Subsonic Airfoils

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Configuration Aerodynamics Class
**Typical Subsonic Methods: Panel Methods**

- For subsonic inviscid flow, the flowfield can be found by solving an integral equation for the potential on the surface.
- This is done assuming a distribution of singularities along the surface, and finding the “strengths” of the singularities.
- The airfoil is represented by a series of (typically) straight line segments between “nodes”, and the nonpenetration boundary condition is typically satisfied at control points.
- Some version of a Kutta condition is required to close the system of equations.
Comparison of Panel Method Pressure Distribution with Exact Conformal Transformation Results

\[ C_p \]

\[ \frac{x}{c} \]
Convergence with increasing numbers of panels

NACA 0012 Airfoil, $\alpha = 8^\circ$
A better way to examine convergence: Lift

NACA 0012 Airfoil, $\alpha = 8^\circ$
Convergence with Panels: Moment

NACA 0012 Airfoil, $\alpha = 8^\circ$
Convergence with Panels: Drag

NACA 0012 Airfoil, $\alpha = 8^\circ$
Pressures: 20 and 60 panels

NACA 0012 airfoil, $\alpha = 8^\circ$
Pressures: 60 and 100 panels

NACA 0012 airfoil, $\alpha = 8^\circ$
Comparison with WT Data: Lift
- recall: panel methods are inviscid!
Comparison with Data: Pitching Moment
- about the quarter chord -

\[ C_{m_c/4} \]

NACA 0012
NACA 4412

\[ \alpha \]
For Completeness: Drag Data

Effect of Camber

Re = 6 million

NACA 4412
NACA 0012

data from Abbott and von Doehhoff
Comparison with WT Pressure Distribution

$\alpha = 1.875^\circ$

$M = 0.191$

$Re = 720,000$

transition free

NACA 4412 airfoil

Predictions from PANEL

data from NACA R-646
XFOIL: the code for subsonic airfoils

- Panel Methods: Inviscid!
- Couple with a BL analysis to include viscous effects
- The single element viscous subsonic airfoil analysis method of choice: XFOIL
  - by Prof. Mark Drela at MIT
- Link available from my software site
Airfoil pressures: What to look for

NACA 0012 airfoil, $\alpha = 4^\circ$

- Expansion/recovery around leading edge (minimum pressure or max velocity, first appearance of sonic flow)
- Rapidly accelerating flow, favorable pressure gradient
- Upper surface pressure recovery (adverse pressure gradient)
- Lower surface
- Trailing edge pressure recovery
- Leading edge stagnation point
Effect of Angle of Attack

NACA 0012 airfoil
Inviscid calculation from PANEL

\( C_P \) vs. \( x/c \)

- \( \alpha = 0^\circ \)
- \( \alpha = 4 \)
- \( \alpha = 8 \)
Comparison of NACA 4-Digit Airfoils
0006, 0012, 0018
Thickness Effects on Airfoil Pressures
Zero Lift Case

Inviscid calculation from PANEL

C_p vs. x/c

- NACA 0006, $\alpha = 0^\circ$
- NACA 0012, $\alpha = 0^\circ$
- NACA 0018, $\alpha = 0^\circ$
Thickness Effects on Airfoil Pressures, $C_L = 0.48$

Inviscid calculation from PANEL

- NACA 0006, $\alpha = 4^\circ$
- NACA 0012, $\alpha = 4^\circ$
- NACA 0018, $\alpha = 4^\circ$
Comparison of NACA 4-Digit Airfoils
the 0012 and 4412

-0.30
-0.20
-0.10
-0.00
0.10
0.20
0.30
-0.1
0.1
0.3
0.5
0.7
0.9
1.1

NACA 0012 (max t/c = 12%)
NACA 4412 foil (max t/c = 12%)

y/c
x/c
Highly Cambered Airfoil Pressure Distribution
- NACA 4412 -

Inviscid calculation from PANEL

Note: For a comparison of cambered and uncambered pressure distributions at the same lift, see Fig. 18.
Camber Effects on Airfoil Pressures, $C_L = 0.48$

Inviscid calculation from PANEL

- NACA 0012, $\alpha = 4^\circ$
- NACA 4412, $\alpha = 0^\circ$
Camber Effects on Airfoil Pressures, $C_L = 0.96$

Inviscid calculations from PANEL

- **NACA 0012, $\alpha = 8^\circ$**
- **NACA 4412, $\alpha = 4^\circ$**
Camber Effects on Airfoil Pressures, $C_L = 1.43$

Inviscid calculations from PANEL

- NACA 0012, $\alpha = 12^\circ$
- NACA 4412, $\alpha = 8^\circ$
NACA 6712 Airfoil
- Heavy Aft Camber Geometry -
NACA 6712 Airfoil

- Heavy Aft Camber, Pressure Distribution -

Inviscid calculations from PANEL

\[ \alpha = -0.6 \ (C_L = 1.0) \]
Whitcomb GA(W)-1 Airfoil

Inviscid calculations from PANEL

GA(W)-1

$\alpha = 0^\circ$
Liebeck’s Hi-Lift Airfoil: Geometry and Lift  
- note shape of pressure recovery -

From R.T. Jones, *Wing Theory*

3.19a. Laminar rooftop airfoil, geometry and pressure distribution.

Liebeck’s Hi-Lift Airfoil: Drag

From Bertin, *Aerodynamics for Engineers*
Camberline Design: DesCam

\( \frac{(Z-Z_0)}{C} - \text{DesCam} \)

\( \frac{Z}{C} - \text{from Abbott & vonDoenhoff} \)

Design Chord Loading

\( \Delta C_p \)
Airfoil Selection

Issues:

• Cruise $C_L$, and $C_{L\text{max}}$, don’t forget $C_{m0}$
  -large LE radius?
  -Near parallel trailing edge closure
• Profile Drag: Laminar flow?
• Thickness for low weight and internal volume
• Tails: often symmetric, 6 series foils picked
To Conclude

You have the tools to do single element airfoil design