# Some Supersonic Aerodynamics

**W.H. Mason**

**Configuration Aerodynamics Class**

Grumman Tribody Concept – from 1978 Company Calendar

# The Key Topics

- Brief history of serious supersonic airplanes
  - There aren't many!
- The Challenge
  - *L*/*D*, $C_{D0}$ trends, the sonic boom
- Linear theory as a starting point:
  - Volumetric Drag
  - Drag Due to Lift
- The *ac* shift and *cg* control
- The Oblique Wing
- Aero/Propulsion integration
- Some nonlinear aero considerations
- The SST development work
- Brief review of computational methods
- Possible future developments

# Are “Supersonic Fighters” Really Supersonic?

- If your car’s speedometer goes to 120 mph, do you actually go that fast?
- The official F-14A supersonic missions (max Mach 2.4)
  - CAP (Combat Air Patrol)
    - 150 miles subsonic cruise to station
    - Loiter
    - Accel, $M = 0.7$ to 1.35, then dash 25nm
      - 4 ½ minutes and 50nm total
    - Then, head home or to a tanker
  - DLI (Deck Launch Intercept)
    - Energy climb to 35K ft., $M = 1.5$ (4 minutes)
    - 6 minutes at 1.5 (out 125-130nm)
    - 2 minutes combat (slows down fast)

    After 12 minutes, must head home or to a tanker

# Very few *real* supersonic airplanes

- 1956: the B-58 ($L/D_{max} = 4.5$)
  - In 1962: Mach 2 for 30 minutes
- 1962: the A-12 (SR-71 in ’64) ($L/D_{max} = 6.6$)
  - 1st supersonic flight, May 4, 1962
  - 1st flight to exceed Mach 3, July 20, 1963
- 1964: the XB-70 ($L/D_{max} = 7.2$)
  - In 1966: flew Mach 3 for 33 minutes
- 1968: the TU-144
  - 1st flight: Dec. 31, 1968
- 1969: the Concorde ($L/D_{max} = 7.4$)
  - 1st flight, March 2, 1969
- 1990: the YF-22 and YF-23 (supercruisers)
  - YF-22: 1st flt. Sept. 29, 1990, F-22 1st flt. Sept. 7, 1997
  - YF-23: 1st flt. Aug. 27, 1990

# The B-58

Static margin, 3% for longitudinal stability, > 3% needed for directional stability margin in the engine out case. An ARI (Aileron-Rudder Interconnect) was used to cancel the yawing moment due to aileron deflection.

Used GE J79 engines

See Erickson, “Flight Characteristics of the B58 Mach 2 Bomber,” *J. of the Royal Aero. Soc.*, Nov. 1962, Vol. 66, No. 623, pp 665-671

# SR-71

- See Ben Rich's paper
- Heating issues make it "hypersonic"
- Used the P&W J58 turboramjet

Dryden Flight Research Center EC96-43902-1
SR-71B photographed from Air Force tanker.
28Jan1997 NASA photo by Jim Ross

Dryden Flight Research Center EC99-45065-1 Photographed 1999
SR-71 taking off with F-18 Chase in the background.
NASA/Dryden Tom Tschida

See Peter W. Merlin, *Design and Development of the Blackbird*, AIAA Library of Flight Series, 2008

# XB-70

Dryden Flight Research Center ECN-792 Photographed 1965
XB-70

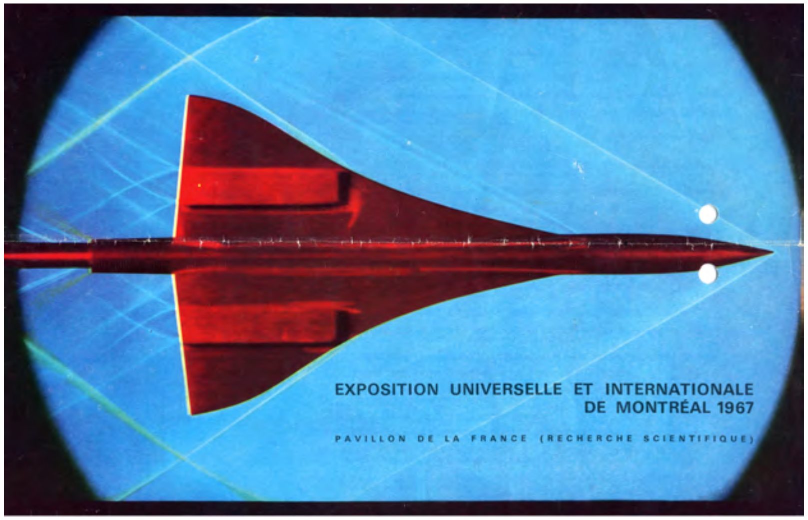
- The single remaining (of 2) XB-70 is at the USAF Museum in Dayton, Ohio
- 2nd airplane collision with F-104, June 8, 1966

Wingtips deflected down at high speed: almost no *ac* shift, sub- to supersonic speeds

Retired: Feb. 4, 1969

Dryden Flight Research Center EC68-2131 Photographed 1968
XB-70 NASA photo

# The Concorde



Front cover of the French display brochure at Expo 67, held in Montreal, Canada

Introduced into service: Jan. 21, 1976
Retired from service: Nov. 26, 2003

# Reality

Do you think this "supersonic" fighter can fly supersonic with this load??

# The Challenge

- Entirely different physics (hyperbolic vs elliptic *pde* - remember?)

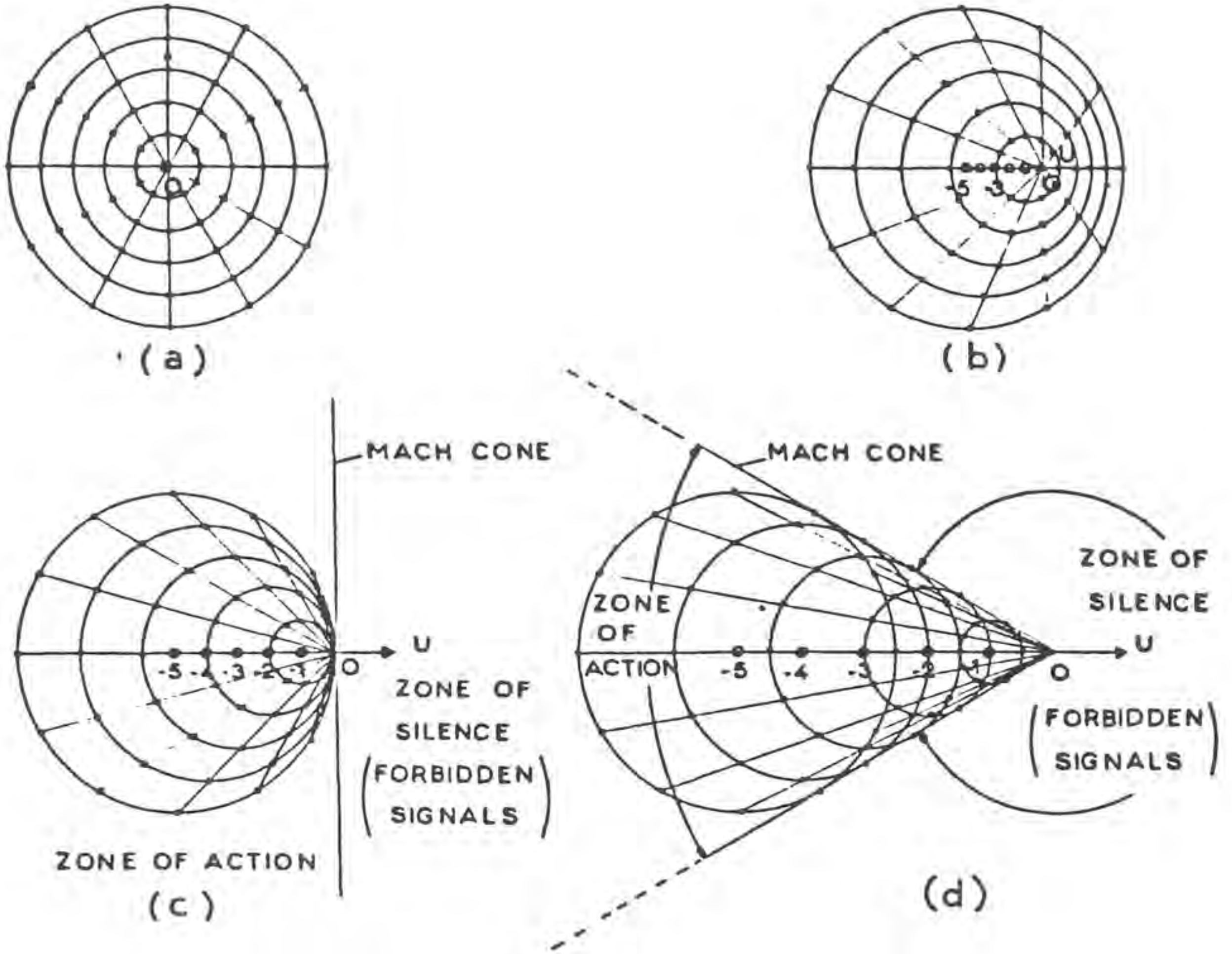
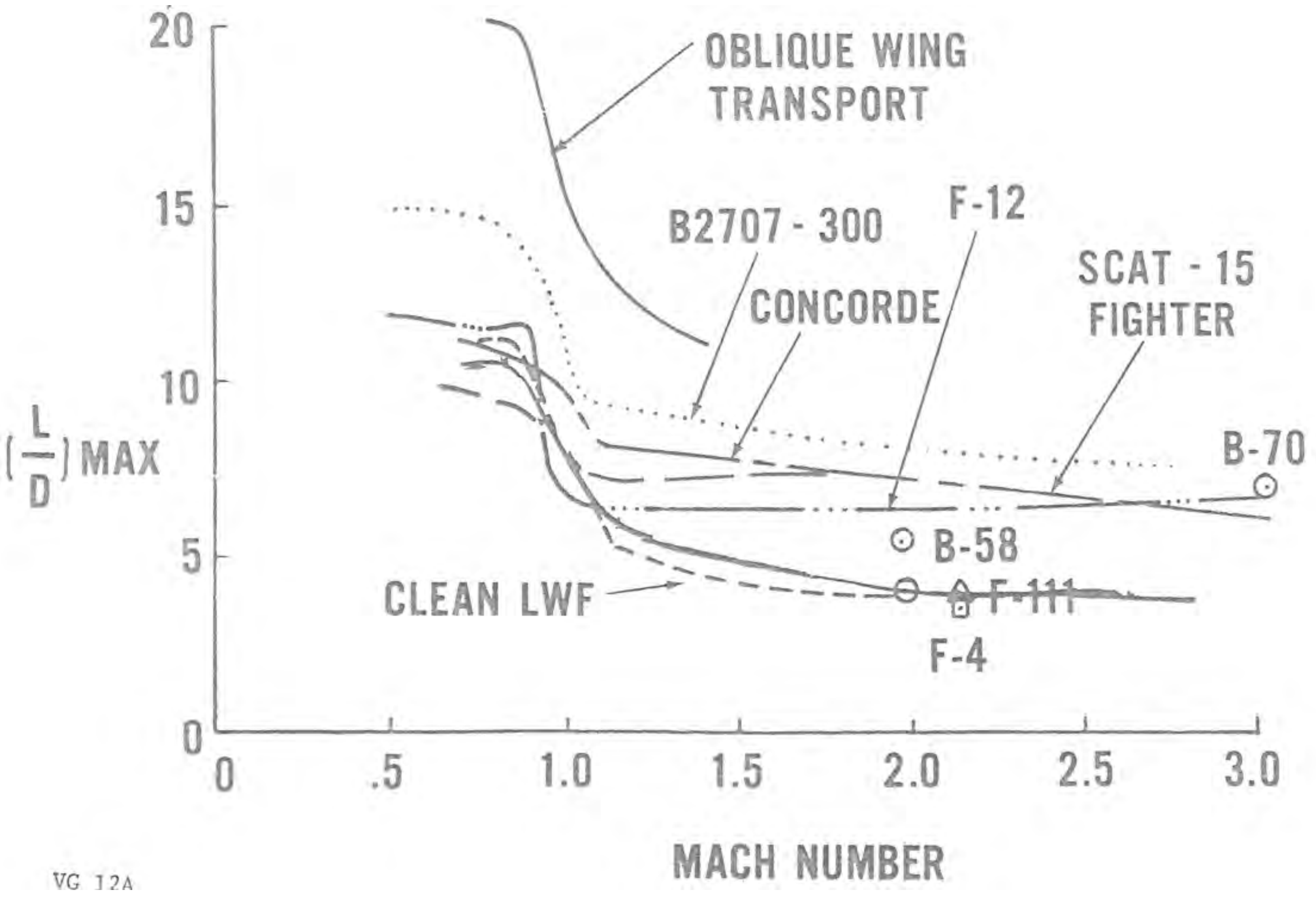


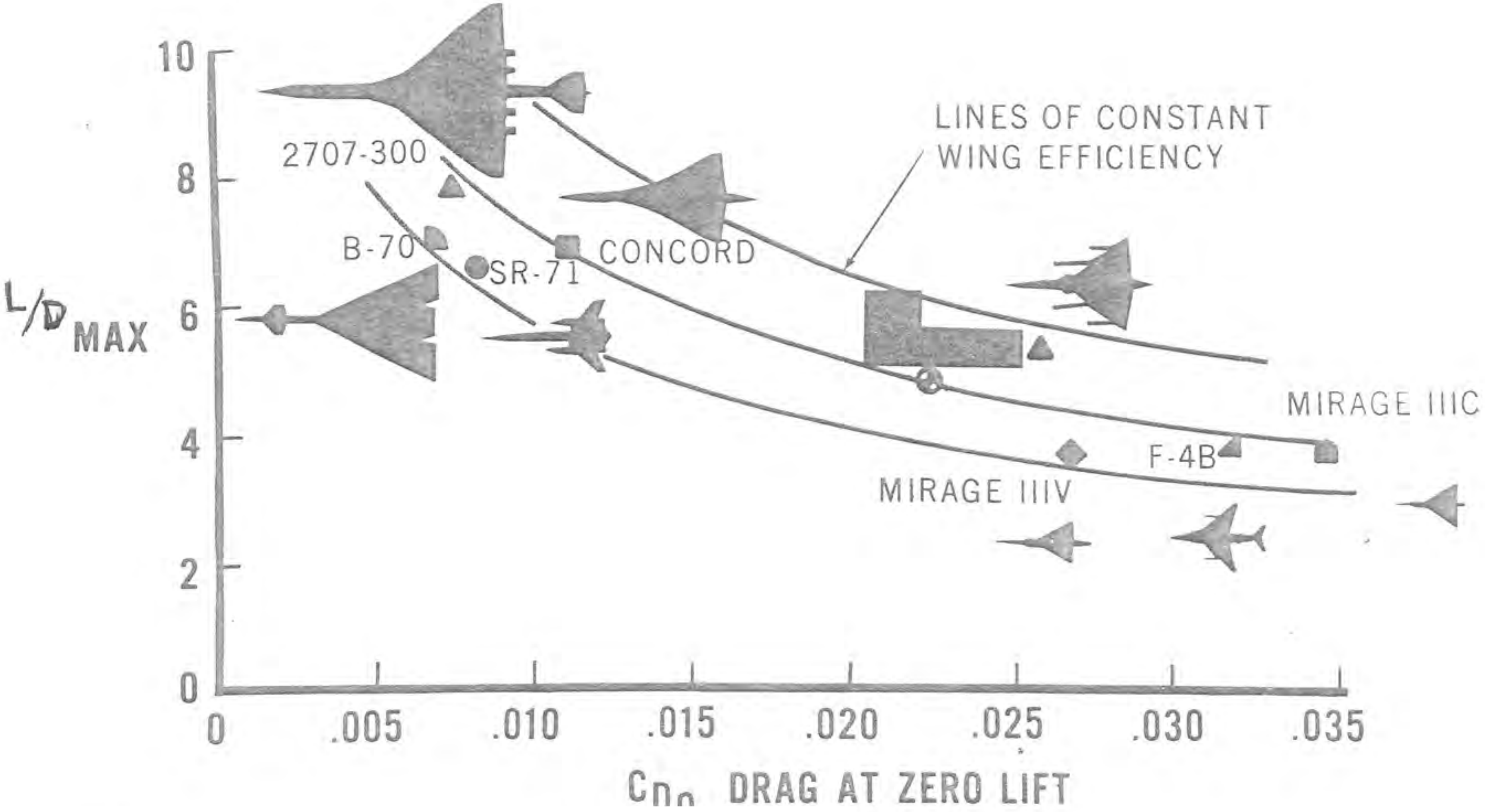
*Fig.* 42. Point source moving in compressible fluid. (*a*) Stationary source. (*b*) Source moving at half the speed of sound. (*c*) Source moving at the speed of sound. (*d*) Source moving at twice the speed of sound. (From Th. von Kármán, in *Journal of the Aeronautical Sciences*, *14* [1947], 374, by permission of the Institute of the Aeronautical Sciences.)

