Transonic Aerodynamics Wind Tunnel Testing Considerations

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Configuration Aerodynamics Class

Transonic Aerodynamics History

- Pre WWII propeller tip speeds limited airplane speed
  - Props *did* encounter transonic losses
- WWII Fighters started to encounter transonic effects
  - Dive speeds revealed loss of control/Mach "tuck"
- Invention of the jet engine revolutionized airplane design
- Now, supersonic flow occurred over the wing at cruise
- Aerodynamics couldn't be predicted, so was *mysterious*!
  - Wind tunnels didn't produce good data
  - Transonic flow is inherently nonlinear, there are no useful theoretical methods

The Sound Barrier!

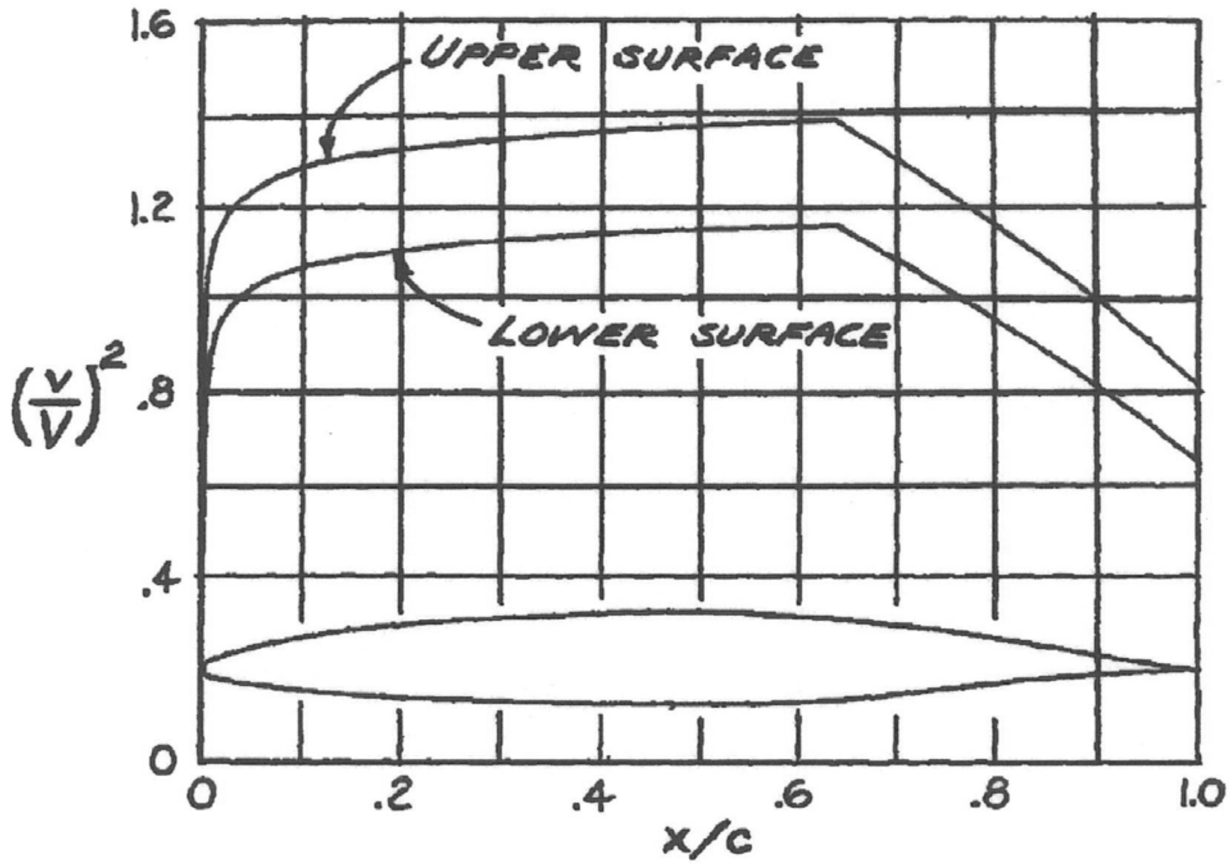
The P-38, and X-1 reveal transonic control problems/solutions

