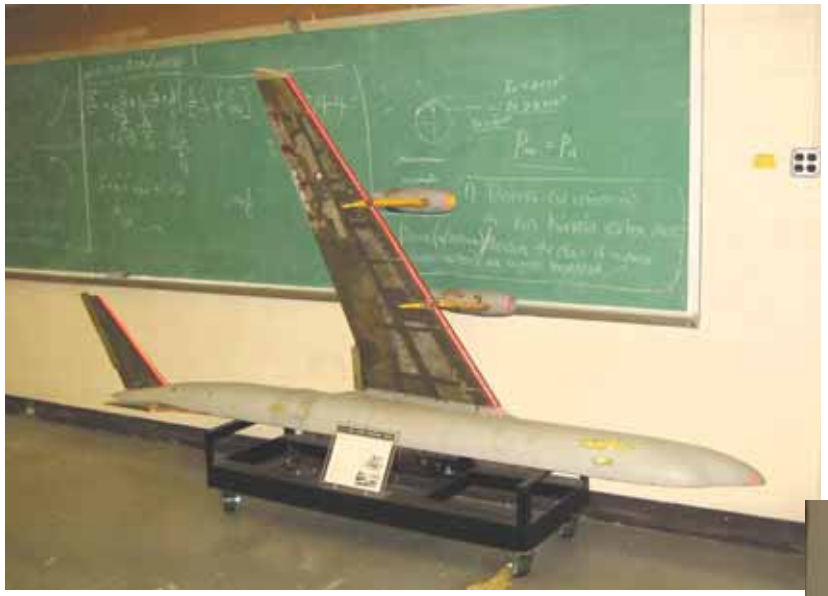
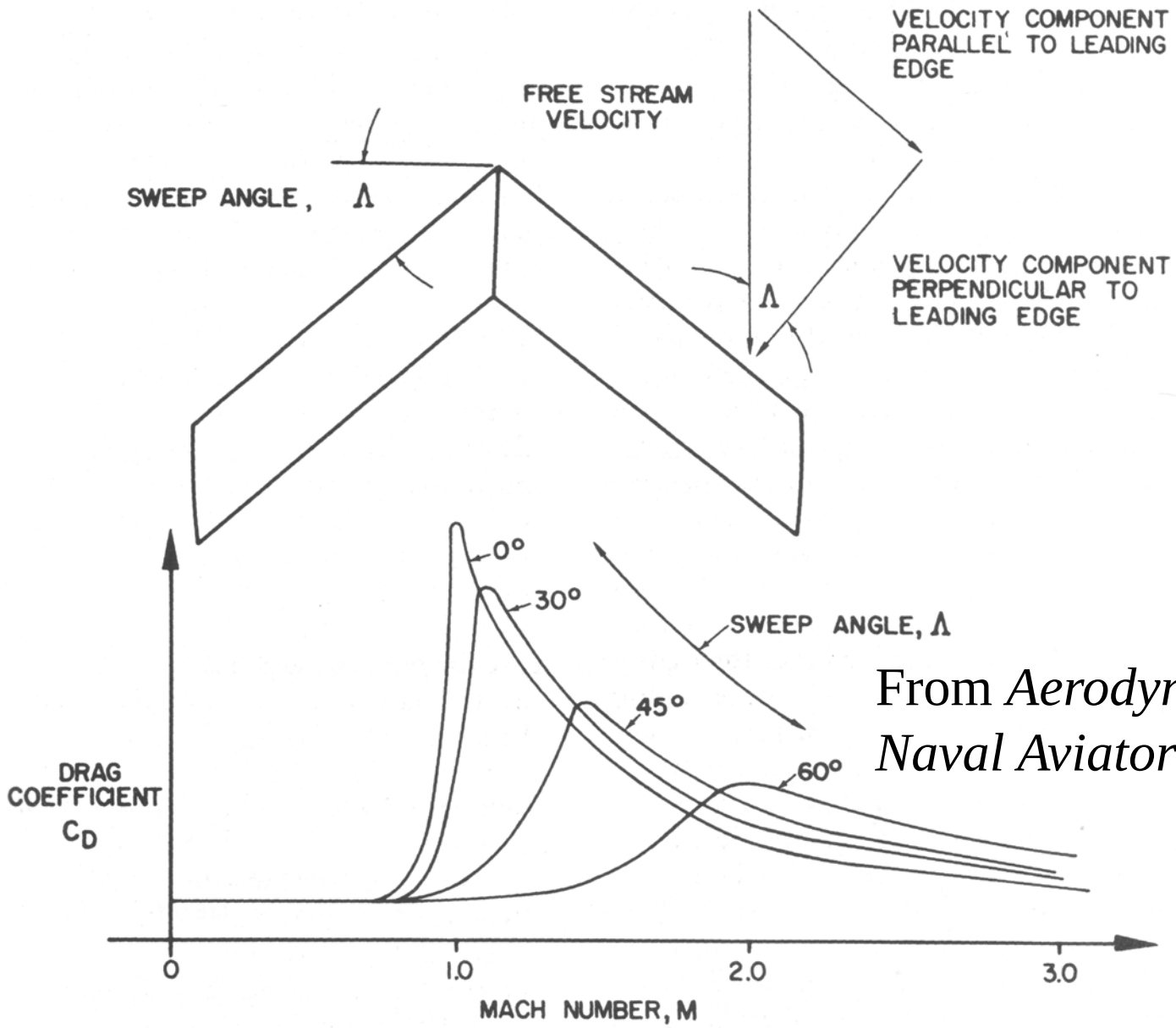
# Lesson 27: Wings at Transonic Speed



The original DC-8 reflection plane model, in the VT WT Lab

An advanced Douglas transport WT Model, also in the VT WT Lab

# The Swept Wing – A Major Advance



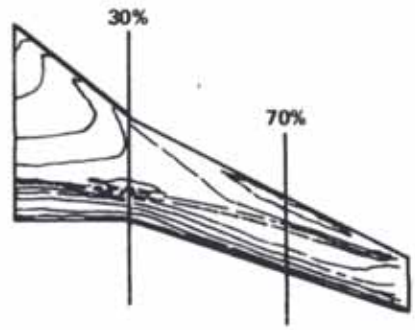

From *Aerodynamics for Naval Aviators* by Hurt

# The original swept wing model carved by George Shairer

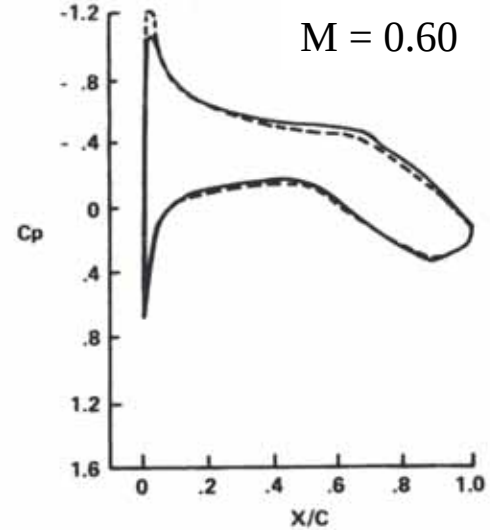
**Picture of B-52 made in Dayton Hotel over a weekend by Boeing engineers**

picture taken by Mason at the Museum of Flight, Seattle, WA

# The problem of transonic wing design




TRANSONIC CRUISE WING

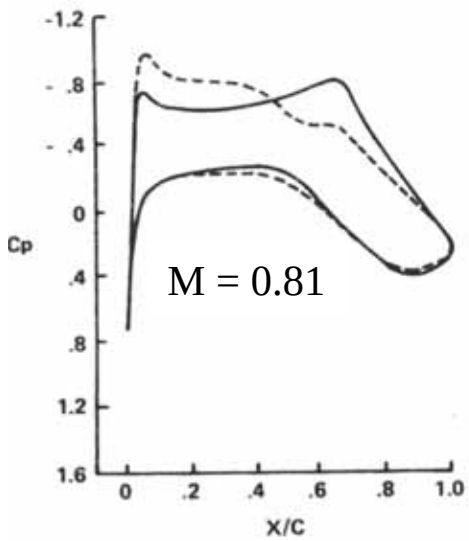


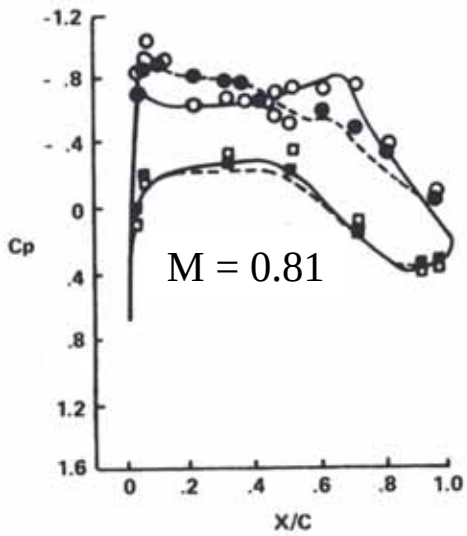

W. Mason, D.A. MacKenzie, M.A. Stern, and J.K. Johnson, "A Numerical Three-Dimensional Viscous Transonic Wing-Body Analysis and Design Tool," AIAA Paper 78-101, Jan. 1978