# Max L/D trends with Mach number



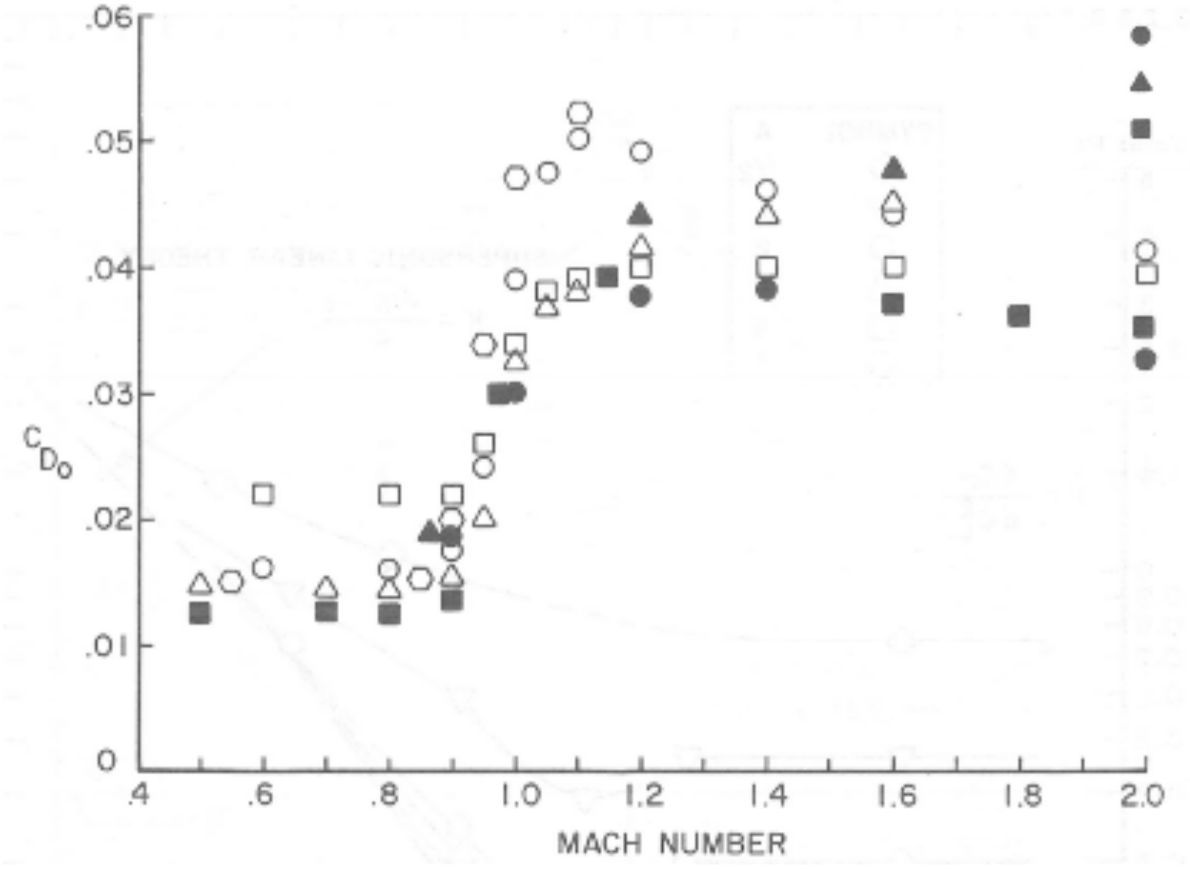
AIAA 1976-0892, Everest Riccioni

# Low $C_{D0}$ is critical



AIAA 1976-0892, Everest Riccioni

# Typical $C_{D0}$ trends for Fighters



| SYMBOL | AIRCRAFT | REFERENCE AREA |
|---|---|---|
| ○ | F-104G | 196 |
| □ | F-4E | 530 |
| ○ | A-7D | 375 |
| △ | T-38 | 170 |
| ● | Northrop P600(YF-17) | 350 |
| ▲ | General Dynamics Model 401(YF-16) | 280 |
| ■ | F-8J | 350 |

From Nicolai, *Fundamentals of Aircraft Design*

# The real problem

You will probably never have enough thrust to reach $L/D_{\max}$

- at cruise, $C_{D0}$ dominates

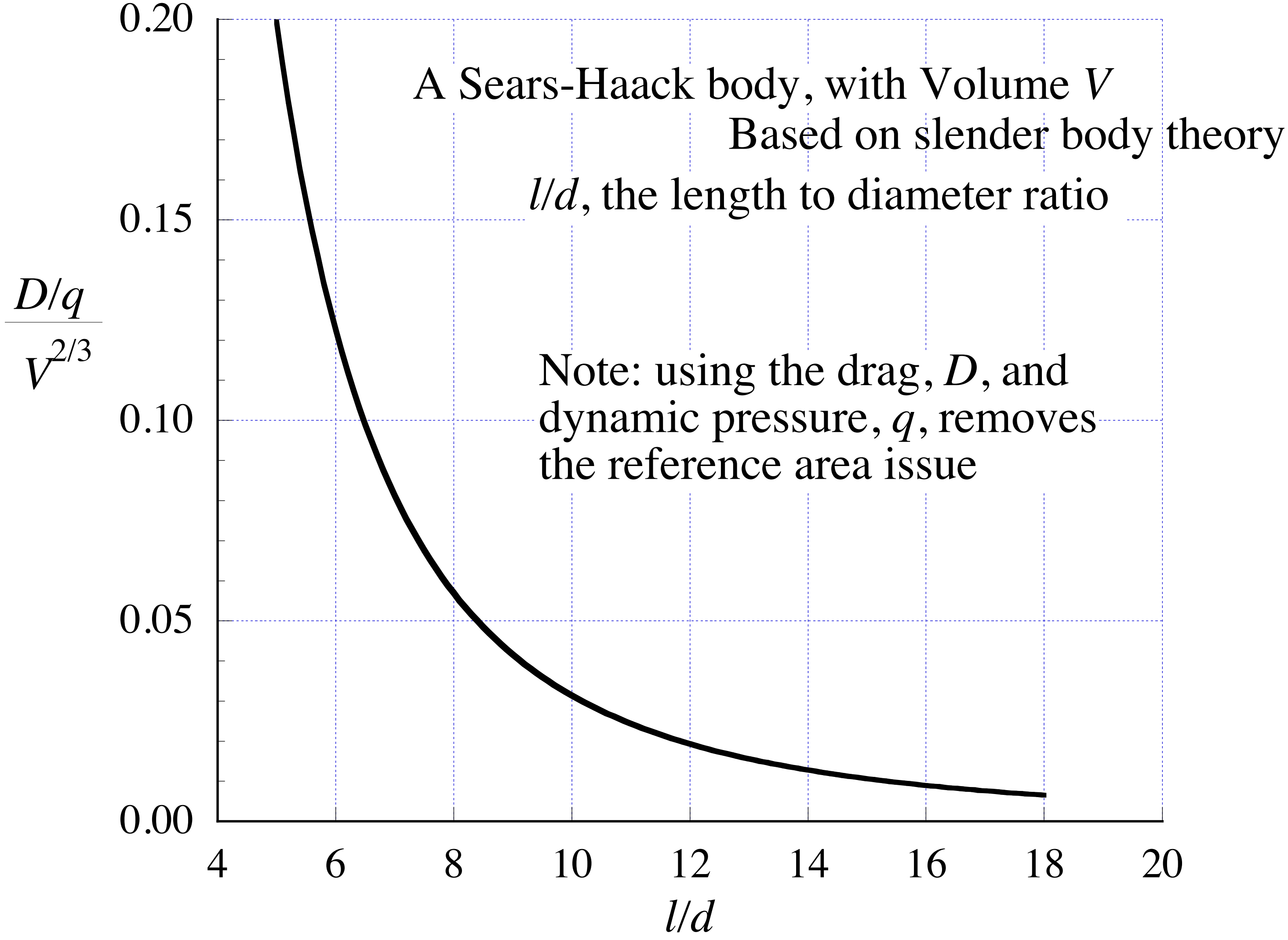
# Understanding Drag

- Break into zero lift and drag due to lift
  - Use linear theory to provide conceptual basis for your design thinking

# Wave Drag

- Primarily due to volume, but also lift
- Minimum drag area distributions and fineness ratio are your primary tools
  - We talked about the area rule discussing drag in general earlier

# Fineness Ratio, *l/d*: A powerful way to reduce wave drag



A Sears-Haack body, with Volume $V$

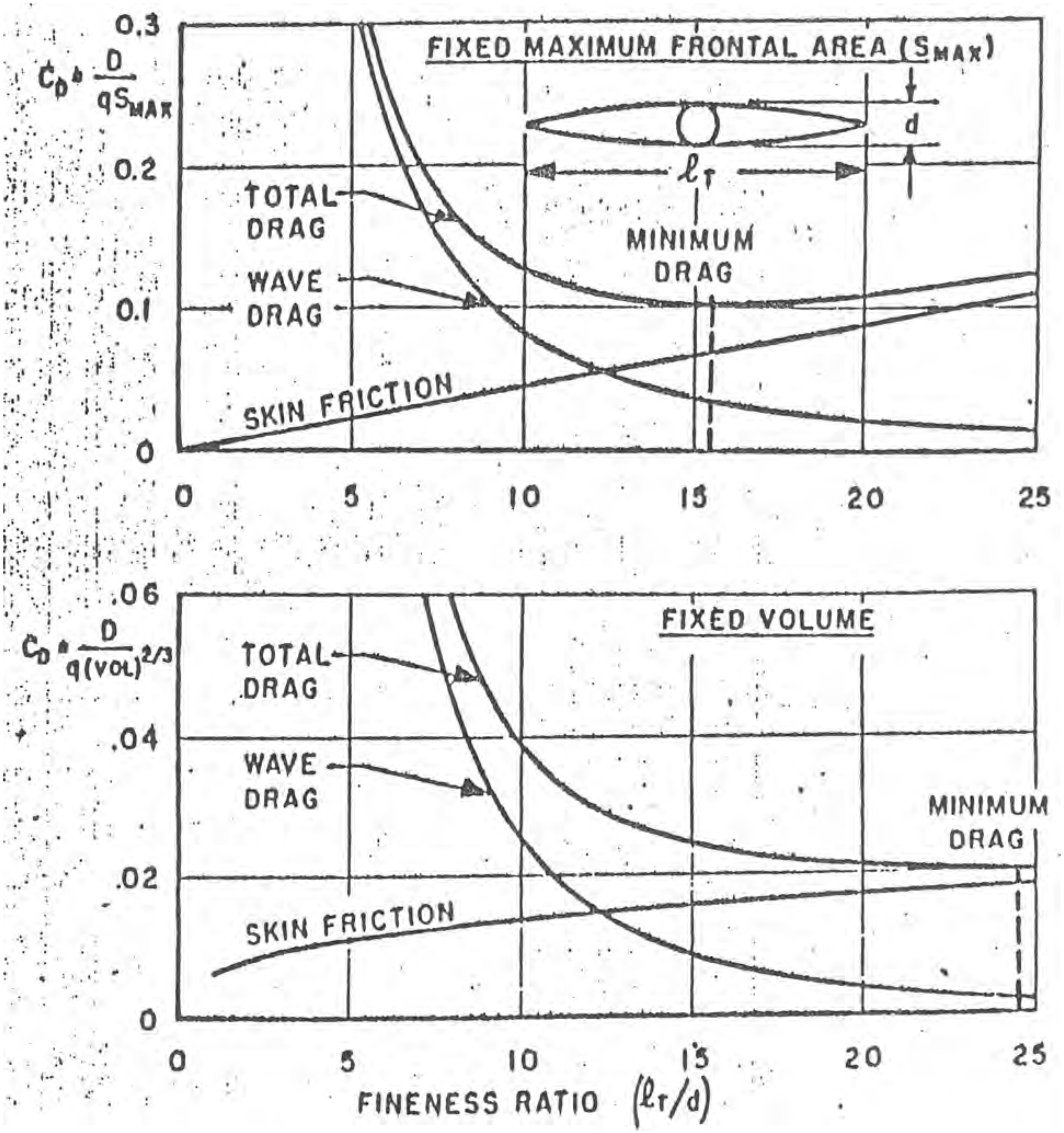
Based on slender body theory

$l/d$, the length to diameter ratio

Note: using the drag, $D$, and dynamic pressure, $q$, removes the reference area issue