Airfoil Example: Transonic Mach Number Effects

- From classical 6 series results

NACA TN No. 1396 Fig. 1

Subsonic design pressures



NACA 66-210 a = 1.0

Lift

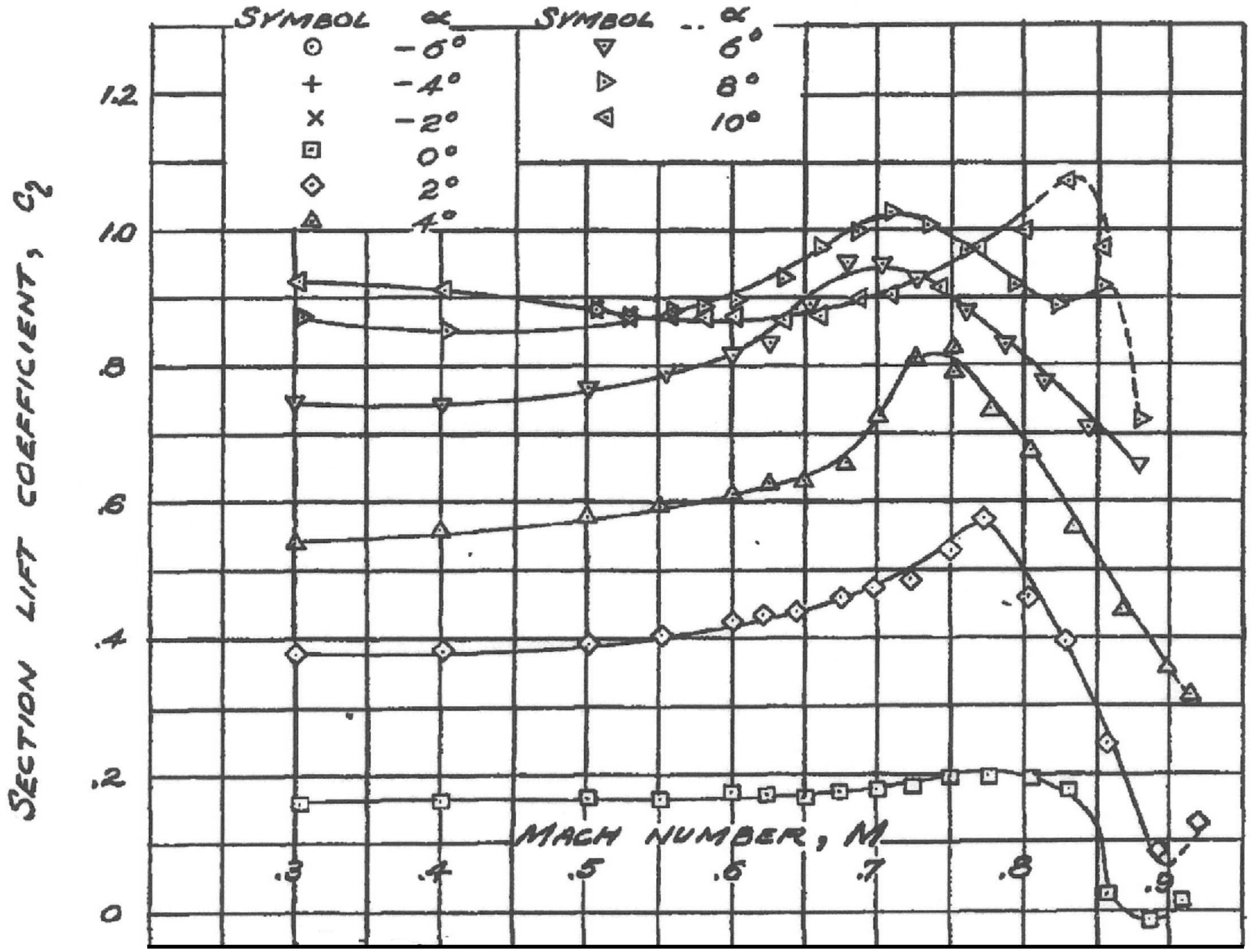


FIGURE 6.- THE VARIATION OF SECTION LIFT COEFFICIENT WITH MACH NUMBER AT VARIOUS ANGLES OF ATTACK FOR THE NACA 66-210 AIRFOIL.

Re ≈ 2 Mill

NACA Ames
1 x 3.5 ft 2D WT
6 inch chord foil

From NACA TN 1396, by Donald Graham, Aug. 1947

Drag

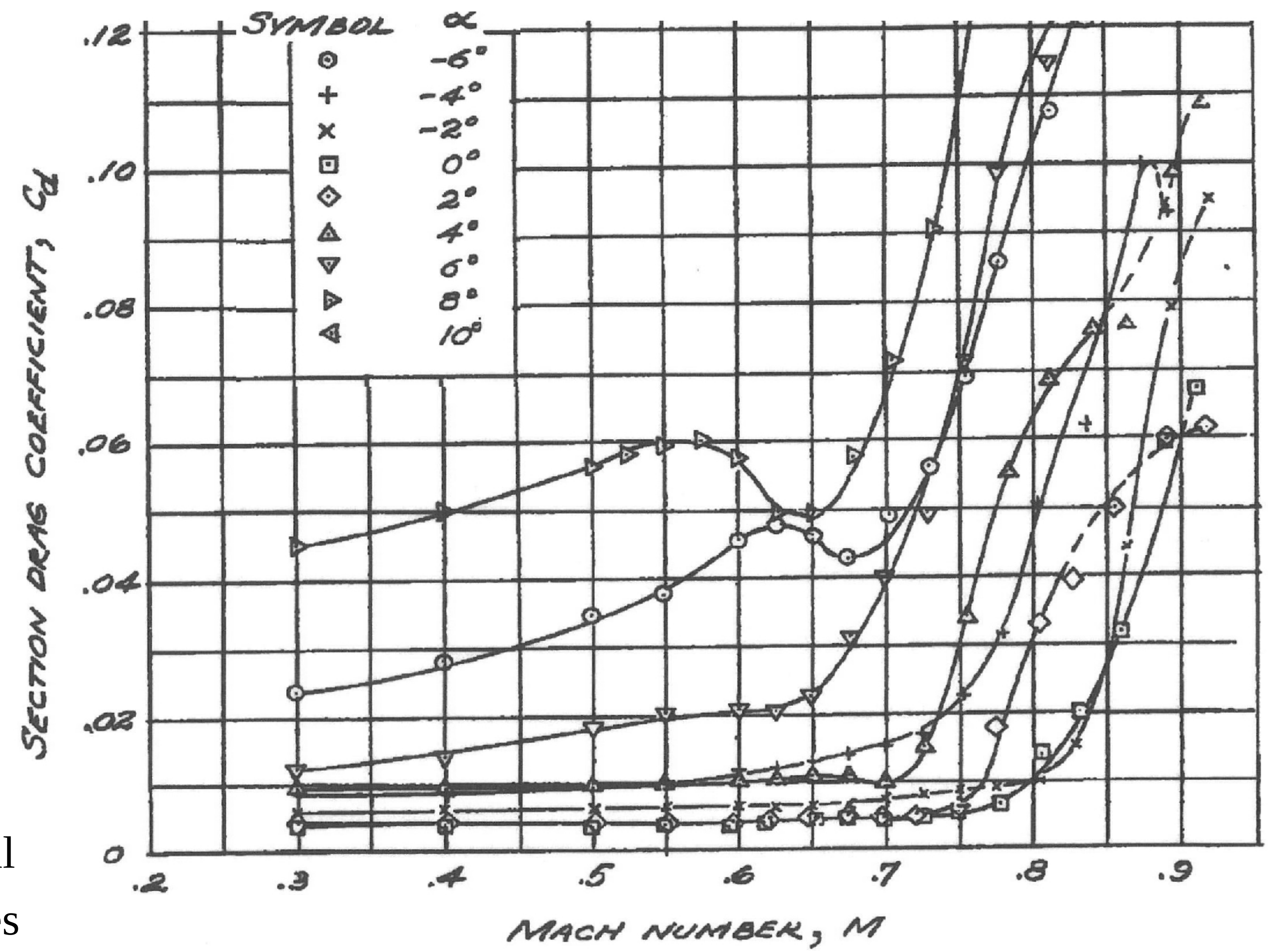


FIGURE 7.- THE VARIATION OF SECTION DRAG COEFFICIENT WITH MACH NUMBER AT VARIOUS ANGLES OF ATTACK FOR THE NACA 66-210 AIRFOIL.

