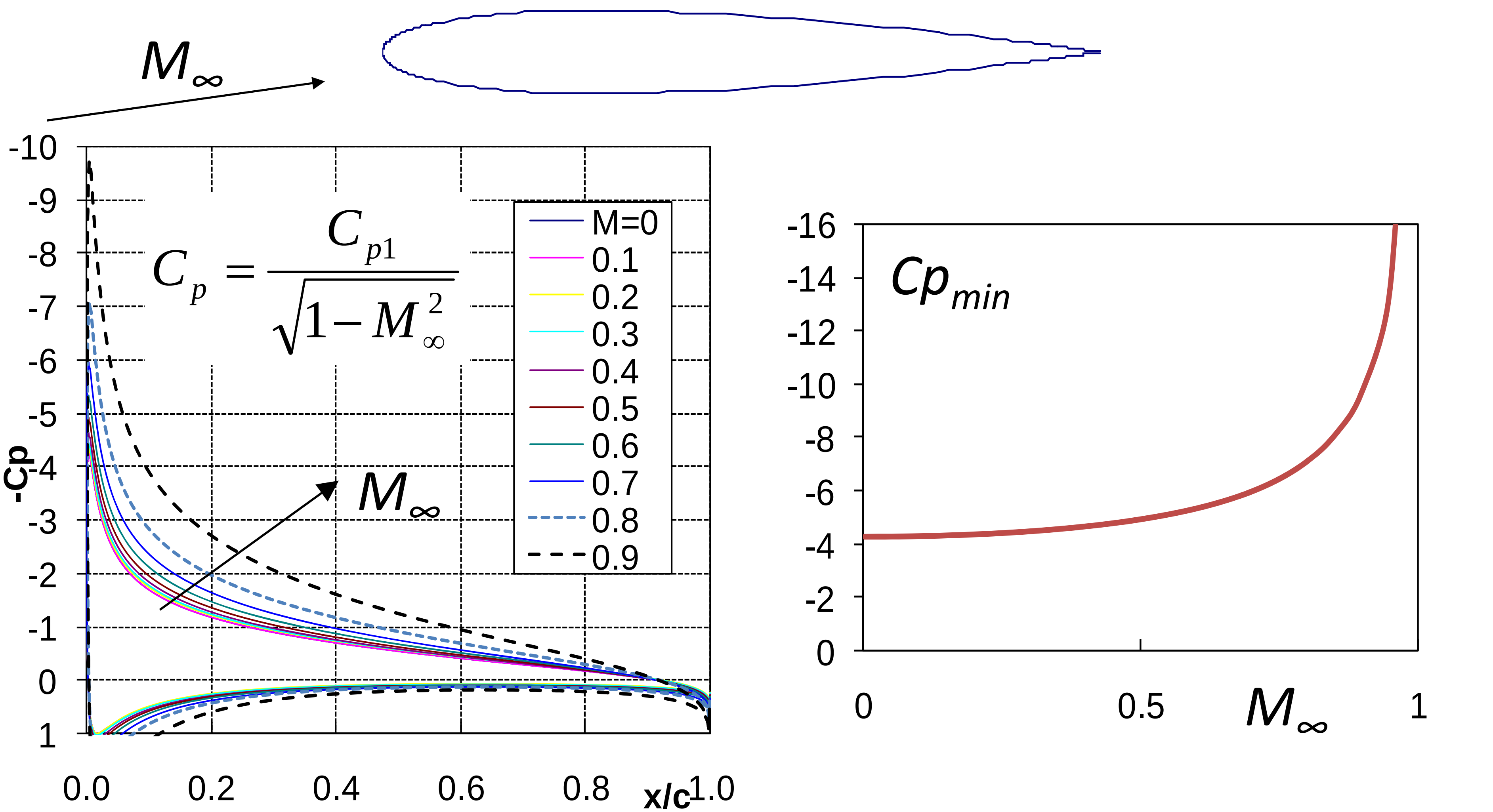
Transonic Aerodynamics

- Critical Pressure Coefficient and Critical Mach Number
- Drag Divergence
- Mitigating the Drag Problem
  - The supercritical airfoil
  - Sweep
  - The Area Rule

Limit of the Compressibility Correction

NACA 0012 AT 8 DEGREES



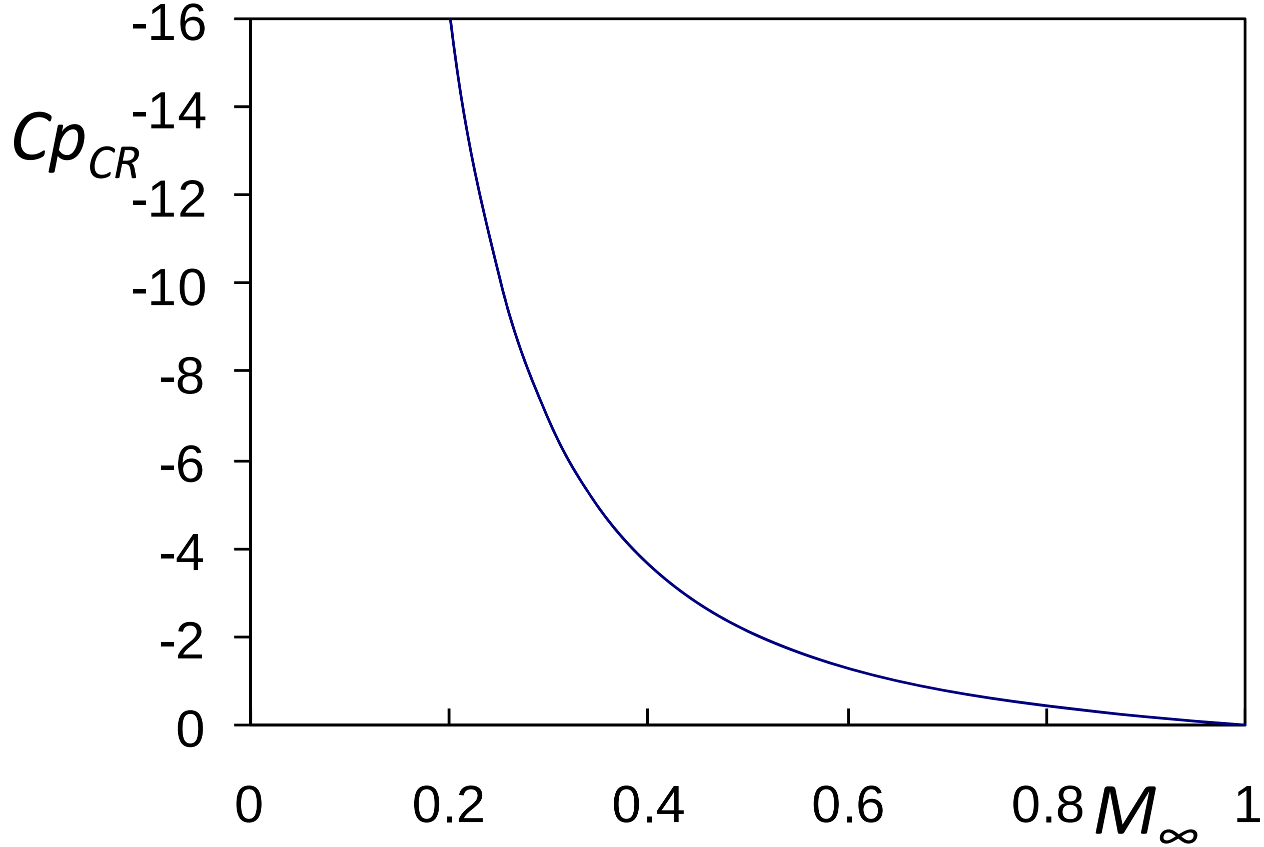
Critical Pressure Coefficient

PRESSURE COEFFIENT WHERE THE LOCAL MACH NUMBER IS 1

Critical Pressure Coefficient

PRESSURE COEFFIENT WHERE THE LOCAL MACH NUMBER IS 1

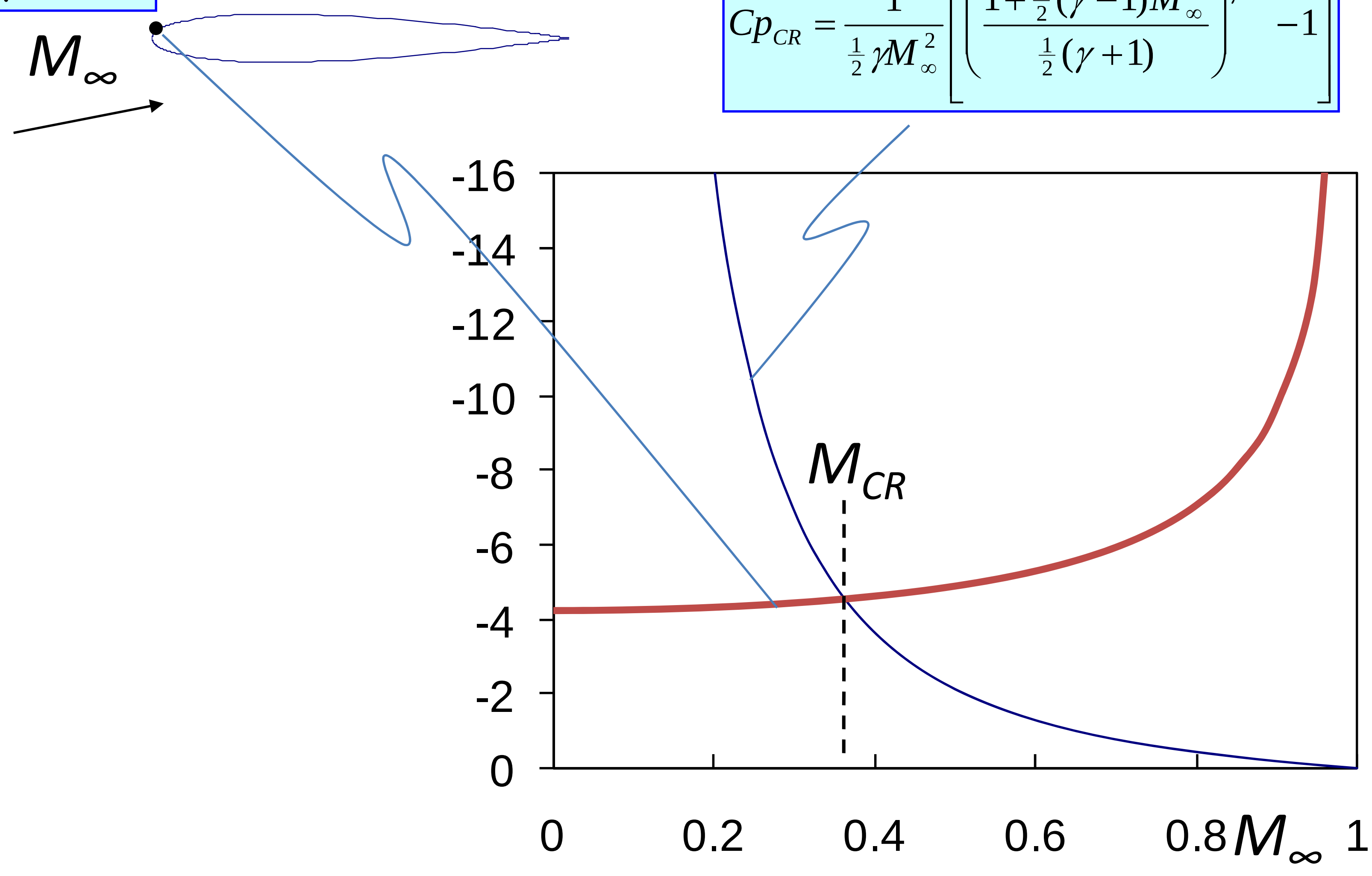
$$Cp_{CR} = \frac{1}{\frac{1}{2}\gamma M_\infty^2}\left[\left(\frac{1+\frac{1}{2}(\gamma-1)M_\infty^2}{\frac{1}{2}(\gamma+1)}\right)^{\frac{\gamma}{\gamma-1}} - 1\right]$$