# Wave drag and friction drag combined

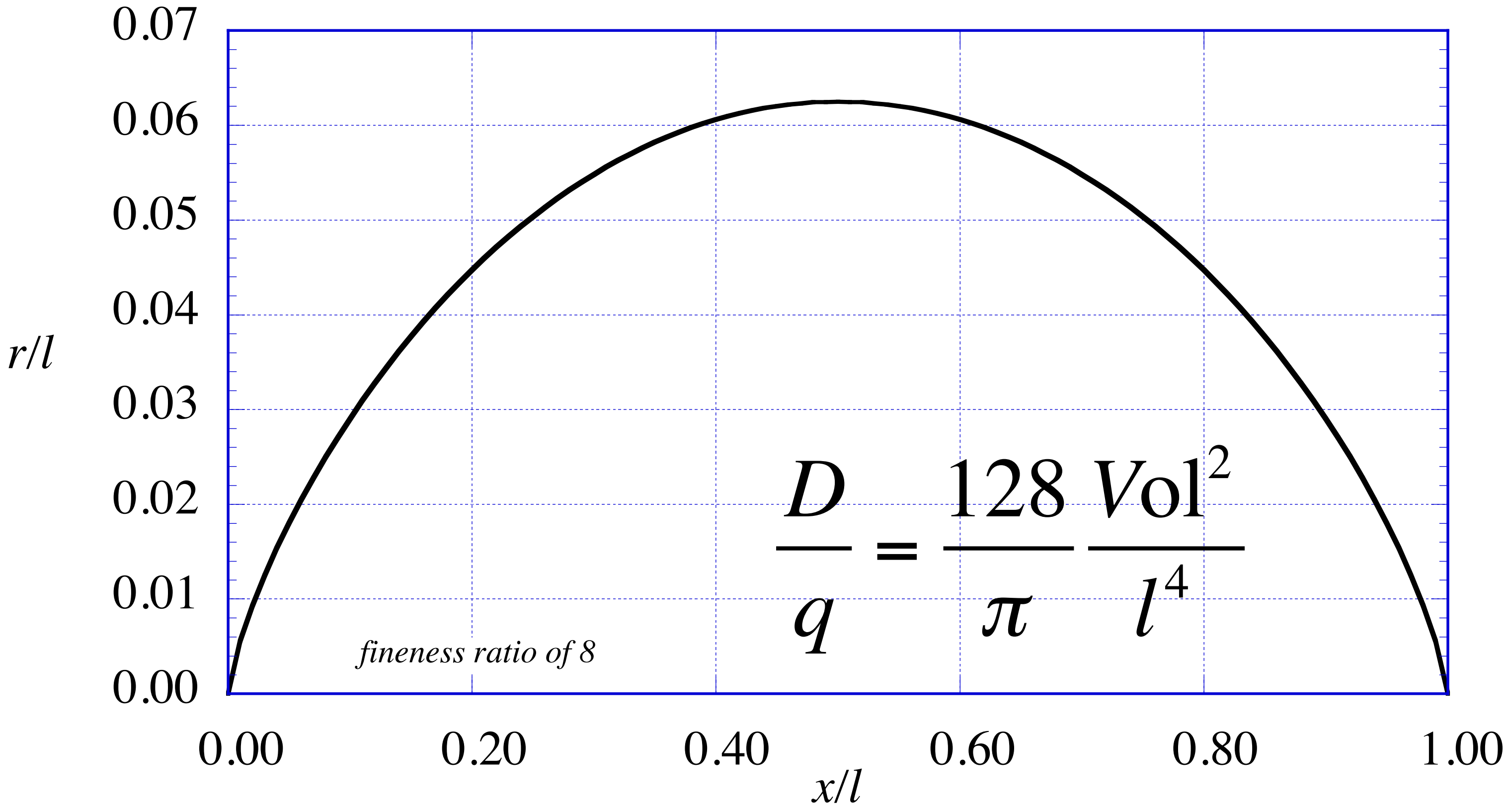
From “Applied Aerodynamics and Flight Mechanics,” by W. Bailey Oswald, *Journal of the Aeronautical Sciences*, May 1956.



**Note the difference in fineness ratio for min drag for the two cases**

Mason did this and then found it had already been done, but it is a good exercise

# Min Wave Drag of Axi-body with zero base area: Radius Given Volume & Length

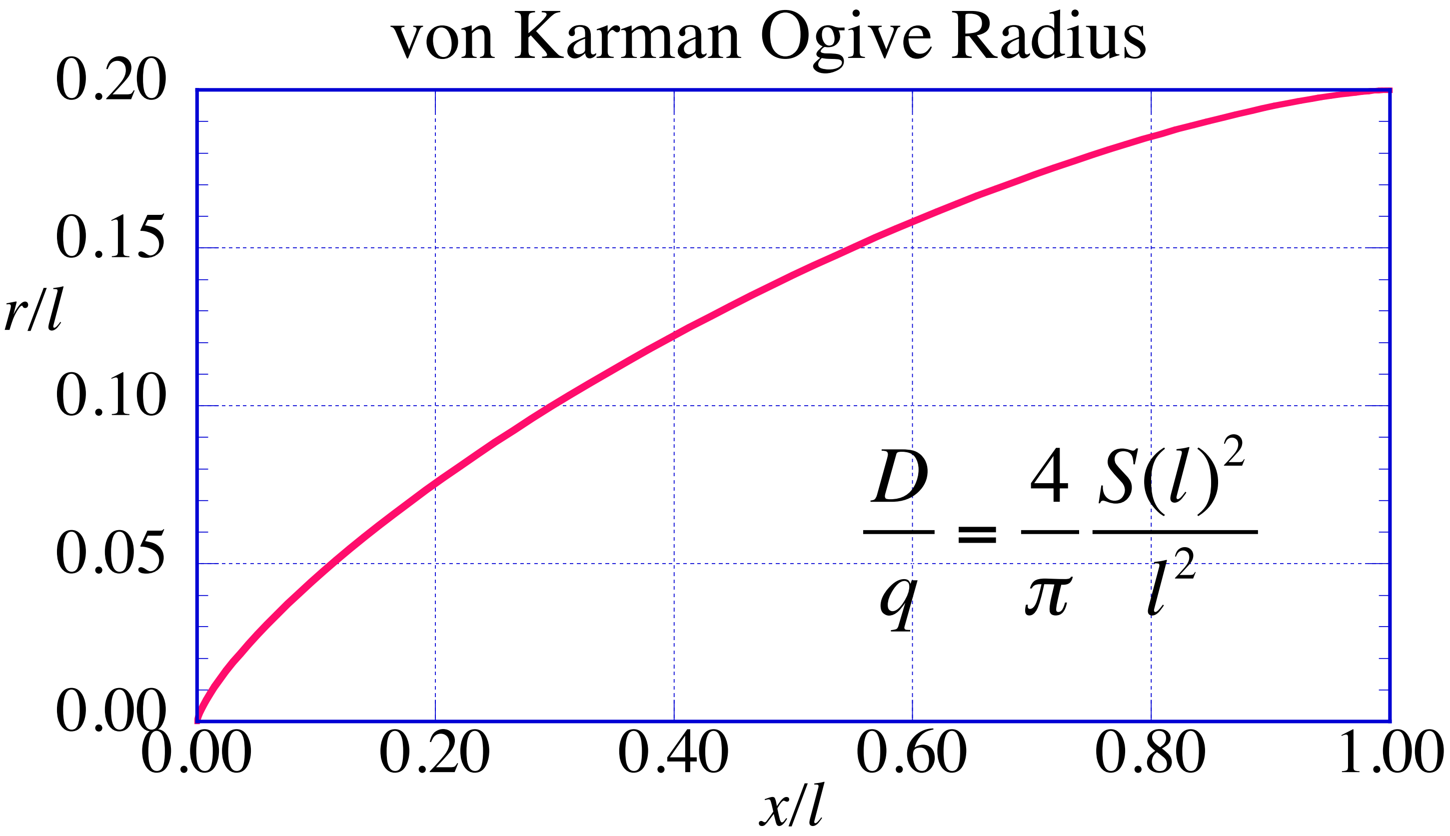


Sears Haack Body Radius Distribution

$$\frac{D}{q} = \frac{128}{\pi}\frac{\mathrm{Vol}^2}{l^4}$$

Note: No Mach number dependence with the slender body theory used here.

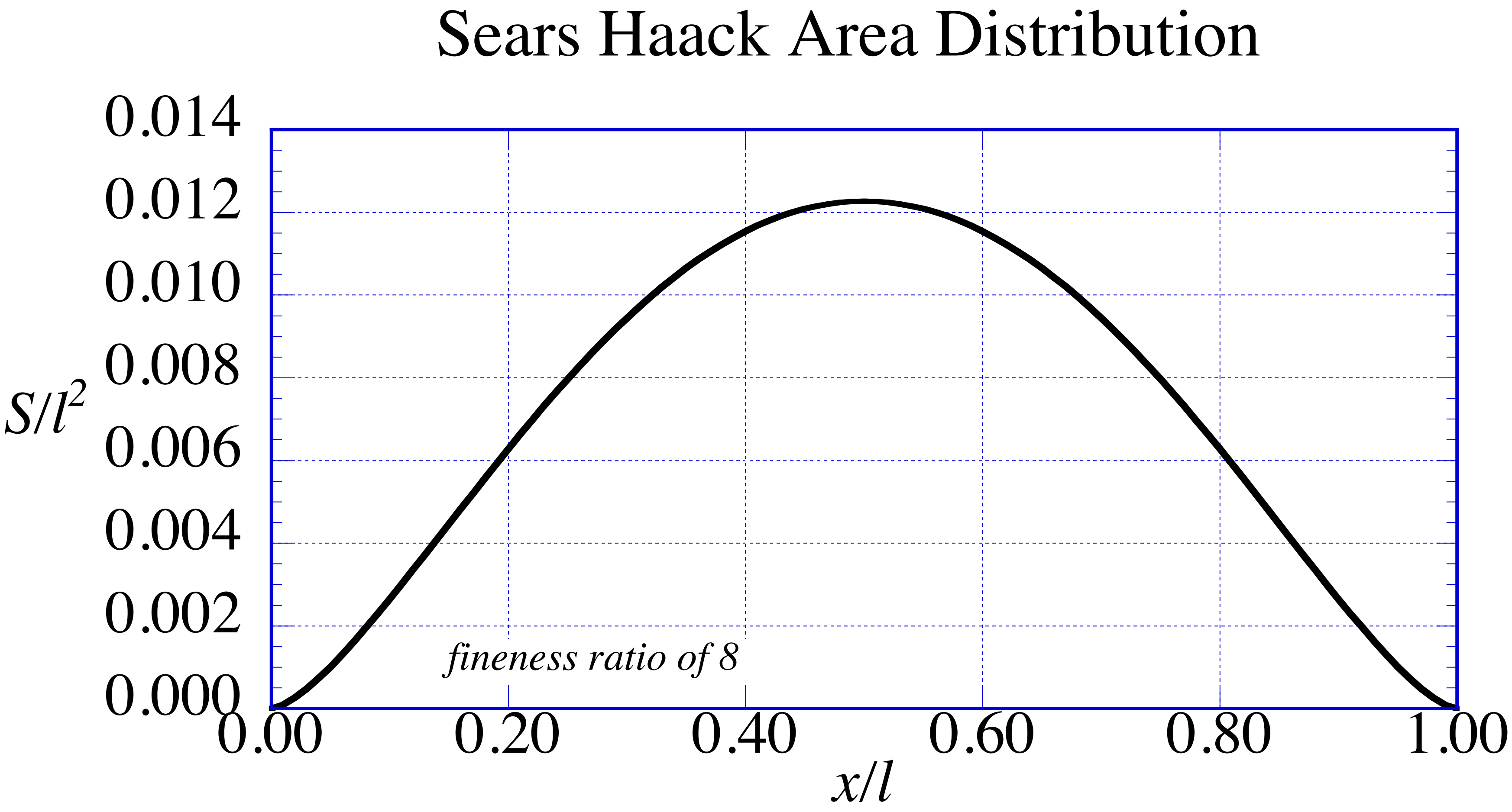
# Min Drag Radius for Axi-body Given Base Area/Length


von Karman Ogive Radius

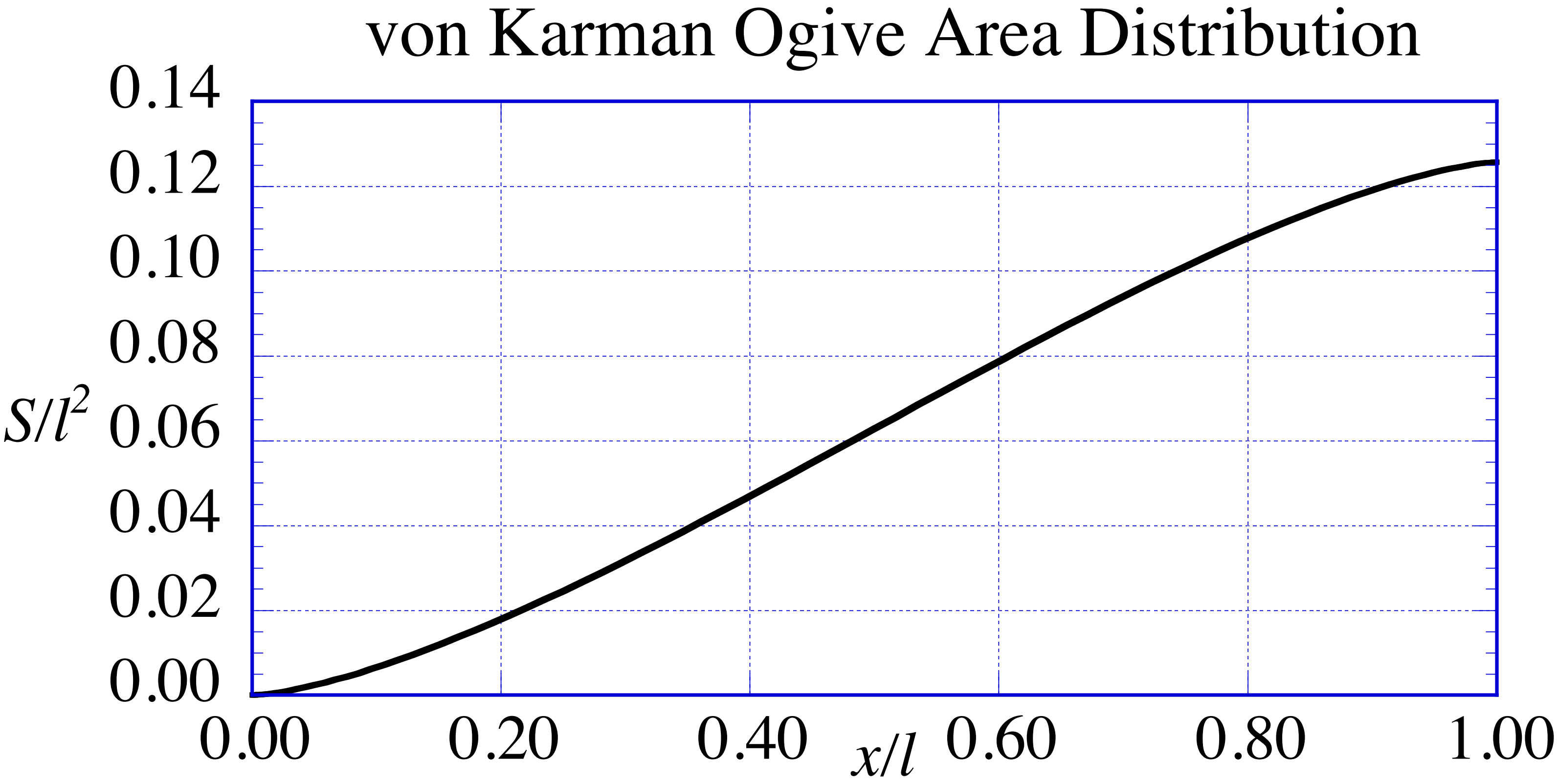
$$\frac{D}{q} = \frac{4}{\pi} \frac{S(l)^2}{l^2}$$

Note: No Mach number dependence with the slender body theory used here.

