MECH 539: Computational Aerodynamics
Department of Mechanical Engineering, McGill University

Project #4: Investigating Aerodynamic Performance of Airfoils using a Coupled Potential Equation and Integral Boundary Layer Method
Due 26th March, 2013

Employ the PABLO [1] to investigate the aerodynamic performance of various airfoils. PABLO [1] couples the solution to the potential equations via a panel method code with an integral boundary layer method to predict the lift, drag, and pitching moment of an airfoil, together with laminar-turbulent transition prediction. Use 100 panels for all the results unless otherwise stated and represent each panel as a doublet.

Provide the following in a written report with a thorough discussion of your observation for each of the subsequent question:

1. Establish the minimum necessary number of panels to acquire a reasonably accurate pressure distribution, and lift and drag coefficients. Solve the flow over a NACA0012 airfoil at a Reynolds number of $1e6$ and an angle of attack of 4 degrees. Start with 20 panels and increase by 10 until 100 panels. Compare the pressure distributions on the same figure and list the lift and drag coefficients in a table for all the cases. Discuss your findings thoroughly and explain the effect of the number of panels on the pressure distribution, and lift and drag coefficients.

2. Compare the pressure distribution for the NACA 0012 airfoil at an angle of attack of 2 degrees and 6 degrees at a Reynolds number of $1e6$ using both inviscid and viscous results against experimental data [Gregory & OReilly, NASA R&M 3726, Jan 1970] at the same conditions. Provide two c_p plots, one for each angle of attack. Each plot must contain the inviscid, viscous, and experimental pressure coefficients for both the lower and upper surfaces. Discuss your findings thoroughly.

3. Compare the aerodynamic characteristics of the NACA 0012 airfoil at four different angles of attack in viscous flow at a Reynolds number of $1e6$, starting at an angle of zero degrees with increments of 2 degrees.

   (a) Compare the c_p distributions for all four angles on the same plot. Describe the changes in the distribution and explain your observation using physical reasoning.

   (b) Plot the lift curve slope and drag polar. Describe the changes in the distribution and explain your observation using physical reasoning. [Note. Use several additional angles of attack within a range of $0^o \leq \alpha \leq 10^o$ to obtain a well defined curve.]

   (c) As the angle of attack increases, what is the affect on the drag coefficient? What is the source of the drag force?

4. Compare the aerodynamic characteristics of the NACA0012, GA(W)-1, and DAE31 airfoils for $-2^o \leq \alpha \leq 10^o$ at a Reynolds number of $1e6$.

(a) Compare the drag polars for the three airfoils. Discuss your findings.

(b) At an equivalent lift coefficient of 1.0, provide in a table, the values of the drag coefficients for the three airfoils and explain your findings.

(c) At an angle of attack of 4 degrees, plot the pressure distributions on the same graph and discuss your observations. Report on the differences in the favourable pressure gradients. Is lift produced from the same region for all three airfoils?

(d) Compare the skin friction coefficient at an angle of attack of 4 degrees on the same figure for the upper and lower surfaces on separate figures. Label the location of transition for both the upper and lower surfaces. Discuss the differences in the transition points and explain your observation using physical reasoning.

5. Investigate the effect of thickness, camber, and camber location for the NACA airfoil series. Report c_d for 3 sets of NACA airfoils at zero angle of attack and Reynolds Number of 1e6:

   (a) One with variable thickness (NACA 00XX, XX varying between 04 and 26 by increment of 2),

   (b) Second with variable camber (NACA X412, with X varying between 2 and 8),

   (c) Third with variable camber location (NACA 4X12, with X varying between 2 and 8).

   Plot the corresponding sensitivity curves cd vs parameter and the c_p distribution on the same figure for each case. Indicate on the curves the points at which turbulent separation takes place. Draw a conclusion which sums up what you obtain on these curves.

6. [Optional] Investigate the effect of Reynolds Number on the aerodynamic performance for the NACA 4412 airfoil. [Note: Use Re = $1e5$, $1e6$, and $1e7$]

   (a) Compare the c_p distributions at an angle of attack of 4 degrees on the same figure and discuss your findings.

   (b) Compare the lift and drag coefficients at the same angle of attack and comment on the results.

   (c) Compare the skin friction distributions for the upper surface at the same angle of attack. Comment on the location of the transition points and the trends for both the laminar and turbulent regions.

References

[1] Christian Wauquiez and Arthur Rizzi. Potential flow around airfoils with boundary layer coupled one-way. Technical report, KTH- The Royal Institute of Technology, Stockholm, Sweden, 1999.