Re ≈ 2 Mill

NACA Ames
1 x 3.5 ft 2D WT
6 inch chord foil

From NACA TN 1396, by Donald Graham, Aug. 1947

Pitching Moment: a major problem!

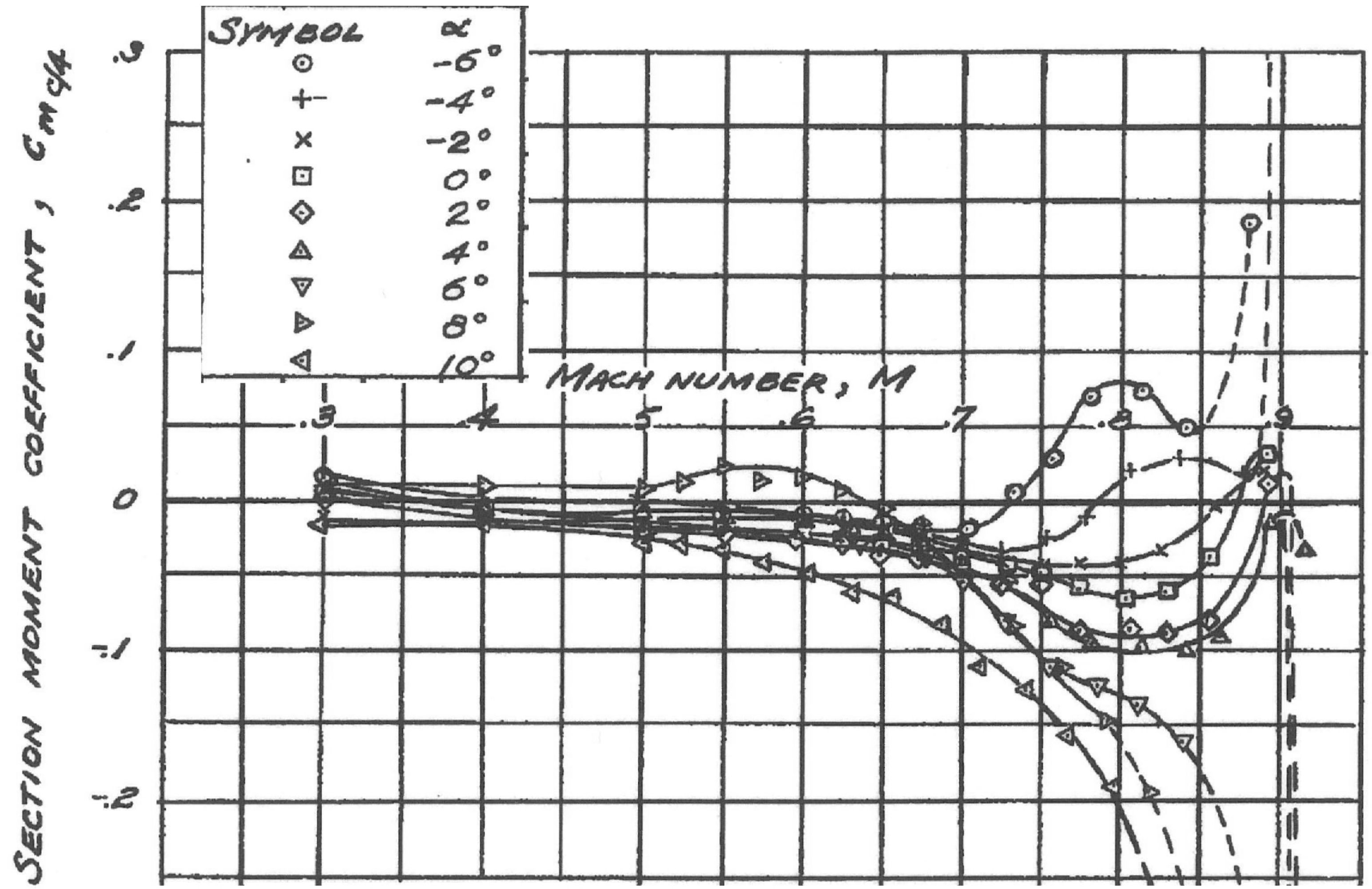


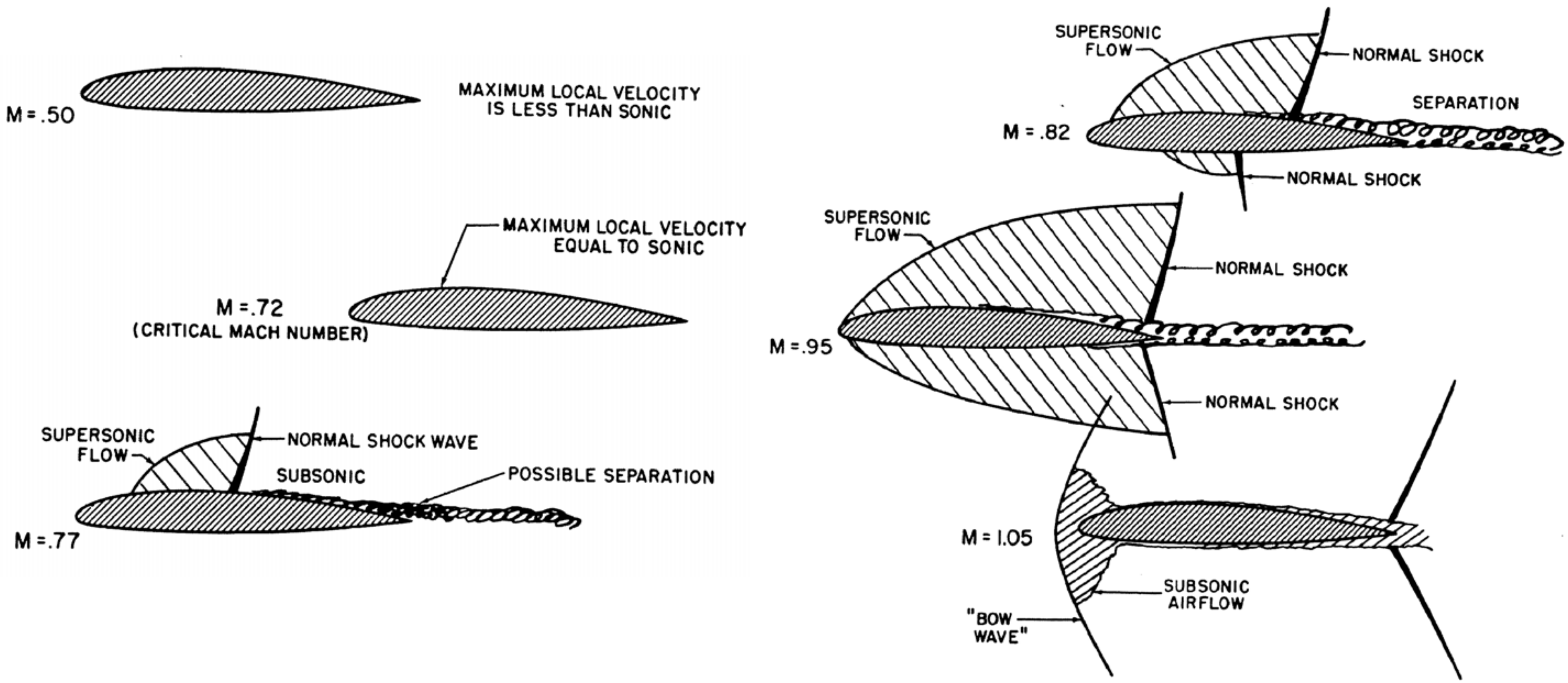
FIGURE 8.- THE VARIATION OF SECTION MOMENT COEFFICIENT WITH MACH NUMBER AT VARIOUS ANGLES OF ATTACK FOR THE NACA 66-210 AIRFOIL.