# Min Drag Area Distribution for axi-body with zero base area Given Length & Volume



# Min Drag Area Distribution for Axi-body Given Base Area and Length

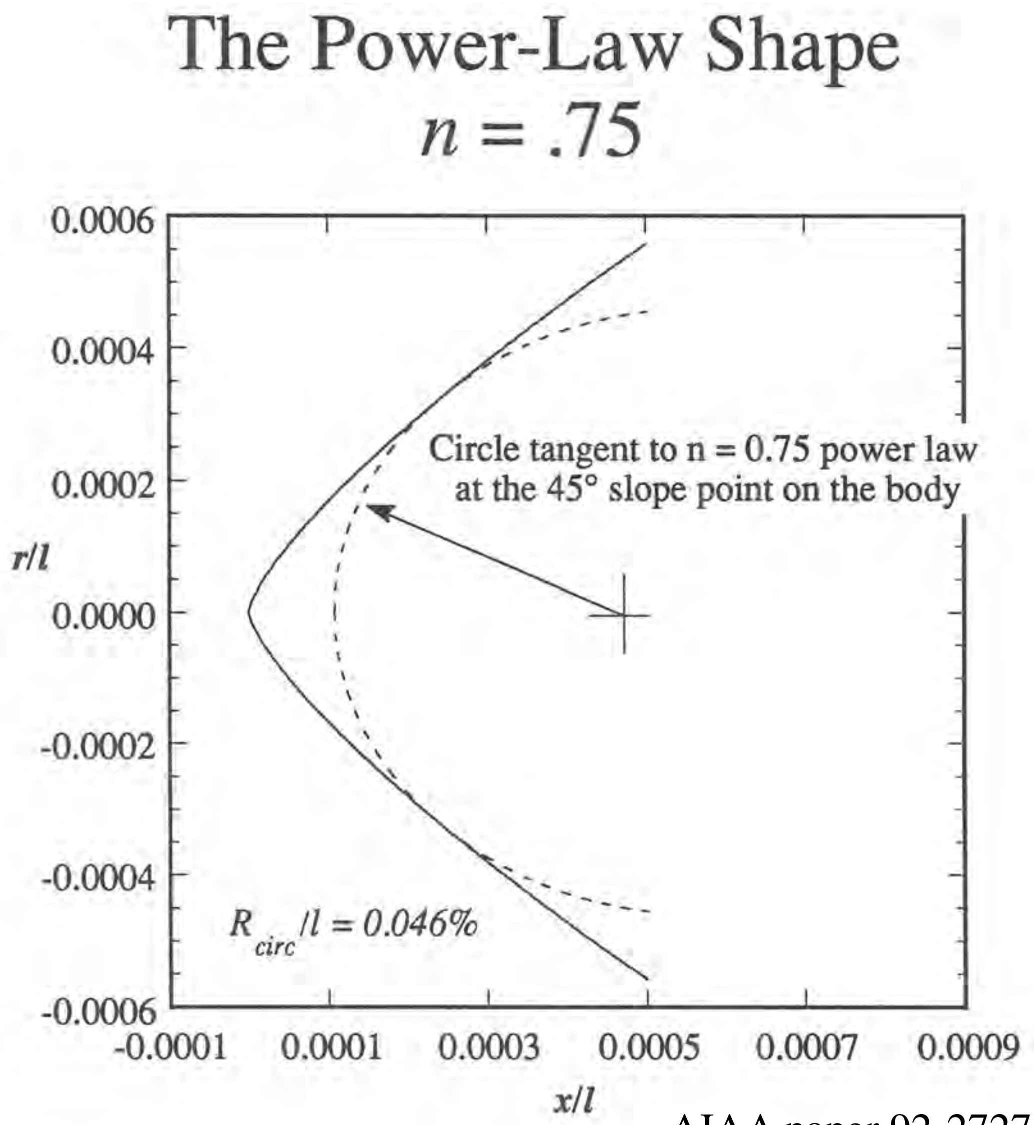


# The strange story of the LE radius

Both the Sears-Haack body and the von Karman ogive behave like a power law body with an exponent, *n*, of 0.75 at the nose.

$$\frac{r}{l} \approx \left(\frac{x}{l}\right)^{n}$$

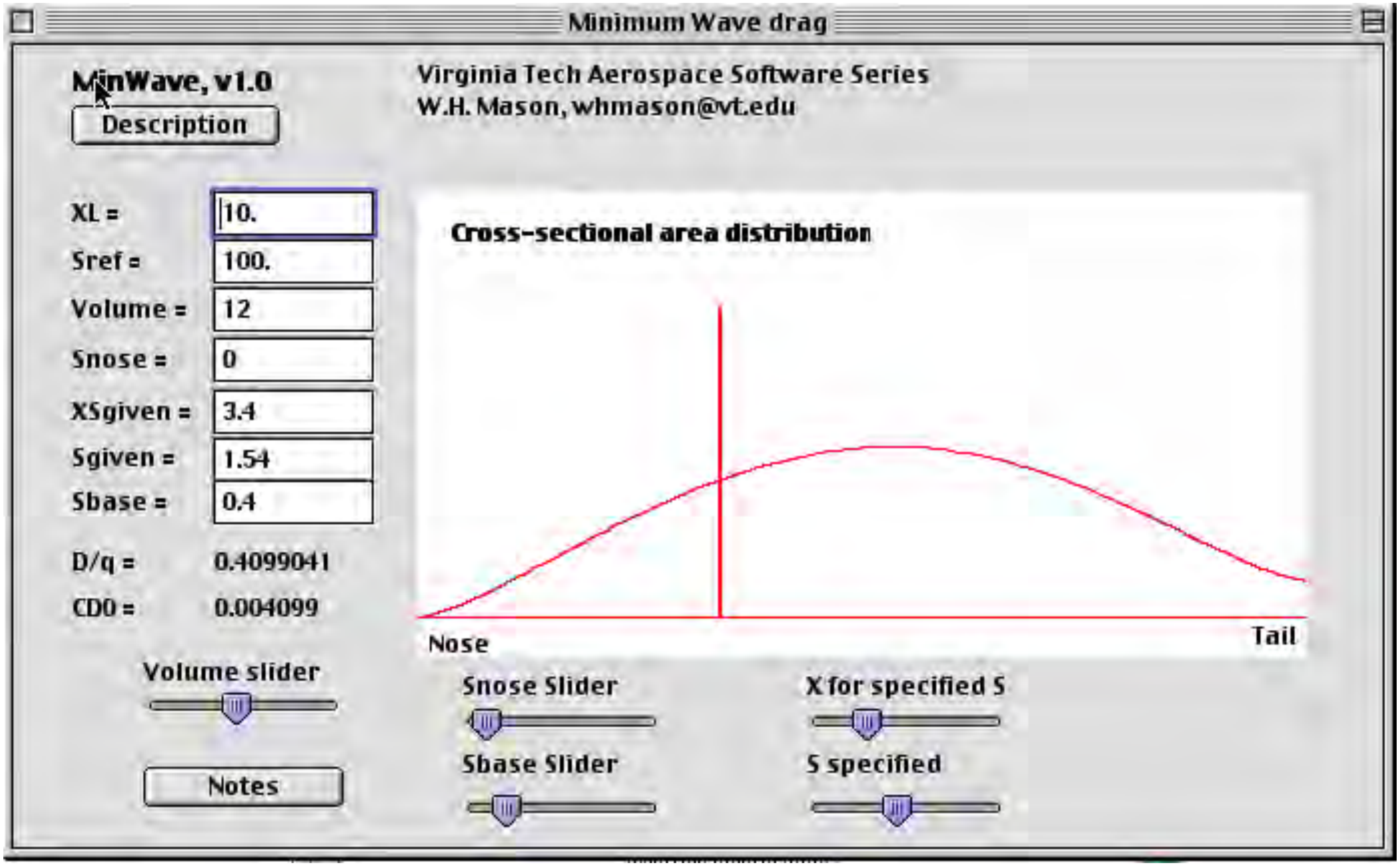
**The slope at the nose is 90°, but the leading edge radius is zero!**



AIAA paper 92-2727

# Demo Wave Drag Interactive Toy

*Note: opening up the base allows a reduction in drag*



Minimum Wave drag

**MinWave, v1.0**

Virginia Tech Aerospace Software Series
W.H. Mason, whmason@vt.edu

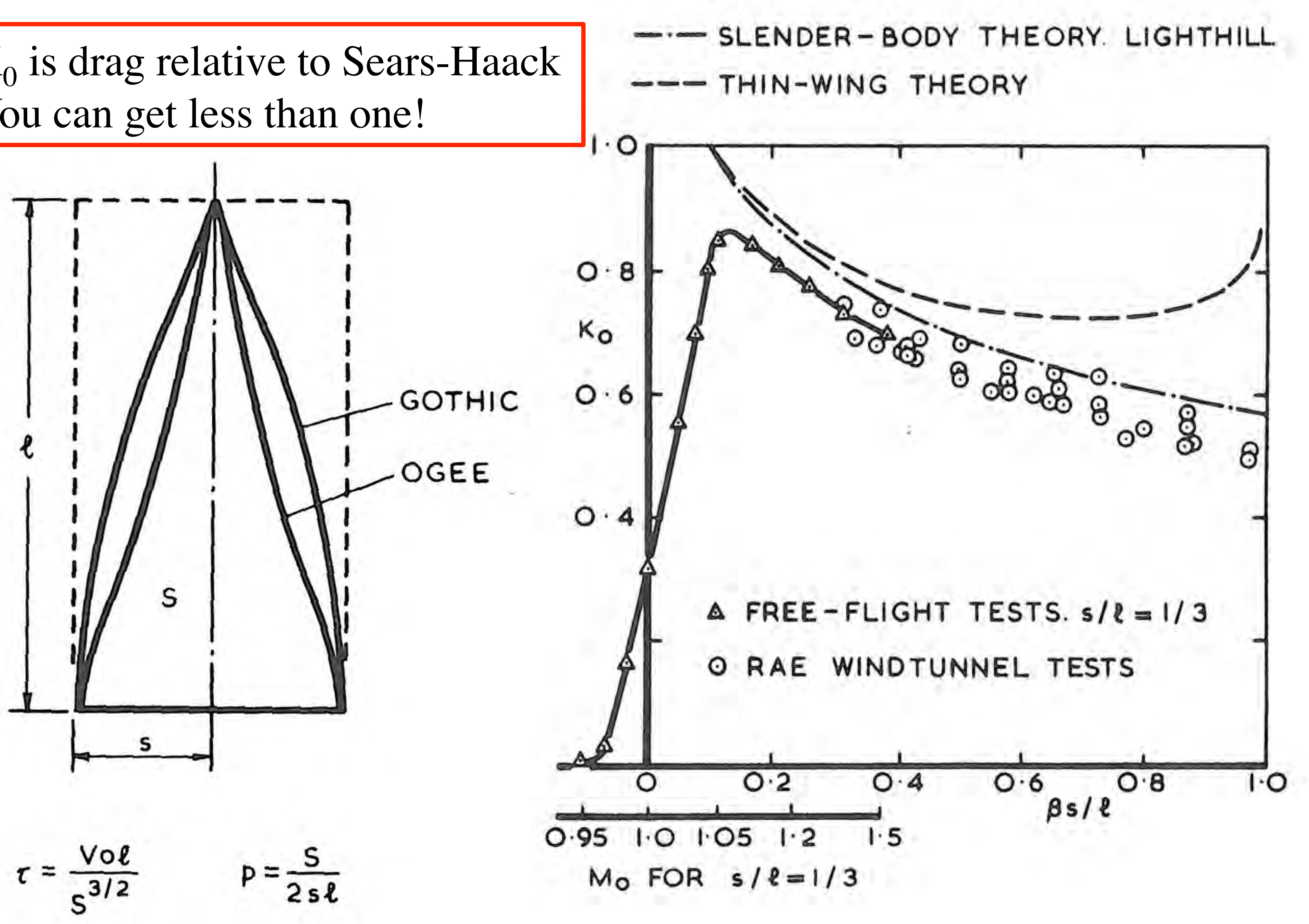
XL = 10.
Sref = 100.
Volume = 12
Snose = 0
XSgiven = 3.4
Sgiven = 1.54
Sbase = 0.4

D/q = 0.4099041
CD0 = 0.004099

Available on http://www.aoe.vt.edu/~mason/Mason_f/MRsoft.html

# Wave drag of slender wing planar surfaces relative to the Sears-Haack body

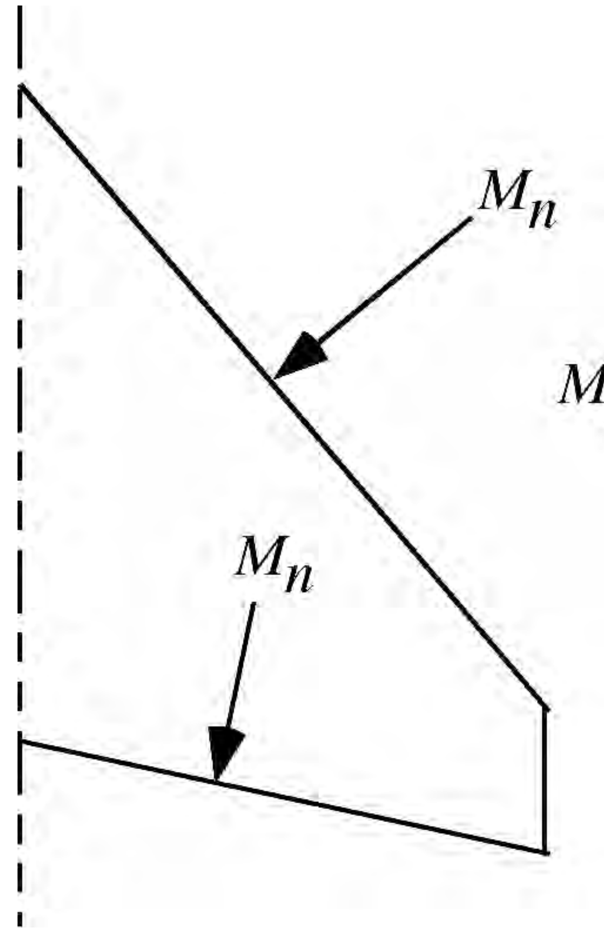
$K_0$ is drag relative to Sears-Haack
You can get less than one!



