MECH 539 Computational Aerodynamics
Final Project

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1 Question 1

For this question I changed the way $\frac{dy}{dx}$ was evaluated in my TSD code, which now uses a central difference to find it, instead of directly using the differential of the $y(x)$ function and compared it to the expected solutions from Project 3 to make sure the code is working.
Next we are asked to find the pressure drag (C_{dp}) for each Mach number specified in Project 3 which is from $[0.80, 0.90]$ with 0.02 increments in Mach number. The values for the pressure drag coefficient found for the various Mach numbers are tabulated below:

Mach Number	0.80	0.82	0.84	0.86	0.88	0.90
Pressure Drag, C_{dp}	0.005832	0.005839	0.006034	0.009385	0.020513	0.067656

I have also made a plot of the Pressure drag coefficient as function of Mach number:

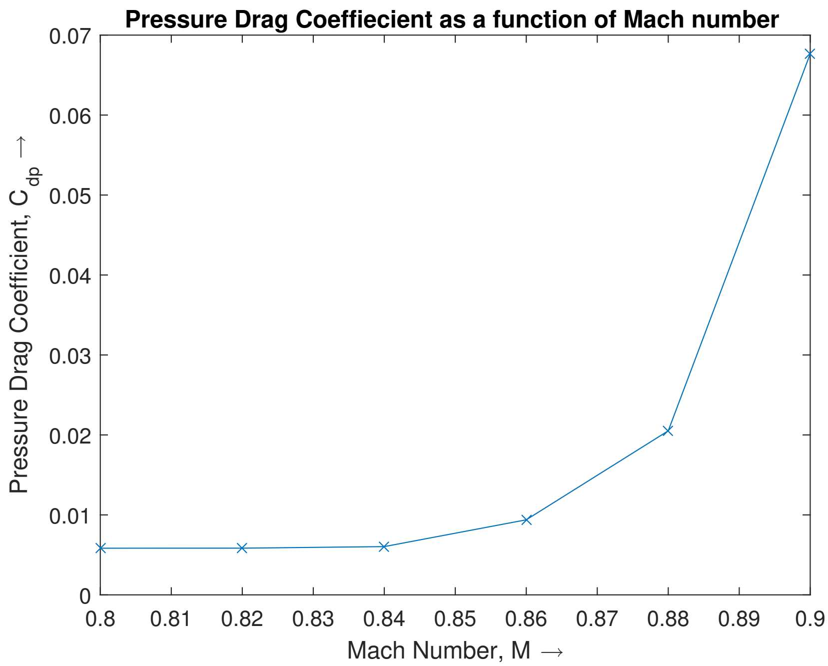

Figure 1: Pressure drag coefficient as function of Mach number

2 Question 2

In this question, I completed the boundary layer code by linearizing the equations. The x versus u_e plot is given below:

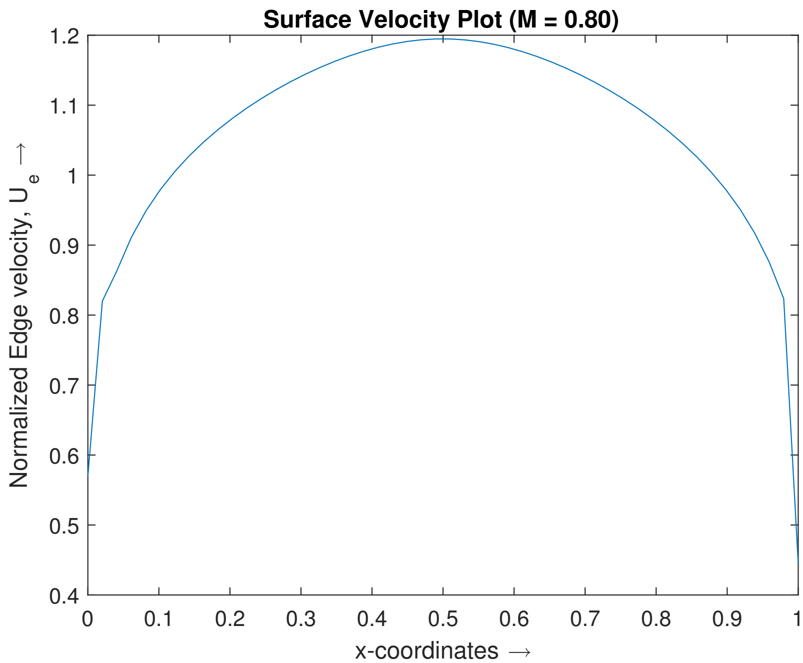

Figure 2: x versus u_e Plot

3 Question 3

3.1 Part (a)

In this question, we are asked to plot the boundary layer profile at the 0.25c, 0.50c and 0.75c. The following graphs were obtained:

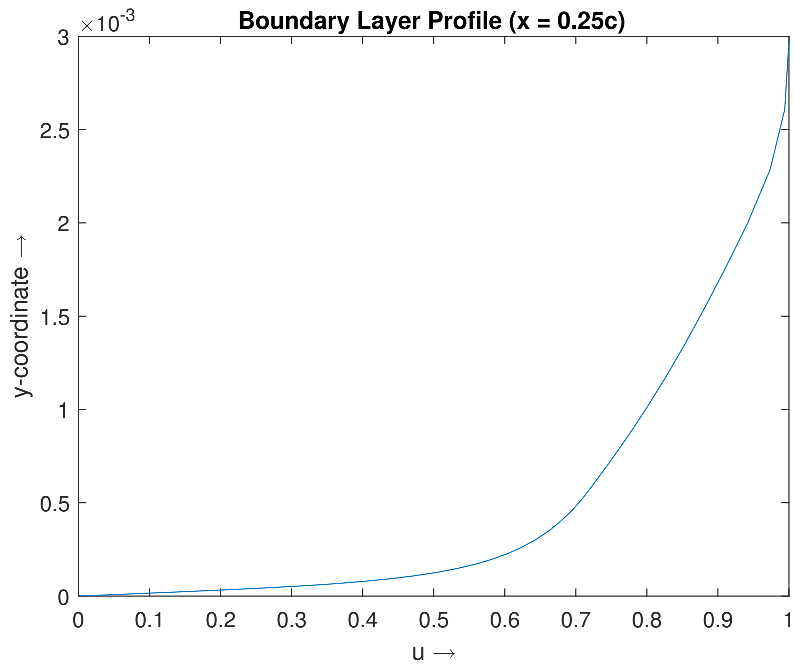

Figure 3: Boundary Layer Profile

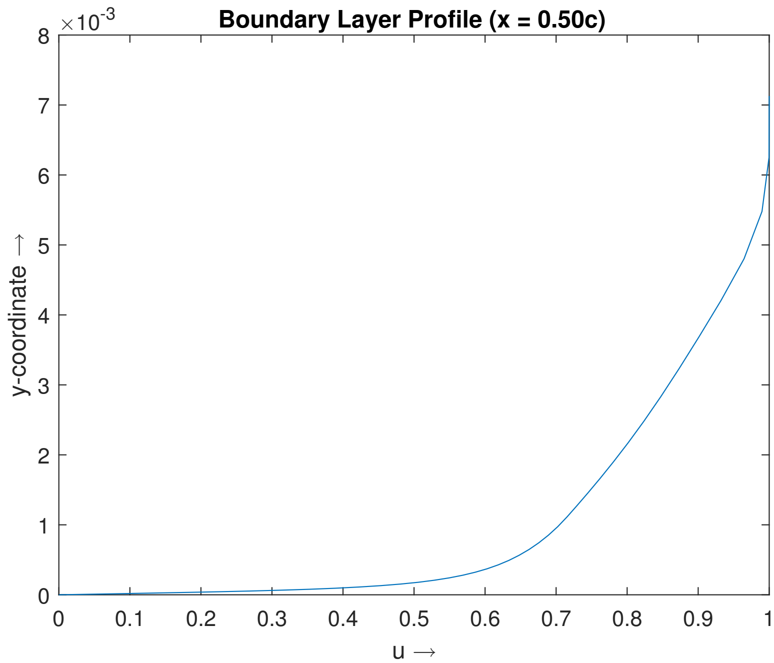

Figure 4: Boundary Layer Profile

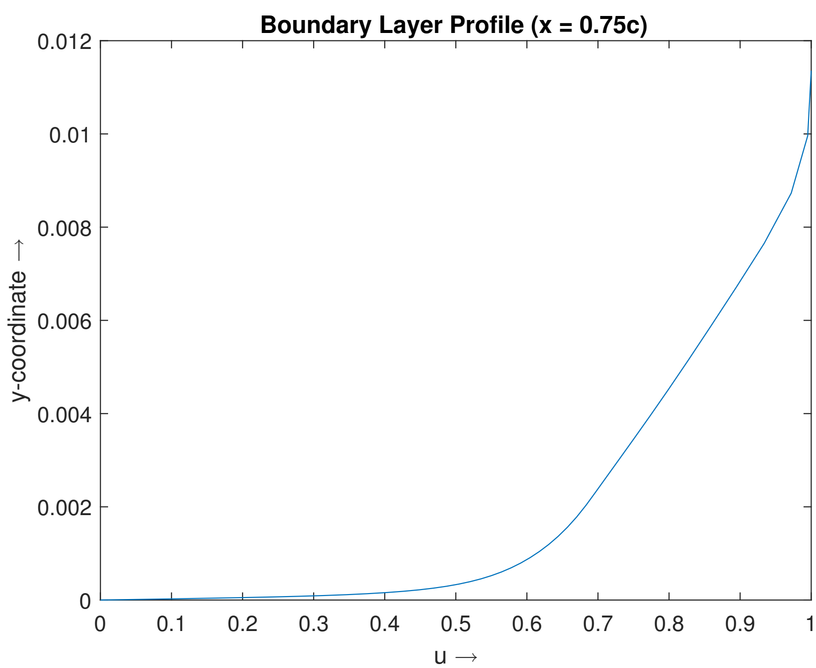

Figure 5: Boundary Layer Profile

From the above graph we see that the flow is turbulent and as we go further back on the airfoil, the boundary layer grows.

3.2 Part (b)

Here, I plot the displacement thickness, δ^*, and skin friction coefficient, C_f along the x-coordinate at three Mach numbers 0.80, 0.84 and 0.84. The following plots were obtained:

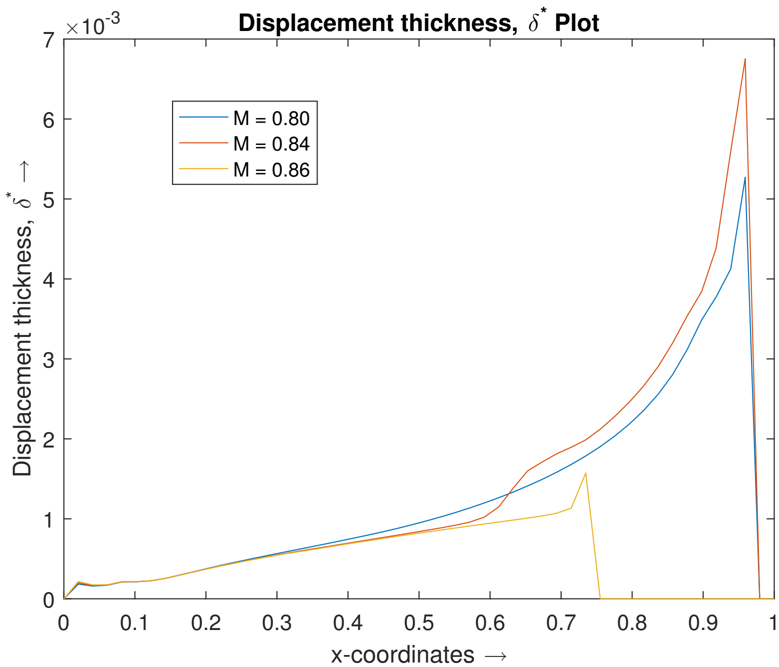

Figure 6: Displacement thickness Plot

From the above graph, we see that the displacement thickness is a smooth curve when the Mach number is 0.80 as there are no shocks over the airfoil, but when the Mach number is 0.84, we see a sudden increase in the displacement thickness, this is because there is a shock at that point however the flow does not separate. When the Mach number is set to 0.86, we notice that the displacement thickness suddenly drops to zero, this is because the flow separates from the airfoil at that point.

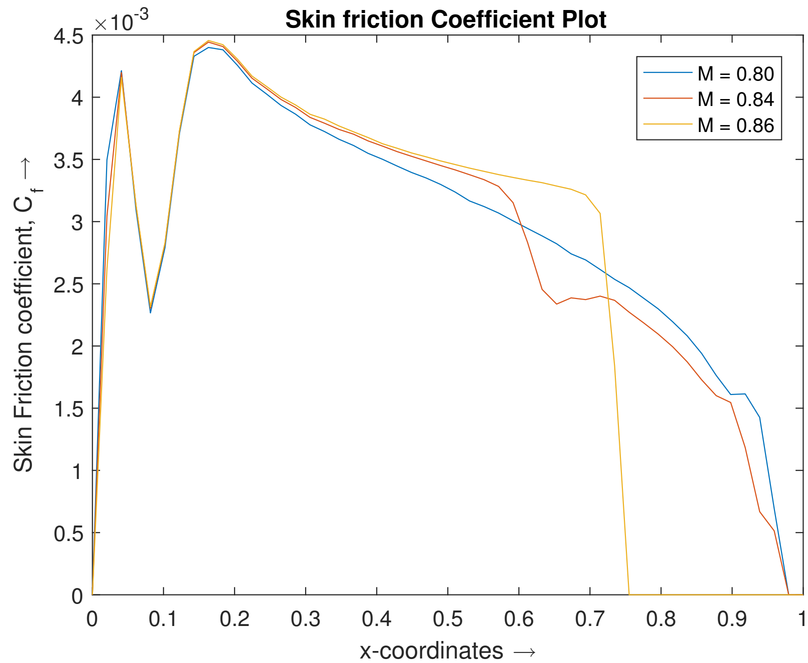

Figure 7: Surface friction coefficient Plot

we notice from the above graph that there is a temporary drop in the surface friction coefficient at the beginning of the airfoil, this is because the airflow is turning over the airfoil which causes the flow to separate due to centrifugal forces and then the flow reattaches again causing the surface friction coefficient to rise again. Another thing we notice is that for Mach number 0.86, we see around $x = 0.75$ the surface friction coefficient drops to zero, this is because the airflow separates at this point.

3.3 Part (c)

In this question, I evaluate the aerodynamic coefficients for the different Mach numbers. The results have been tabulated below:

Mach Number	C_l	C_d	C_{lf}	C_{lp}	C_{dp}	C_{df}
0.80	0	0.0168	0	0	0.0138	0.0029
0.84	0	0.0204	0	0	0.0175	0.0029
0.86	0	0.0232	0	0	0.0206	0.0026

3.4 Part (d)

In this question I plot the coefficient of pressure from the original TSD code and the coupled TSD code for the different Mach numbers $[0.80, 0.84, 0, 86]$.The following plots were obtained:
NOTE: The negative direction of the y-axis is facing upwards.

