

Project Assignment #4  
Transonic Effects on BWB Root Airfoil  
Due: November 9 at the end of lab

Prof. David L. Darmofal  
Department of Aeronautics and Astronautics  
Massachusetts Institute of Technology

## 1 Objective

The objective of this Project Assignment is to determine the transonic effects on the wing root airfoil section of the BWB using a two-dimensional compressible Euler Computational Fluid Dynamics (CFD) method.

## 2 Two-dimensional Euler Solver

The two-dimensional Euler solver to be used for this assignment has been developed in the ACDL and is called **ProjectX**. The most important aspect of the solver the you most keep in mind is that you are using it to solve the 2-D compressible Euler equations. As a result, you will not be able to use it to estimate viscous drag contributions (i.e. skin friction or pressure drag) nor will you be able to use it to estimate three-dimensional effects (i.e. induced drag). Any drag you find will be due to one of two effects: (1) wave drag, or (2) discretization error. The discretization error arises because we are finding an approximate solution to the Euler equations and in general this means the CFD solution will have an error which tends to produce drag. The hope is that the drag due to discretization error is small and that wave drag will dominate.

Instructions for using **ProjectX** are available on the MIT Server.

## 3 Required Tasks

Note: the points for each of the tasks is given with each item.

- **(40 pts)** Use **ProjectX** to estimate the lift and drag coefficient for  $M_\infty = 0.3, 0.5, 0.7, 0.8, 0.85, 0.9,$  and  $0.95$ . Plot  $c_l$  and  $c_d$  versus  $M_\infty$ .
- **(15 pts)** Comment on the behavior of the lift and drag coefficients versus Mach number. Specifically, at what Mach number does the wave drag start to become significant?
- **(15 pts)** At low Mach numbers (before the appearance of shock waves), the drag should be zero when simulating the 2-D Euler equations yet you will find it is not quite zero. To see how large the error is, compare it to the skin friction drag coefficient for the airfoil. Specifically, estimate the skin friction drag coefficient for this airfoil at  $M_\infty = 0.3$  at the cruise altitude (note that the chord of this airfoil is 144.4 feet). How does the 2-D Euler  $c_d$  (from **ProjectX**) compare to this skin friction drag estimate (i.e. is it small)?

- (15 pts) For  $M_\infty = 0.85$  and  $0.95$ , include a plot of the Mach contours. Be sure to zoom in around the airfoil to see the solution behavior (in particular the location of any shocks waves). Describe the flow features, in particular any shocks.
- (15 pts) In the lecture notes, the following approximation was derived as a means to estimate the wave drag on a transonic airfoil,

$$c_{dw} \approx \frac{8}{3} \frac{\gamma}{(\gamma + 1)^2} \frac{(M_s^2 - 1)^3}{M_\infty^2} \frac{h_{s2}}{c}.$$

From the solution from the  $M_\infty = 0.85$  case, estimate  $M_s$  and  $h_{s2}/c$ , then use these estimates to estimate  $c_{dw}$ . How does this estimate compare to the **ProjectX** result?

### 3.1 Report Conventions

- Only one report is required for each team.
- Include a breakdown of how the work was accomplished between you and your partner.
- Both partners must sign the report.