Critical Mach Number

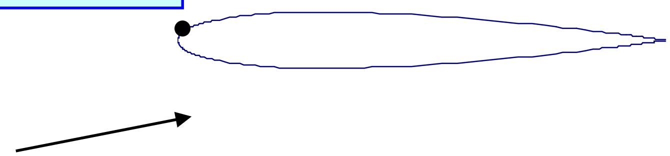
$$Cp_{\min} = \frac{Cp1_{\min}}{\sqrt{1-M_\infty^2}}$$

$$Cp_{CR} = \frac{1}{\frac{1}{2}\gamma M_\infty^2}\left[\left(\frac{1+\frac{1}{2}(\gamma-1)M_\infty^2}{\frac{1}{2}(\gamma+1)}\right)^{\frac{\gamma}{\gamma-1}} - 1\right]$$

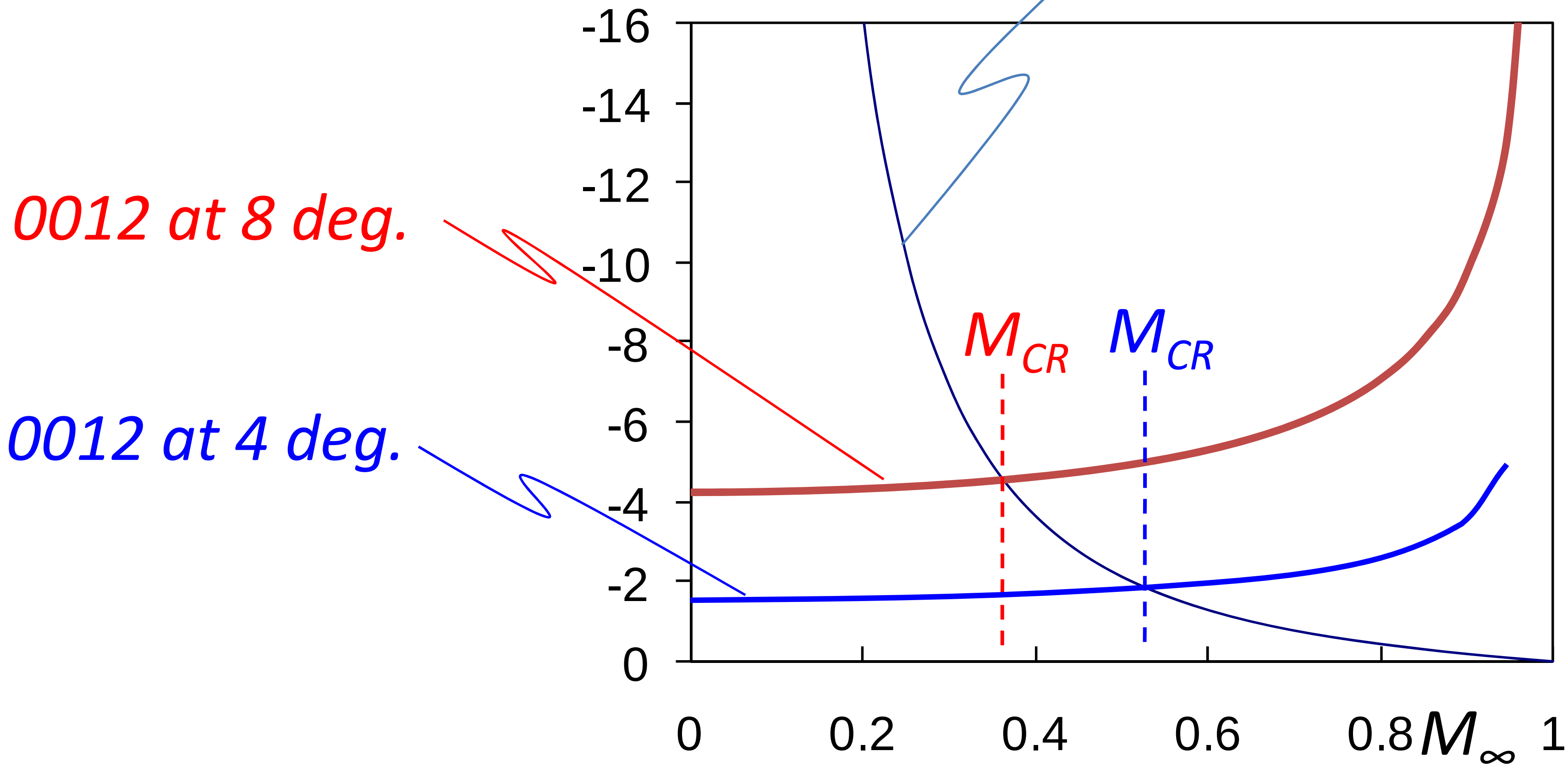


Critical Mach Number M_{CR}

$$Cp_{\min} = \frac{Cp1_{\min}}{\sqrt{1 - M_\infty^2}}$$

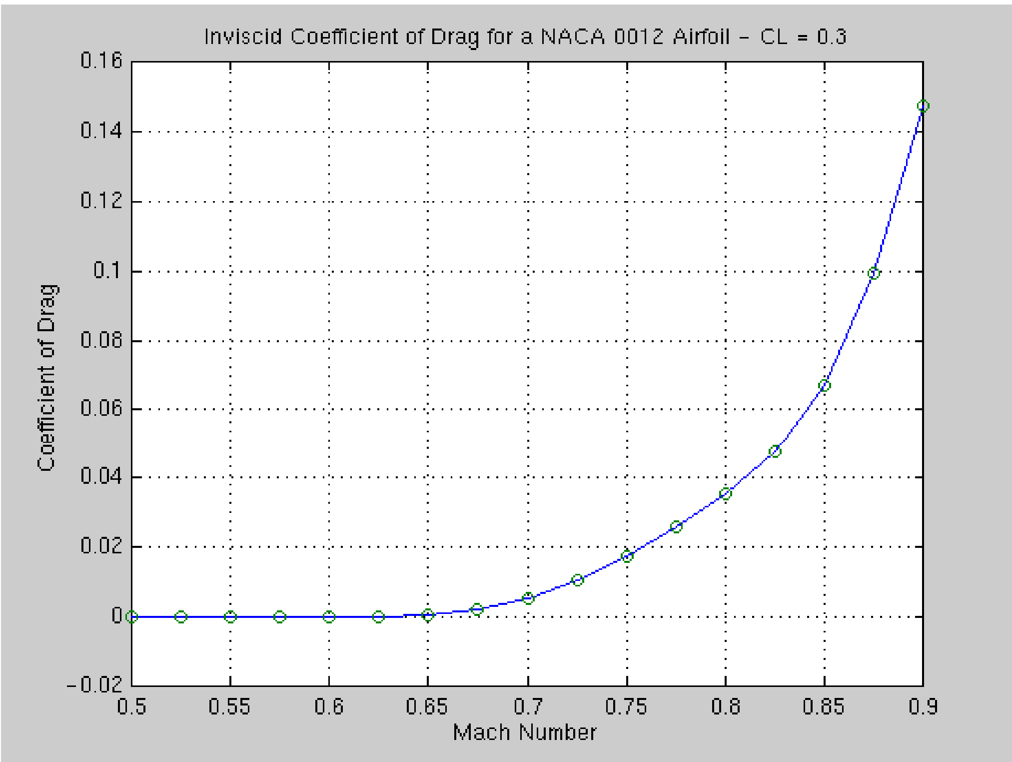


$$Cp_{CR} = \frac{1}{\frac{1}{2}\gamma M_\infty^2}\left[\left(\frac{1 + \frac{1}{2}(\gamma - 1)M_\infty^2}{\frac{1}{2}(\gamma + 1)}\right)^{\frac{\gamma}{\gamma - 1}} - 1\right]$$