From D. Küchemann, *The Aerodynamic Design of Aircraft*, Pergamon Press, 1978

# Drag Due To Lift and Wings I

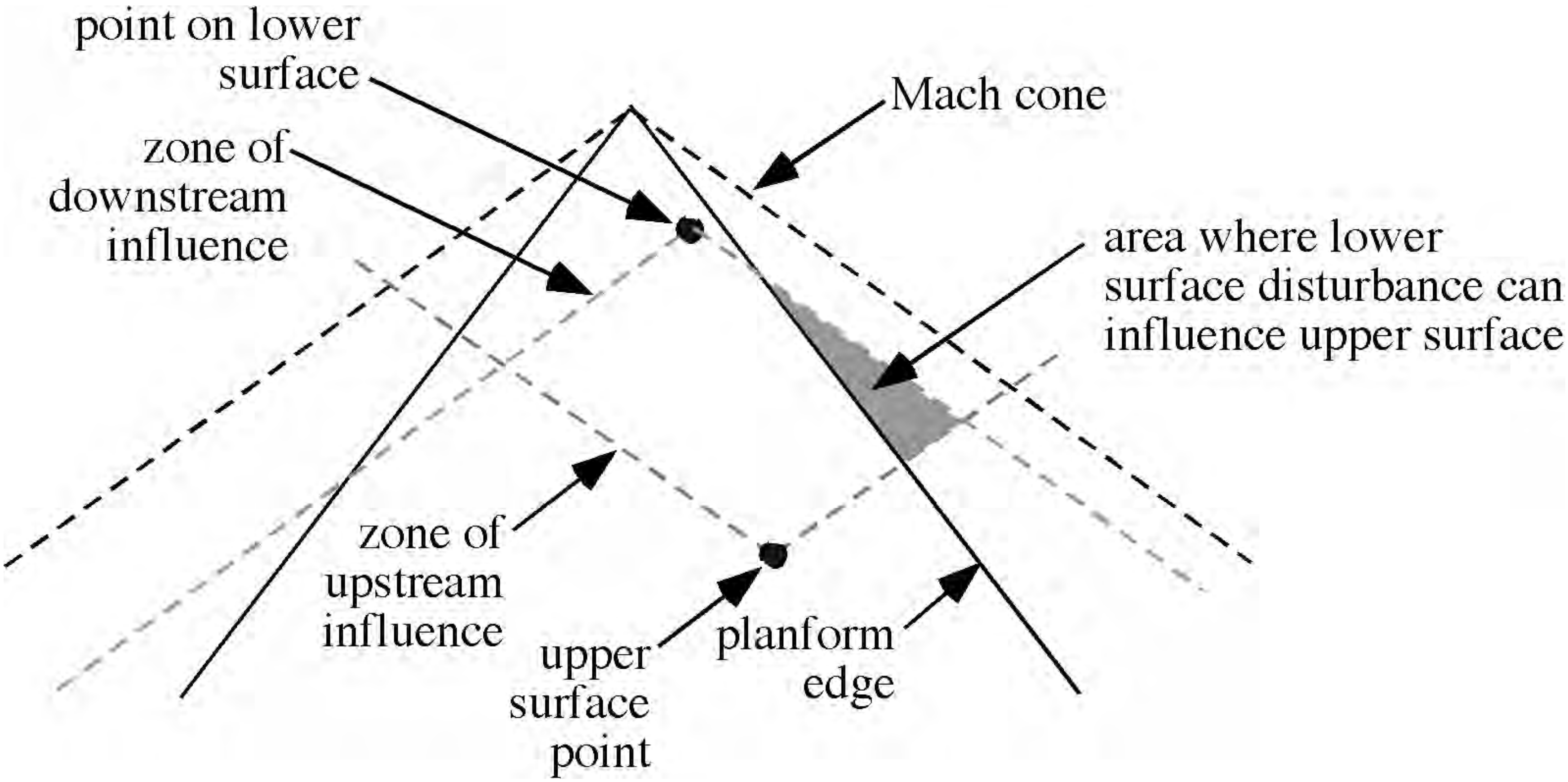
The distinction between a subsonic and supersonic edge is important



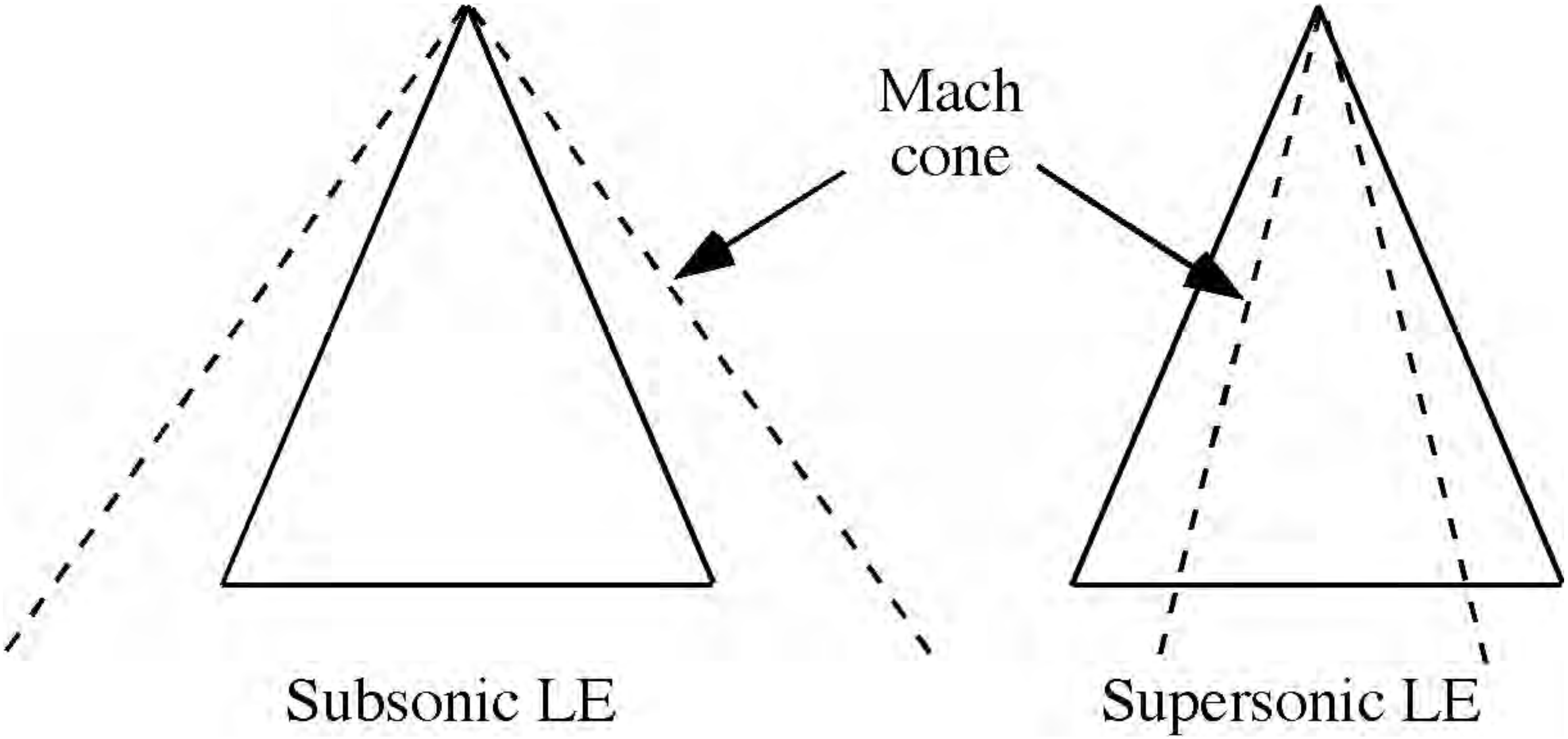
$M_n$ $< 1$, subsonic edge
$> 1$, supersonic edge

# Mach number zones of influence

For a subsonic edge, the top and bottom surfaces can communicate



# Drag Due To Lift and Wings II

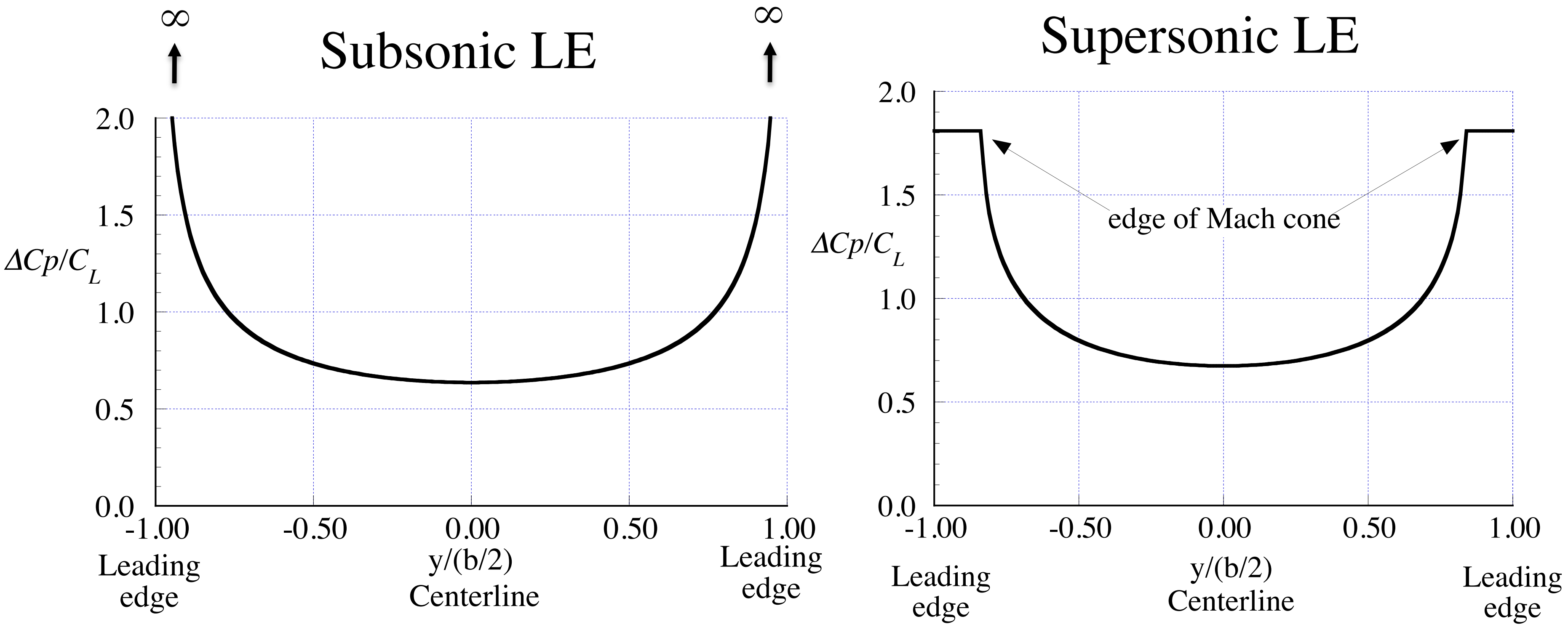


Note: the supersonic flow model equivalent to a 2D subsonic flow is the conical flow model. The figure shows how constant values along rays through the apex can lead to a 2D problem to solve

# *Spanwise* Pressure Distributions

Note: conical flow means the spanwise pressure distributions look the same at every longitudinal station

Delta *Cp* on an uncambered delta wing (conical flow). Implies the pressures at the trailing edge don't have to come together as in subsonics, the consequence of a supersonic TE

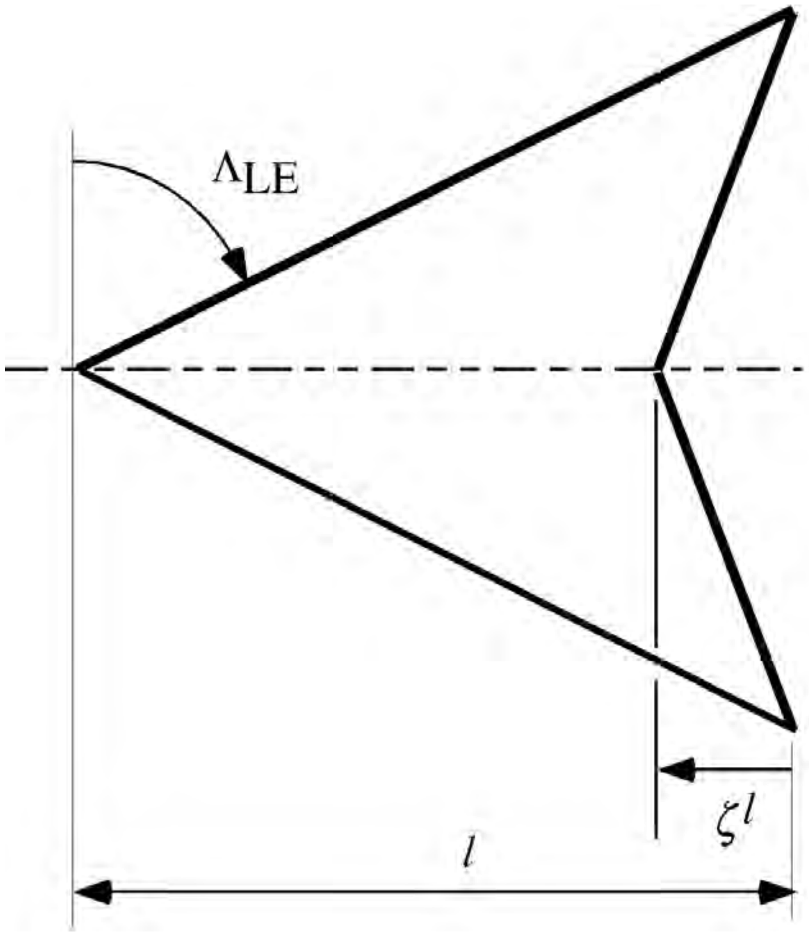


Subsonic LE

Supersonic LE

- Subsonic edges ***CAN*** generate leading edge suction
- Supersonic edges ***CANNOT*** produce leading edge suction

# The Arrow Wing



Parameters

– $\beta \cot \Lambda$

– $\zeta$ (the notch ratio)

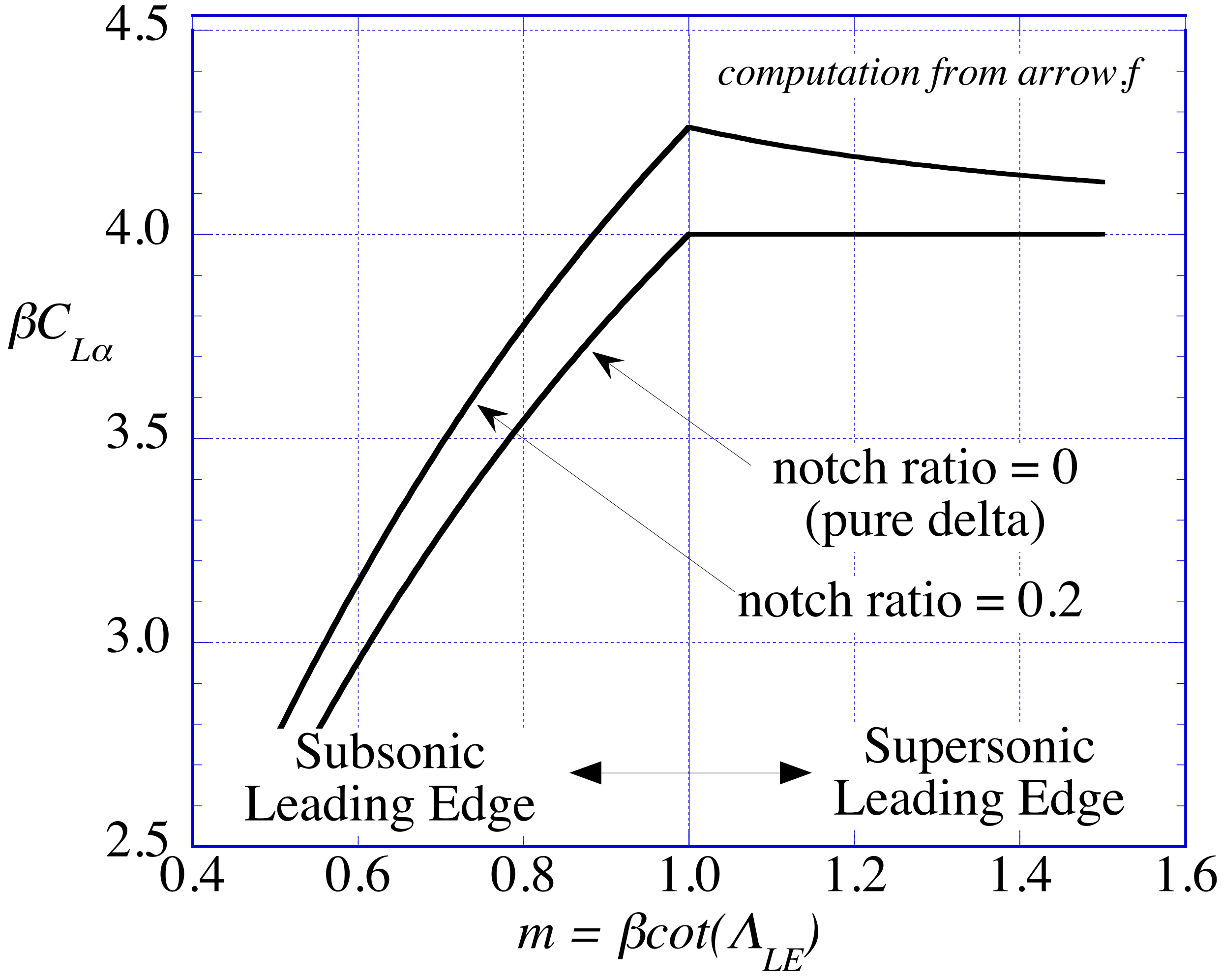
where

$$\beta = \sqrt{M^2 - 1}$$

arrow.f can be used to find the supersonic aerodynamics of these wings:
http://www.aoe.vt.edu/~mason/Mason_f/MRsoft.html