DATA PREDICTION

○ □ —— 30% SPAN STATION

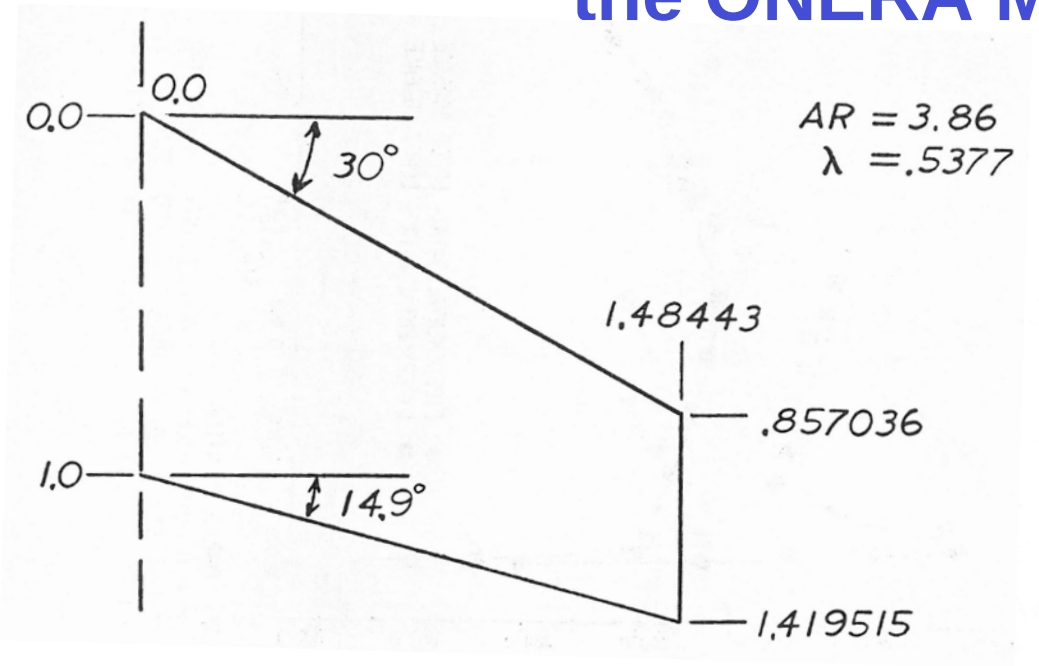
● ■ – – – 70% SPAN STATION



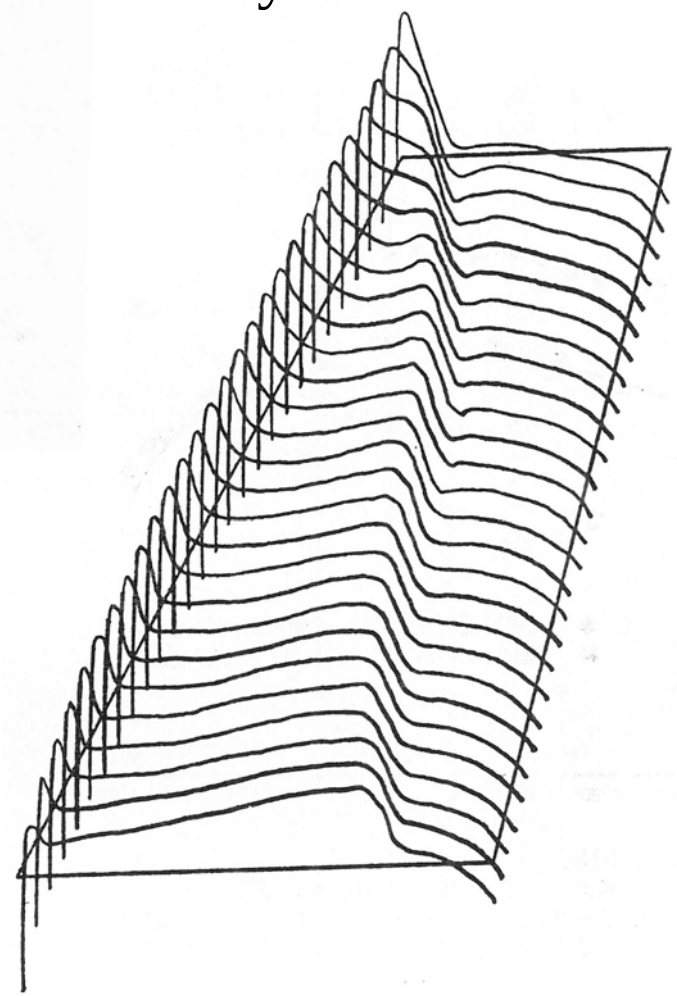




**Remember the importance of good straight isobars!**

# The Standard Transonic Test Case: the ONERA M6 Wing




A standard way to look at your results



The wing is symmetrical with no twist: note the unsweep of the shock and the build up of the pressure peak at the tip

# Comparison: computations to data for the ONERA M6

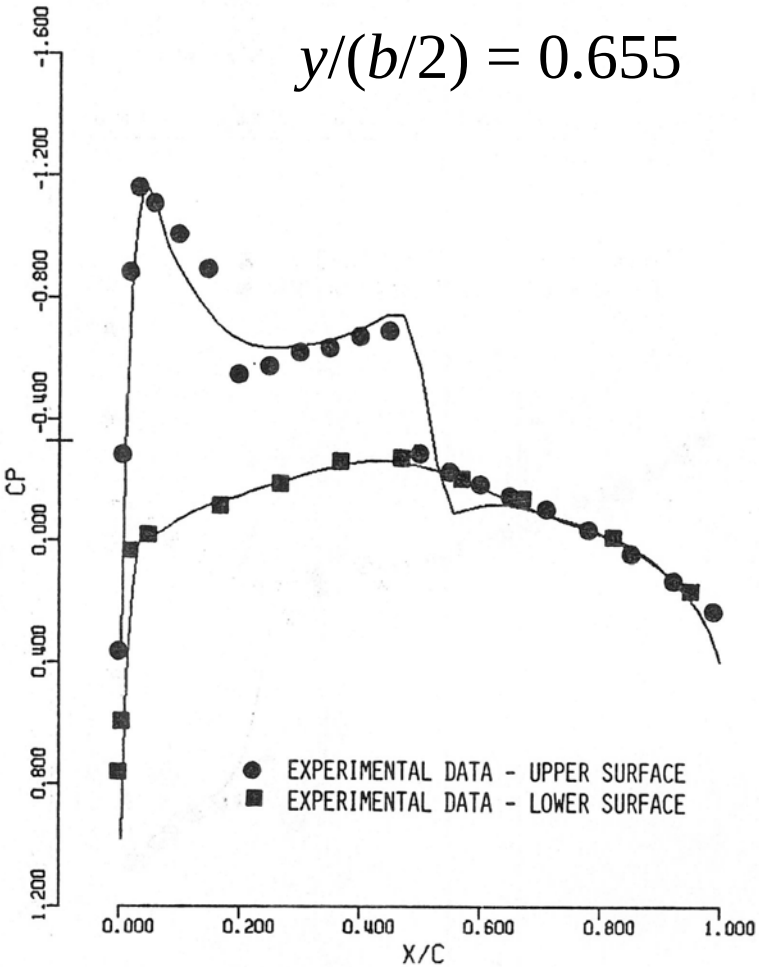
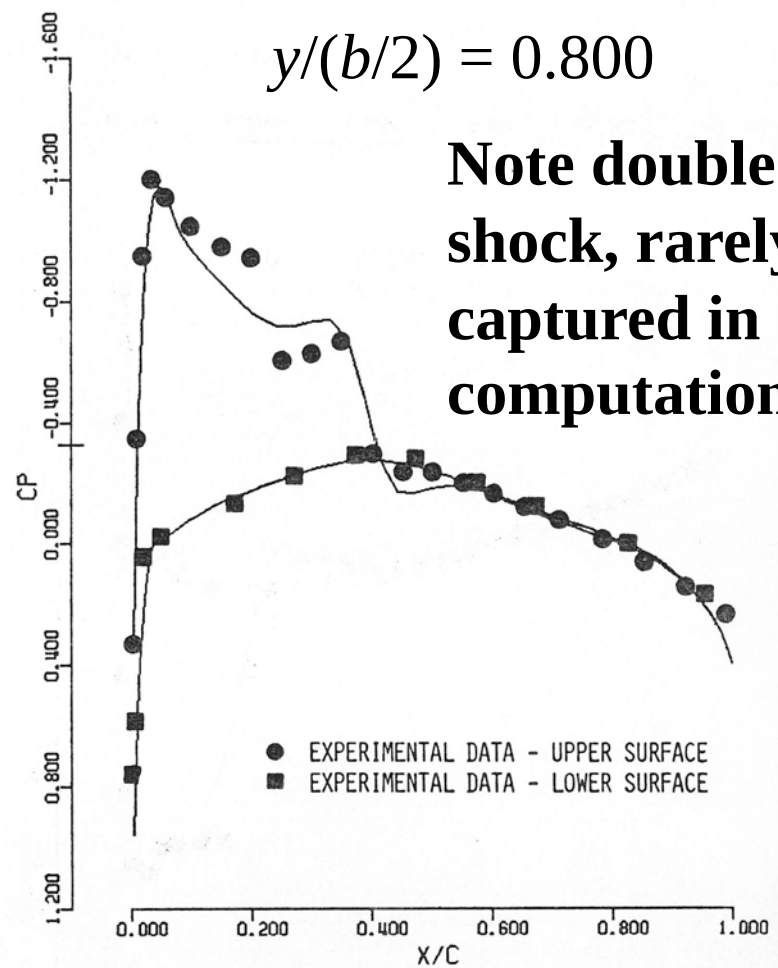



FIGURE 32E. ONERA M6 WING
M = 0.840 ALF = 3.000 CONV = .327E-04
LOCAL CL= 0.292 LOCAL CM=-0.288 LOCAL CD=-.0032
SPAN STATION 19 Y/S=0.655 44 MESH PTS ON CHD




**Note double shock, rarely captured in computations**

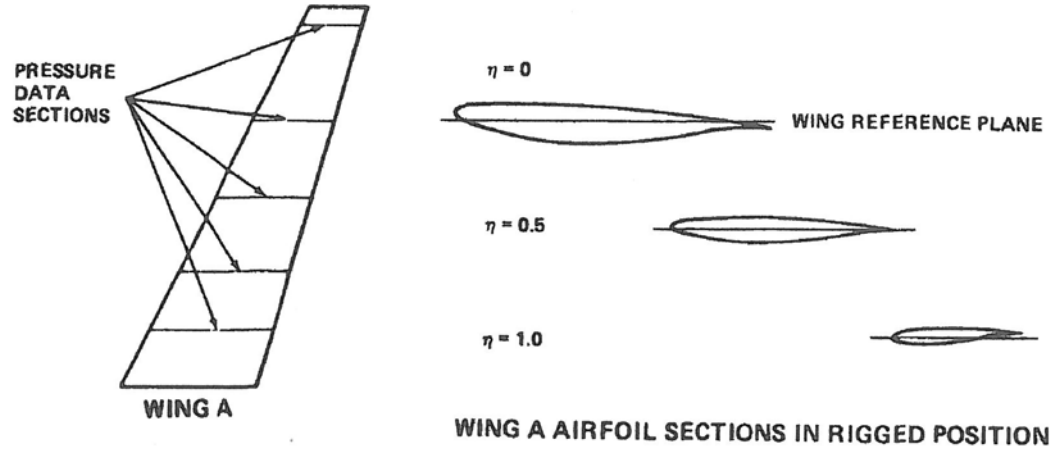
FIGURE 32F. ONERA M6 WING
M = 0.840 ALF = 3.000 CONV = .327E-04
LOCAL CL= 0.258 LOCAL CM=-0.312 LOCAL CD=-.0089
SPAN STATION 23 Y/S=0.800 44 MESH PTS ON CHD

W.H. Mason, D.A. MacKenzie, M.A. Stern, W.F Ballhaus Jr., and J. Frick, “Automated Procedure for Computing the Three-Dimensional Transonic Flow Over Wing-Body Combinations, including Viscous Effects,” AFFDL-TR-77-122, February 1978.

