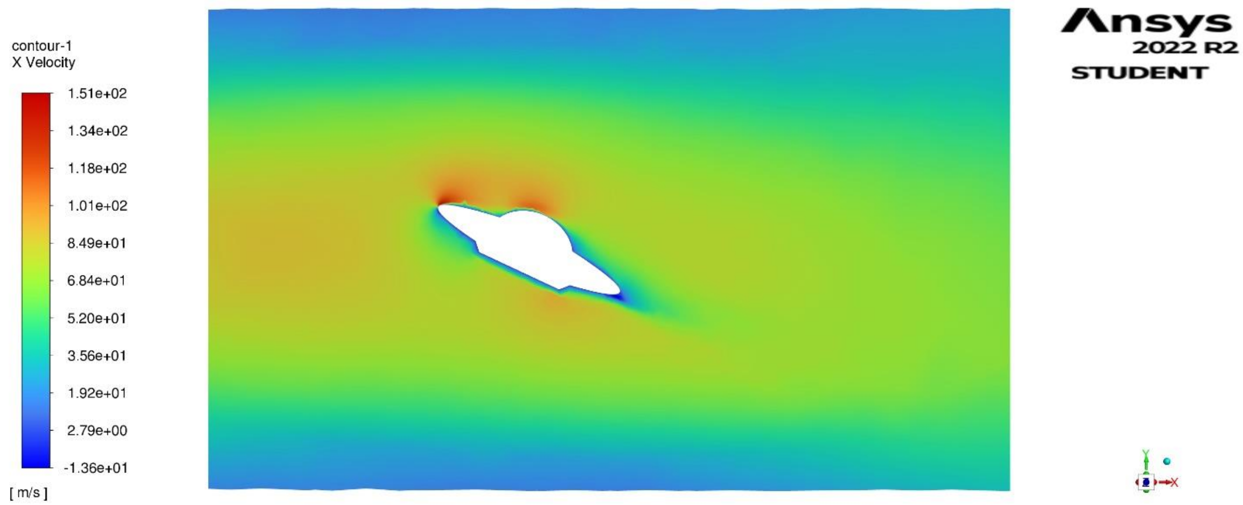


**Figure 16:** Contour plot of x-velocity on the plane of symmetry for the three cases with θ = 25° [D6]

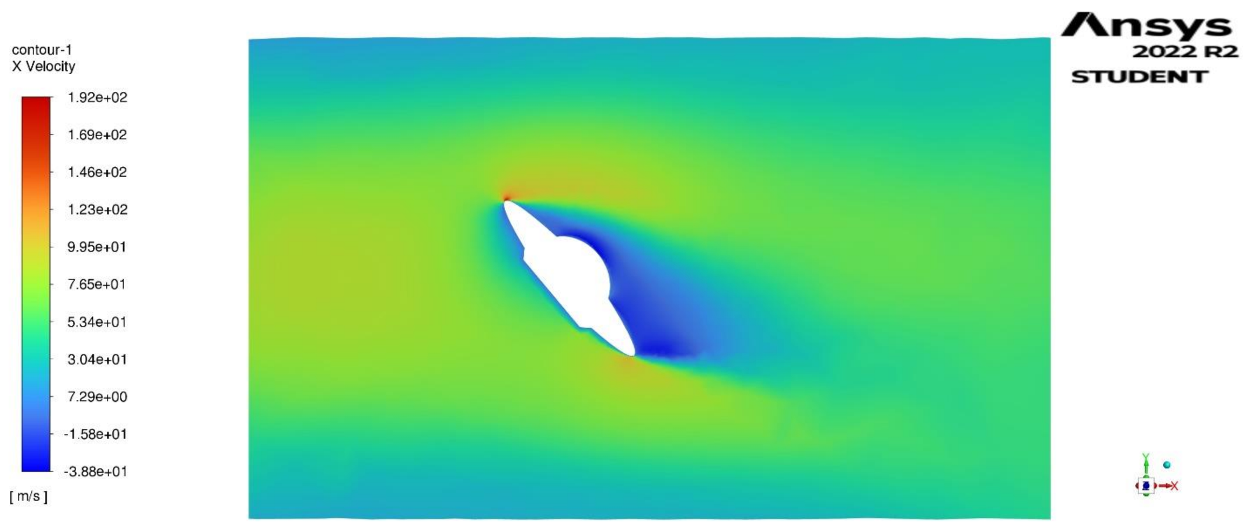


**Figure 17:** Contour plot of x-velocity on the plane of symmetry for the three cases with θ = 50° [D6]

**(D7)**

**Table 2:** Lift force and drag force as a function of the tilt angle

| $\theta$ | Lift Force (N) | Drag Force (N) |
|---|---|---|
| 0° | 10.99 | 7.67 |
| 25° | 107.28 | 32.78 |
| 50° | 93.39 | 106.50 |