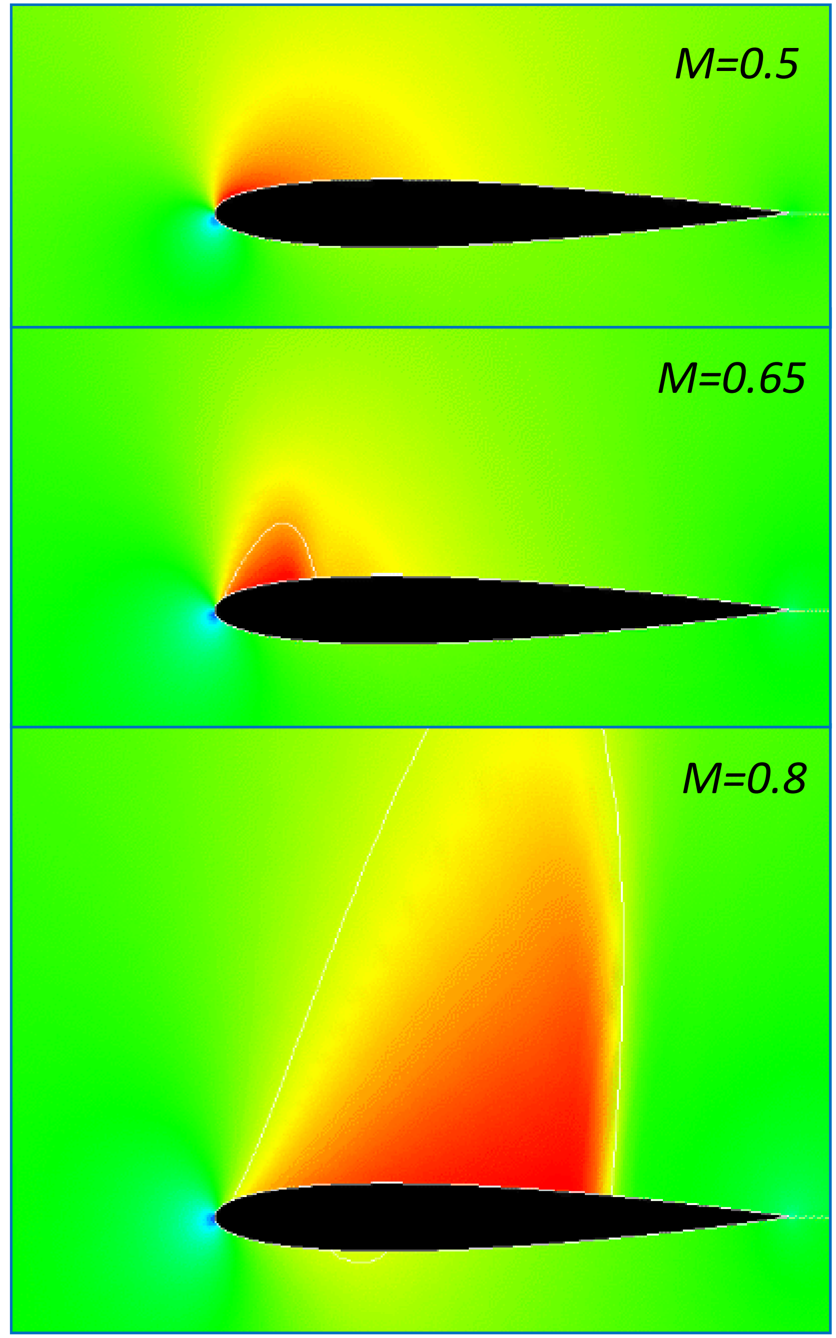


Drag Divergence

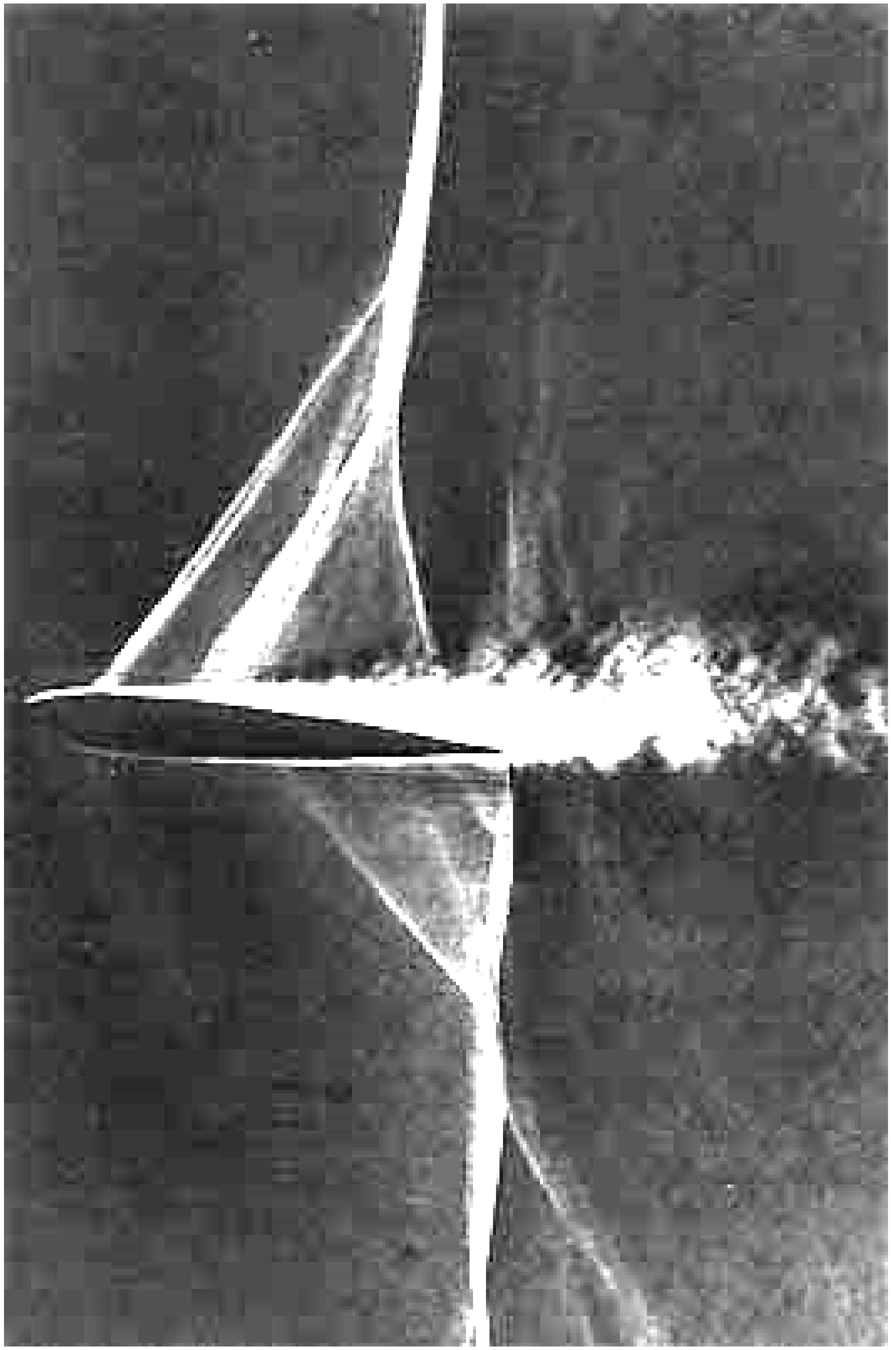
INVISCID CALCULATION



Ilan Kroo and J Alonso, Stanford University
http://adg.stanford.edu/aa241/drag/dragrise.html



