

Lesson 12 part 2

Implementation of Panel Methods

Worth the effort? Useful?

Yes. Valuable for initial sizing, $S+C$, etc. Any aircraft with poor aerodynamics at low Mach and no viscosity will be worse at high Mach and lower Re .

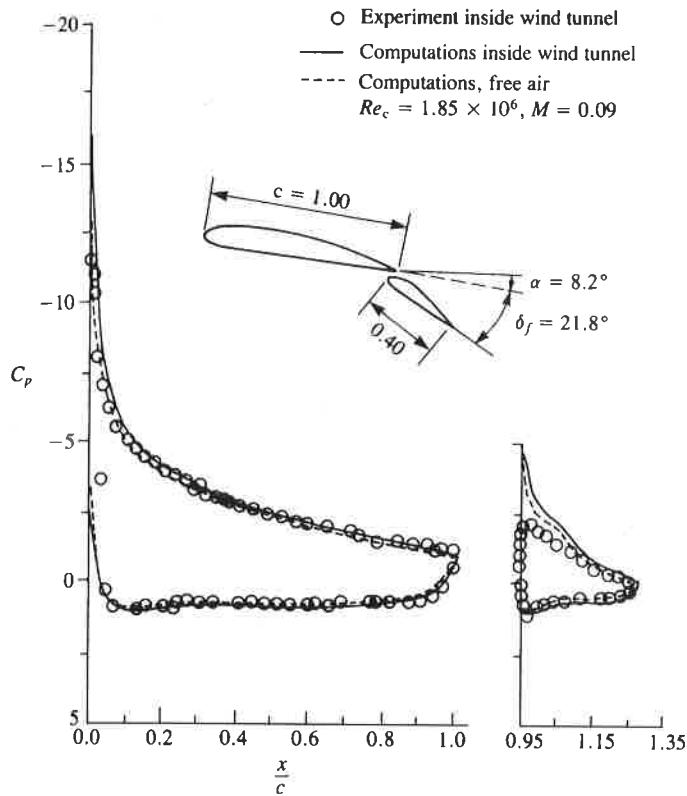


Figure 11.41 Two-dimensional experimental and computed (constant-source/doublet, with Dirichlet B.C.) chordwise pressure distribution on a NACA 4412 wing and a NACA 4415 flap (flap chord is 40% of wing chord). Experiments from Adair, D., and Horne, W. C., "Turbulent Separated Flow in the Vicinity of a Single-Slotted Airfoil Flap," *AIAA Paper 88-0613*, Jan. 1988.

Why might the flap C_p magnitude be lower in experiments when compared to inviscid?

Later, we will even study a method for predicting stall and $C_{p,\text{max}}$ from an inviscid C_p field. Foresighting that lesson, $C_{p,\text{crit}} \approx -13$ and strongly dependent on Re .

A primary source for implementing panel methods is

Low Speed Aerodynamics

by

Katz and Plotkin

ISBN 0-521-66219-2

This book includes

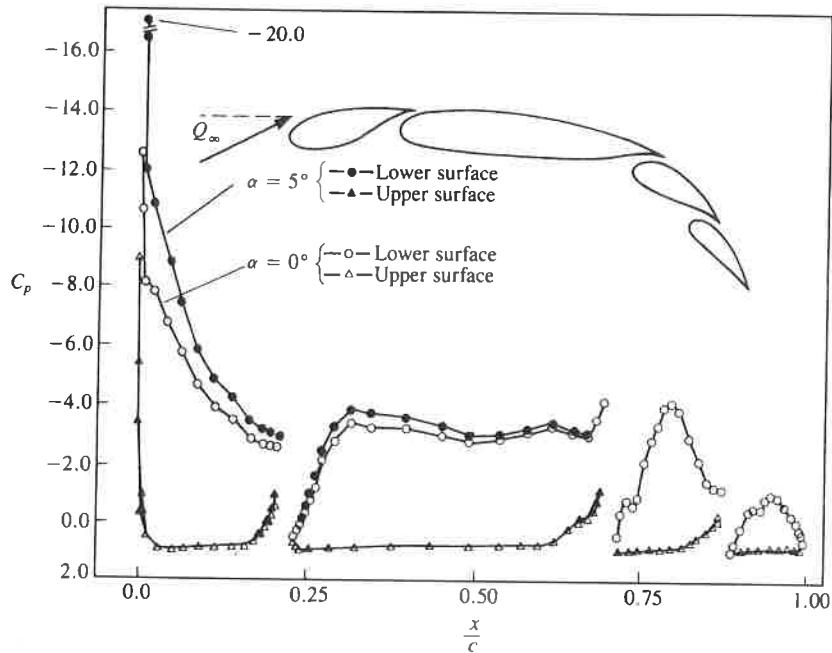
- 2D and 3D panel methods.
- Closed form integrals and perturbation velocities for different sheet and panel distributions.
- Implementation hints
- Unsteady panel methods.