## Task 3

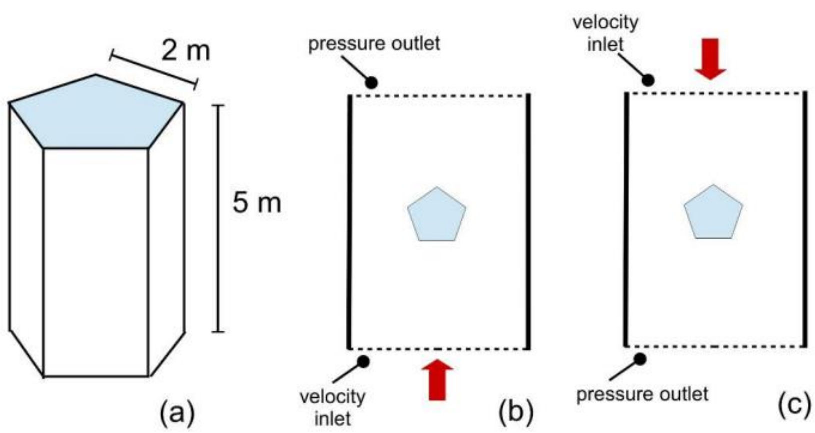


**Figure 18:** The geometry of the building is shown in (a). The setups for Run 1 and Run 2 are shown in (b) and (c) as the top view of the system [1]

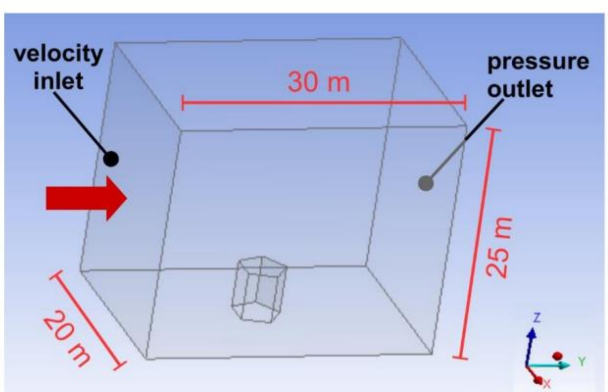


**Figure 19:** The setup of the virtual wind tunnel for Task 3. Shown is the setting for Run 1. (Not drawn to scale) [1]

**Objective:**

Simulate a 3D flow passing a pentagon-shaped building in a virtual wind tunnel.

**Instructions:**

- The building is shown in Fig. 16a. It is 5 m tall, and each side of the pentagon is 2 m long. The building is placed at the center of the bottom plate (i.e., the "ground") of the tunnel, as shown in Fig. 17. The dimension of the computational domain is given in Fig. 17. The left and right openings are set as velocity inlet and pressure outlet for Run 1 (Fig. 16b) and set as pressure outlet and velocity inlet for Run 2 (Fig. 16c). All other surfaces are walls. The bottom plate (i.e., the ground) and the surface of the pentagon building are regular walls with no-slip boundary condition. The two side walls and the top wall of the virtual wind tunnel are walls with zero shear stress.
- The tunnel is filled with air with constant density and viscosity, using the default values from Fluent database. At the velocity inlet, we impose a profile of y-velocity as $v = 2z$, with z in meter and v in m/s. This gives $v = 0$ at the ground and $v = 50$ m/s at $z = 25$ m, i.e., the top of the domain. Otherwise, the imposed y-velocity is independent of x. (See Fig. 17 for the definitions of the x-, y-, and z-direction in this context.) All simulations in this task use turbulence k-omega model (with the default setting) and seek steady solution.
- Perform two simulations with the setup based on Fig. 16b and 16c, respectively. For Run1 (Fig. 16b), the wind coming from the inlet is attacking a flat edge of the pentagon. For Run 2 (Fig. 17c), a vertex of the pentagon is facing the incoming flow from the inlet.