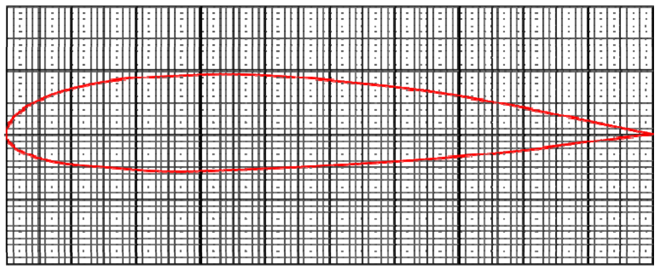
Shock Induced Separation

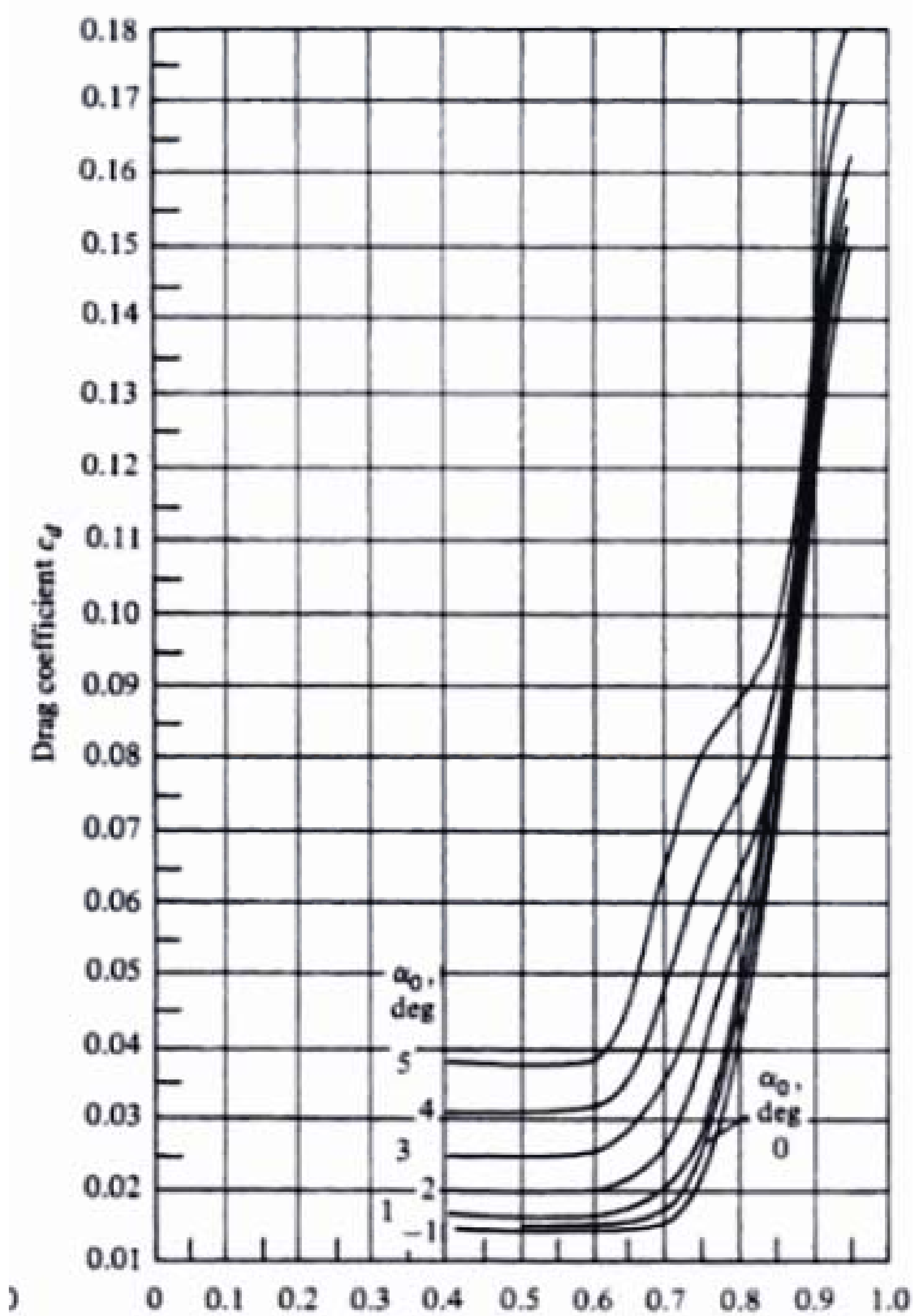


www.hq.nasa.gov/pao/History/SP-440/ch7-2.htm

Drag Divergence

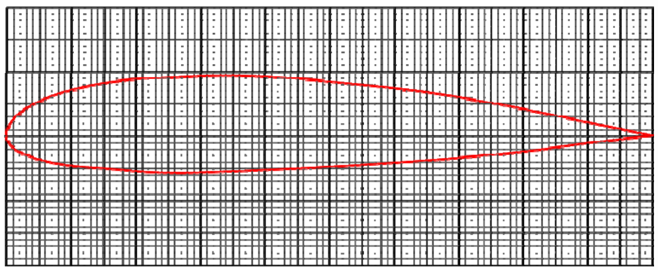
NACA 2315

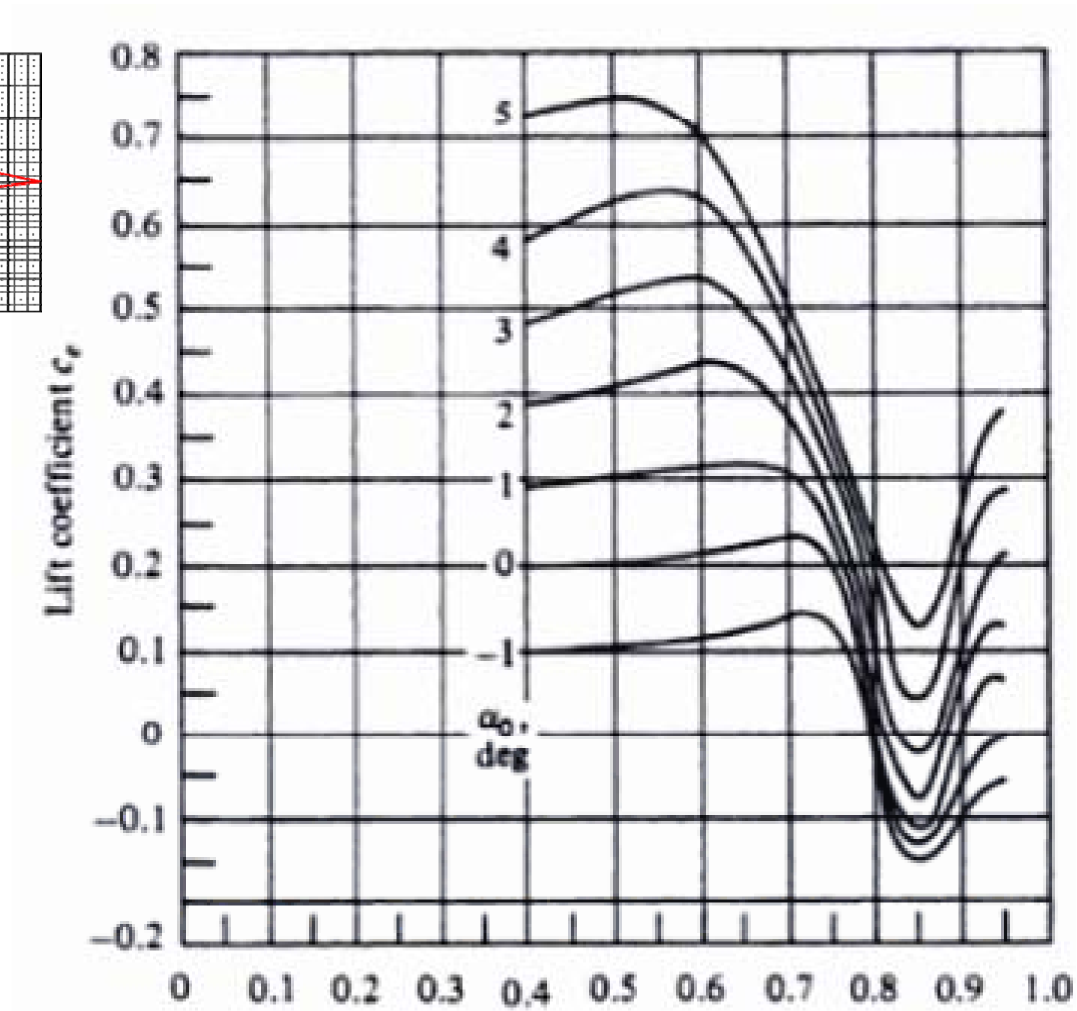




Effects on Lift

NACA 2315





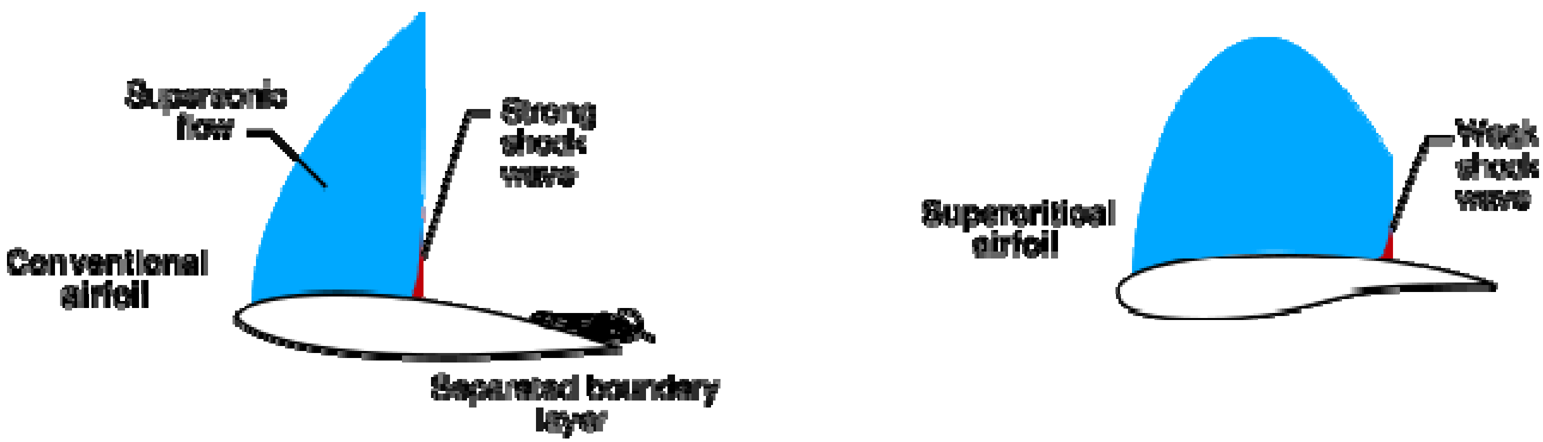
M_∞

Mitigating the Drag Problem

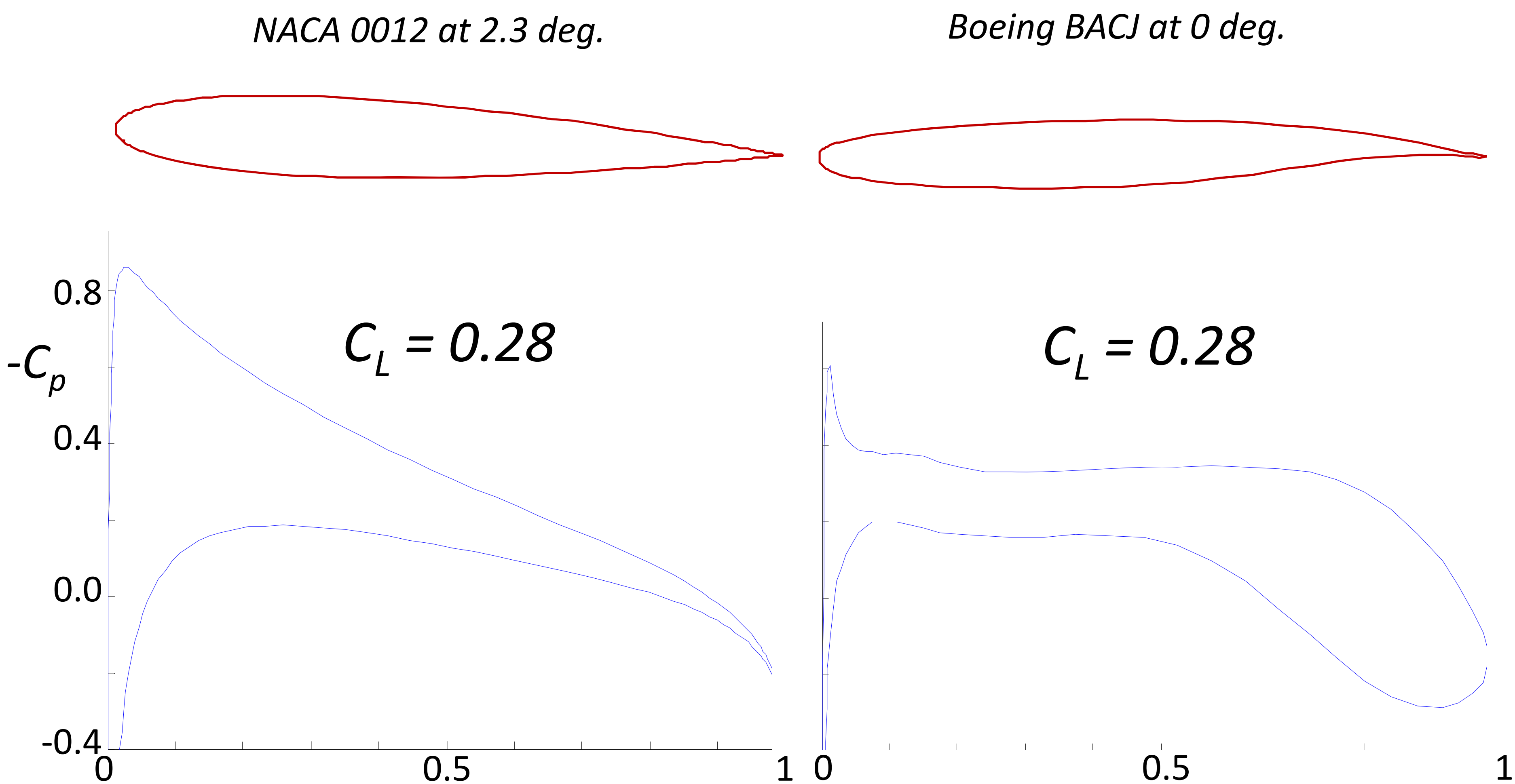
- The Supercritical Airfoil
- Sweep
- The Area Rule