Re ≈ 2 Mill

NACA Ames
1 x 3.5 ft 2D WT
6 inch chord foil

From NACA TN 1396, by Donald Graham, Aug. 1947

What's going on?
The flow development illustration



From *Aerodynamics for Naval Aviators* by Hurt

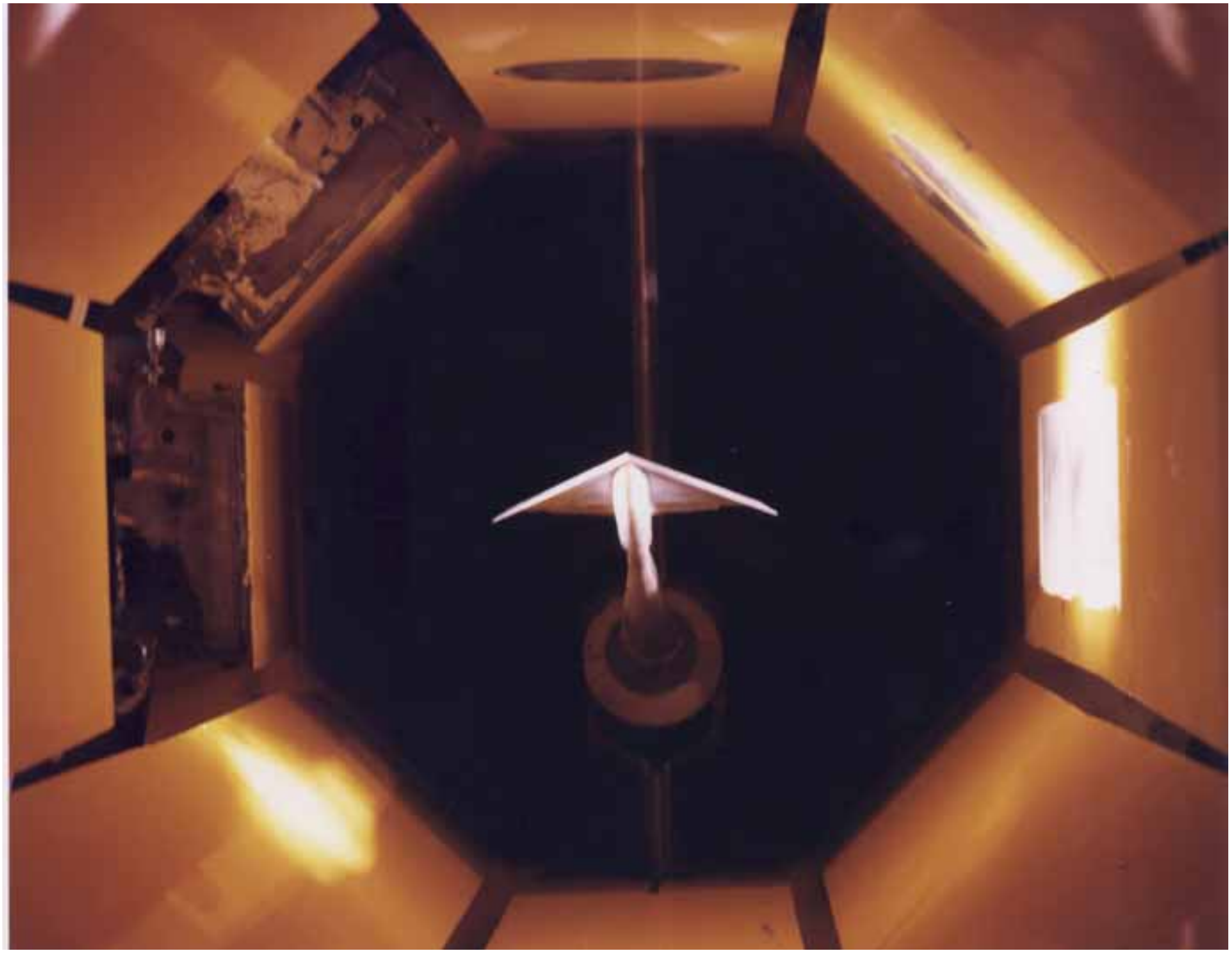
The Testing Problem

- The tunnels would choke, shocks reflected from walls!
- Initial solutions:
  - Bumps on the tunnel floor
  - Test on an airplane wing in flight
  - Rocket and free-fall tests
- At Langley (1946-1948):
  - Make the tunnel walls porous: slots
  - John Stack and co-workers: the Collier Trophy
- Later at AEDC, Tullahoma, TN:
  - Walls with holes!

Wall interference is still an issue - corrections and uncertainty

