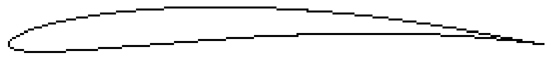
EAE 127 Project 1



Quasi – Joukowski Airfoils

Fall 2009 Due Friday, 10/02 (Drop Box C)

The goal of this project is to understand the influence of the geometric parameters (**thickness**, **camber**, **incidence**) on the local coefficient of pressure C_p and on the global coefficients C_l and $C_{m,0}$ for a family of airfoils, using analytical inviscid flow results. Remember that the pressure coefficient is given by:

$$C_p = \frac{p - p_\infty}{0.5 \cdot \rho_\infty \cdot U^2} \qquad (1)$$

and can be expressed in terms of the velocity *V* via the Bernoulli equation. (One confusing aspect is that it is traditional to plot $-C_p(x)$ so that high pressure is negative and low pressure is positive).

The profile geometry of the Quasi-Joukowski airfoil is given in parametric form as

$$x = \frac{1}{2}(1 + \cos\Theta) \qquad -\pi \leq \Theta \leq \pi$$

$$z = \frac{1}{2}\left[\varepsilon(1 - \cos\Theta)\sin\Theta + \delta \cdot \sin^2\Theta\right] \qquad (2)$$

where

$\varepsilon = \frac{4}{3\sqrt{3}}\frac{em}{cm}$, $\delta = 2\frac{dm}{cm}$ are given in terms of the relative **thickness** $\frac{em}{cm}$ and **camber** $\frac{dm}{cm}$.

Note that a flat plate would correspond to $\frac{em}{cm}$ = $\frac{dm}{cm}$ = 0, and a parabolic cambered plate would have a given $dm \neq 0$ with $\frac{em}{cm}$ = 0.

Consider four airfoils (all with cm = *1* which amounts to making all lengths dimensionless with the airfoil chord); flat plate, parabolic cambered plate (dm ≅ *0.086*), symmetric Q-J airfoil (em ≅ *0.12*) and a cambered Q-J airfoil (em ≅ *0.12* , dm ≅ *0.086*).

1. Study of Exact Solution Using *qjairflow.f*

1.1 Keeping zero incidence, run the code *qjairflow.f* and plot the output files *qjairflow.cpu* and *qjairflow.cpo.* Compare the $C_p(x)$ plots, the C_l and $C_{m,0}$ coefficients you read on the screen and discuss the effect of thickness and camber on the pressure coefficient distributions and global results on the profiles (flat plate, thin parabolic plate, symmetric Q-J profile, cambered Q-J profile). To exit the code, when prompted for the Reynolds number, type zero.

1.2 The exact lift and moment coefficients are given by

$$C_l(\alpha) = 2\pi[(1+\varepsilon)\sin\alpha + \delta\cos\alpha]$$

$$C_{m,0}(\alpha) = -\frac{\pi}{2}[(1+\varepsilon)\cos\alpha\sin\alpha + 2\delta] \tag{3}$$

Plot these coefficients for all 4 types of airfoils over a range of –12° to 12° incidence and discuss how they compare with the "small disturbance" coefficients, $C_{l,sd}(\alpha)$ and $C_{m,0,sd}(\alpha)$ that you read on the screen. The "small disturbance" result correspond to $\left|\frac{em}{cm}\right|, \left|\frac{dm}{cm}\right|, |\alpha| << 1$.

Compare and discuss your results C_l versus α over the same range of incidences for the cambered Q-J airfoil with the well-known Selig 1223 profile results, obtained with the XFOIL code (Dr. Mark Drela, MIT) at Reynolds number *Re=200,000*. The latter include viscous effects and is often used in the SAE "Heavy Lift" competition, due to its high $C_{l\max}$ value of *2.1*. The results are found in the file *polarS1223-200.dat*.

2. Thin Airfoil Derivations

2.1 Derive the equation for the "small disturbance" pressure coefficient in terms of the small disturbance velocity field $V = (U+u, w)$, where $|u/U|$ and $|w/U| << 1$. (Hint: express the pressure coefficient in terms of the small disturbance velocity components and neglect second order terms.

Compare $-C_p(x)$ with $-C_{p,sd}(x)$ by plotting the file *qjairflow,cpusd* and *qjairflow.cposd* on the same graph with the exact C_p for each profile. Using again the small disturbance results, find the coefficients $\frac{dC_l}{d\alpha}$ (lift slope), C_{l0}, $\frac{dC_{m,0}}{d\alpha}$ (moment slope), $C_{m,00}$ for all 4 profiles, where the linearized C_l and $C_{m,0}$ are written as

$$C_l = \frac{dC_l}{d\alpha}\alpha + C_{l0}$$

$$C_{m,0} = \frac{dC_{m,0}}{d\alpha}\alpha + C_{m,00} \qquad (4)$$

2.2 Find the location of the aerodynamic center x_{ac}/cm of the airfoils (small disturbance), given that $\frac{dC_{m,ac}}{d\alpha} = 0$. Use the change of moment formula:

$$C_{m,A} = C_{m,B} + \frac{x_A - x_B}{cm} C_l \qquad (5)$$