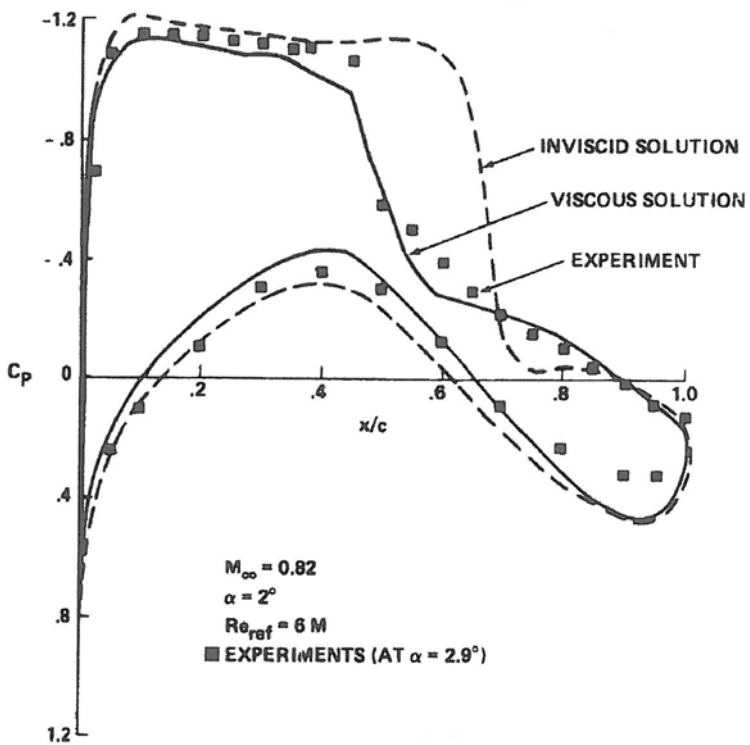
# Viscous Effects Still Important

**Lockheed Wing A**

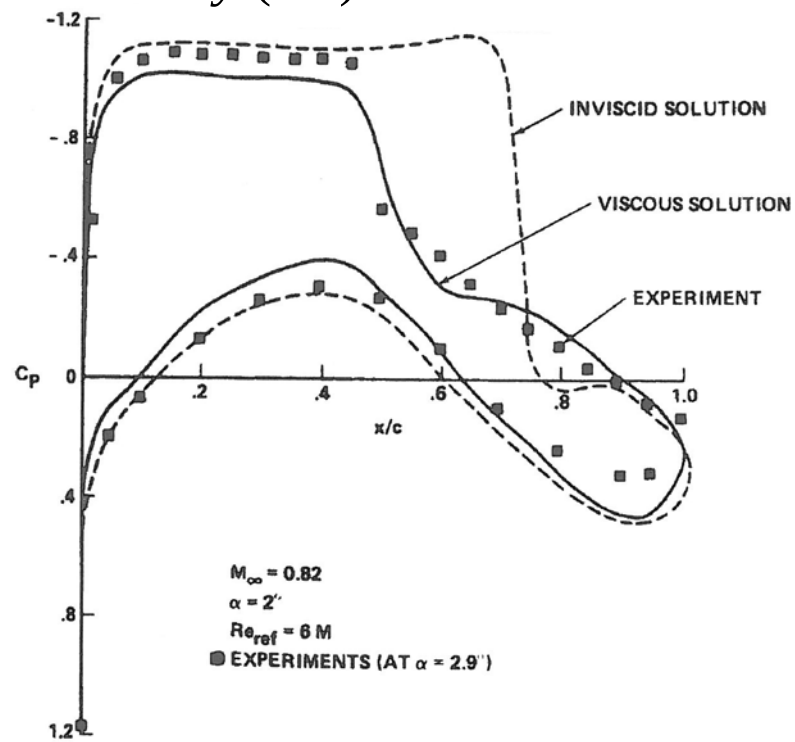
From NASA CR178156, Oct. 1986




$y/(b/2) = 0.50$

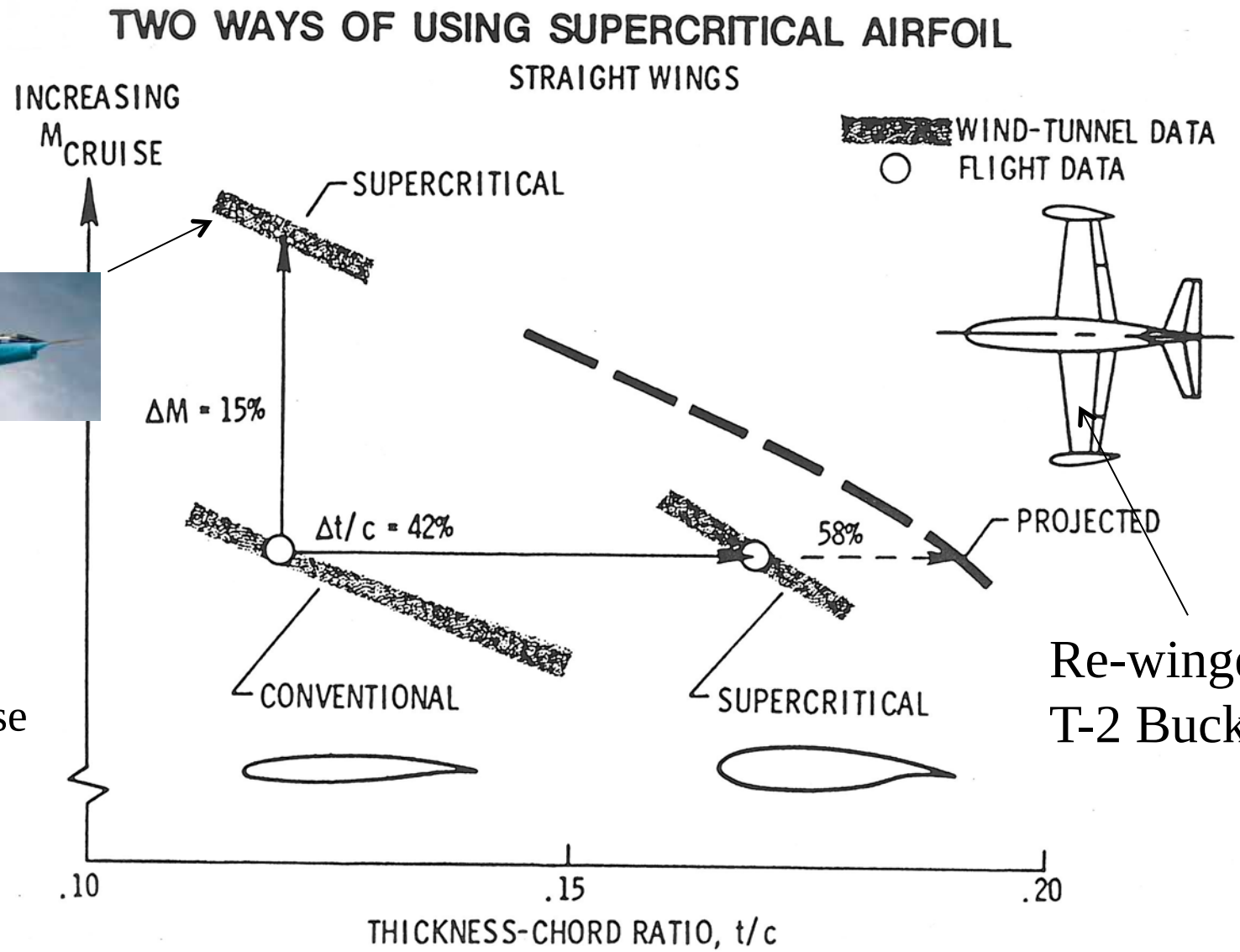



$y/(b/2) = 0.70$



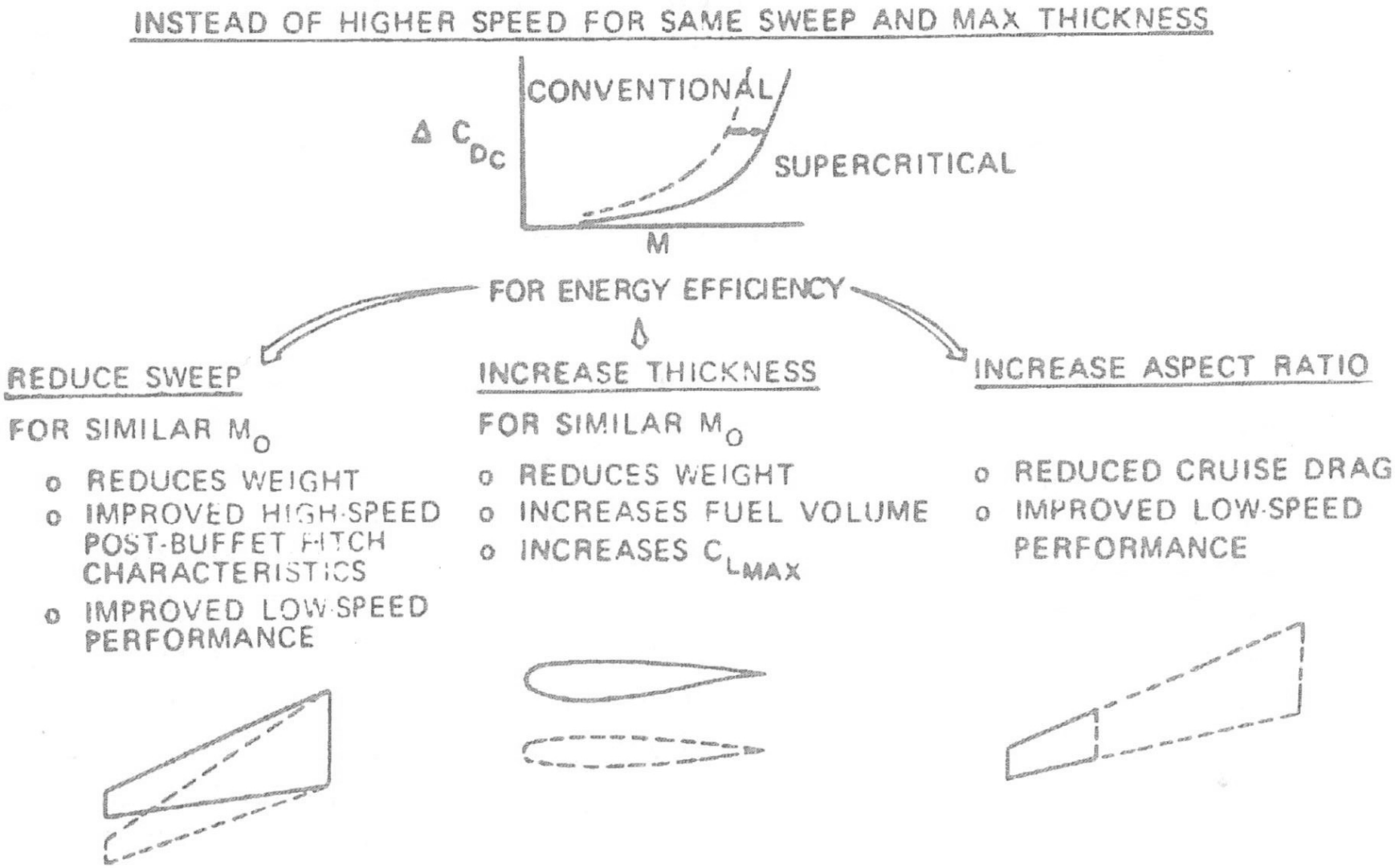
# How to use advanced airfoil capability in wing design

Whitcomb's original (pre-1st oil embargo) idea: increase speed




Re-winged T-2 Buckeye

# Ways to use Advanced Aerodynamics
# Frank Lynch's Wing Chart




F.T. Lynch, "Commercial Transports—Aerodynamic Design for Cruise Performance Efficiency," in *Transonic Aerodynamics*, ed. By D. Nixon, AIAA, 1982.