From the previous lesson 12 part 1, the integrals are:

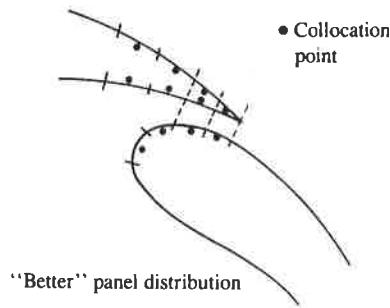
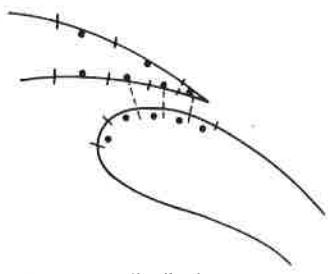
$$u_p = \frac{\gamma_0}{2\pi} \left[\tan^{-1} \frac{z}{x - x_2} - \tan^{-1} \frac{z}{x - x_1} \right] \quad (\text{panel coordinates}) \\ + \frac{\gamma_1}{4\pi} \left[z \ln \frac{(x - x_1)^2 + z^2}{(x - x_2)^2 + z^2} + 2x \left(\tan^{-1} \frac{z}{x - x_2} - \tan^{-1} \frac{z}{x - x_1} \right) \right] \quad (11.97)$$

$$w_p = -\frac{\gamma_0}{4\pi} \ln \frac{(x - x_1)^2 + z^2}{(x - x_2)^2 + z^2} \quad (\text{panel coordinates}) \\ - \frac{\gamma_1}{2\pi} \left[\frac{x}{2} \ln \frac{(x - x_1)^2 + z^2}{(x - x_2)^2 + z^2} + (x_1 - x_2) \right. \\ \left. + z \left(\tan^{-1} \frac{z}{x - x_2} - \tan^{-1} \frac{z}{x - x_1} \right) \right] \quad (11.98)$$

Panel methods are suited to multi-element experiments and intuition increasing configuration design



However, there are some issues to avoid.



Compared to full Computation Fluid Dynamics grids, these panel method restrictions and distributions are simple.

How sensitive are panel methods to missing, bad, or moved collocation boundary conditions?

The TE is where most problems appear.