**Notes:**

- All simulations were run for 20 iterations.

**(D8)**

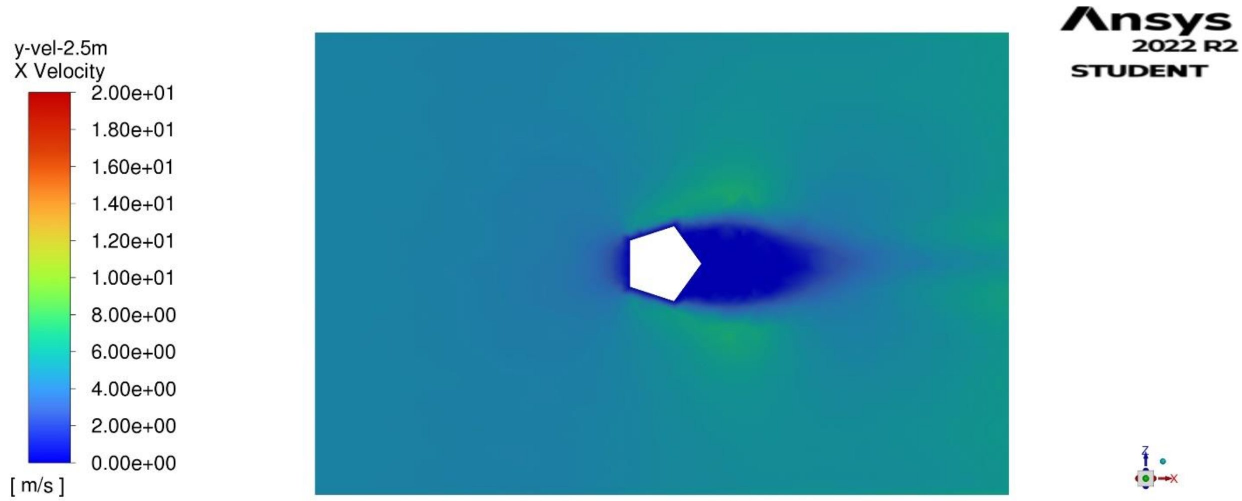


**Figure 20:** Contour plots of y-velocity of Run 1 on the horizontal plane at z = 2.5 m [D8]

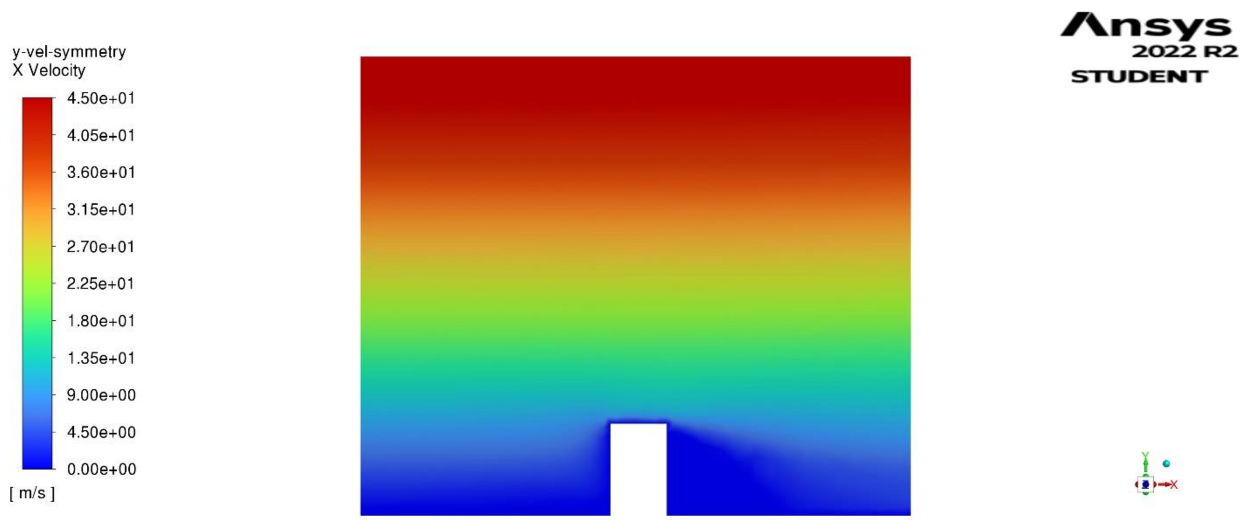


**Figure 21:** Contour plots of y-velocity of Run 1 on the vertical plane of symmetry [D8]

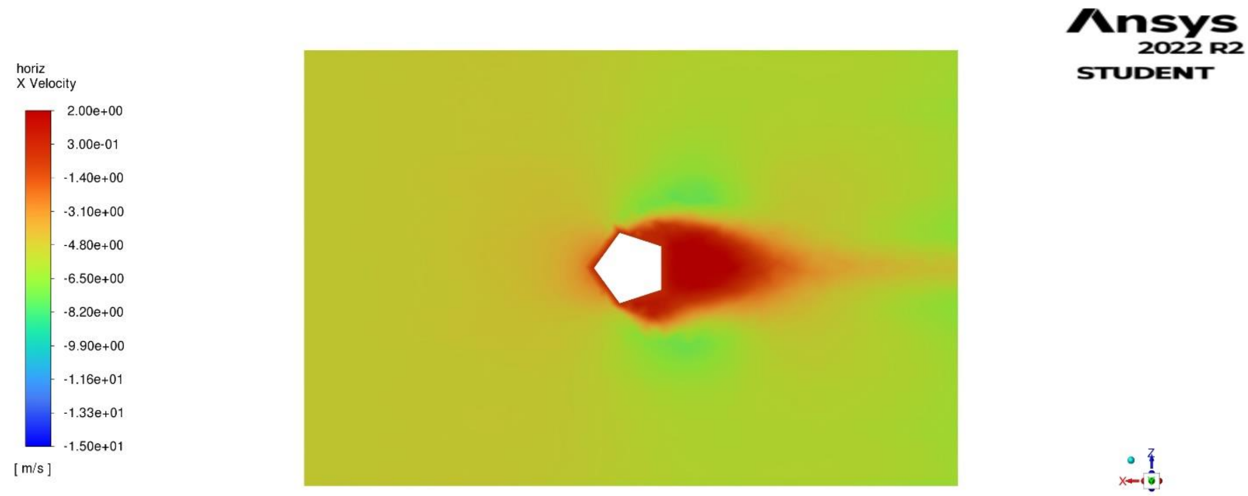


**Figure 22:** Contour plots of y-velocity of Run 2 on the horizontal plane at z = 2.5 m [D8]

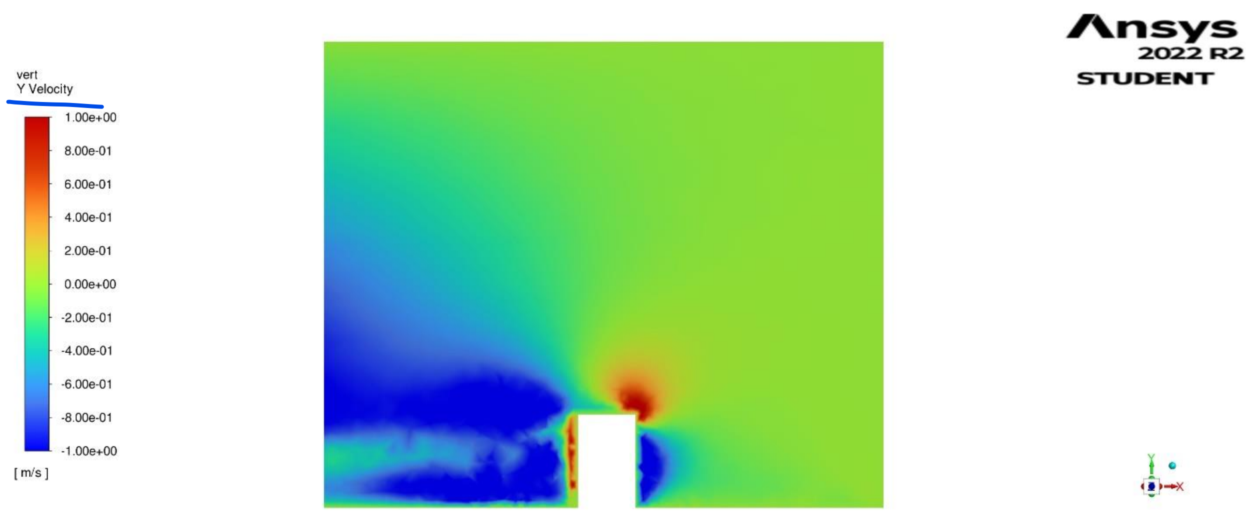


**Figure 23:** Contour plots of y-velocity of Run 2 on the vertical plane of symmetry [D8]

**(D9)**

**Table 3:** Total drag force (that fluid exerts on the building) and the individual contributions to the drag force from the pressure and viscous terms vs. runs

| Run | Total drag (N) | Pressure term of drag (N) | Viscous term of drag (N) |
|---|---|---|---|
| 1 | **328.98** | **328.3046** | **0.6751** |
| 2 | **3.868** | **3.852** | **0.0158** |

# Task 4

**Objective:**

Simulate the 2D flow of diesel over an asymmetric form of a cylinder to show unstable flow.

**Instructions:**

- In the 3rd video shown in Lecture 20 (related to the background for Task 1), it was mentioned that some asymmetric forms of cylinder are unstable, in that a flow passing the cylinder induces a large-amplitude response so as to damage the structure. Using the setup in Task 1, try to run a transient simulation with a cylinder that has an asymmetric shape but otherwise a cross-sectional area comparable to that of the "circular cylinder" in Task 1a. (Here, we ask that the cross-sectional area in both the x- and y-direction be comparable to the original circle.) The goal is to demonstrate that a large-amplitude response in the lift as shown in the video can be reproduced by numerical simulation. The transient simulation should be initialized in the same way as Task 1a, and be run to at least t = 1 min.

**Notes:**

- To have a similar area, I chose a half circle with a $r = \sqrt{8}$ that is rotated by 45° about its center.