# Korn Eqn and Simple Sweep Theory

*- a sort of Poor Man's method (no CFD) -*

Extend Korn to swept wings using simple sweep theory

$$M_{dd} = \frac{\kappa_A}{\cos\Lambda} - \frac{(t/c)}{\cos^2\Lambda} - \frac{c_l}{10\cos^3\Lambda}$$

and then use Lock's approximation:

$$C_{D_{Wave}} = 20(M - M_{crit})^4 \qquad M > M_{crit}$$

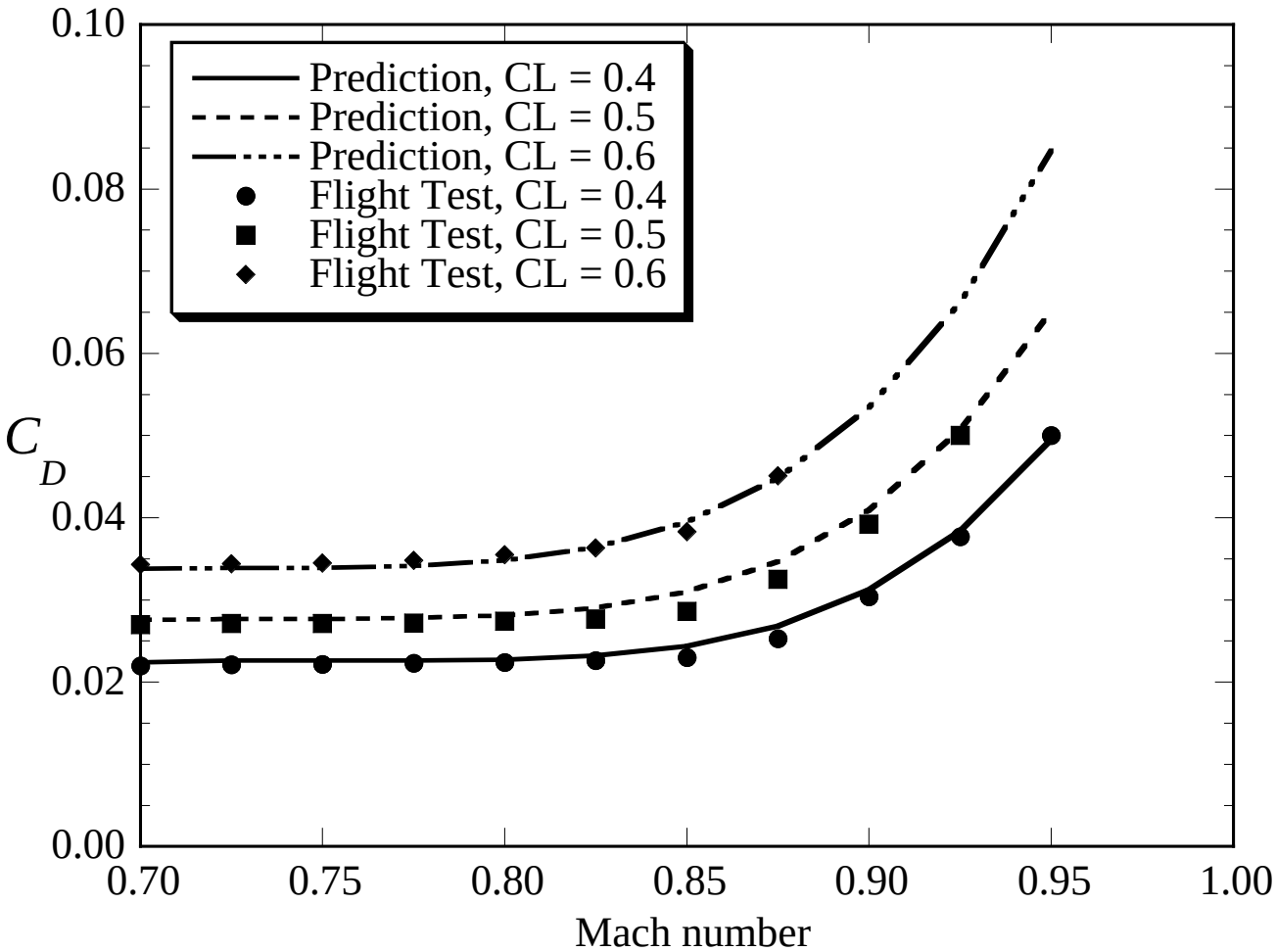
where using: $\frac{\partial C_D}{\partial M} = 0.1$, $\qquad \frac{\partial C_D}{\partial M} = 0.1 = 80\,(M - M_{crit})^3$

so that we find $M_{crit}$: $\quad M_{crit} = M_{dd} - \left(\frac{0.1}{80}\right)^{1/3}$

**Remember this is only a rough approximation!**

# Transonic Drag Rise Estimate: B747

Example computed by Joel Grasmeyer, $\kappa_A = 0.89$

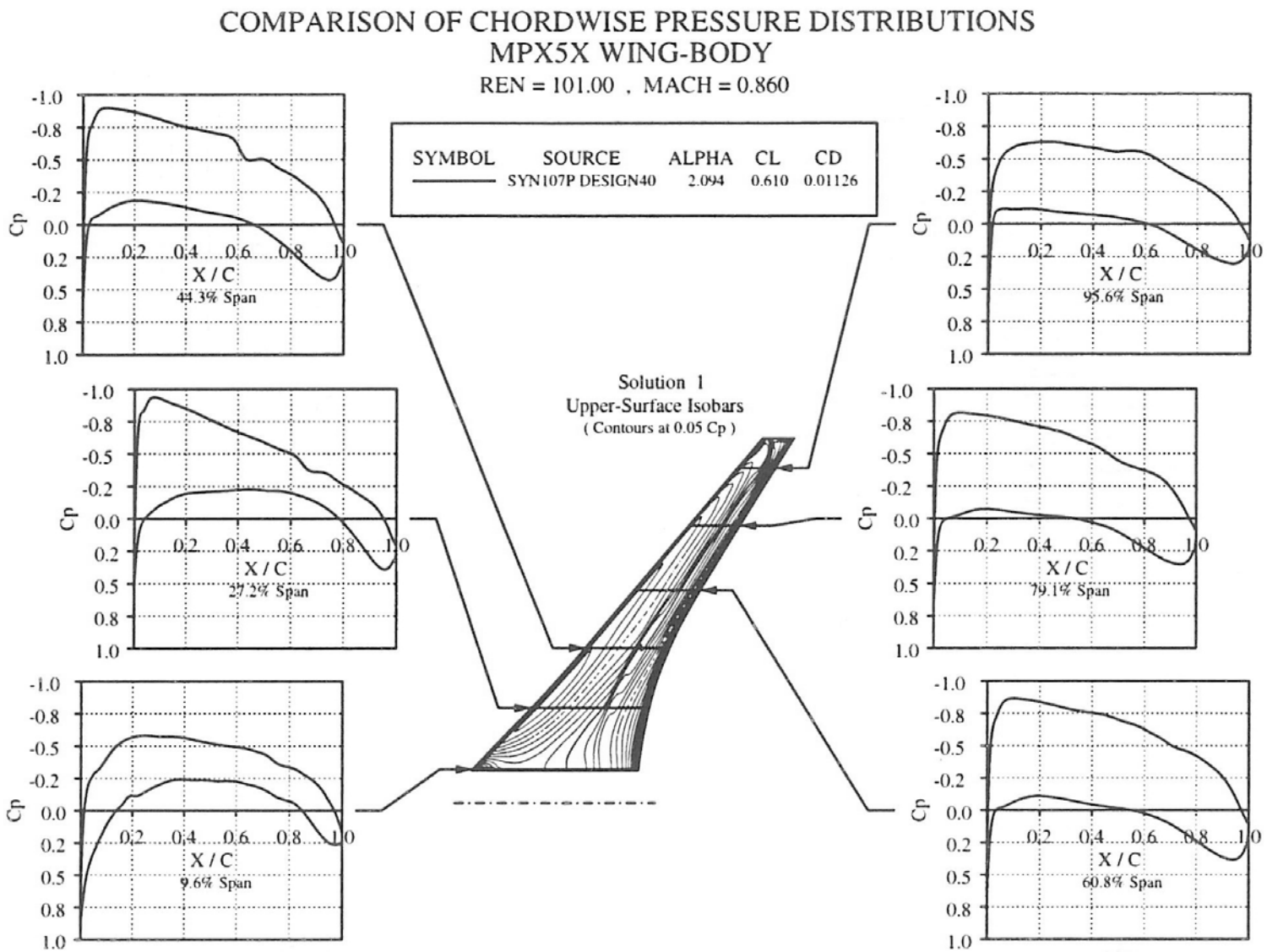



747-100 test data taken from Mair and Birdsall,
*Aircraft Performance*, Cambridge University Press, 1992, pp. 255-257

# So how do you design the wing?

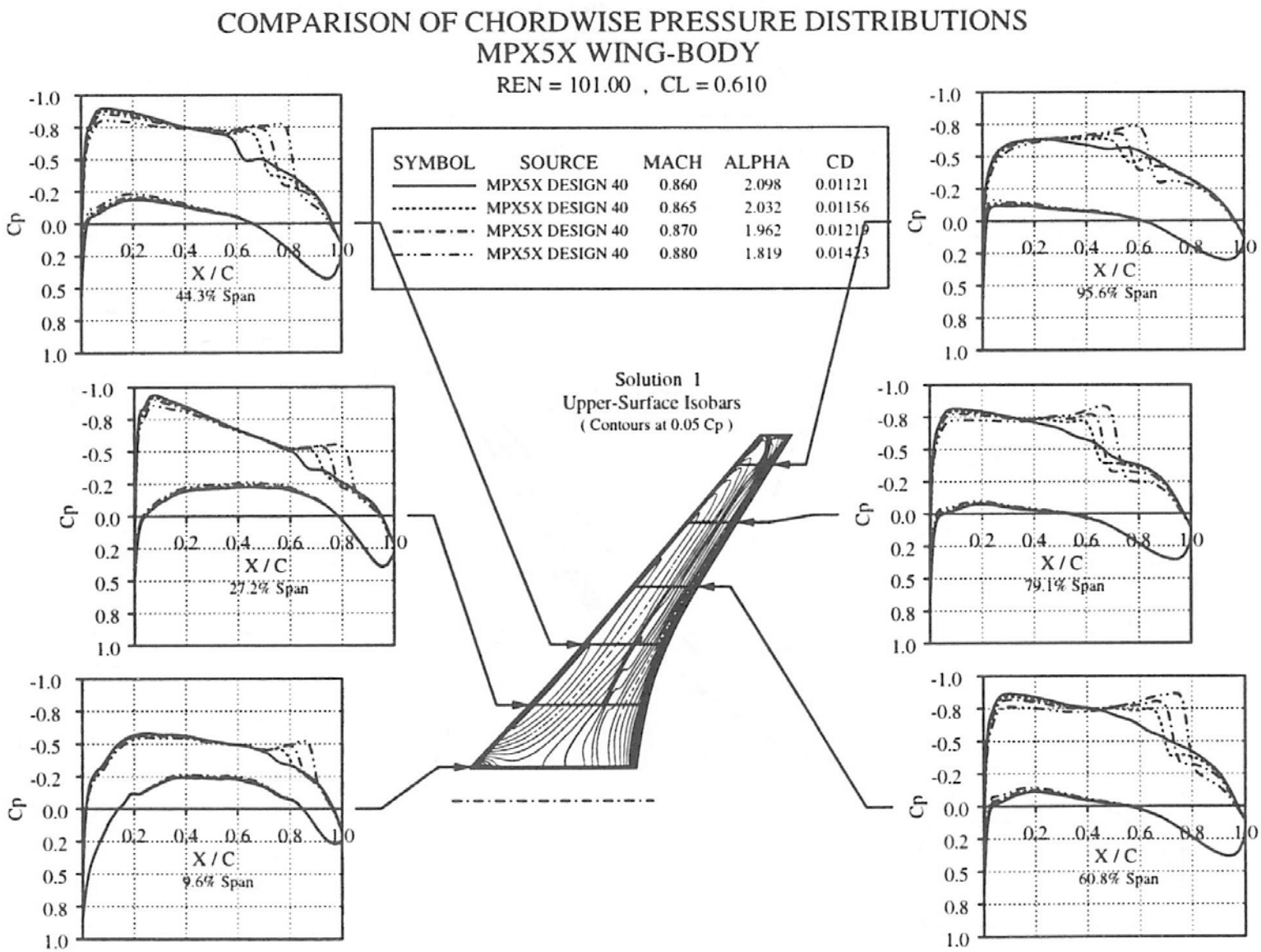
- Set the spanload in an MDO trade
- Linear theory gives a good first guess for the twist distribution
- Design the airfoils in 2D to start, and place in wing
- Finally, full 3D nonlinear analysis and design
- Special attention to root and tip mods to maintain isobar sweep
- Well known considerations:
  - Viscous effects are important
  - You must also model and include the fuselage
  - Need to address off design: buffet onset and overspeed

# Jameson Wing Design for the MD-12




Antony Jameson, “Re-Engineering the Design Process through Computation” AIAA Paper 97-0641, January 1997