See Becker *The High Speed Frontier* for the LaRC tunnel story

Wall Interference Solution 1: Slotted Tunnel



Grumman blow-down pilot of Langley tunnel

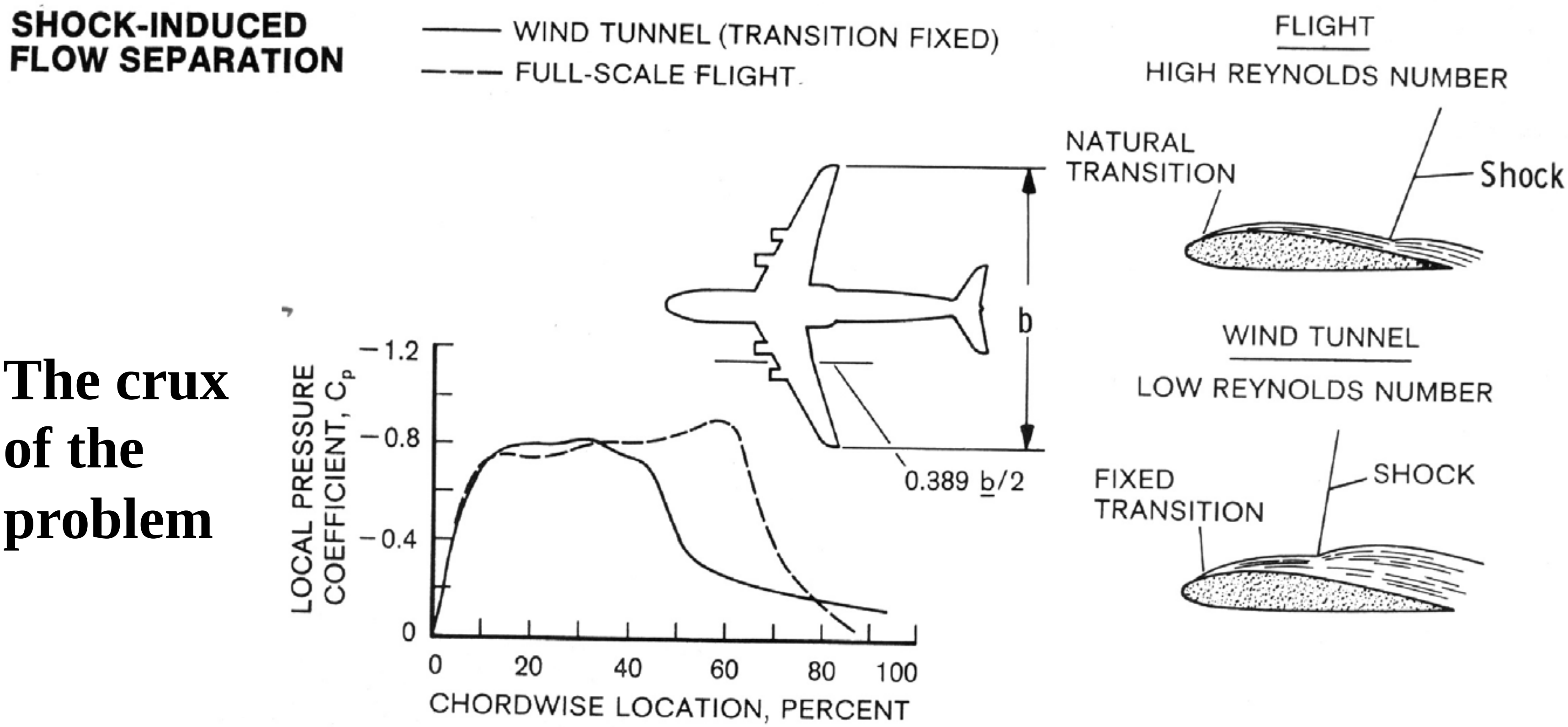
Wall Interference Solution 2: Porous Wall

The AEDC 4T, Tullahoma, TN

The Next Problem: Flow Similarity
- particularly critical at transonic speed -

- *Reynolds Number (Re)*
  - To simulate the viscous effects correctly, match the Reynolds Number
  - Usually you can't match the Reynolds number, we'll show you why and what aeros do about the problem
- *Mach Number (M)*
  - To match model to full scale compressibility effects, test at the same Mach number, sub-scale and full scale