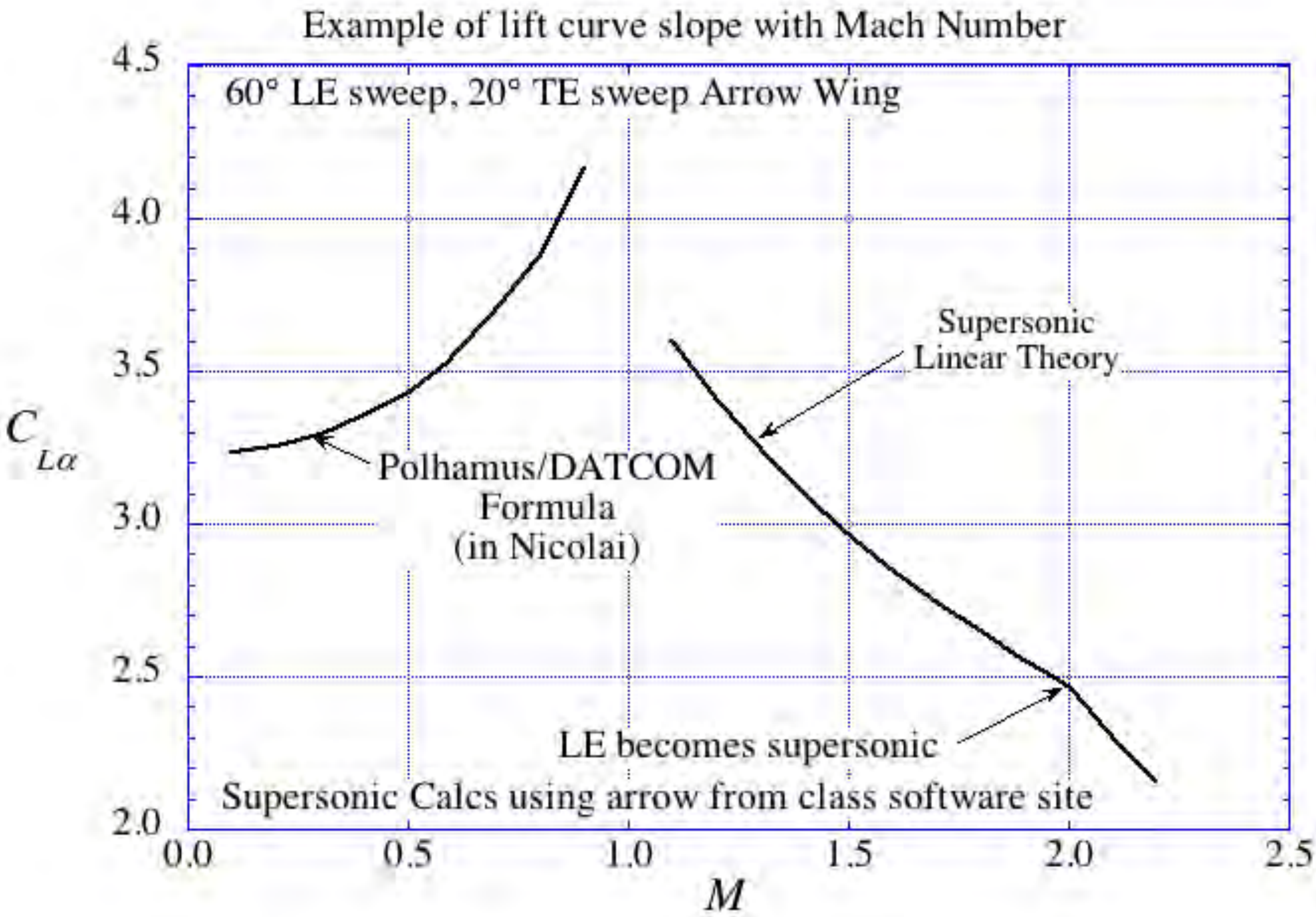
# The Arrow Wing Lift Curve Slope

(code on class website)



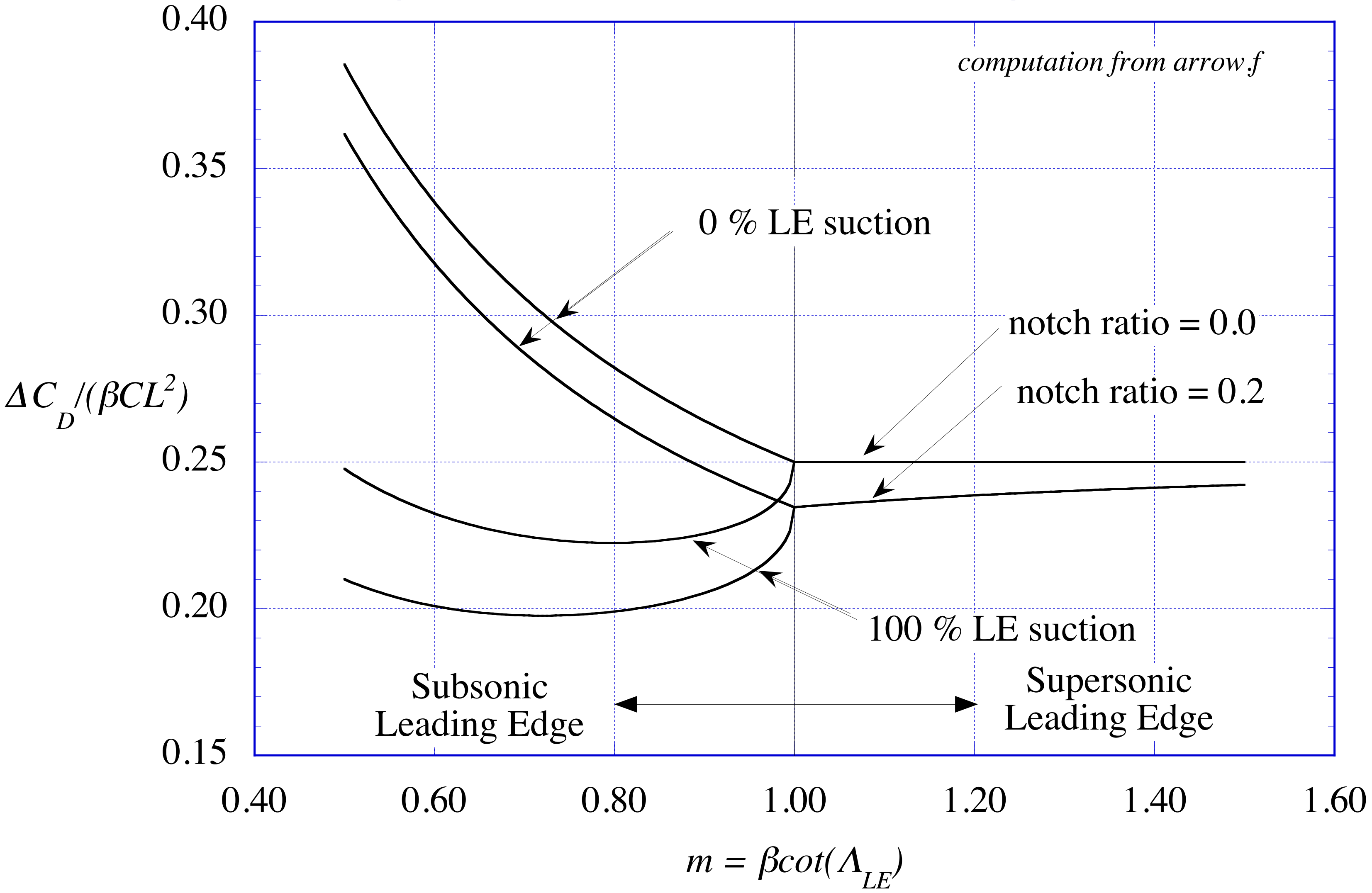
Formulas available in R.T. Jones and D. Cohen, *High-Speed Wing Theory*, Princeton University Press, Princeton, NJ, 1957

# Unwrapping the theoretical nondimensionalization



# Arrow Wing Drag

## (code on class website)



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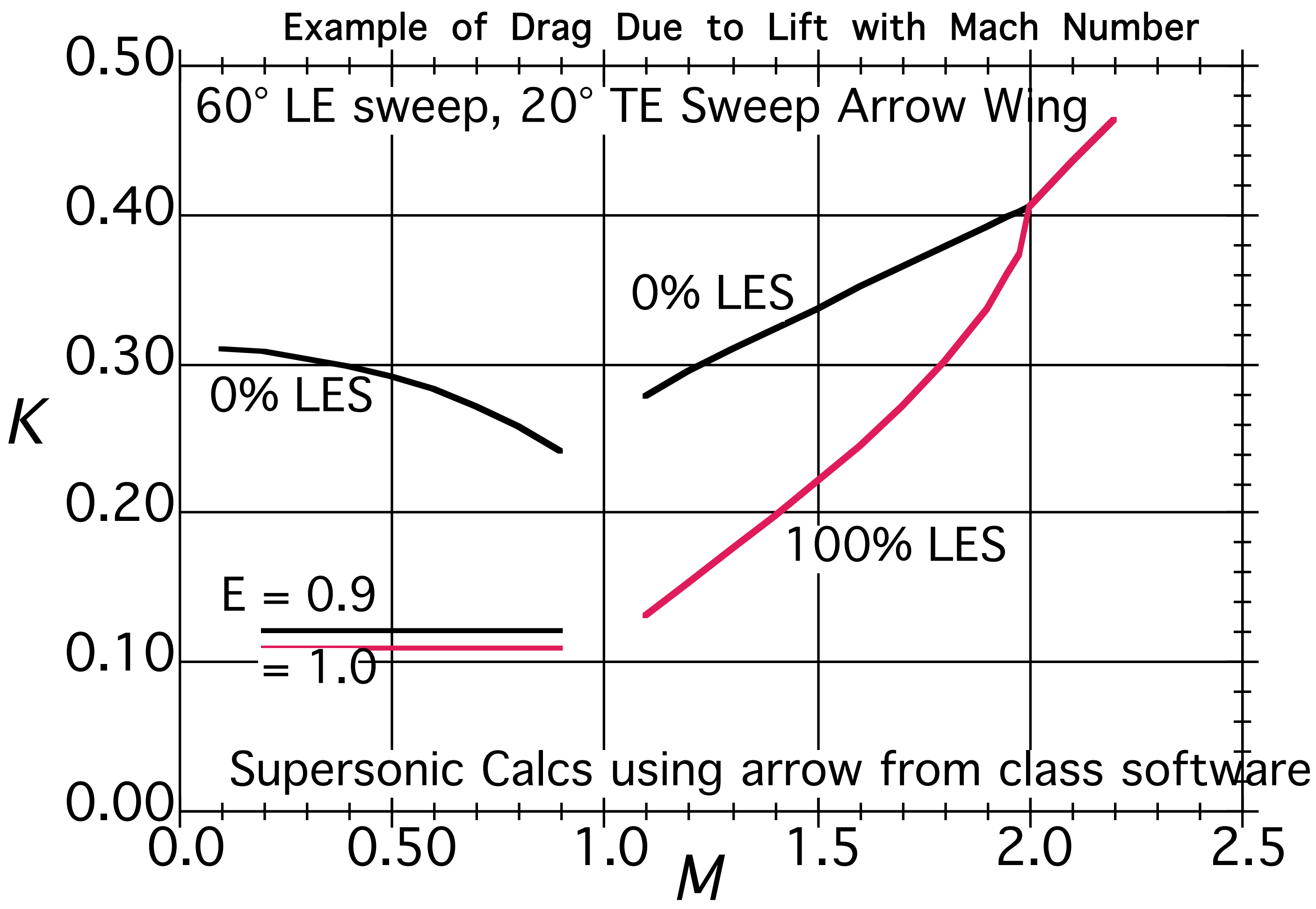
# Unwrapping the theoretical nondimensionalization



# Conical Camber to achieve the effect of LE Suction

F-102, taken at the Pima Air Museum, Tucson, AZ

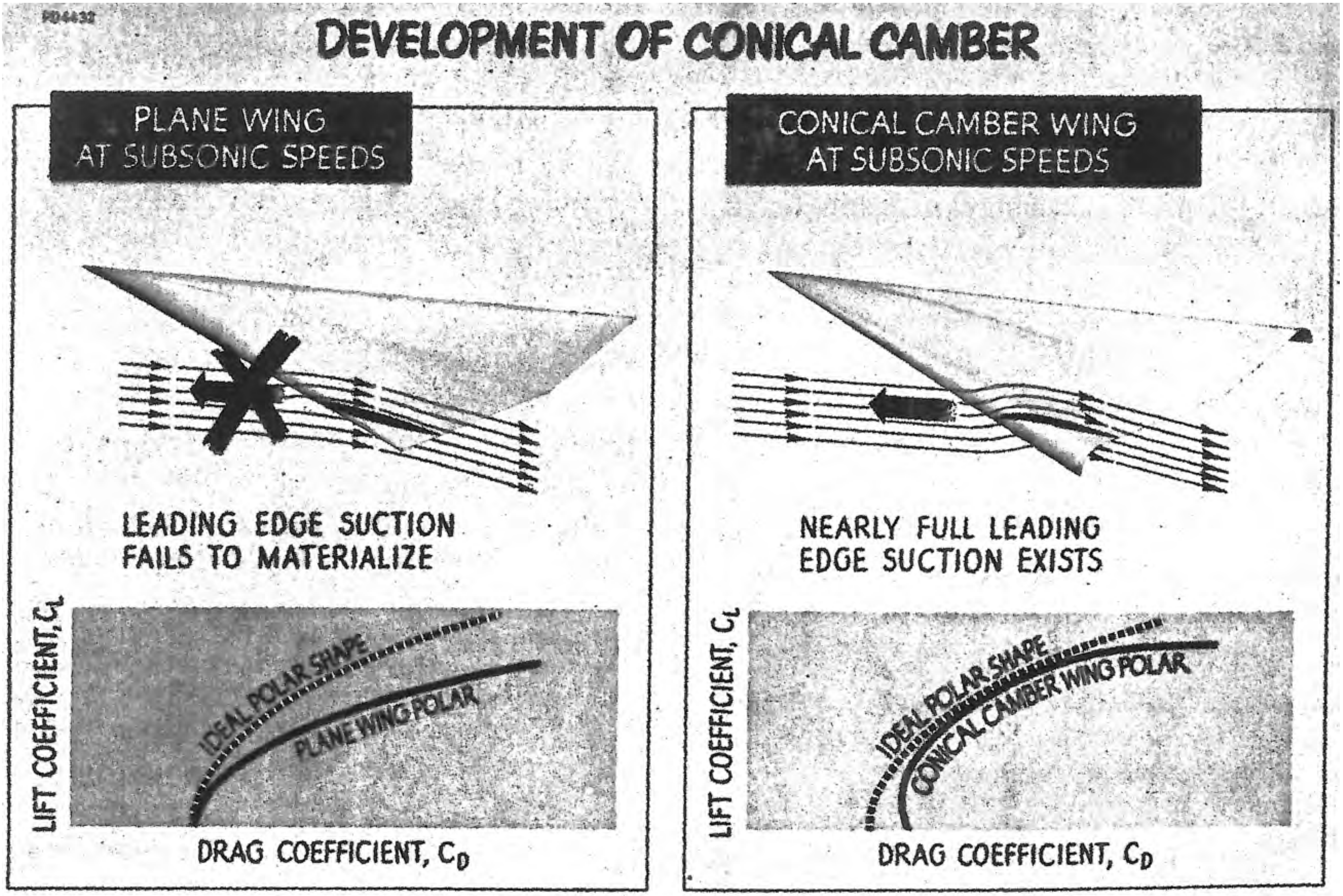
# The Application of the concept

*Conical Camber was used on the F-102, the F-106 and the B-58 Hustler, as well as the F-15*

Charles Hall, inventor, looking at a WT model with conical camber.