# Off Design Characteristics of the Jameson Wing




Antony Jameson, “Re-Engineering the Design Process through Computation” AIAA Paper 97-0641, January 1997

# Transonic Transport Wing Design
# Other Lessons learned at Boeing

- You can increase the root thickness w/o a drag penalty
- Nacelle/pylon wing interference can be done with CFD with almost no penalty

# Real Current Example, The A-380


Quarter Chord Sweep: 33.5°
Aspect Ratio: 7.67
Root chord: 0.132 *t/c*
Tip chord: 0.087 *t/c*

From *Aerodynamic Design of Transport Aircraft*, Ed Obert, Delft Press, 2009

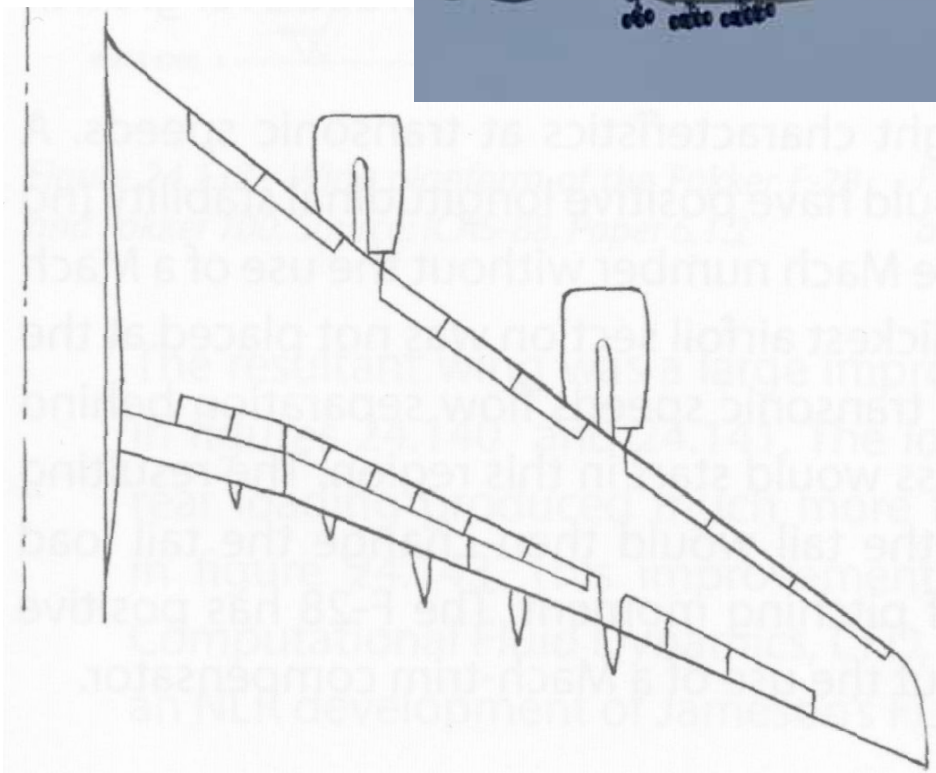


*Figure 24.133 - Airbus A380 wing planform*

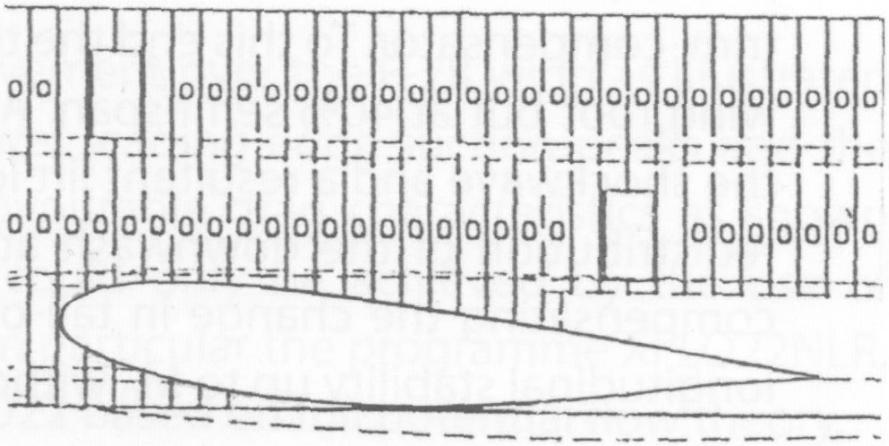
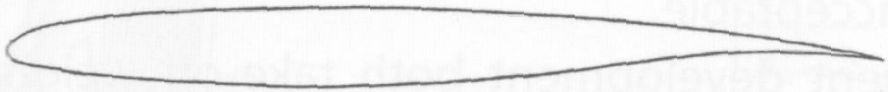
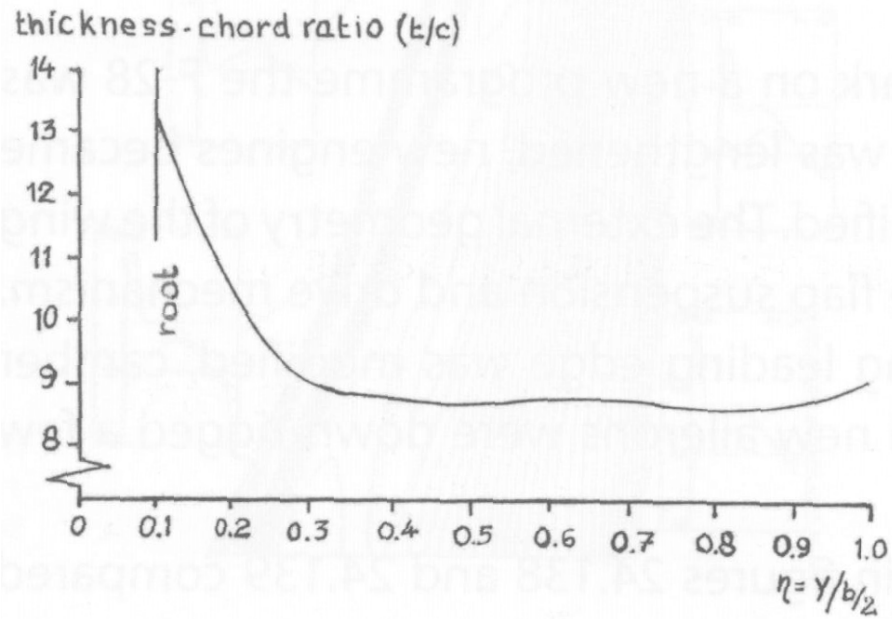


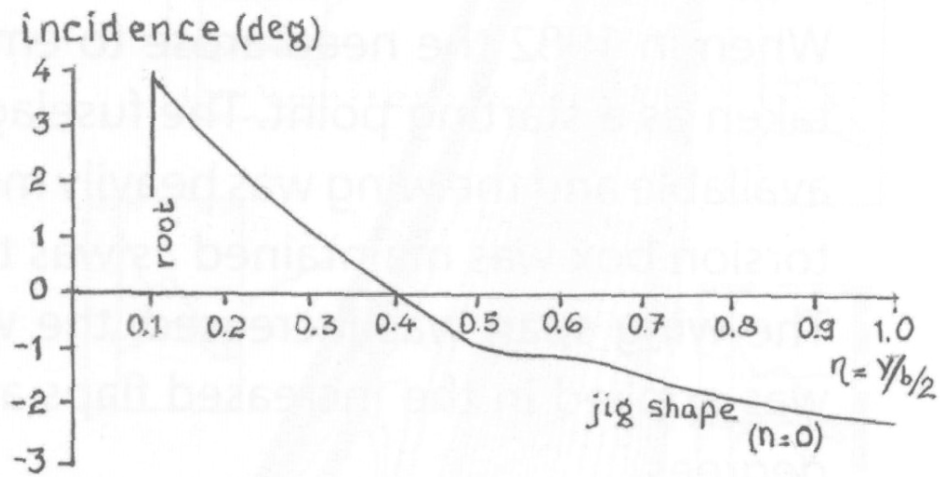
*Figure 24.134 - Airbus A380 wing root section*



# A-380 Thickness and Twist Distributions

*- a rare find -*



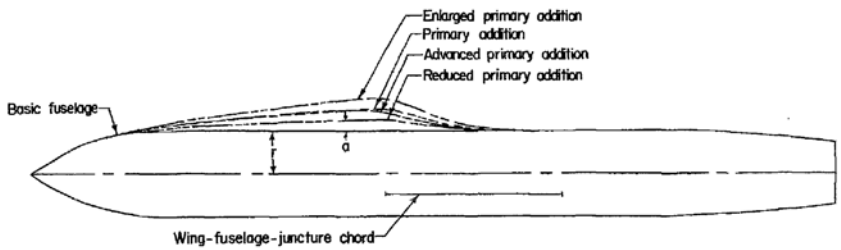




Note: “jig shape” means before the change in twist due to aerodynamic load

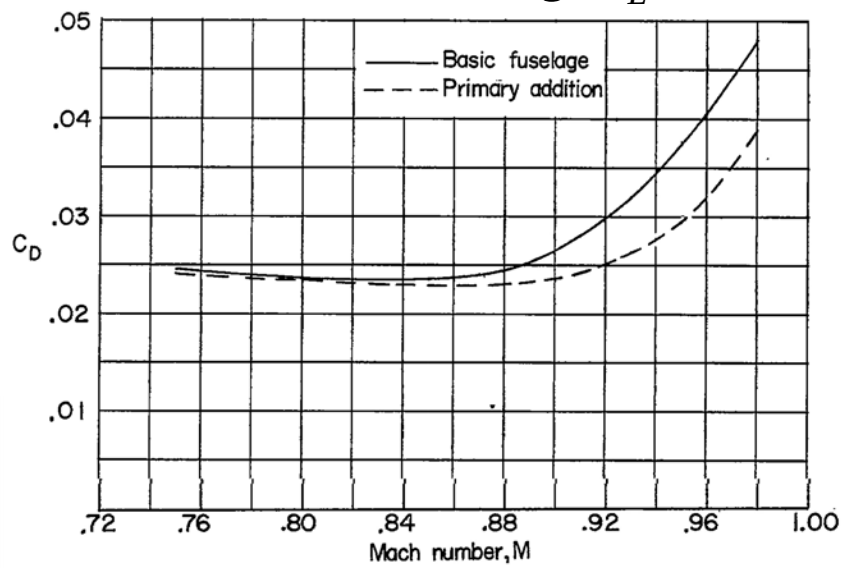
From *Aerodynamic Design of Transport Aircraft*, Ed Obert, Delft Press, 2009

# Finally: the fuselage can effect drag

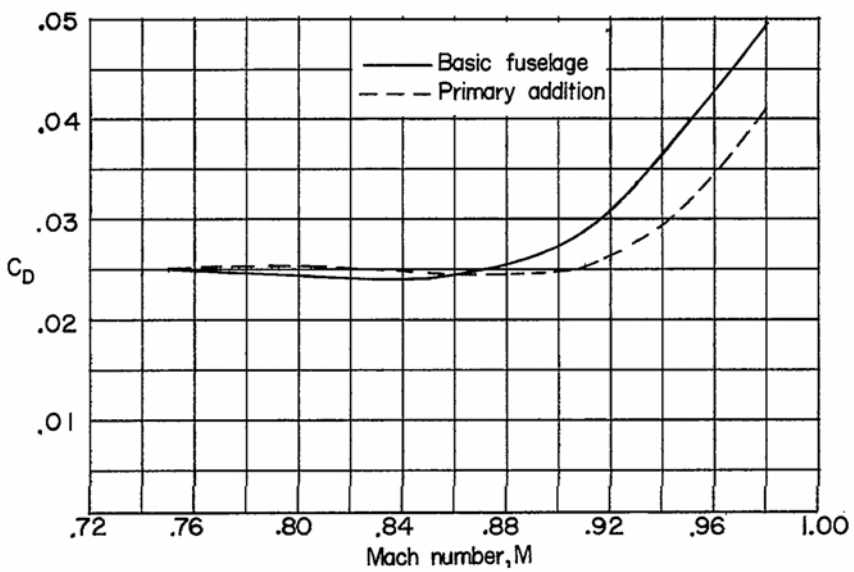
## Another Whitcomb Contribution: Fuselage Area Addition