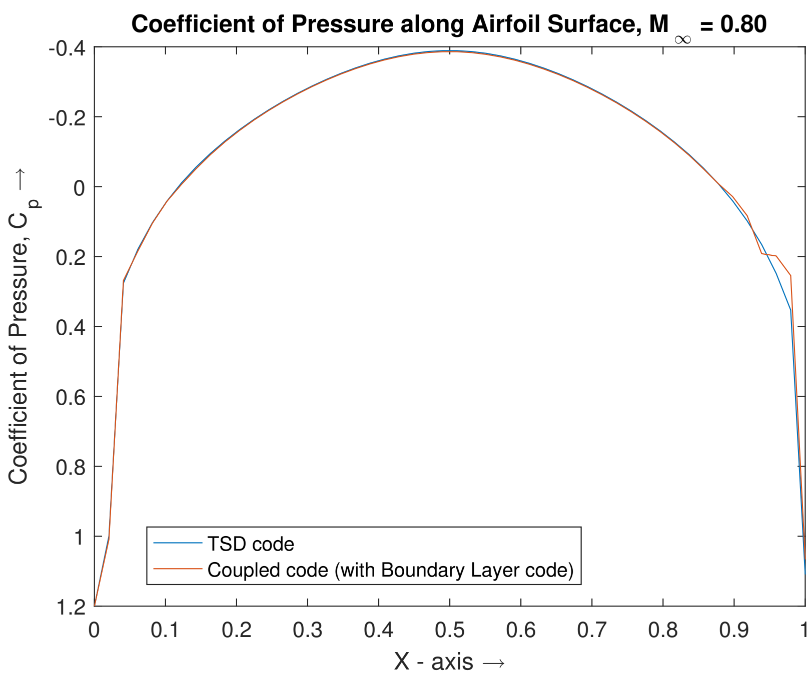

Figure 8: Pressure drag coefficient Plot

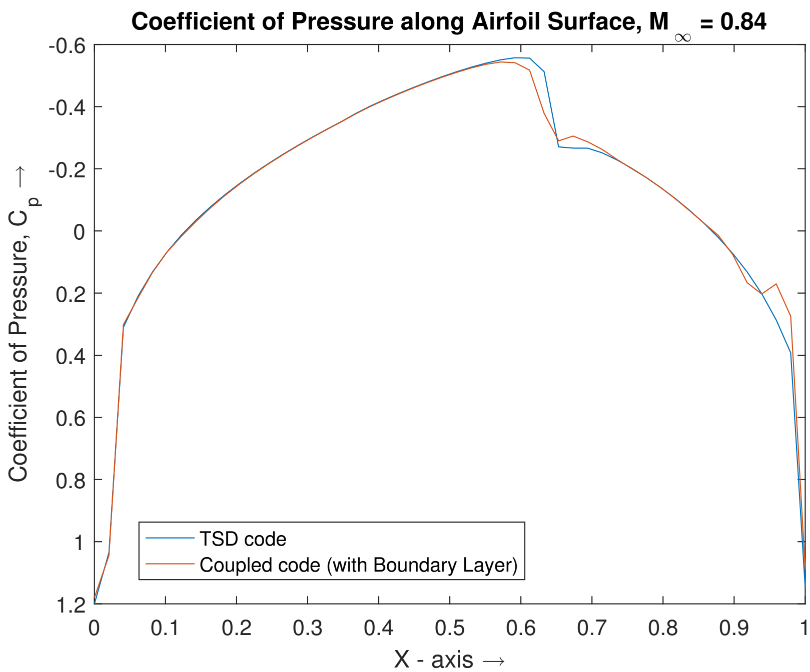

Figure 9: Pressure drag coefficient Plot

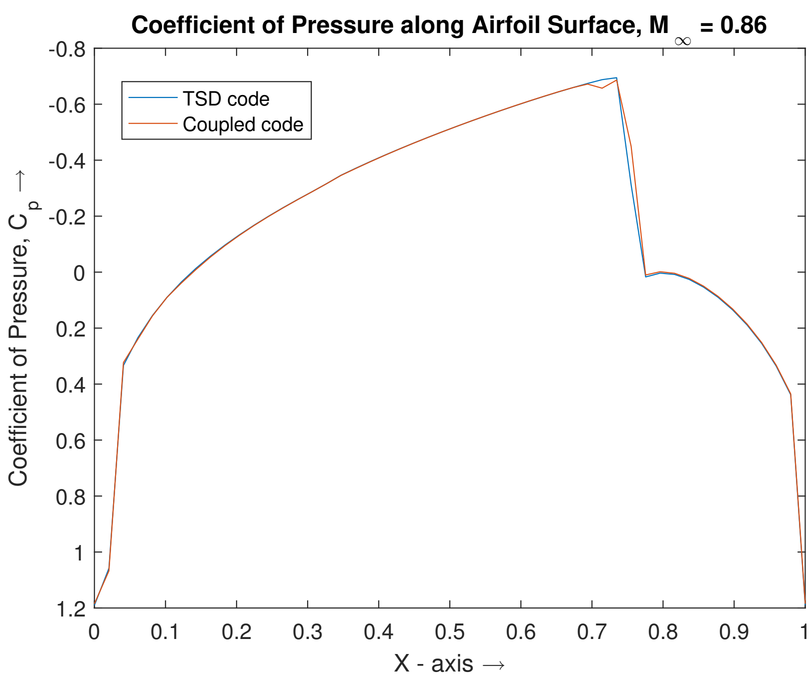

Figure 10: Pressure drag coefficient Plot

It is clear from the above graphs that we obtained that the difference in the coefficient of pressure obtained from the TSD code and the coupled code are very similar and there are very minimal differences.

3.5 Part (e)

The following plot was obtained when the displacement thickness, δ^* was plotted after each iteration during the three iteration coupled solution:
NOTE: The Mach number was chosen as 0.80 for these iterations.

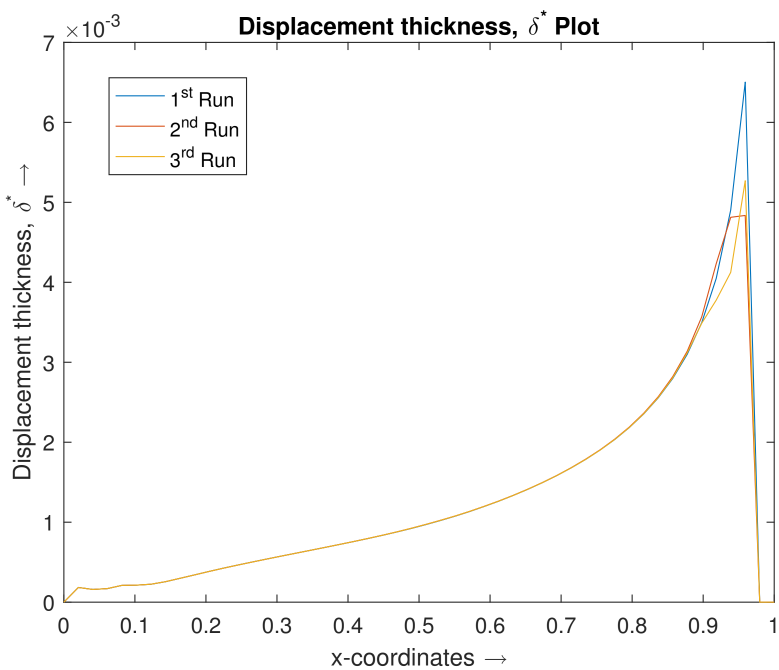

Figure 11: Displacement Thickness

We can see from the above graph, the boundary layer thickness drops by a lot after the first coupled iteration and the difference between the two is quite large. After the second coupled iteration the displacement thickness increases but the difference between the second and third coupled iteration is smaller than the difference between the first and the second. So we can see that the displacement thickness is beginning to converge to a solution.