$$A_{asym} = A_{circle}$$

$$\frac{\pi r^2}{2} = \pi 2^2$$

$$r = \sqrt{8}$$

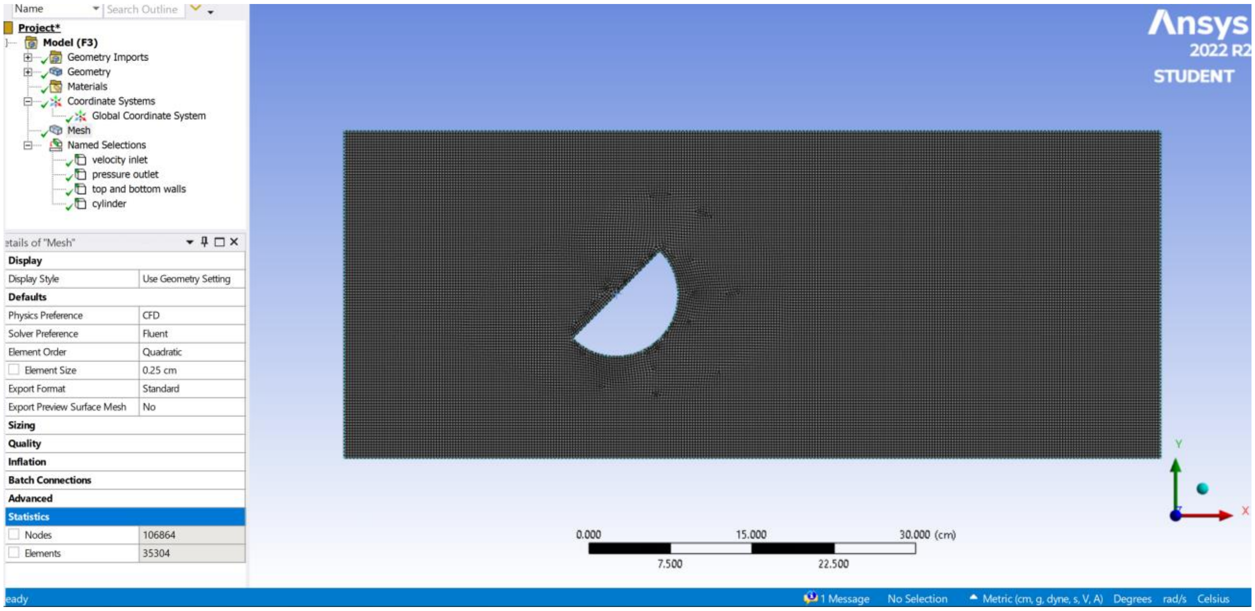


**Figure 24:** Mesh of Task 4 with the asymmetric cylinder

**(D10)**

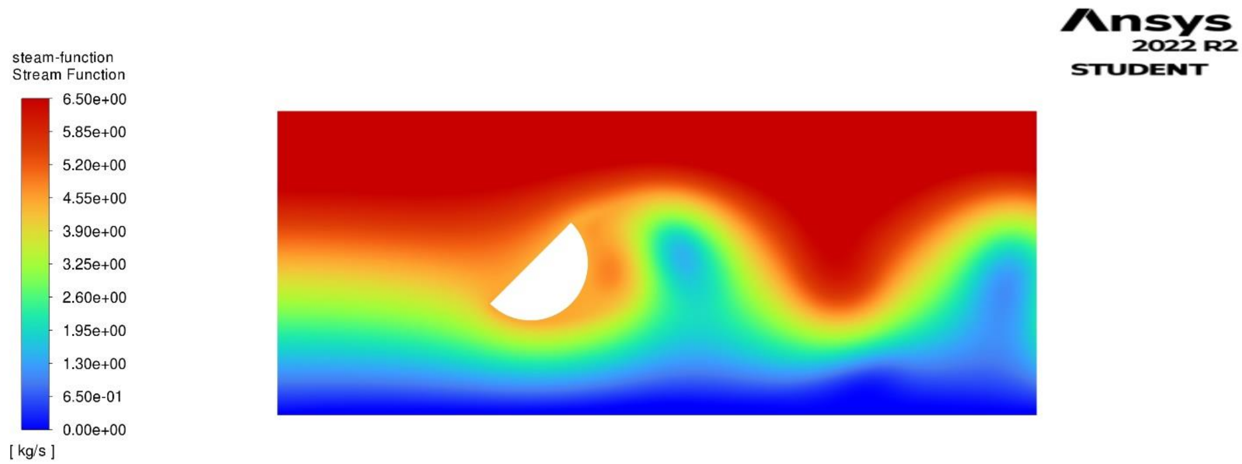


**Figure 25:** Contour plot of the stream function of liquid diesel over the asymmetric cylinder at t = 1 min (D10)

**(D11)**

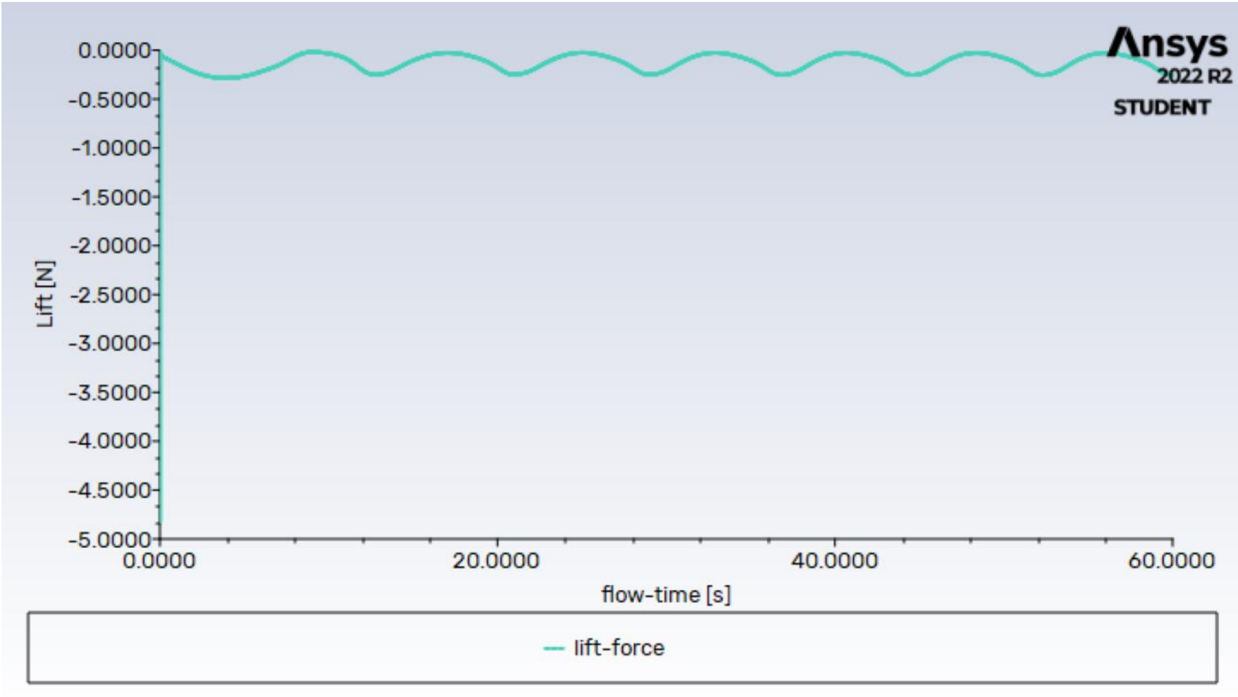


**Figure 26: P**lot of the lift force (N) on the asymmetric cylinder vs. time (s) from t = 0s to 60s (D11)

**Resources:**

** *All instructions sections directly from* [1]. **

[1] MAE 560/460 Applied CFD, Fall 2022, Project 3 – External flow Instructions

**Appendix:**

Data from *flyingsaucer2DH.txt:*

| | | | | |
|---|---|---|---|---|
| 1 | 1 | 0.000000 | 9.316950 | 0.000000 |
| 1 | 2 | 0.585134 | 9.304181 | 0.000000 |
| 1 | 3 | 1.168664 | 9.265911 | 0.000000 |