Example of the Re Issue: The C-141 Problem



The crux of the problem

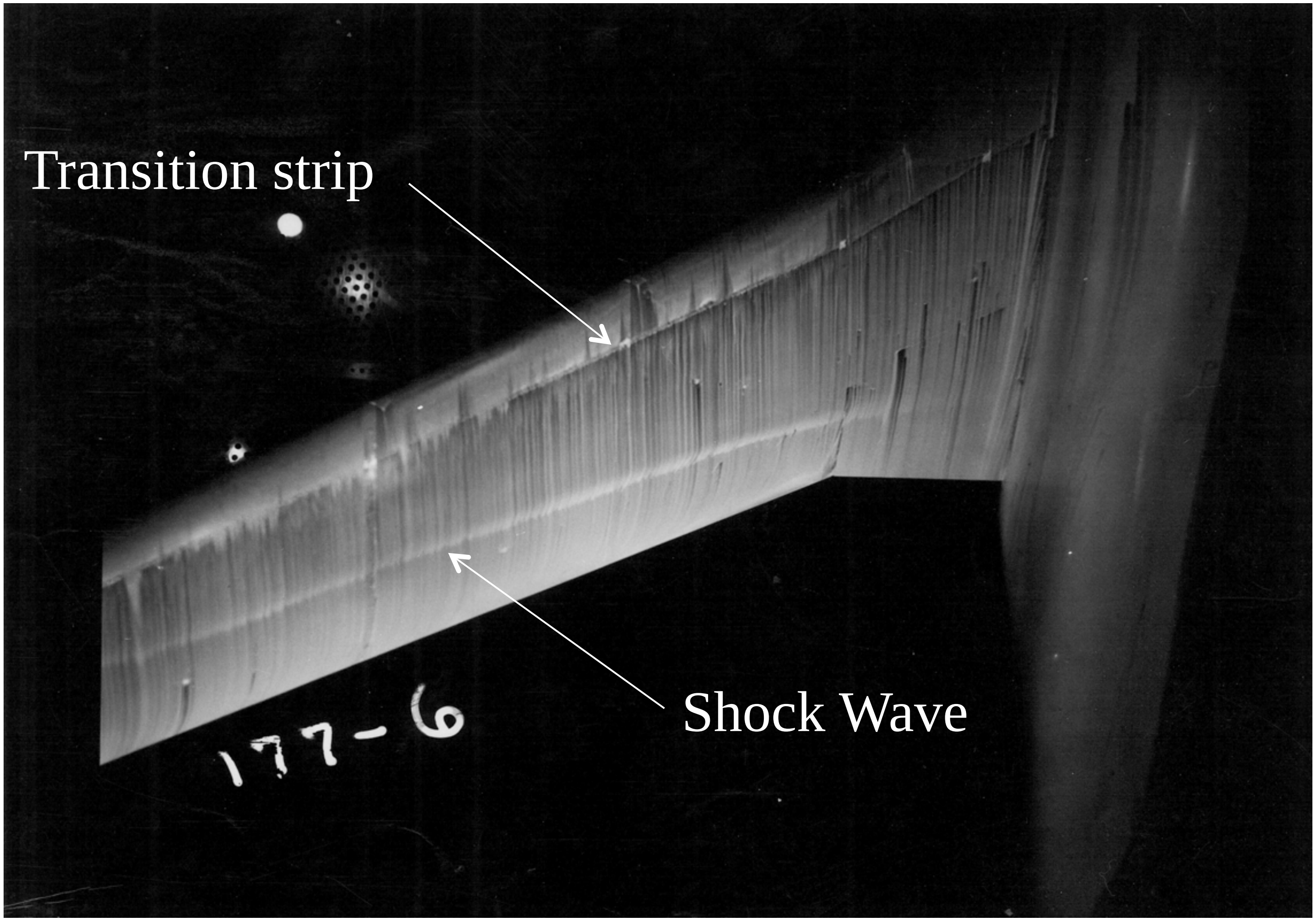
"The Need for developing a High Reynolds Number Transonic WT"
Astronautics and Aeronautics, April 1971, pp. 65-70

To Help Match Reynolds Number

- *Pressure* Tunnels
- *Cold* Tunnels
  - Keeps dynamic pressure "reasonable"
    - Implies acceptable balance forces
    - Also reduces tunnel power requirements
- *Big* Wind Tunnels
- *Games* with the boundary layer
  - Force transition from laminar to turbulent flow: "trips"

- or a combination of the above -

Example: Oil Flow of a transport wing showing both the location of the transition strip and the shock at M = 0.825



Matching the Reynolds Number?