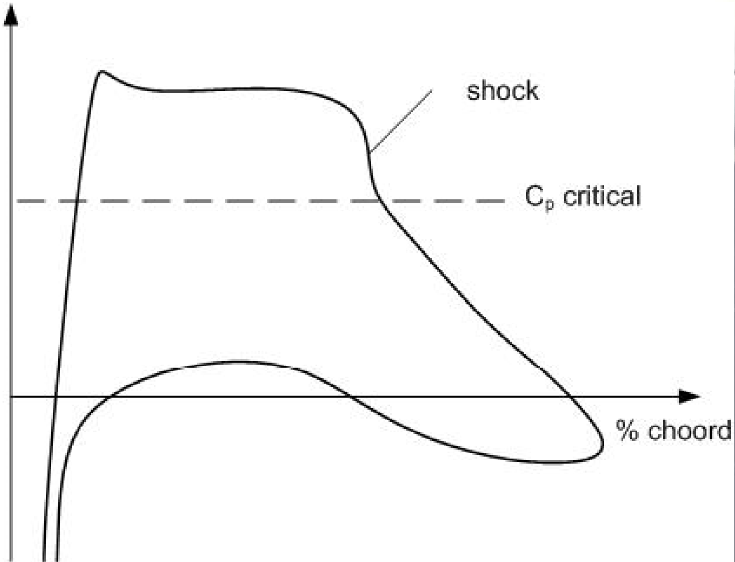
The Supercritical Airfoil

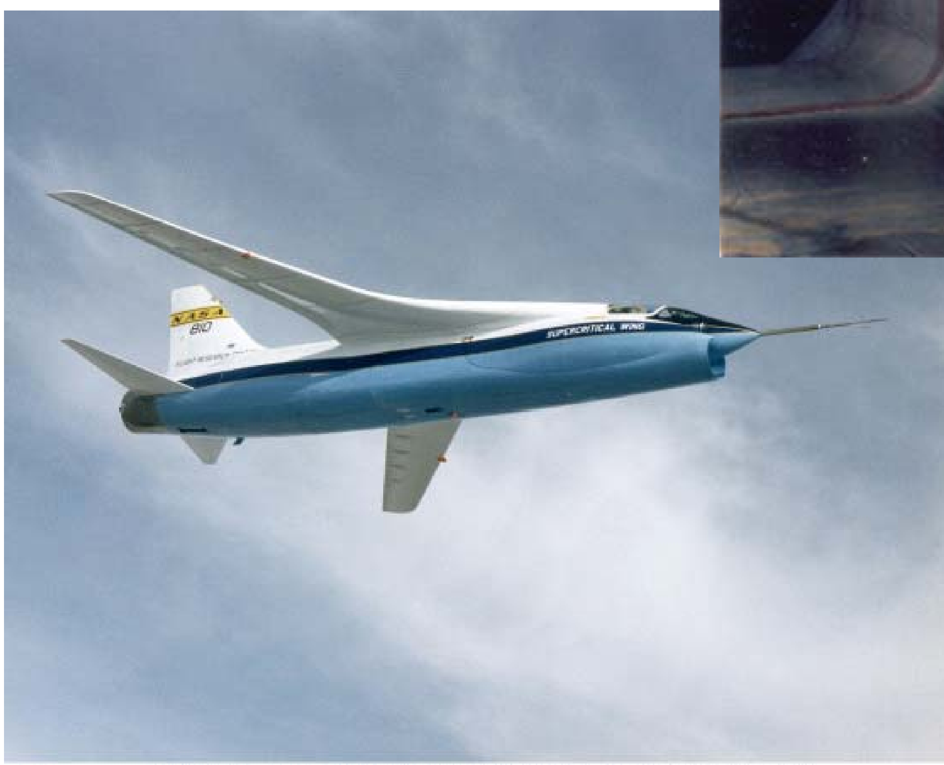
Designed to maximize M_{DIV}



Conventional vs. Supercritical



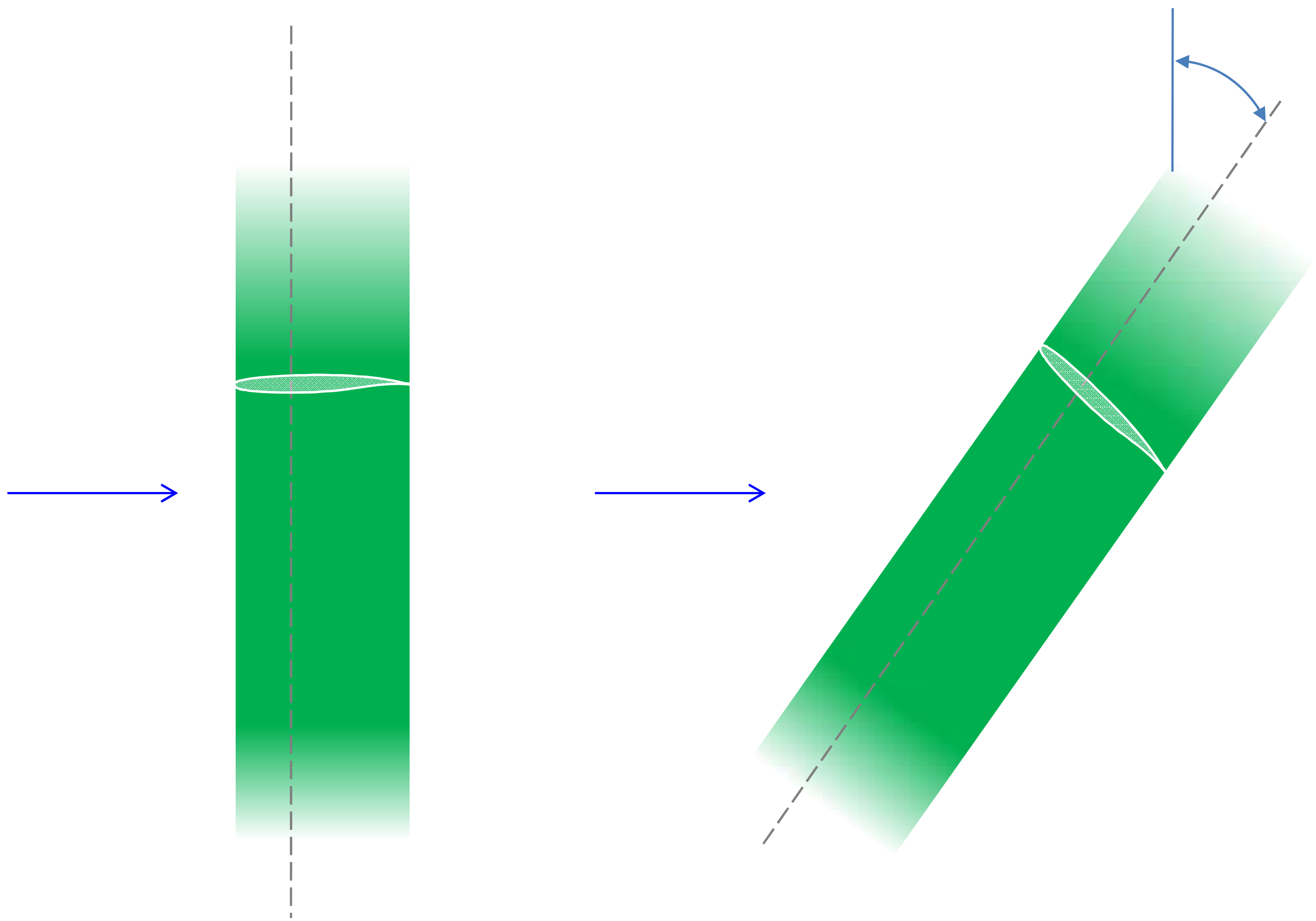




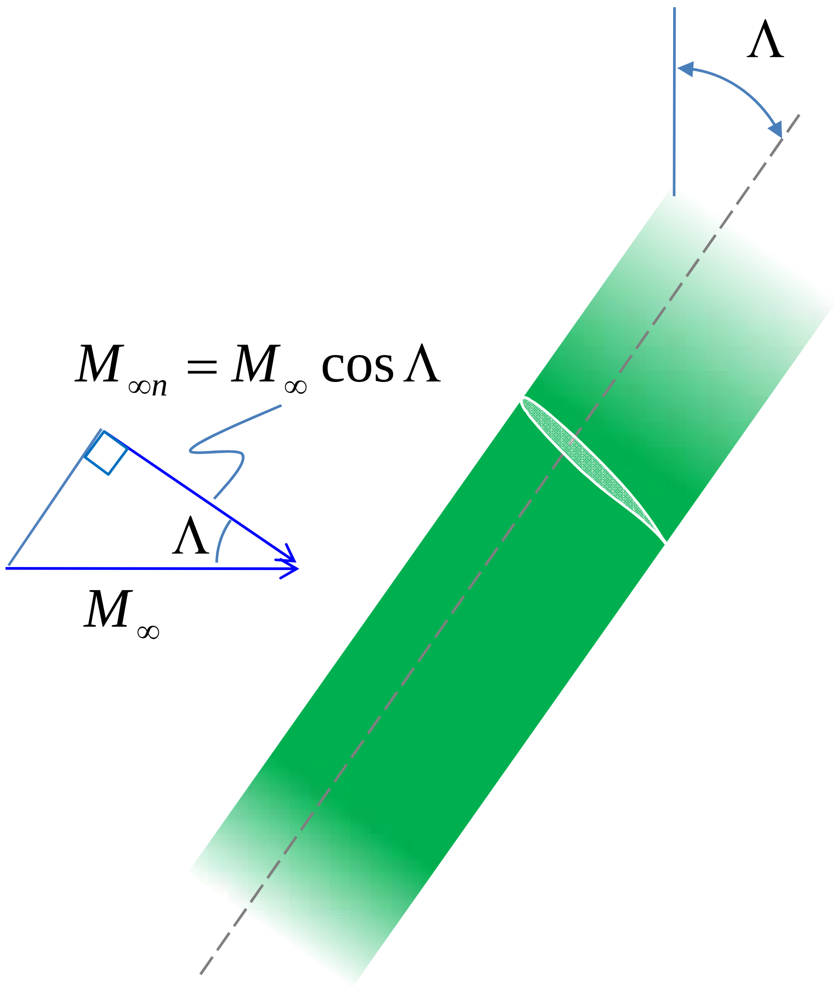
Dryden Flight Research Center E73-3468 Photographed 1973
F-8 modified with Supercritical Wing. NASA photo