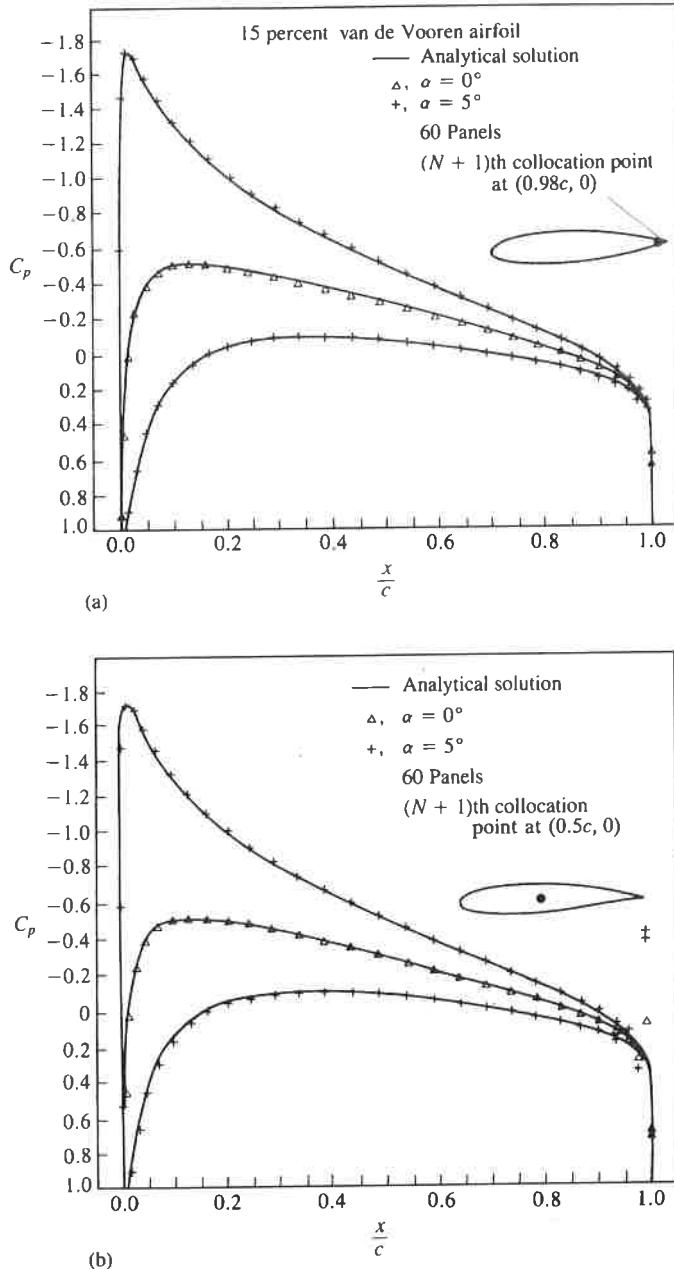
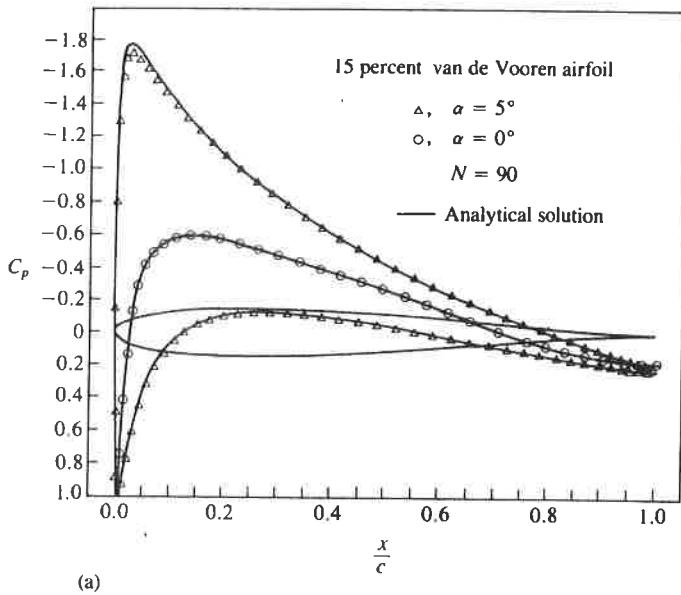
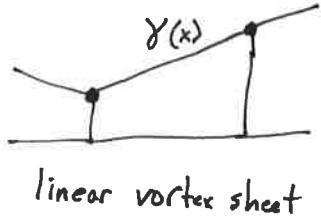
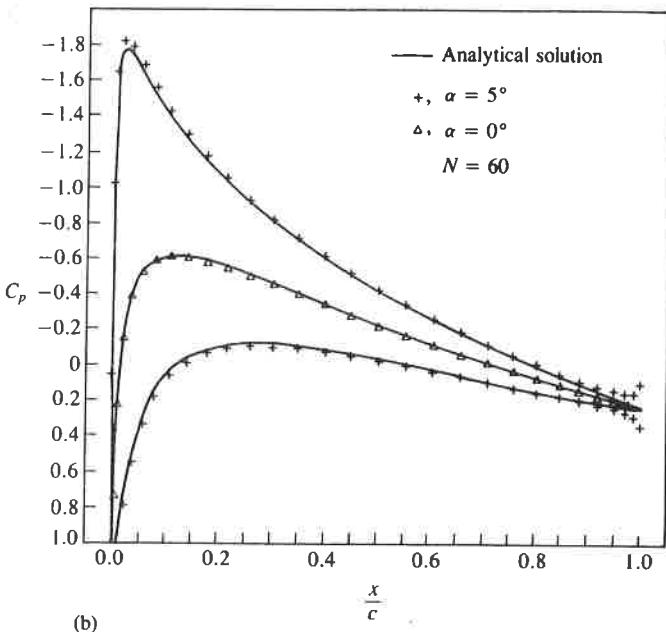
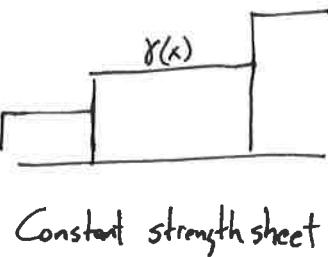