| 1 | 4 | 1.748990 | 9.202243 | 0.000000 |
| 1 | 5 | 2.324523 | 9.113352 | 0.000000 |
| 1 | 6 | 2.893685 | 8.999483 | 0.000000 |
| 1 | 7 | 3.454915 | 8.860946 | 0.000000 |
| 1 | 8 | 4.006675 | 8.698122 | 0.000000 |
| 1 | 9 | 4.547454 | 8.511457 | 0.000000 |
| 1 | 10 | 5.075768 | 8.301463 | 0.000000 |
| 1 | 11 | 5.590170 | 8.068715 | 0.000000 |
| 1 | 12 | 6.089250 | 7.813852 | 0.000000 |
| 1 | 13 | 6.571639 | 7.537571 | 0.000000 |
| 1 | 14 | 7.036016 | 7.240630 | 0.000000 |
| 1 | 15 | 7.481108 | 6.923843 | 0.000000 |
| 1 | 16 | 7.905694 | 6.588078 | 0.000000 |
| 1 | 17 | 8.308612 | 6.234256 | 0.000000 |
| 1 | 18 | 8.688756 | 5.863347 | 0.000000 |
| 1 | 19 | 9.045085 | 5.476366 | 0.000000 |
| 1 | 20 | 9.376622 | 5.074375 | 0.000000 |

| | | | | |
|---|---|---|---|---|
| 1 | 21 | 9.682458 | 4.658475 | 0.000000 |
| 1 | 22 | 9.961756 | 4.229807 | 0.000000 |
| 2 | 1 | 9.961756 | 4.229807 | 0.000000 |