John Boyd, a Hokie, was also a key contributor at NACA Ames

# What Conical Camber Does



From Theodore von Kármán, "Some Significant Developments in Aerodynamics Since 1946," *Journal of the Aero/Space Sciences*, March, 1959.

# The “Modified” Arrow Wing

How the “arrow” starts to disappear

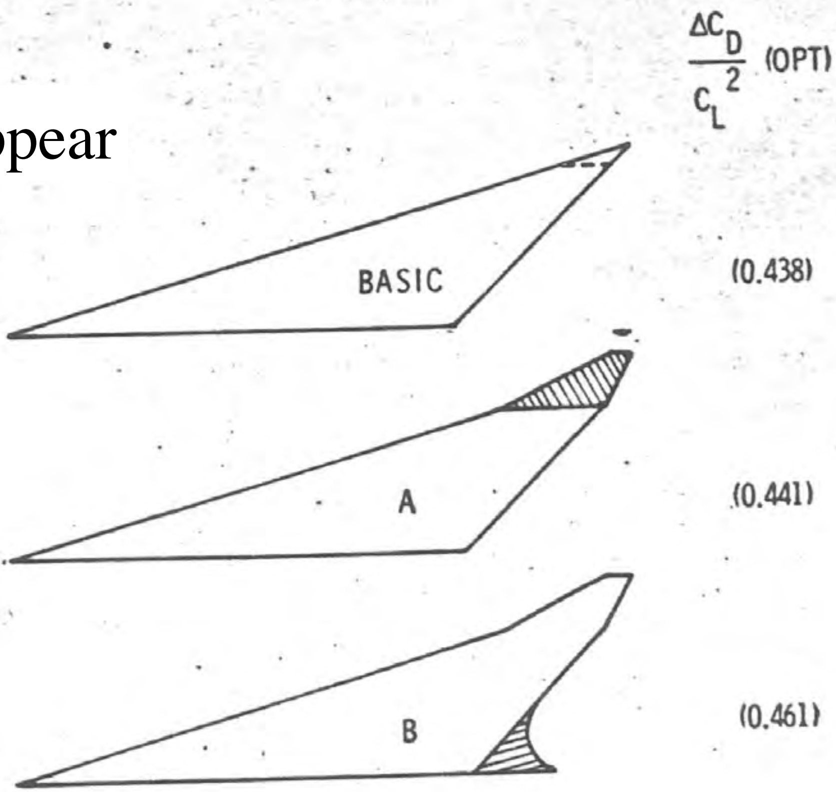


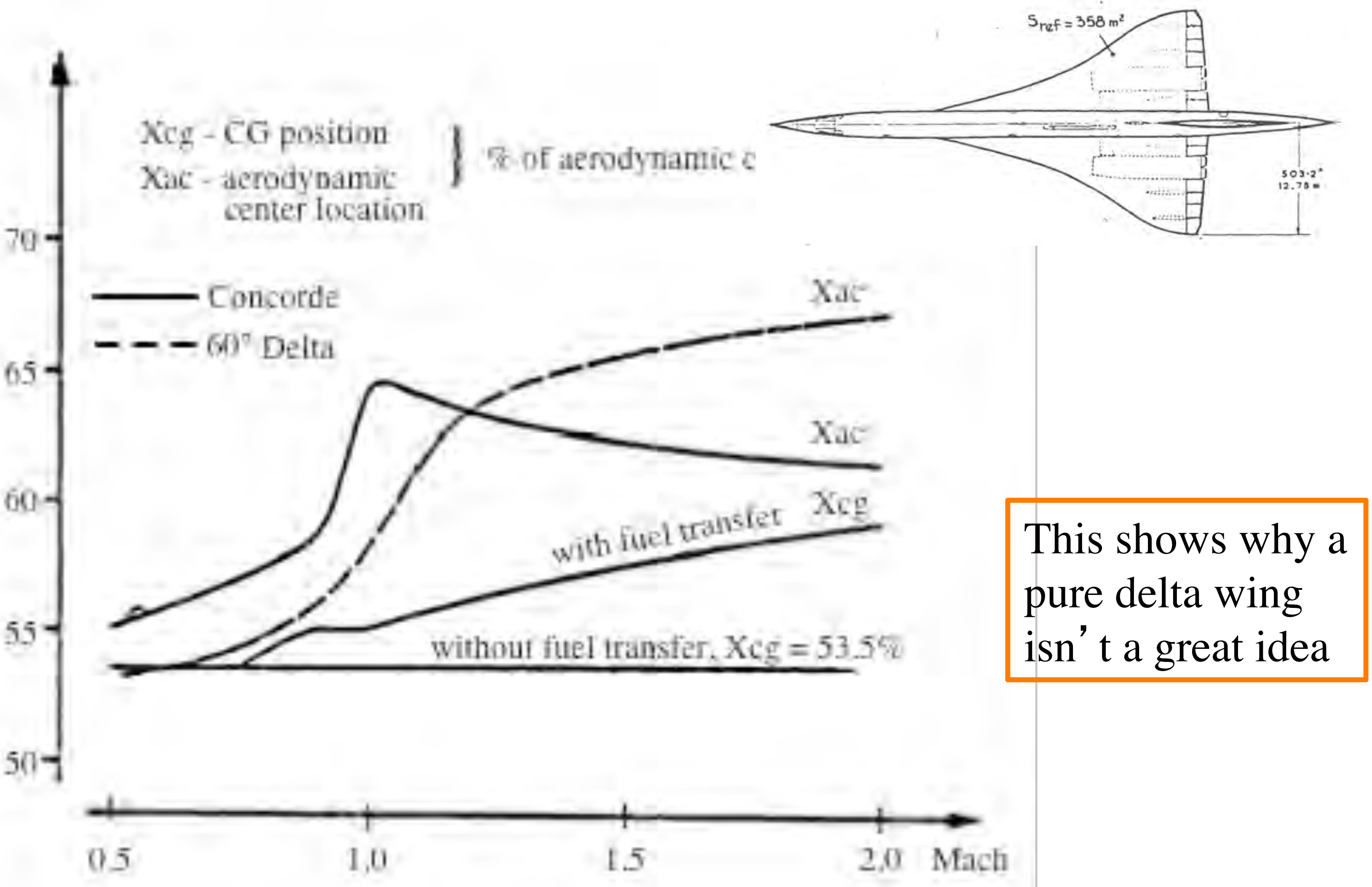
**Fig. 19 Detailed wing planform modifications.**

From Don Baals, Warner Robins and Roy Harris, “Aerodynamic Design Integration of Supersonic Aircraft,” *Journal of Aircraft*, Sept-Oct 1970, Vol. 7, No. 5, pp. 385-394

Note: Warner Robbins is a Hokie

# The ac shift

All supersonic airplanes shift fuel to control the static margin



This shows why a pure delta wing isn’t a great idea

From the AIAA Concorde Case study

# The Concorde cg travel

Note narrow range everywhere, the ref chord is the root chord for the Concorde

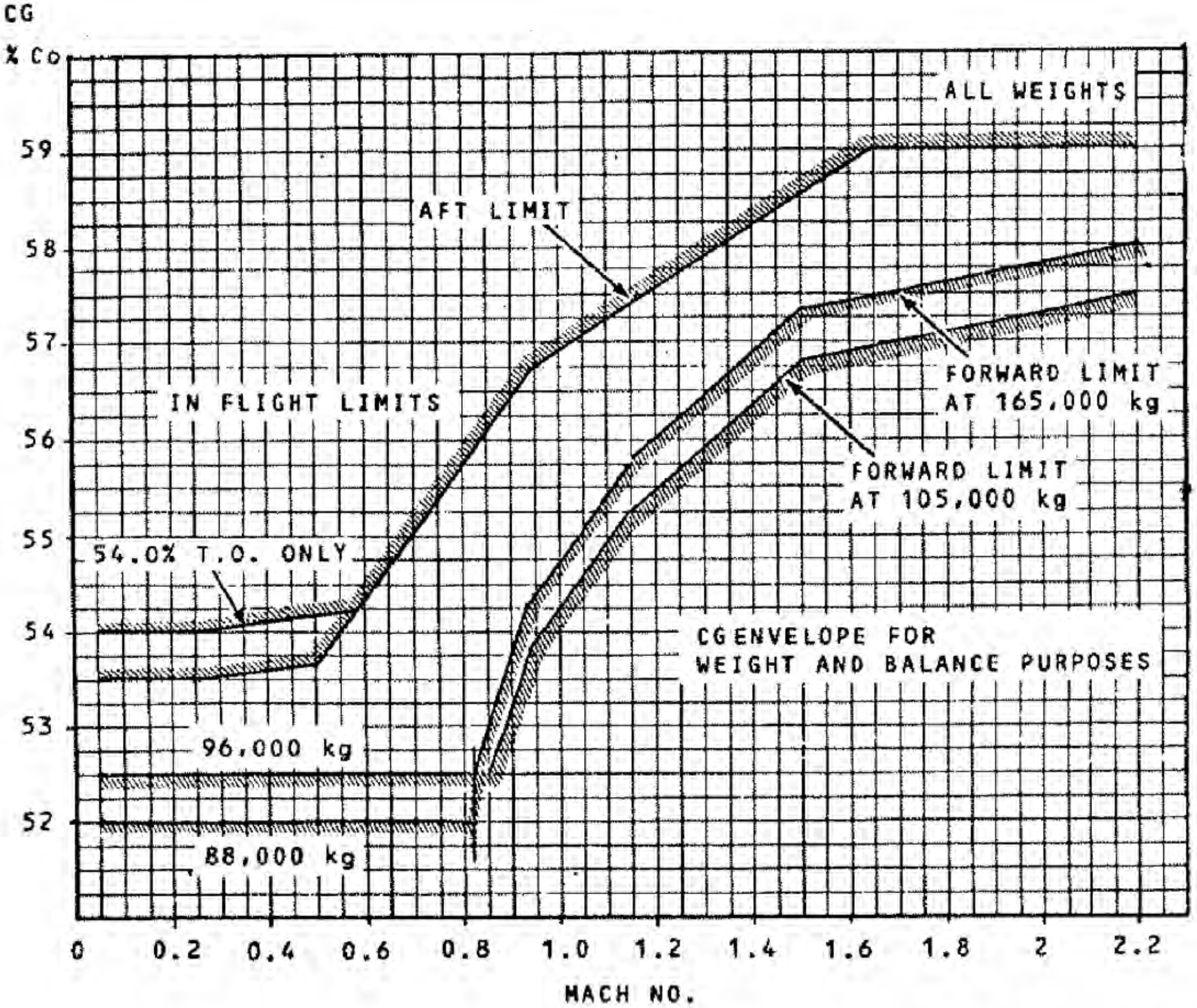


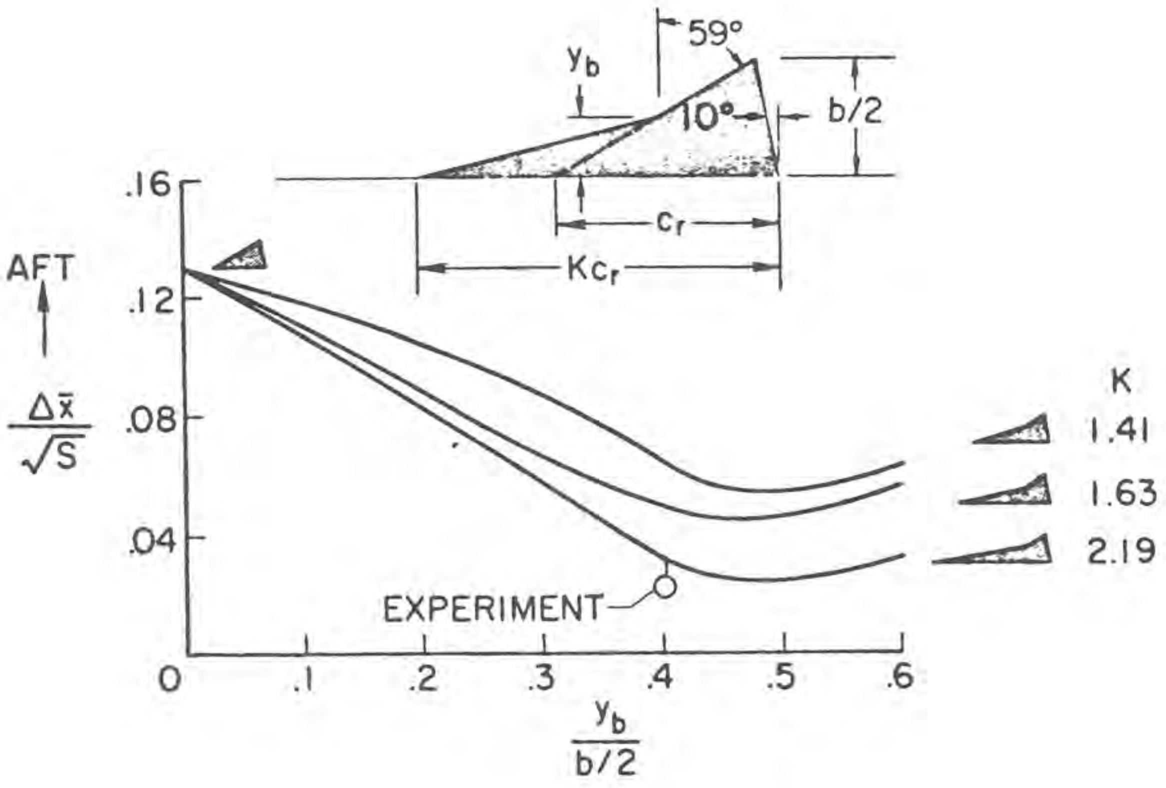
Figure courtesy of British Aerospace

# ac shift II

A double delta planform reduces the shift

COMPOSITE PLANFORMS

EFFECT OF LEADING-EDGE BREAK LOCATION; $\Delta\bar{x} = \bar{x}_{M=3} - \bar{x}_{M=0}$



From NASA TN D-3581, October 1966, by John Lamar and Joe Alford

# ac shift III

Why?