Figure 11.38 Effect of placing the $(N + 1)$ th collocation point inside the 15% thick van de Vooren airfoil (using a quadratic doublet method with the Dirichlet B.C.).

Cusped TEs have a history of causing pathological behavior with some lower order methods.



(a)

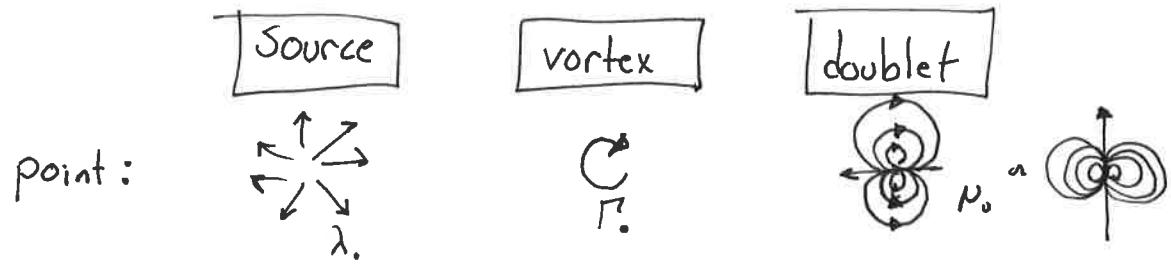


(b)

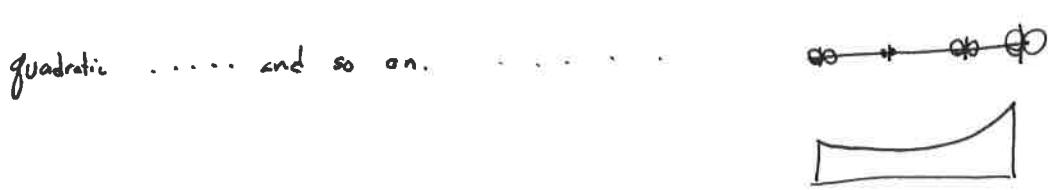
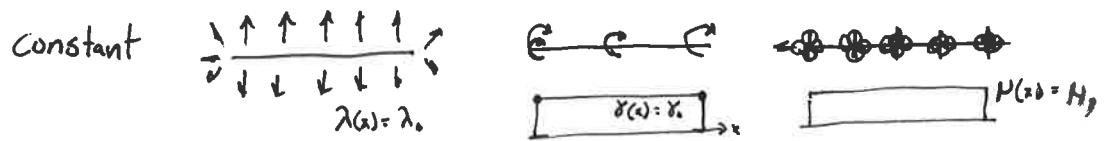
Figure 11.39 Pressure distribution on a cusped trailing edge 15%-thick van de Vooren airfoil using:
(a) linear vortex method with Neumann B.C., and (b) constant-strength source/doublet method with the Dirichlet B.C.

For a cusped trailing edge, use a linear strength vortex sheet and watch for poor behavior.