| 2 | 2 | 10.261756 | 4.130152 | 0.000000 |
| 2 | 3 | 10.561756 | 4.087901 | 0.000000 |
| 2 | 4 | 10.861756 | 4.045208 | 0.000000 |
| 2 | 5 | 11.161756 | 4.002060 | 0.000000 |
| 2 | 6 | 11.461756 | 3.958442 | 0.000000 |
| 2 | 7 | 11.761756 | 3.914338 | 0.000000 |
| 2 | 8 | 12.061756 | 3.869731 | 0.000000 |
| 2 | 9 | 12.361756 | 3.824604 | 0.000000 |
| 2 | 10 | 12.661756 | 3.778938 | 0.000000 |
| 2 | 11 | 12.961756 | 3.732714 | 0.000000 |
| 2 | 12 | 13.261756 | 3.685910 | 0.000000 |
| 2 | 13 | 13.561756 | 3.638504 | 0.000000 |
| 2 | 14 | 13.861756 | 3.590472 | 0.000000 |
| 2 | 15 | 14.161756 | 3.541788 | 0.000000 |
| 2 | 16 | 14.461756 | 3.492426 | 0.000000 |
| 2 | 17 | 14.761756 | 3.442357 | 0.000000 |
| 2 | 18 | 15.061756 | 3.391548 | 0.000000 |
| 2 | 19 | 15.361756 | 3.339966 | 0.000000 |
| 2 | 20 | 15.661756 | 3.287576 | 0.000000 |
| 2 | 21 | 15.961756 | 3.234336 | 0.000000 |