$$Re = \frac{\rho V L}{\mu}$$

ρ : density, V: velocity, L : length, μ : viscosity,

Use perfect gas law, and $\mu = T^{0.9}$

$$\mathrm{Re} = \frac{\sqrt{\gamma}\, p M L}{\sqrt{R}\, T^{1.4}}$$

Increase *Re* by increasing *p* or *L*, decreasing *T* or changing the gas

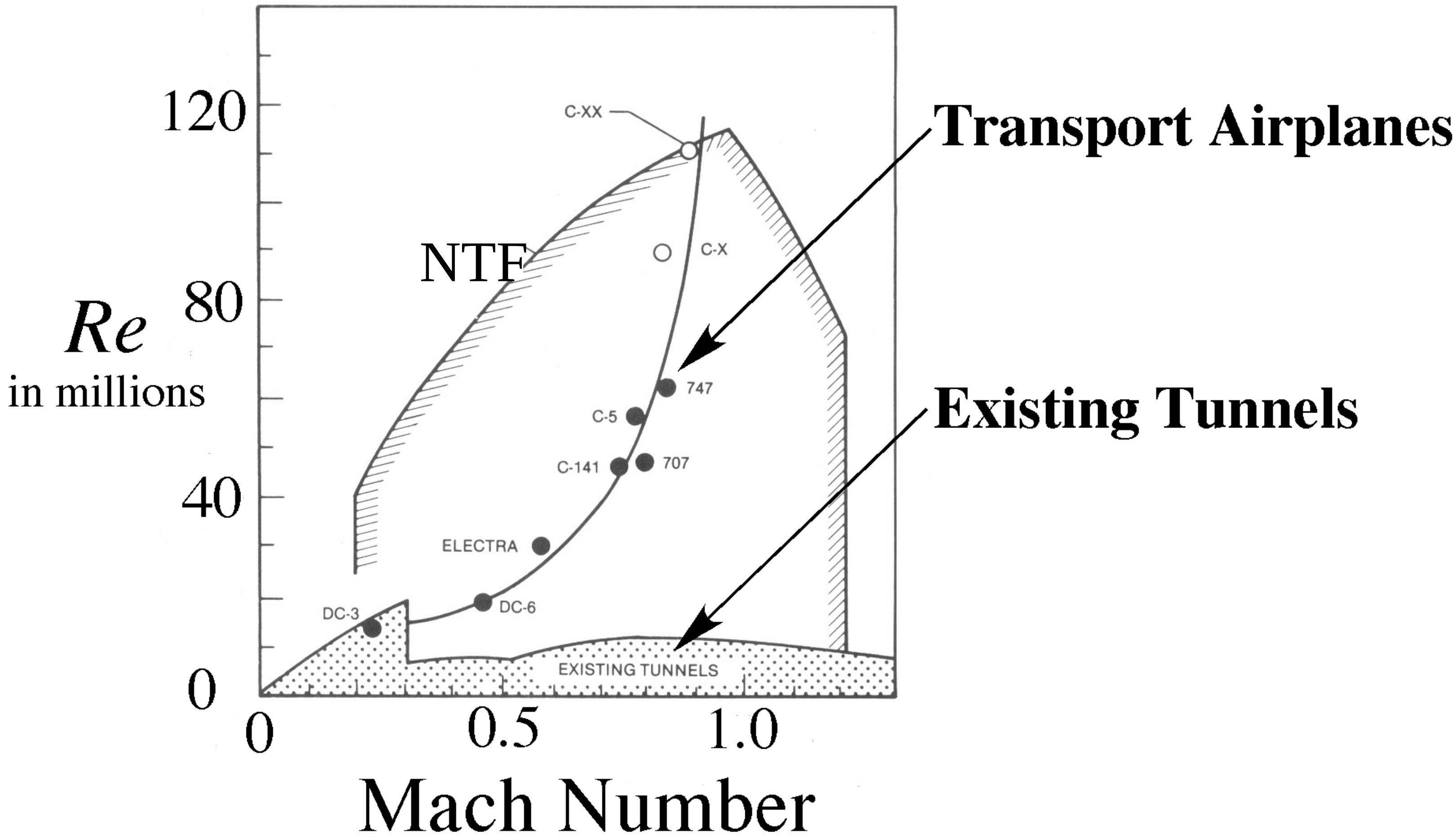
Balance forces are related to, say, $N = qSC_L$

$$q = \frac{\gamma}{2} p M^2$$

Reducing *T* allows *Re* increase without huge balance forces
- note: *q* proportional to *p*, as shown above

AIAA 72-995 or *Prog. in Aero. Sciences*, Vol. 29, pp. 193-220, 1992

WT vs Flight
Why the National Transonic Facility (NTF) was built



“The Large Second Generation of Cryogenic Tunnels”
Astronautics and Aeronautics, October 1971, pp. 38-51

Uses cryogenic nitrogen as the test gas

Trying to match flight *Re* using cryogenic nitrogen: The NTF at NASA Langley, Hampton, VA