Low mounted wing, $C_L = 0.3$



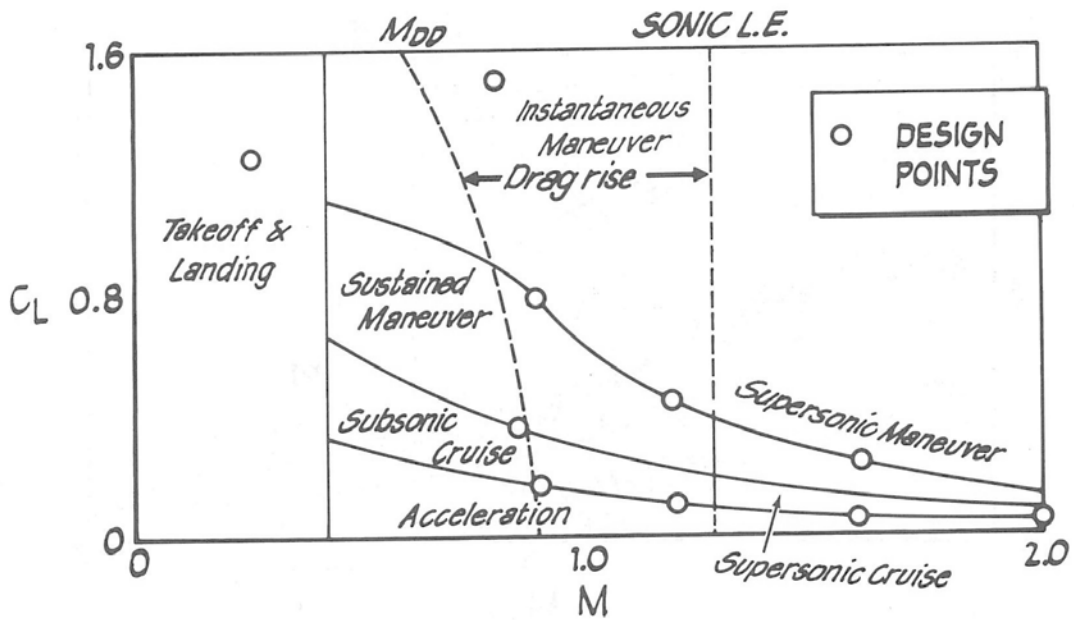

High mounted wing, $C_L = 0.3$




Adding a fuselage bump reduces drag slightly above $M = 0.85$: the Boeing 747 used this idea, it was supposed to cruise at M = 0.90

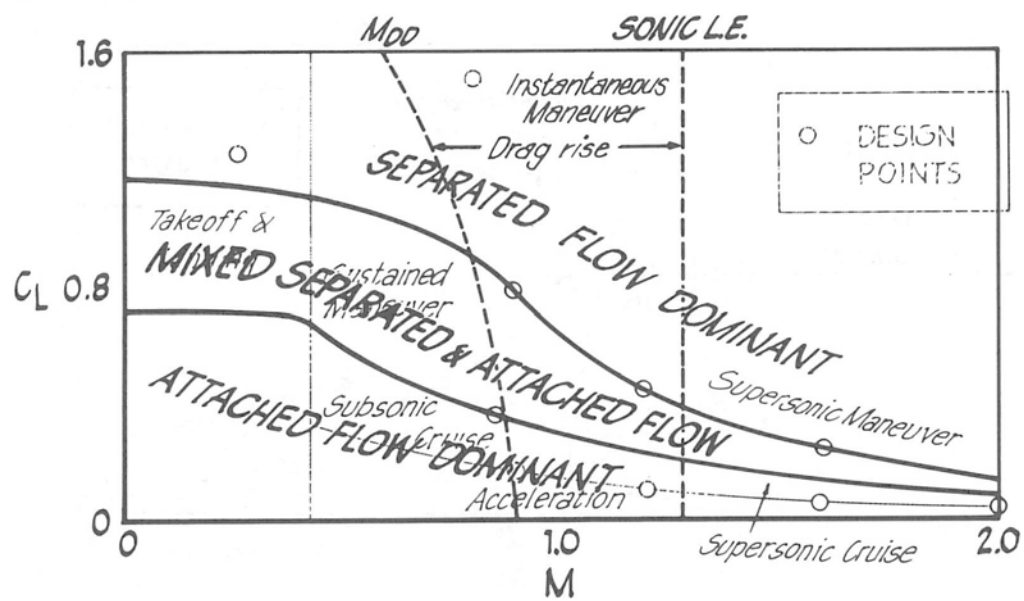
From Whitcomb NACA TN 4290, June 1958.

# Fighter Wings: A more complicated story

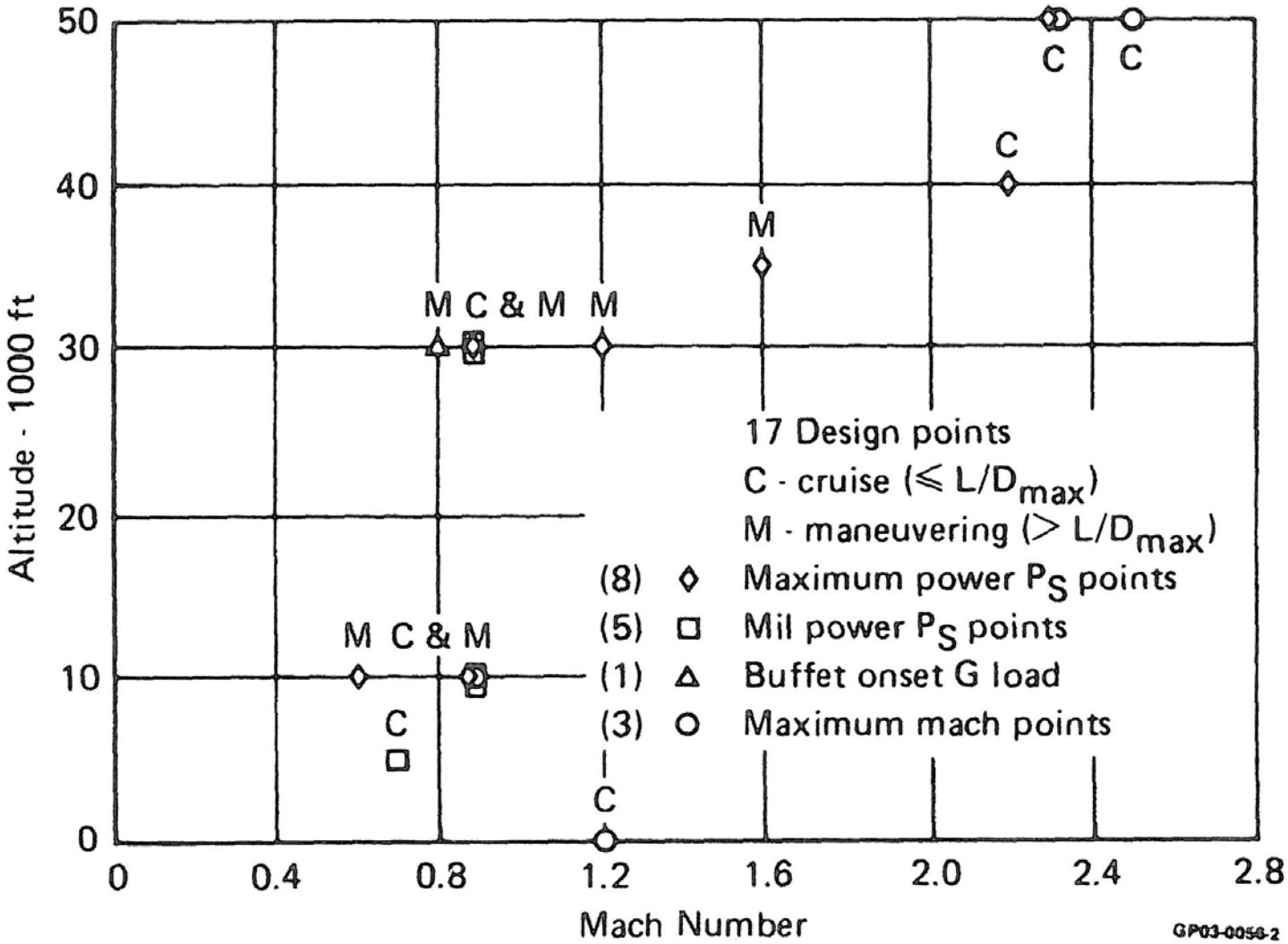



From Richard G. Bradley, "Practical Aerodynamic Problems-Military Aircraft" in *Transonic Aerodynamics*, AIAA 1982

Rather than cruise, fighter wings have to consider supersonics and low speed speed maneuvering as well as transonic cruise and maneuver