2 22 16.261756 3.180206 0.000000

2 23 16.561756 3.125138 0.000000

2 24 16.861756 3.069082 0.000000

2 25 17.161756 3.011983 0.000000

2 26 17.461756 2.953781 0.000000

2 27 17.761756 2.894408 0.000000

2 28 18.061756 2.833792 0.000000

2 29 18.361756 2.771850 0.000000

2 30 18.661756 2.708492 0.000000

2 31 18.961756 2.643617 0.000000

2 32 19.261756 2.577108 0.000000

2 33 19.561756 2.508837 0.000000

2 34 19.861756 2.438656 0.000000

2 35 20.161756 2.366394 0.000000

2 36 20.461756 2.291855 0.000000

2 37 20.761756 2.214808 0.000000

2 38 21.061756 2.134983 0.000000

2 39 21.361756 2.052055 0.000000

2 40 21.661756 1.965632 0.000000

2 41 21.961756 1.875230 0.000000

2 42 22.261756 1.780243 0.000000

2 43 22.561756 1.679893 0.000000

2 44 22.861756 1.573156 0.000000

2 45 23.161756 1.458629 0.000000

2 46 23.461756 1.334307 0.000000

2 47 23.761756 1.197144 0.000000

2 48 24.061756 1.042080 0.000000

2 49 24.361756 0.859482 0.000000

2 50 24.661756 0.625689 0.000000

2 51 25.000000 0.000000 0.000000

3 1 25.000000 0.000000 0.000000

3 2 24.700000 -0.589256 0.000000

3 3 24.400000 -0.833333 0.000000

3 4 24.100000 -1.020621 0.000000

3 5 23.800000 -1.178511 0.000000

3 6 23.500000 -1.317616 0.000000

3 7 23.200000 -1.443376 0.000000

3 8 22.900000 -1.559024 0.000000

3 9 22.600000 -1.666667 0.000000

3 10 22.300000 -1.767767 0.000000

3 11 22.000000 -1.863390 0.000000

3 12 21.700000 -1.954340 0.000000

3 13 21.400000 -2.041241 0.000000

3 14 21.100000 -2.124591 0.000000

3 15 20.800000 -2.204793 0.000000

3 16 20.500000 -2.282177 0.000000

3 17 20.200000 -2.357023 0.000000

3 18 19.900000 -2.429563 0.000000

3 19 19.600000 -2.500000 0.000000

3 20 19.300000 -2.568506 0.000000

3 21 19.000000 -2.635231 0.000000

3 22 18.700000 -2.700309 0.000000

3 23 18.400000 -2.763854 0.000000

3 24 18.100000 -2.825971 0.000000

3 25 17.800000 -2.886751 0.000000

3 26 17.500000 -2.946278 0.000000

3 27 17.200000 -3.004626 0.000000

3 28 16.900000 -3.061862 0.000000

3 29 16.600000 -3.118048 0.000000

3 30 16.300000 -3.173239 0.000000

3 31 16.000000 -3.227486 0.000000

3 32 15.700000 -3.280837 0.000000

3 33 15.400000 -3.333333 0.000000

3 34 15.100000 -3.385016 0.000000

3 35 14.800000 -3.435921 0.000000

3 36 14.500000 -3.486083 0.000000

3 37 14.200000 -3.535534 0.000000

3 38 13.900000 -3.584302 0.000000

3 39 13.600000 -3.632416 0.000000

3 40 13.300000 -3.679900 0.000000

3 41 13.000000 -3.726780 0.000000

4 1 13.000000 -3.726780 0.000000

4 2 11.000000 -5.833333 0.000000

5 1 11.000000 -5.833333 0.000000

5 2 0.000000 -5.833333 0.000000

6 1 0.000000 -5.833333 0.000000

6 2 0.000000 9.316950 0.000000