Classify panel methods



point:



The lower the order, the more singularities and non-natural perturbations show up.
Luckily, the far field flow is sufficient to determine what engineers typically need.

C_L, C_D, etc

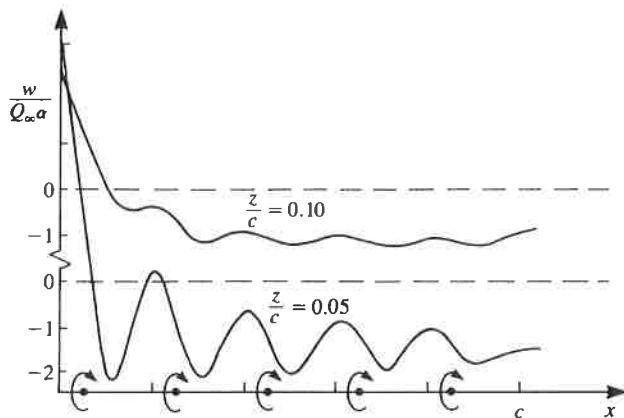


Figure 11.11 Survey of induced normal velocity above a thin airfoil (as shown in Fig. 11.4) modeled by discrete vortices.

Addendum to Lesson 10.

Moment:

$$\begin{aligned}
 (\epsilon c^2) C_{\frac{1}{4}} &= \int_0^c -\Delta C_p (x - \frac{1}{4}c) dx \approx \int_0^c -2 \frac{\gamma}{V_\infty} (x - \frac{1}{4}c) dx = \int_0^c -\frac{2\gamma}{V_\infty} (x - \frac{1}{4}c) dx \\
 &= \int_0^{\pi} -\frac{2\gamma}{V_\infty} \left(\frac{c}{2}(1-\cos\theta) - \frac{c}{4} \right) \frac{c}{2} \sin\theta d\theta \\
 &= -\frac{c^2}{4V_\infty} \int_0^{\pi} \frac{\gamma}{V_\infty} \left(\frac{1}{2} - \frac{\cos\theta}{2} - \frac{1}{4} \right) \sin\theta d\theta = -\frac{c^2}{V_\infty} \int_0^{\pi} \gamma \left(\frac{1}{4} - \frac{2\cos\theta}{8} \right) \sin\theta d\theta \\
 &= -\frac{c^2}{4V_\infty} \int \left(2A_0 \frac{1+\cos\theta}{\sin\theta} + 2 \sum_{n=1}^{\infty} A_n \sin n\theta \right) \sin\theta \cancel{d\theta} \left(\cancel{\frac{1}{8}} 1 - 2\cos\theta \right) d\theta \\
 &= -\frac{\pi c^2 (A_1 - A_2)}{4V_\infty}
 \end{aligned}$$

$$C^2 G_{\frac{1}{4}} = -\frac{\pi}{4} c^2 (A_1 - A_2) \Rightarrow \boxed{C_{\frac{1}{4}} = -\frac{\pi}{4} (A_1 - A_2)}$$

Exam #1 Review

Lessons 1 - 10

- Nomenclature
- Reference frames
- Molecular dynamics
- Ideal Gas (Temperature, sizes, equilibrium)
- Atmosphere (Composition, Compute properties, moisture, std atmosphere)
- Conservation Laws (Control volumes, mass, momentum, energy, state.
write out and simplify N.S terms.
Boundary conditions, Eulerian vs Lagrangian frame
Nondimensionalization)
- Vorticity ($\omega = \nabla \times \mathbf{V}$, transport, stretching,
- Isentropic flow (where is $\Delta S = 0$ valid?)
- Circulation ($\Gamma = - \iint \omega \cdot \hat{n} dA$, integral of vorticity
Irrotational flows and potential flows
Kelvin's theorem)
- Joukowski Airfoil (Transform, conceptual mapping, calculate $C_L, C_D, \text{etc.}$)
- Lumped models (vorticity \rightarrow vortex)
- XFOIL (concepts only, ~~no~~ no problems requiring computer)
- Thin Airfoil Theory (concepts, apply to shape, find shape)
- Compressible σ