3.6 Part (f)

In this question we are asked to plot the drag coefficients as a function of the different Mach numbers. The obtained graph is plotted below:

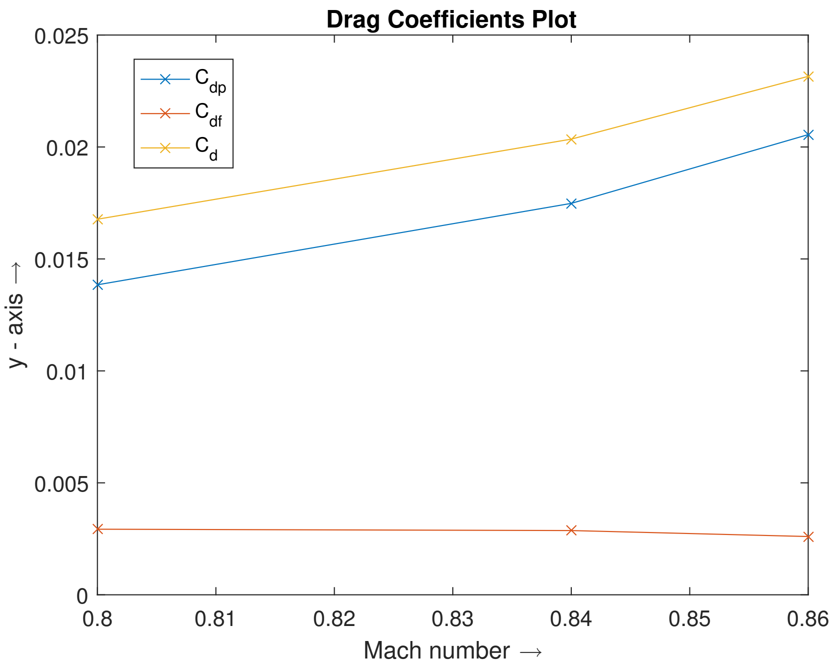

Figure 12: Plot of Drag coefficients

From the above graph, we notice that the coefficient of drag due to friction (C_{df}) is nearly constant and does not change with varying Mach numbers. The total drag and the coefficient of drag due to pressure increase with increasing Mach numbers.

3.7 Part (g)

In this question we are asked to plot the drag coefficients as a function of the different Mach numbers. The obtained graph is plotted below:

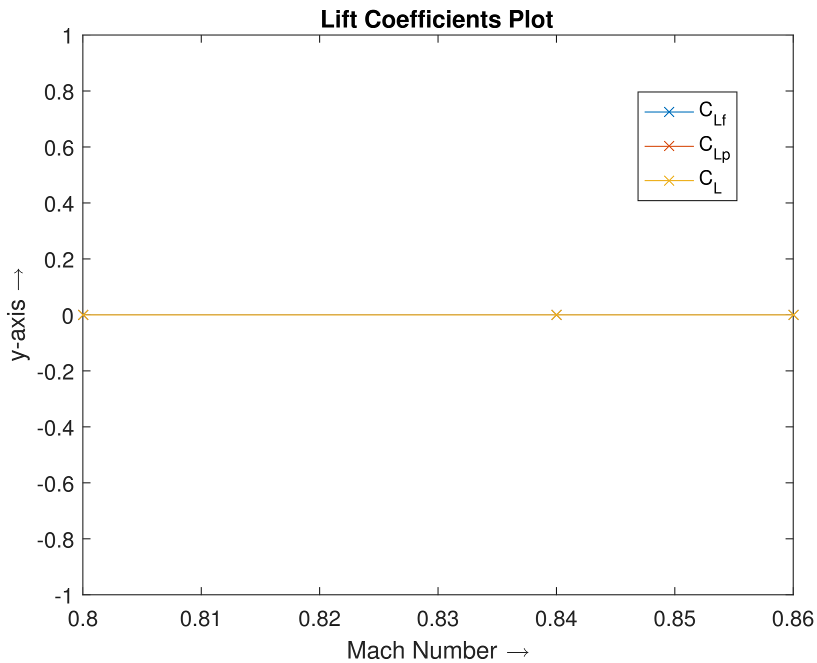

Figure 13: Plot of Lift coefficients

The lift coefficients are zero because there is no angle of attack and the airfoil is symmetric.