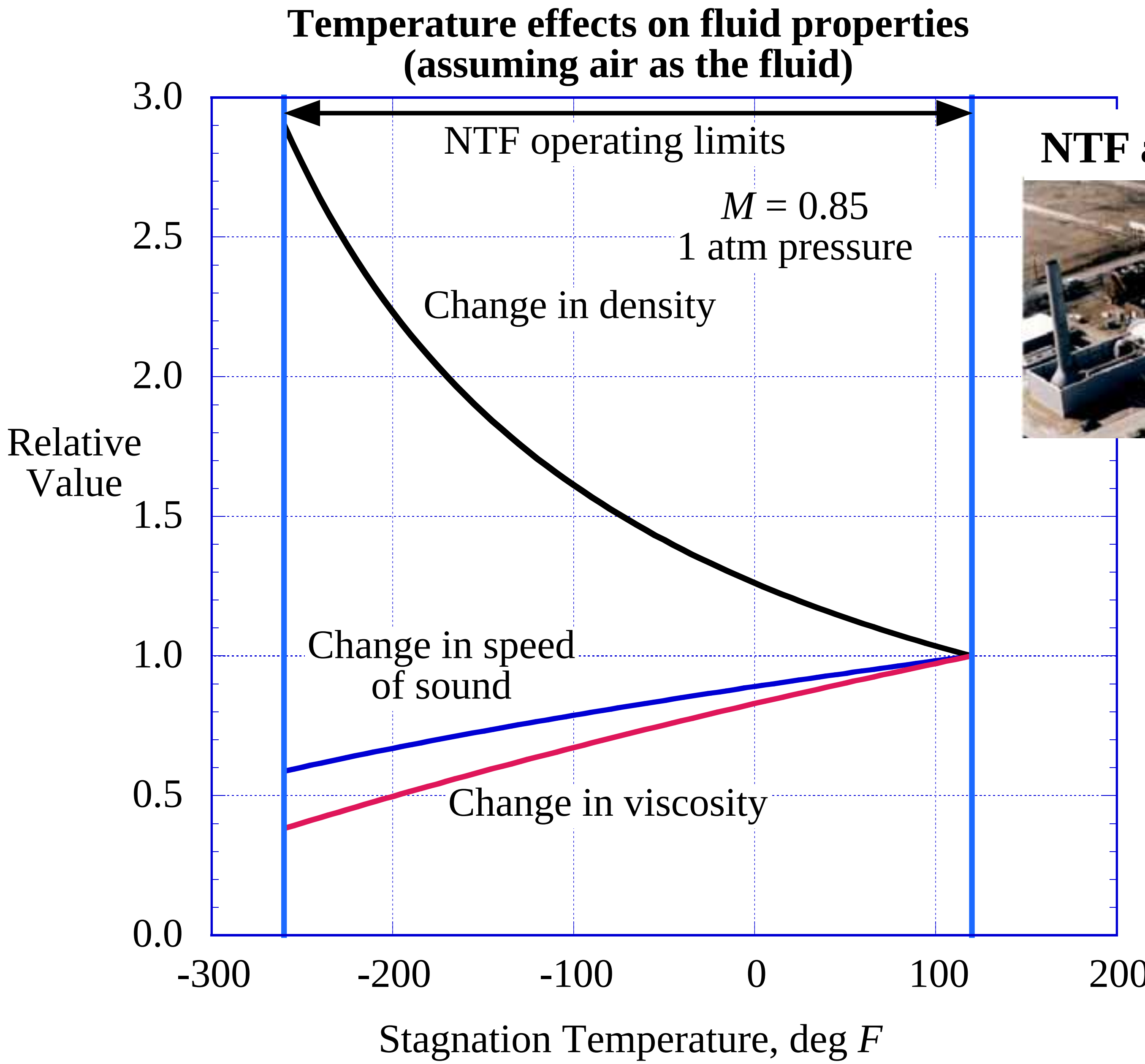
Feb. 1982

Performance: $M = 0.2$ to 1.20

$P_T = 1$ to 9 atm

$T_T = 77°$ to $350°$ Kelvin

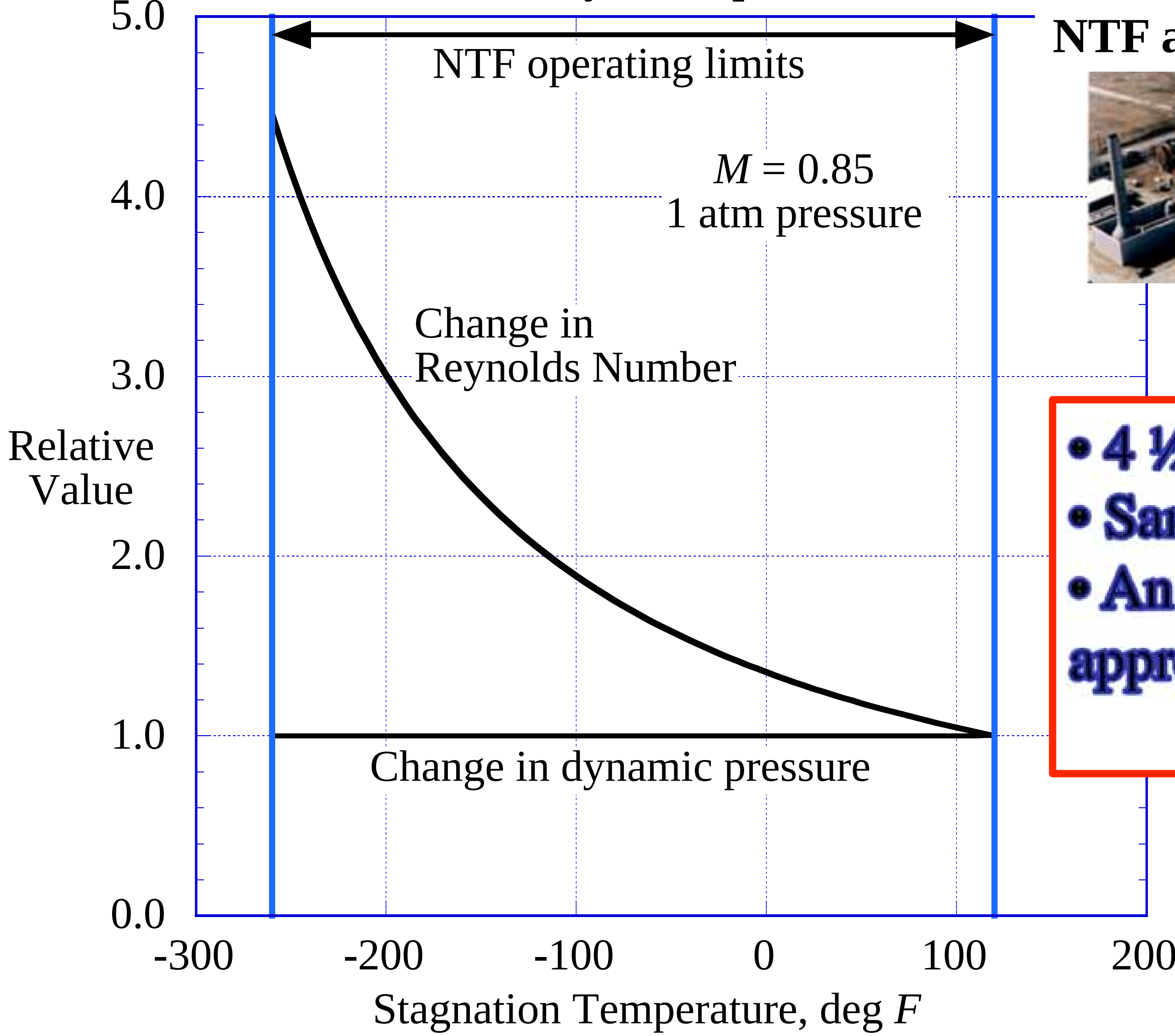
Cryo effects on fluid properties



NTF at NASA LaRC

Cryo Effects on Re and q

Temperature effects on Reynolds Number and test dynamic pressure



NTF at NASA LaRC

- **4 ½ times the *Re***
- **Same *q***
- **An enabling approach!**

Some References

Michael J. Goodyer and Robert A. Kilgore, "High-Reynolds-Number Cryogenic Wind Tunnel," *AIAA J.*, Vol. 11, No. 5, May 1973, pp. 613-619.

Dennis E. Fuller, "Guide for Users of the National Transonic Facility," NASA TM 83124, July 1981.

Michael J. Goodyer, "The Cryogenic Wind Tunnel," *Progress in Aerospace Sciences*, Vol. 29, pp. 193-220, 1992.