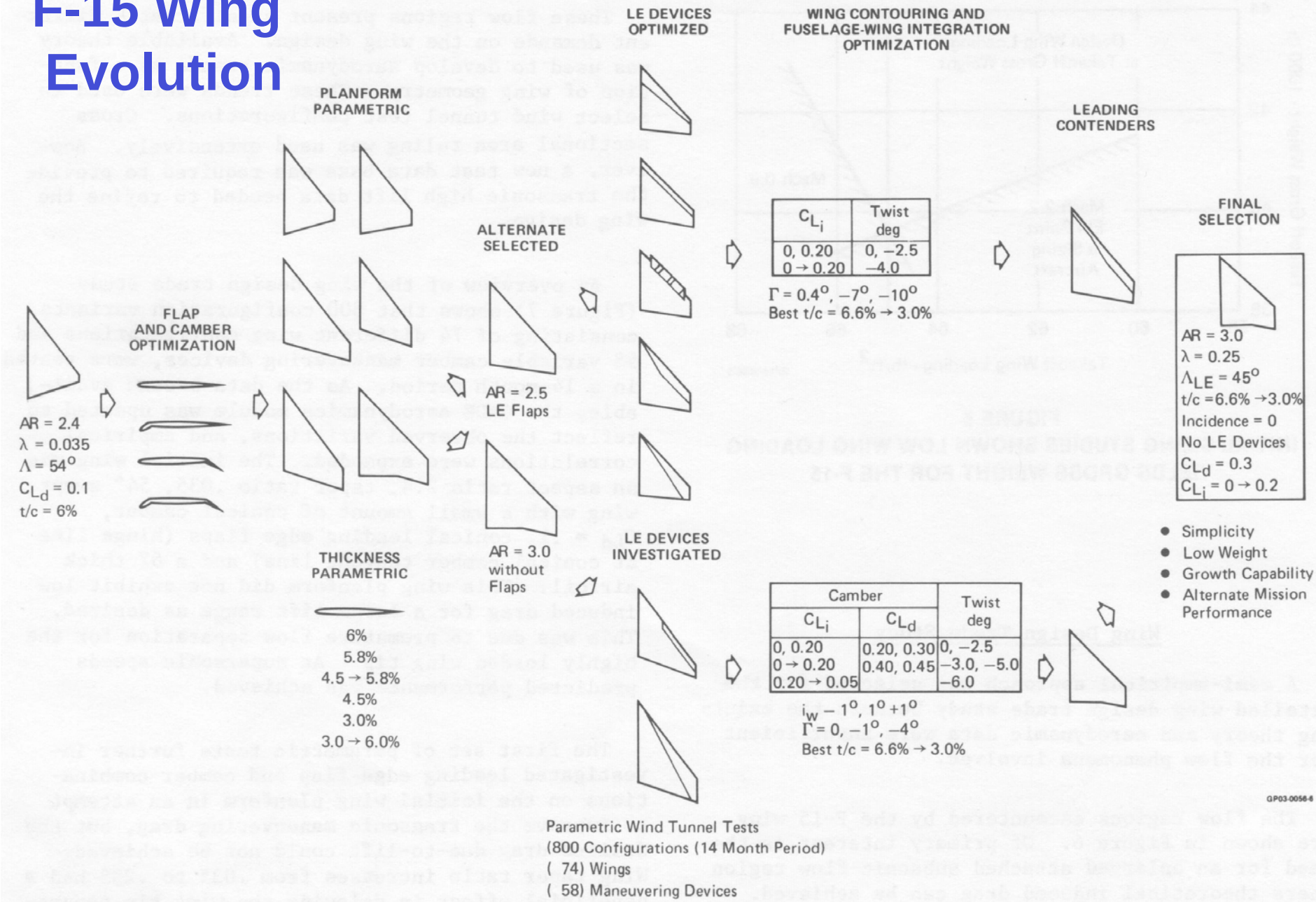


# An Example: the F-15 - Design Points



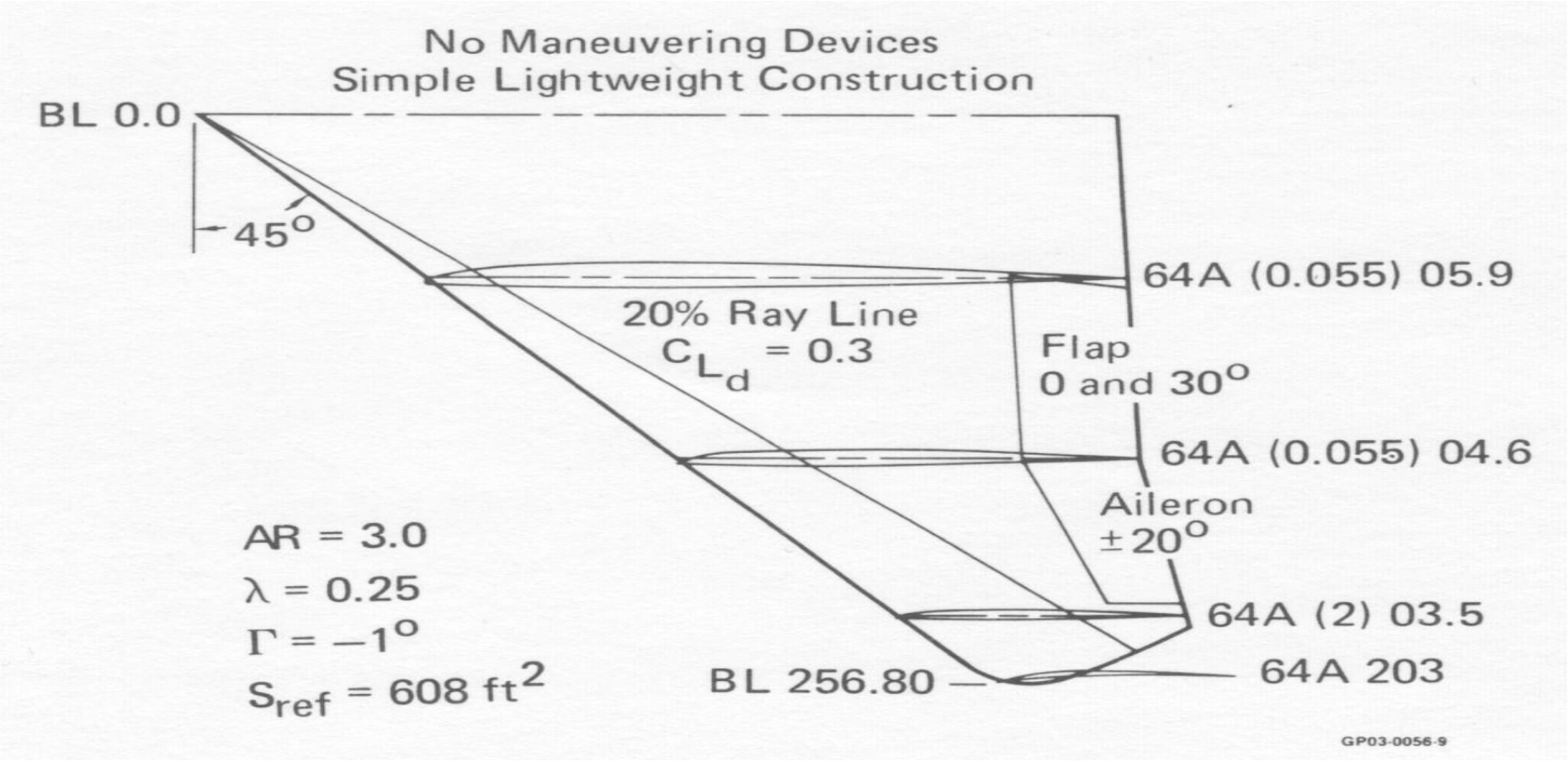

From Larry Niedling, “The F-15 Wing Development Program”, AIAA Paper 80-3044

# F-15 Wing Evolution




From Larry Niedling, “The F-15 Wing Development Program”, AIAA Paper 80-3044

# F-15 Wing Lines

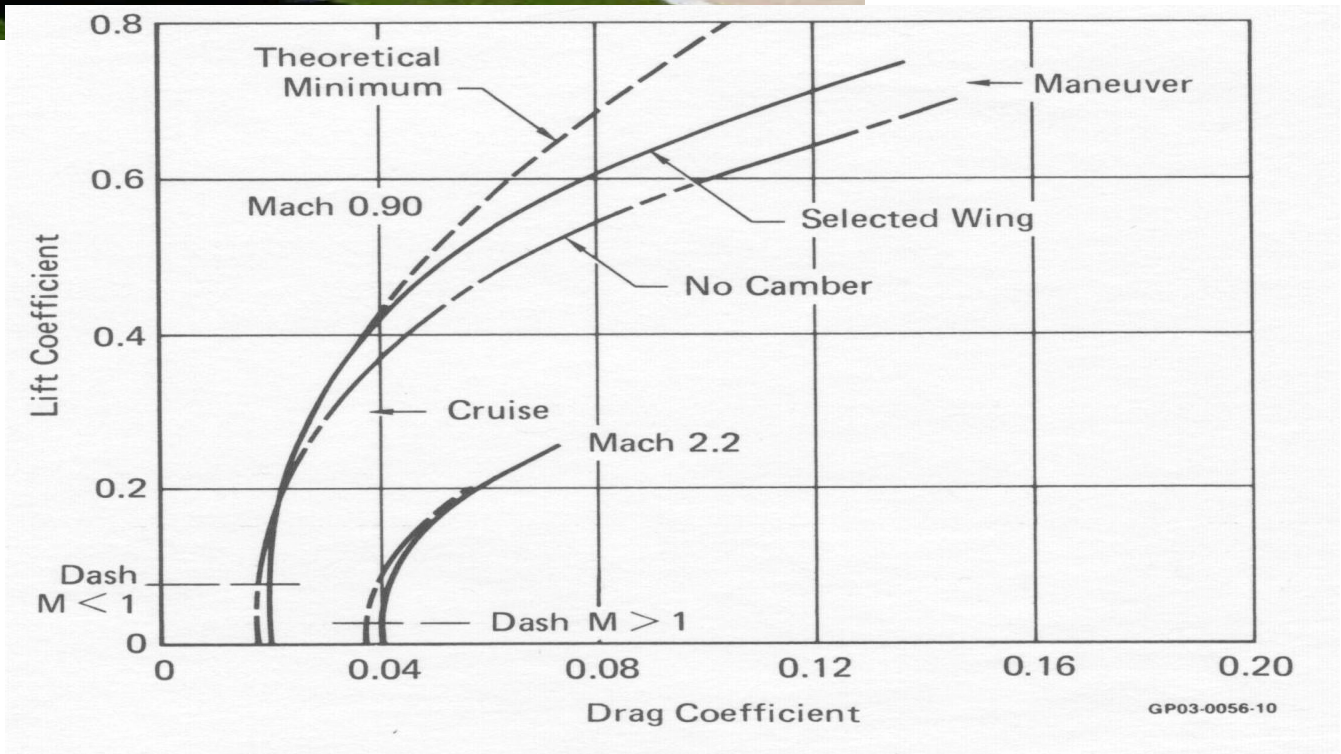



The wing has conical camber: hard to see in streamwise section cuts

From Larry Niedling, “The F-15 Wing Development Program”, AIAA Paper 80-3044

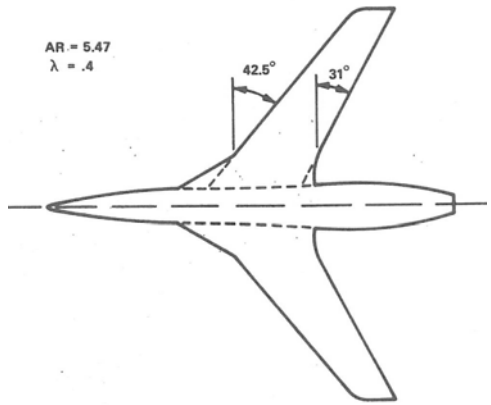
# The final F-15


F-15 on display at the U.S. Air Force Academy




Drag from Larry Niedling, "The F-15 Wing Development Program", AIAA Paper 80-3044

# Example of attached flow fighter design




(a) ADVANCED TECHNOLOGY FIGHTER

Grumman proposed HiMAT, $M = 0.90$

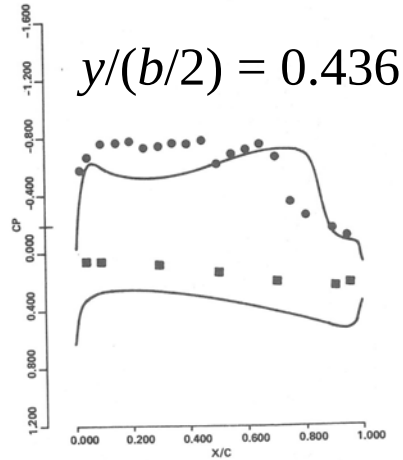



FIGURE 9b. ADVANCED FIGHTER
M = 0.900 ALF = 7.050 CONV = .886E-01
LOCAL CL = 0.890 LOCAL CM = 1.306 LOCAL CD = 0.0585
SPAN STATION 13 Y/S = 0.436 44 MESH PTS ON CHD

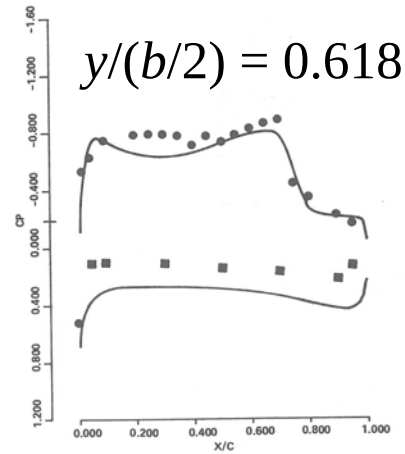



FIGURE 9c. ADVANCED FIGHTER
M = 0.900 ALF = 7.050 CONV = .886E-01
LOCAL CL = 0.911 LOCAL CM = 1.218 LOCAL CD = 0.0357
SPAN STATION 18 Y/S = 0.618 44 MESH PTS ON CHD