http://oea.larc.nasa.gov/PAIS/Concept2Reality/supercritical.html

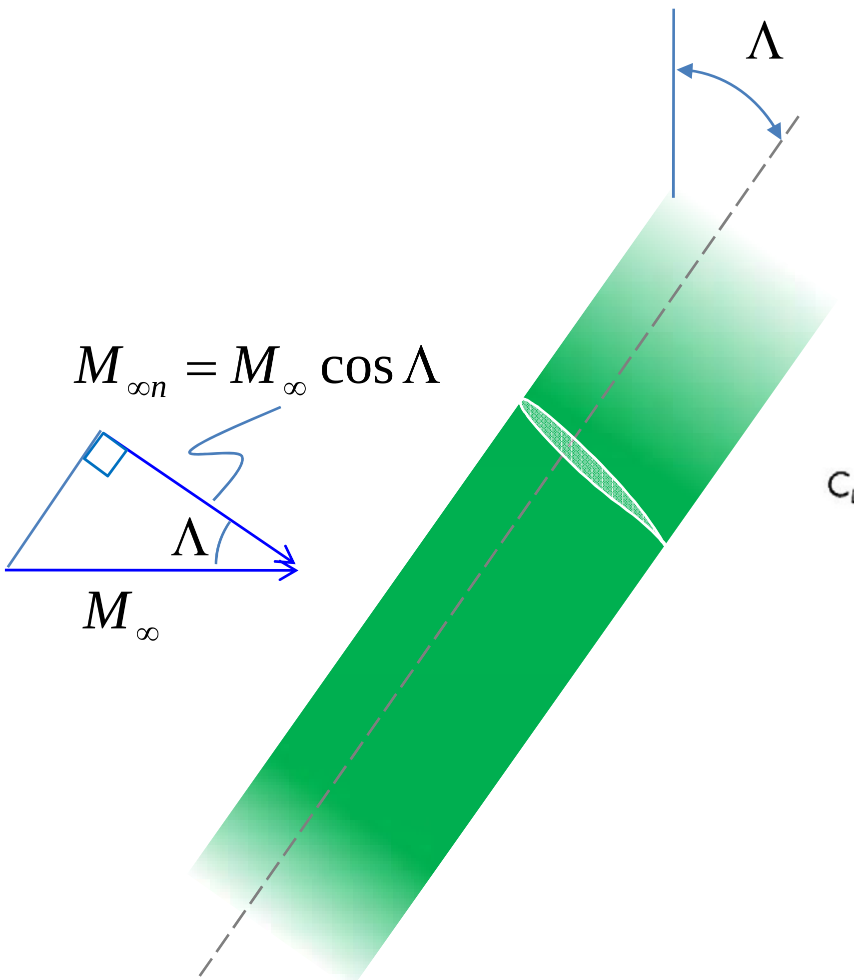
Sweep - The Independence Principle



Necessary Sweep Angle



Effects on Drag Divergence



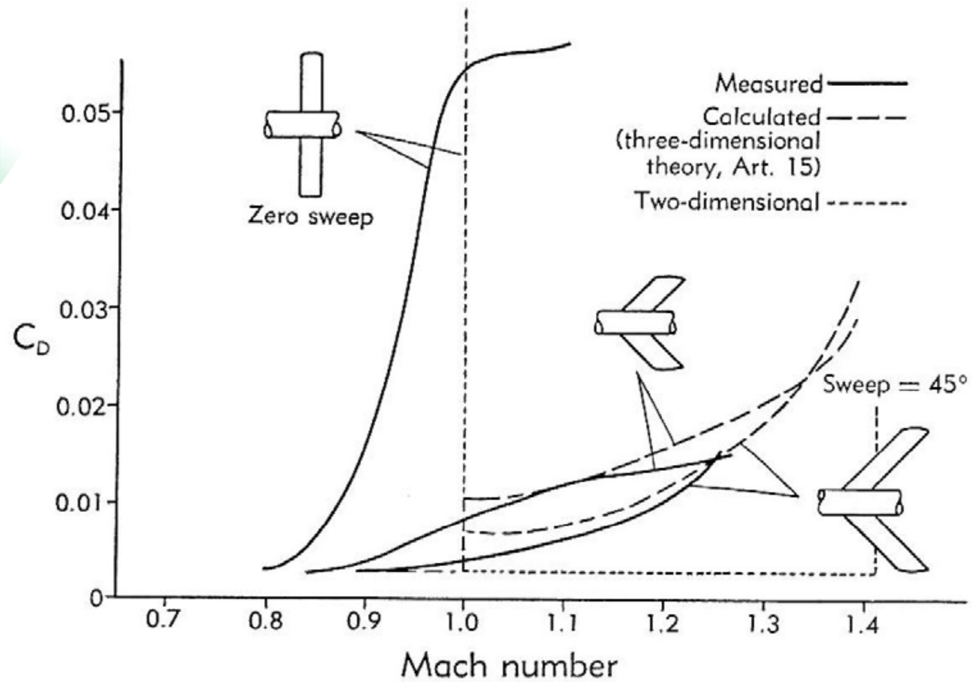
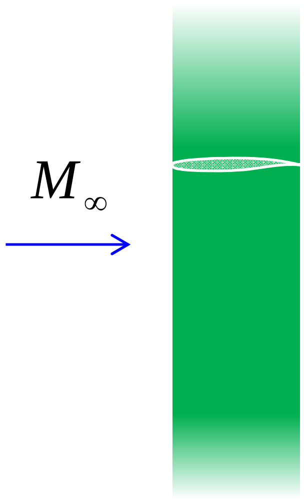
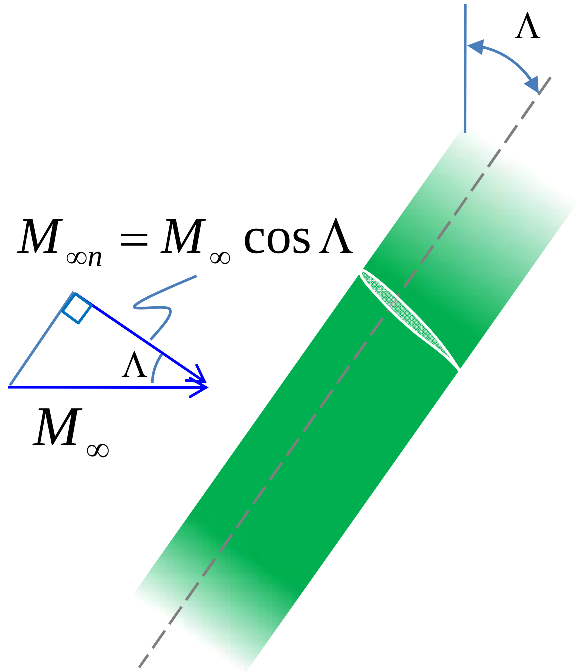


Fig. A,4d. Drag coefficients of straight and swept wings, determined in free-fall experiments.