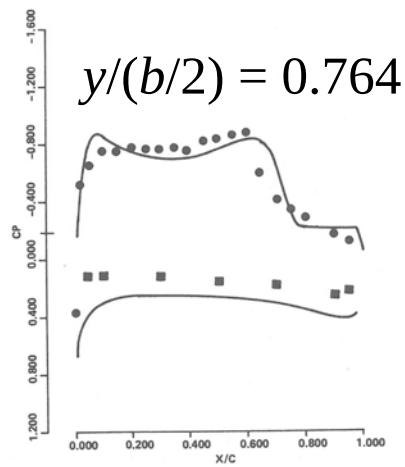



FIGURE 9d. ADVANCED FIGHTER
M = 0.900 ALF = 7.050 CONV = .886E-01
LOCAL CL = 0.910 LOCAL CM = 1.075 LOCAL CD = 0.0206
SPAN STATION 22 Y/S = 0.764 44 MESH PTS ON CHD

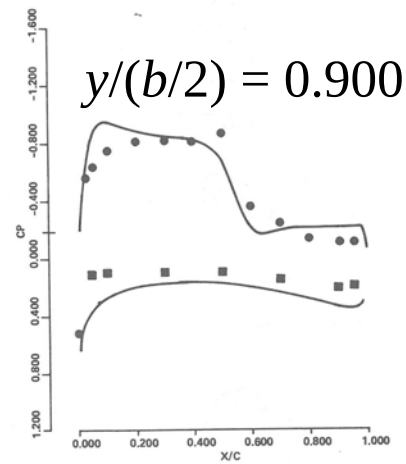
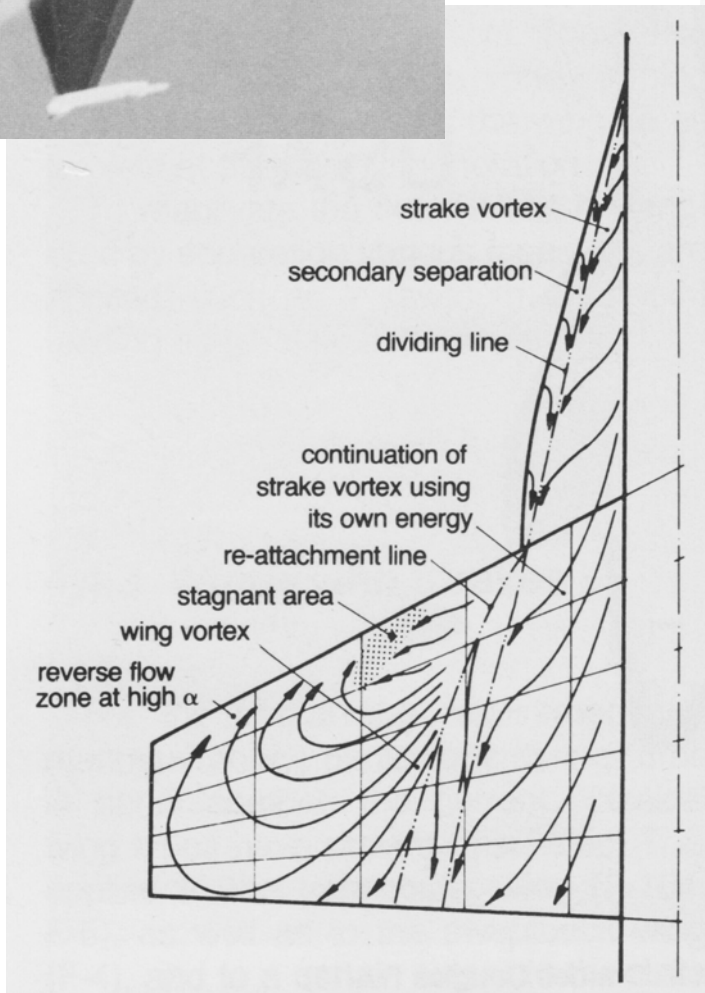
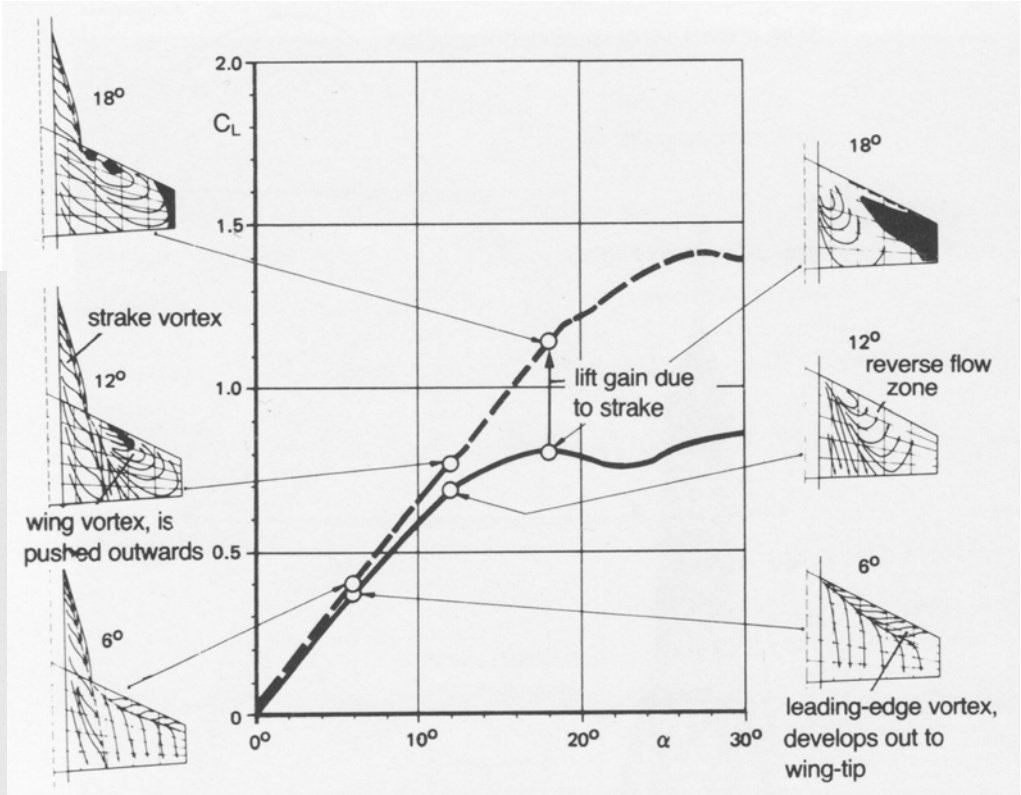



FIGURE 9e. ADVANCED FIGHTER
M = 0.900 ALF = 7.050 CONV = .886E-01
LOCAL CL = 0.782 LOCAL CM = 0.766 LOCAL CD = -.0012
SPAN STATION 26 Y/S = 0.909 44 MESH PTS ON CHD

W.H. Mason, D.A. MacKenzie, M.A. Stern, and J.K. Johnson, "A Numerical Three Dimensional Viscous Transonic Wing-Body Analysis and Design Tool," AIAA Paper 78-101, Jan. 1978.

# Hybrid Wings: the F-16 and F-18

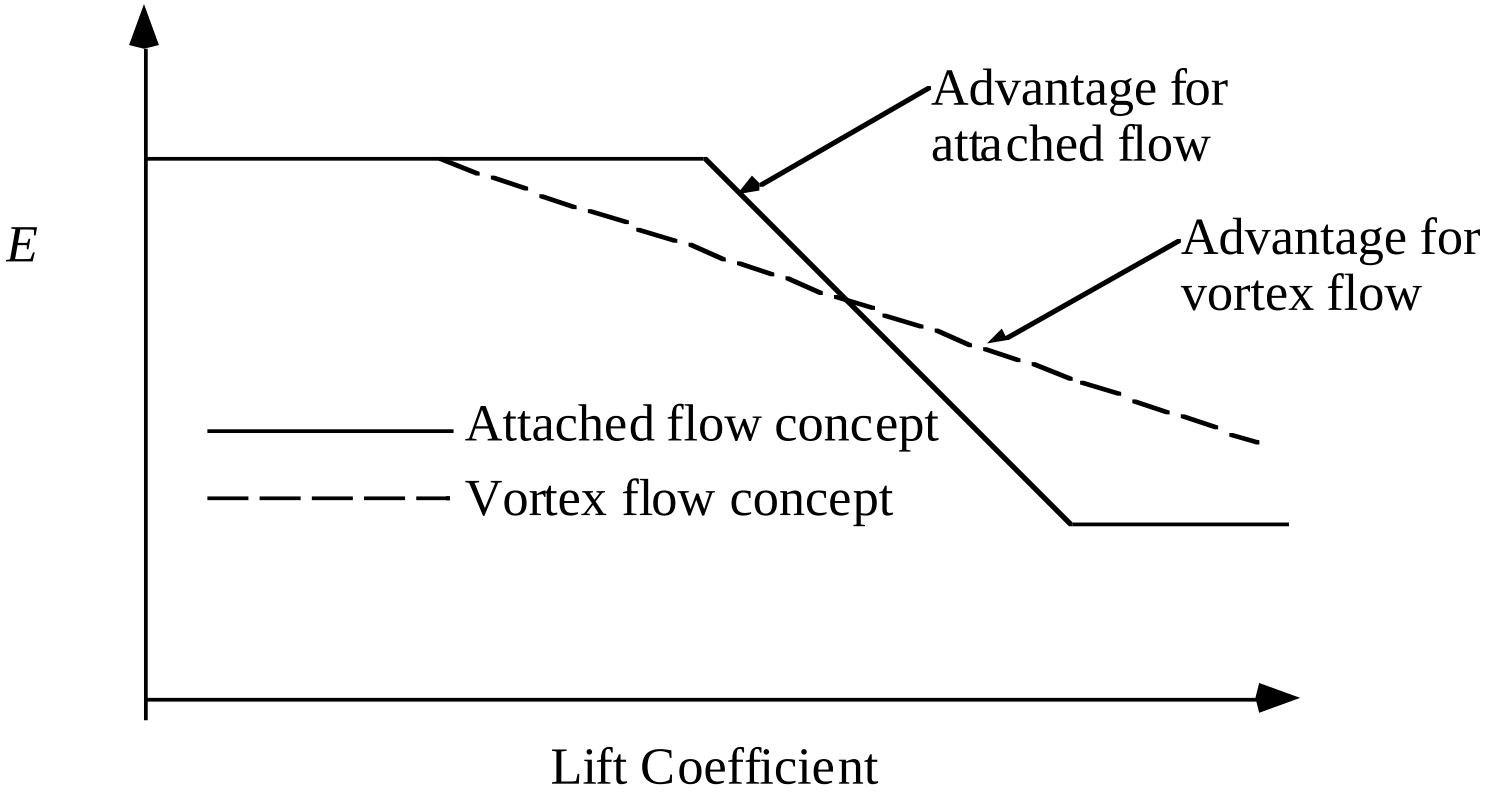



A combined low aspect ratio strake and a traditional wing

From *Modern Combat Aircraft Design*, by Klaus Huenecke, 1987

# Fighter Wings – Drag: Hybrid Wing Vortex Flow Effects Compared to Attached Flow Concepts




Vortex flow concepts have an advantage at high $C_L$s

## To Conclude

- We've given a broad overview
  - Stressed the fundamental physics and issues
- Thousands of papers written on
  - Computational analysis methods
  - Design and optimization methods
  - Applications and design concepts
- You are prepared to start contributing