R. T. Jones, *High Speed Wing Theory*, Princeton University Press, 1960

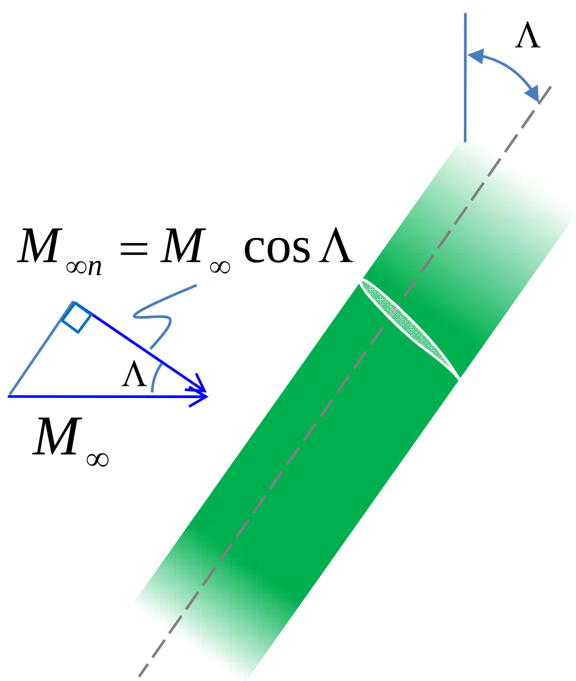
Effects on Lift

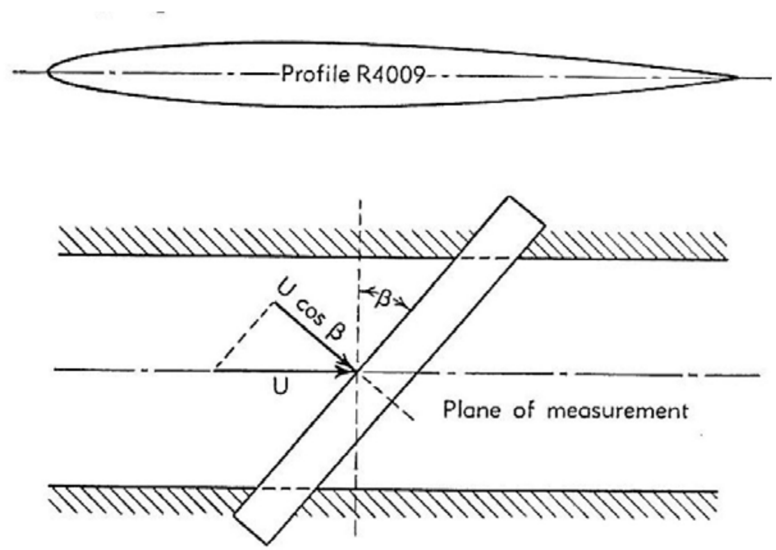




Effects on Lift

$$C_L = \frac{2\pi\alpha\cos^2\Lambda}{\sqrt{1-M_\infty^2\cos^2\Lambda}}$$





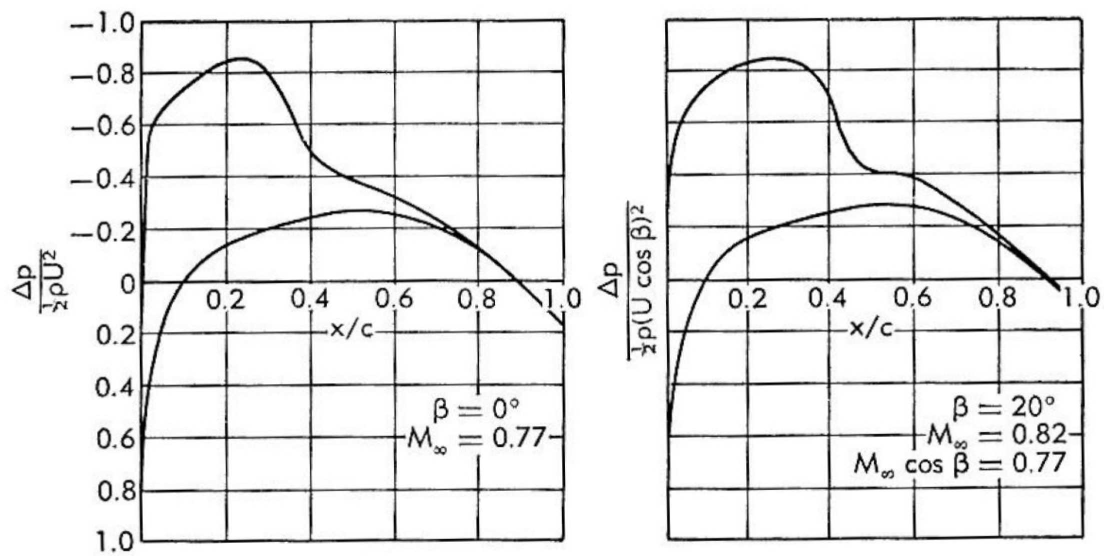
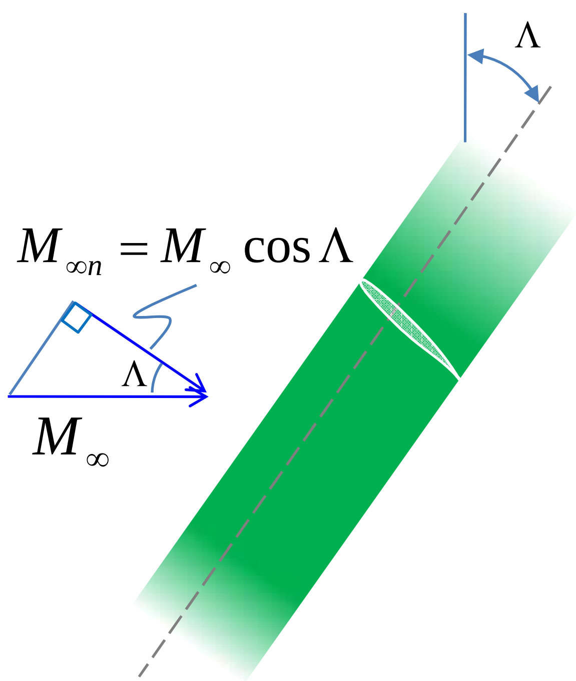


Fig. A,4g. Pressure distributions on oblique airfoil at $M_\infty \cos\beta = 0.77$.

R. T. Jones, *High Speed Wing Theory*,
Princeton University Press, 1960

Effects on Lift

$$C_L = \frac{2\pi\alpha\cos^2\Lambda}{\sqrt{1 - M_\infty^2\cos^2\Lambda}}$$



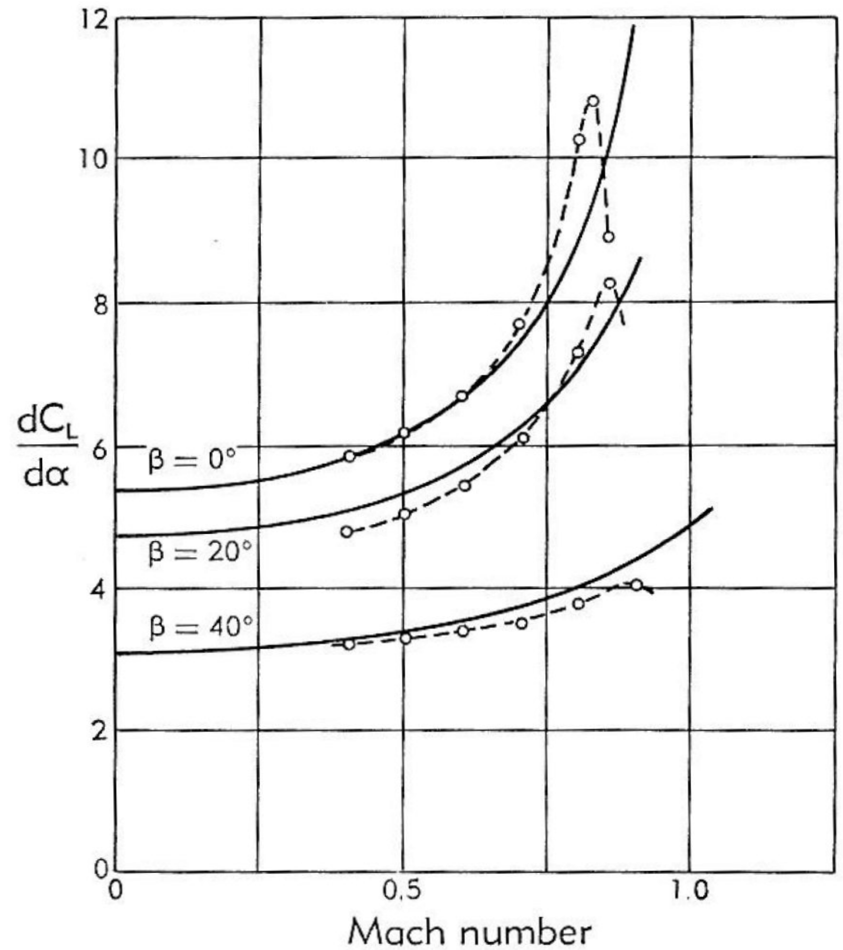
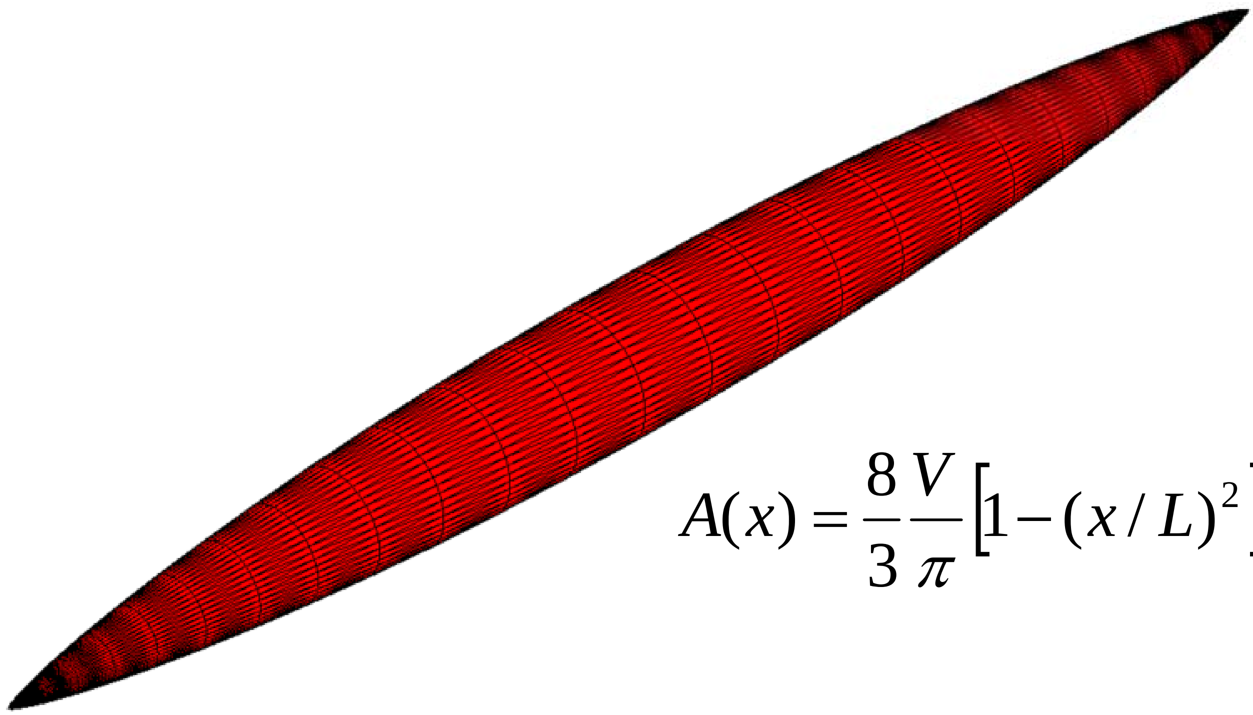


Fig. A,4h. Variation of lift curve slope with Mach number for oblique airfoils.

R. T. Jones, *High Speed Wing Theory*, Princeton University Press, 1960

The Area Rule

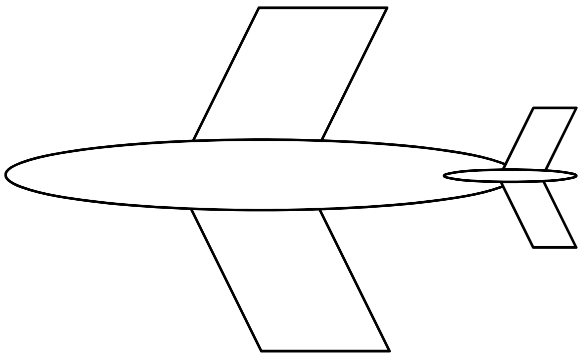
THE SEARS HAACK BODY

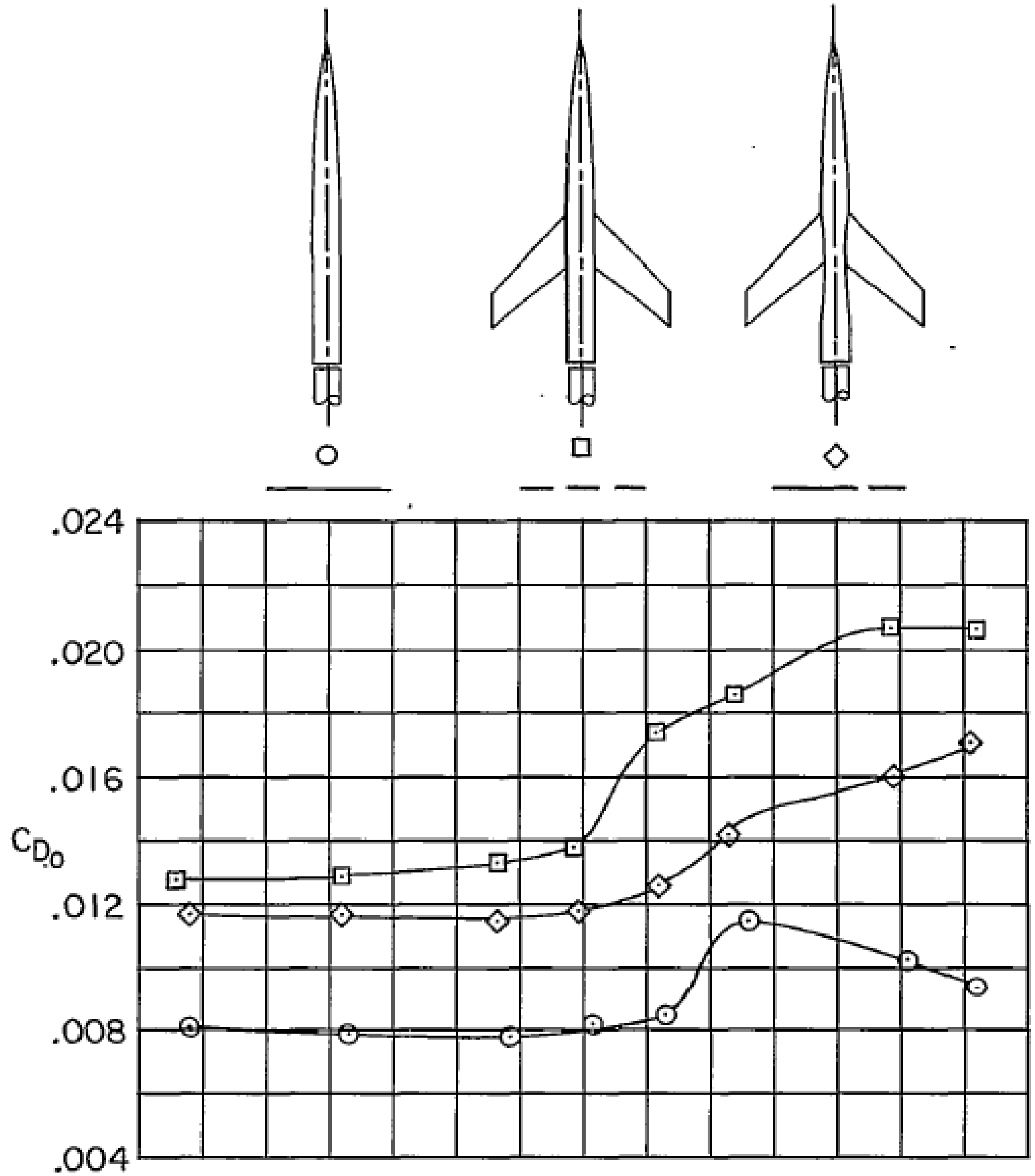


$$A(x) = \frac{8}{3}\frac{V}{\pi}\left[1 - (x/L)^2\right]^{3/2}$$

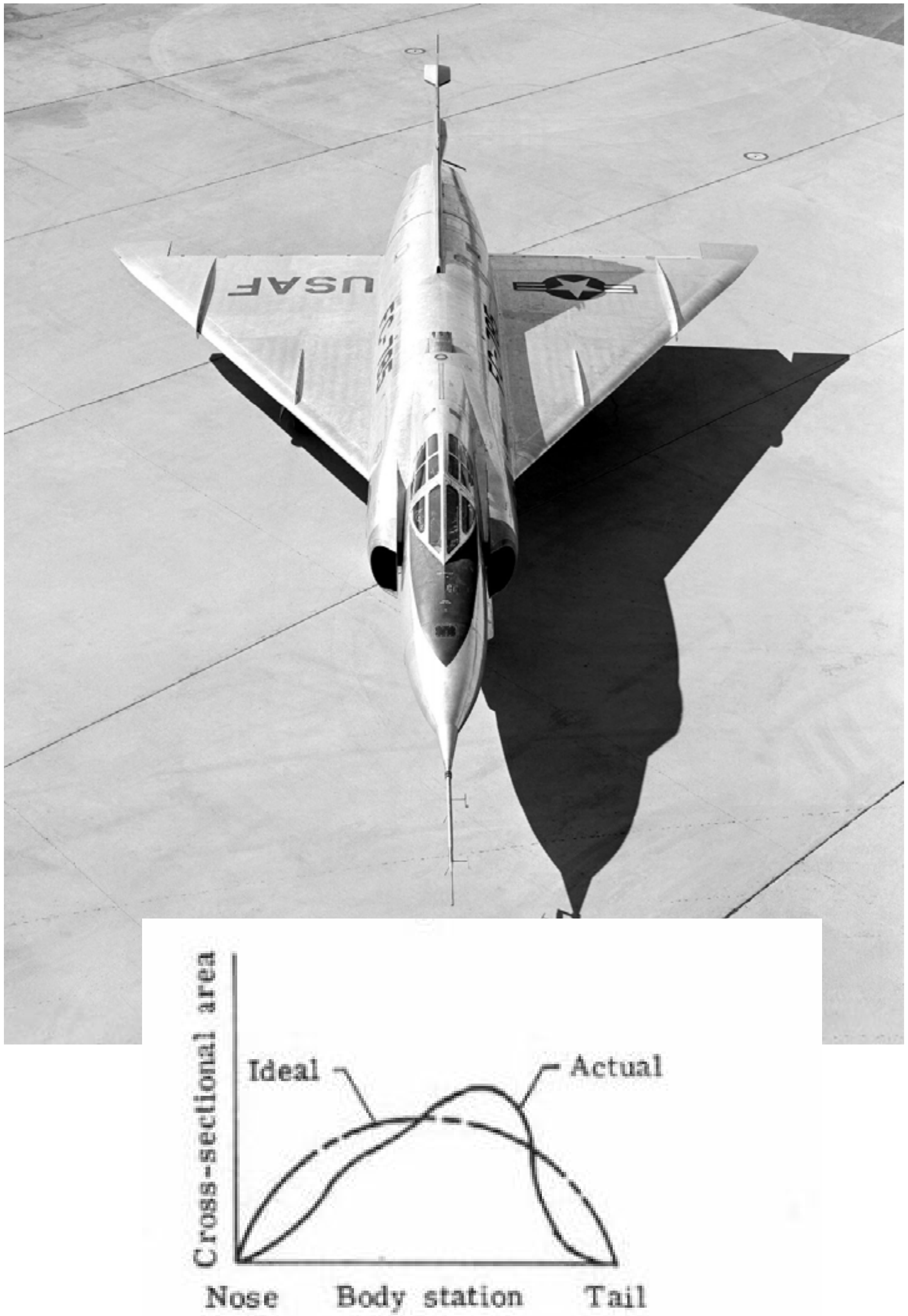
The Area Rule

WHITCOMB'S OBSERVATIONS

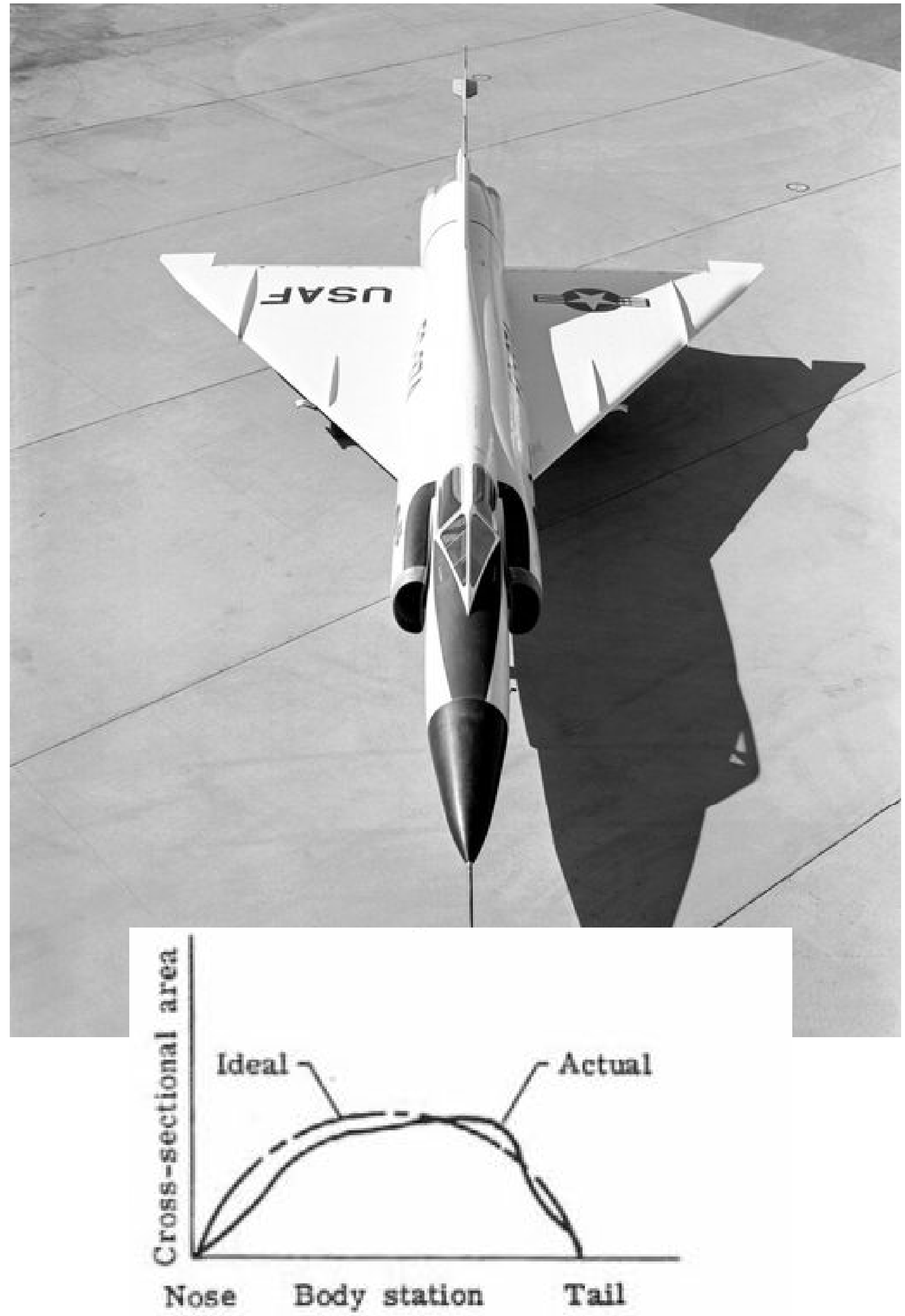




Whitcomb, R., 1952 *A Study of the Zero Lift Drag-Rise Characteristics of Wing Body Combinations Near the Speed of Sound*, NACA RM L52H08



(a) YF-102A before area ruling.



(b) F-102A after area ruling.

Boeing 747

747 200B (Air Force 1), Max Mach 0.89


747 400, Max Mach 0.92

Generalizing the Area Rule

- At supersonic Mach numbers the Area is measured along the Mach plane instead of perpendicular to the flight direction
- Optimal shapes for more general requirements (like finite base areas, area requirements at particular cross sections) are given by W.T. Lord and E. Eminton in "Slender Bodies of Minimum Wave Drag," *Journal of the Aeronautical Sciences*, August, 1954, pages 569-570. These have been programmed by Prof. Mason, see http://www.aoe.vt.edu/~mason/Mason_f/MRsoft.html#MINDRAG