Hypotheses by Ben Rich and Joe Alford

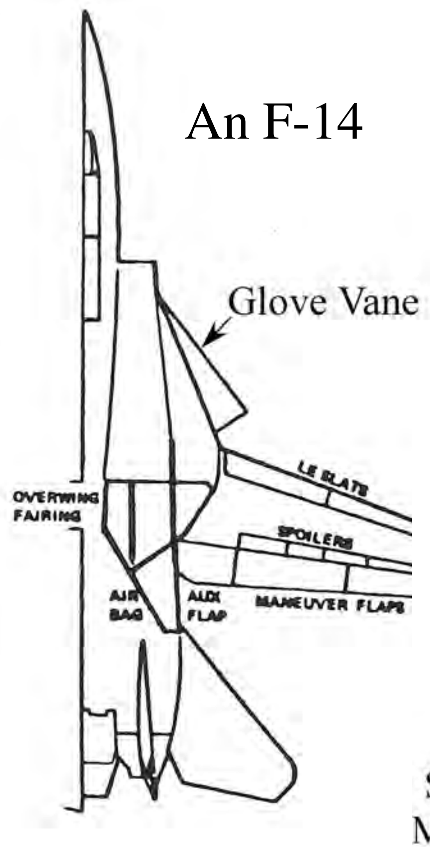
- The inboard wing is more highly swept and the $C_{L\alpha}$ is insensitive to Mach number
- The outboard wing has less sweep and the $C_{L\alpha}$ decreases with Mach number

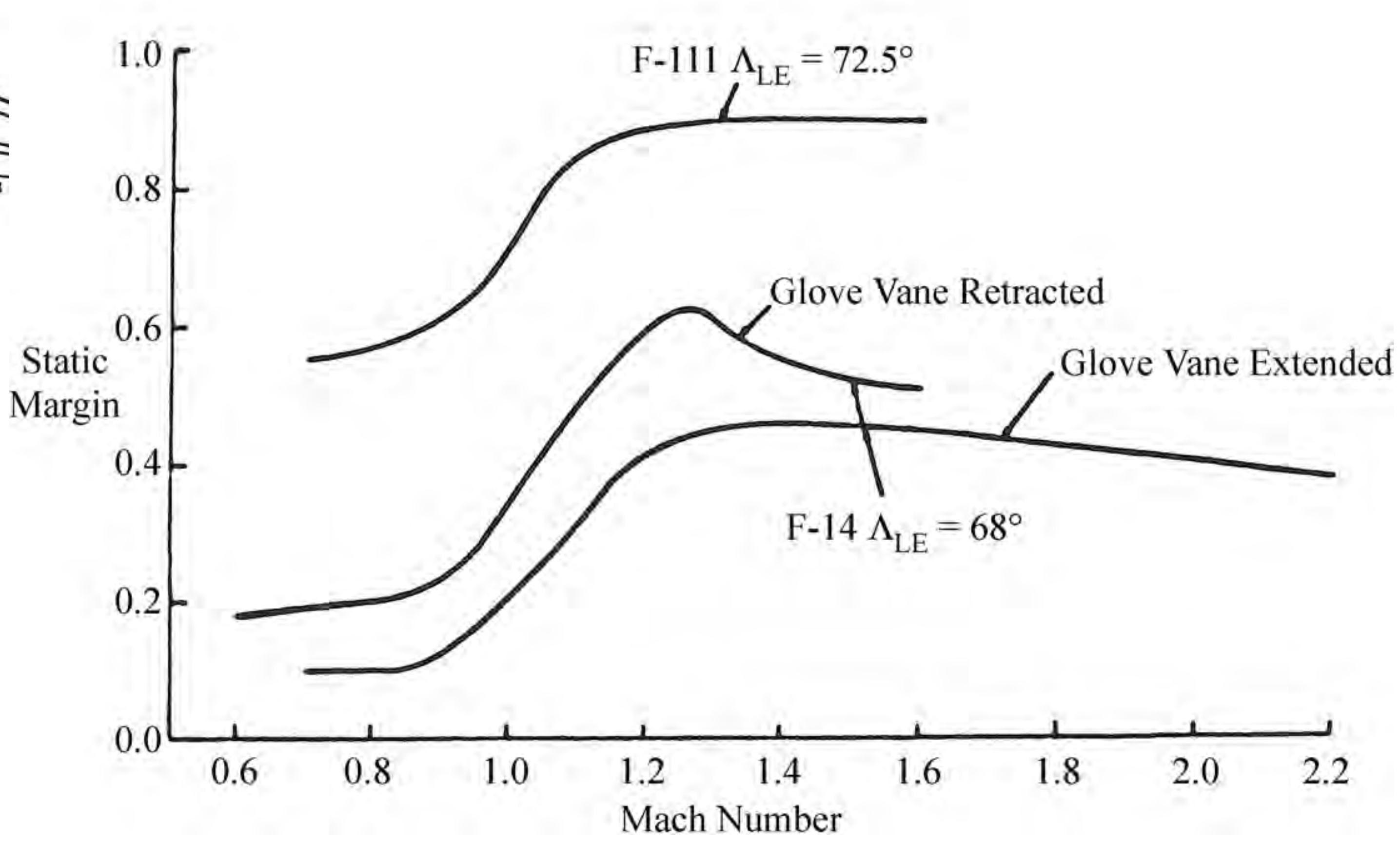
Read: NASA TN D-3581, October 1966, by John Lamar and Joe Alford
Ben Rich, *Journal of Aircraft*, July 1974

# ac shift iv

On a variable sweep wing, the aft swept position leads to the static margin being way too high
– thus the glove vane on the F-14

An F-14





The glove vane was another Bob Kress invention

from AIAA Paper 80-3043

# But, there is one other important concept: The Oblique Wing

Due to R.T. Jones

Photo take outside the NASA Ames Full Scale WT

AD-1 1st Flight: Dec 21, 1979
Last flight: Aug. 7, 1982

Dryden Flight Research Center ECN-17954
Photographed 1982 Pilot: Richard E. Gray

Photo from NASA Dryden photo library

# Possibly the only "practical" supersonic concept

The physics are so compelling, it's worth overcoming all the other problems

The Oblique wing layout improves both:

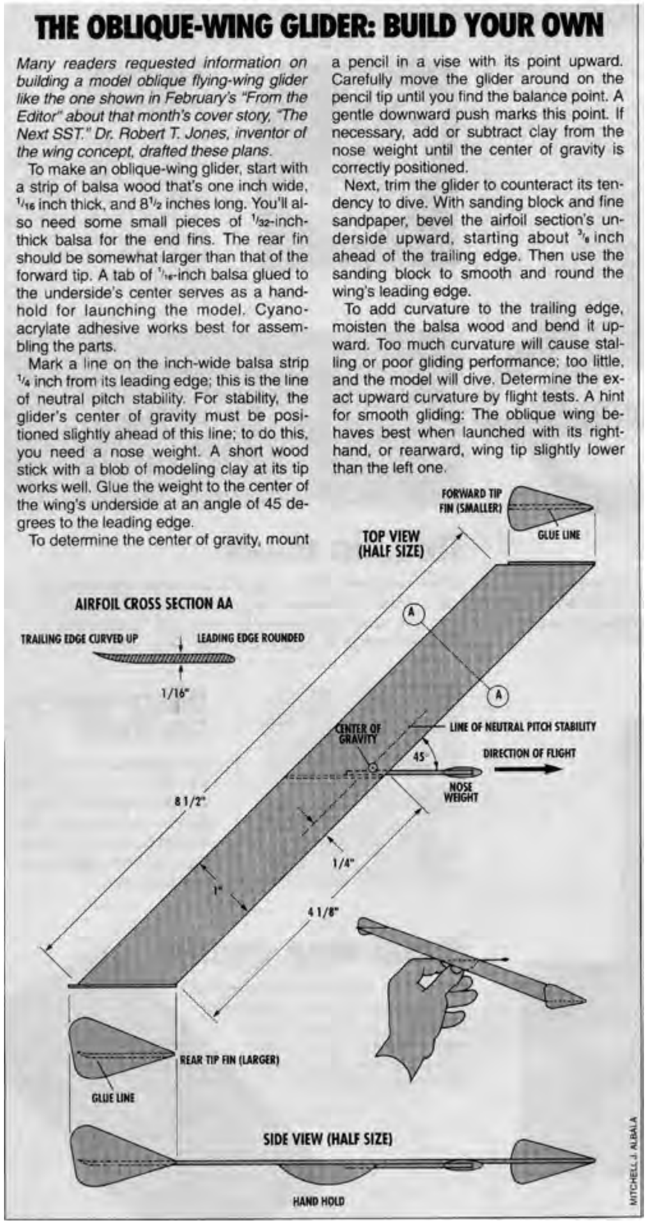
- volumetric area distribution for low zero-lift wave drag,

and

- spreads lift longitudinally *and* laterally to reduce drag due to lift

# Sometimes a homework problem

from *Popular Science*, May 1991, pg 9.



## THE OBLIQUE-WING GLIDER: BUILD YOUR OWN

*Many readers requested information on building a model oblique flying-wing glider like the one shown in February's "From the Editor" about that month's cover story, "The Next SST." Dr. Robert T. Jones, inventor of the wing concept, drafted these plans.*

To make an oblique-wing glider, start with a strip of balsa wood that's one inch wide, $\frac{1}{16}$ inch thick, and $8\frac{1}{2}$ inches long. You'll also need some small pieces of $\frac{1}{32}$-inch-thick balsa for the end fins. The rear fin should be somewhat larger than that of the forward tip. A tab of $\frac{1}{16}$-inch balsa glued to the underside's center serves as a handhold for launching the model. Cyanoacrylate adhesive works best for assembling the parts.

Mark a line on the inch-wide balsa strip $\frac{1}{4}$ inch from its leading edge; this is the line of neutral pitch stability. For stability, the glider's center of gravity must be positioned slightly ahead of this line; to do this, you need a nose weight. A short wood stick with a blob of modeling clay at its tip works well. Glue the weight to the center of the wing's underside at an angle of 45 degrees to the leading edge.

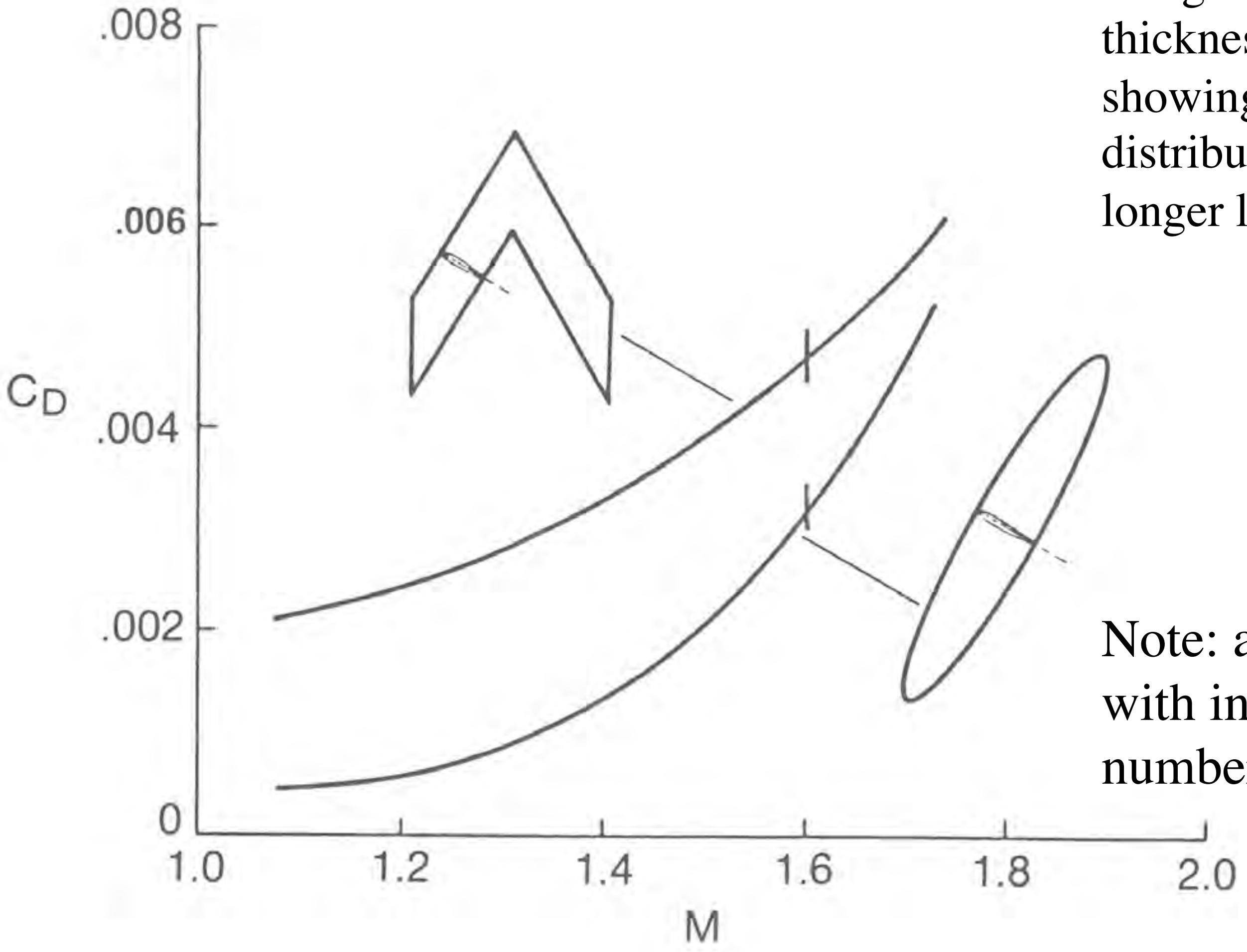
To determine the center of gravity, mount a pencil in a vise with its point upward. Carefully move the glider around on the pencil tip until you find the balance point. A gentle downward push marks this point. If necessary, add or subtract clay from the nose weight until the center of gravity is correctly positioned.

Next, trim the glider to counteract its tendency to dive. With sanding block and fine sandpaper, bevel the airfoil section's underside upward, starting about $\frac{3}{8}$ inch ahead of the trailing edge. Then use the sanding block to smooth and round the wing's leading edge.

To add curvature to the trailing edge, moisten the balsa wood and bend it upward. Too much curvature will cause stalling or poor gliding performance; too little, and the model will dive. Determine the exact upward curvature by flight tests. A hint for smooth gliding: The oblique wing behaves best when launched with its right-hand, or rearward, wing tip slightly lower than the left one.

Elizabeth Eaton, Spring 2006

# Example: wing volumetric wave drag



Wings with the same thickness and aspect ratio, showing the importance of distributing volume over a longer longitudinal distance

Note: advantage decreases with increasing Mach number

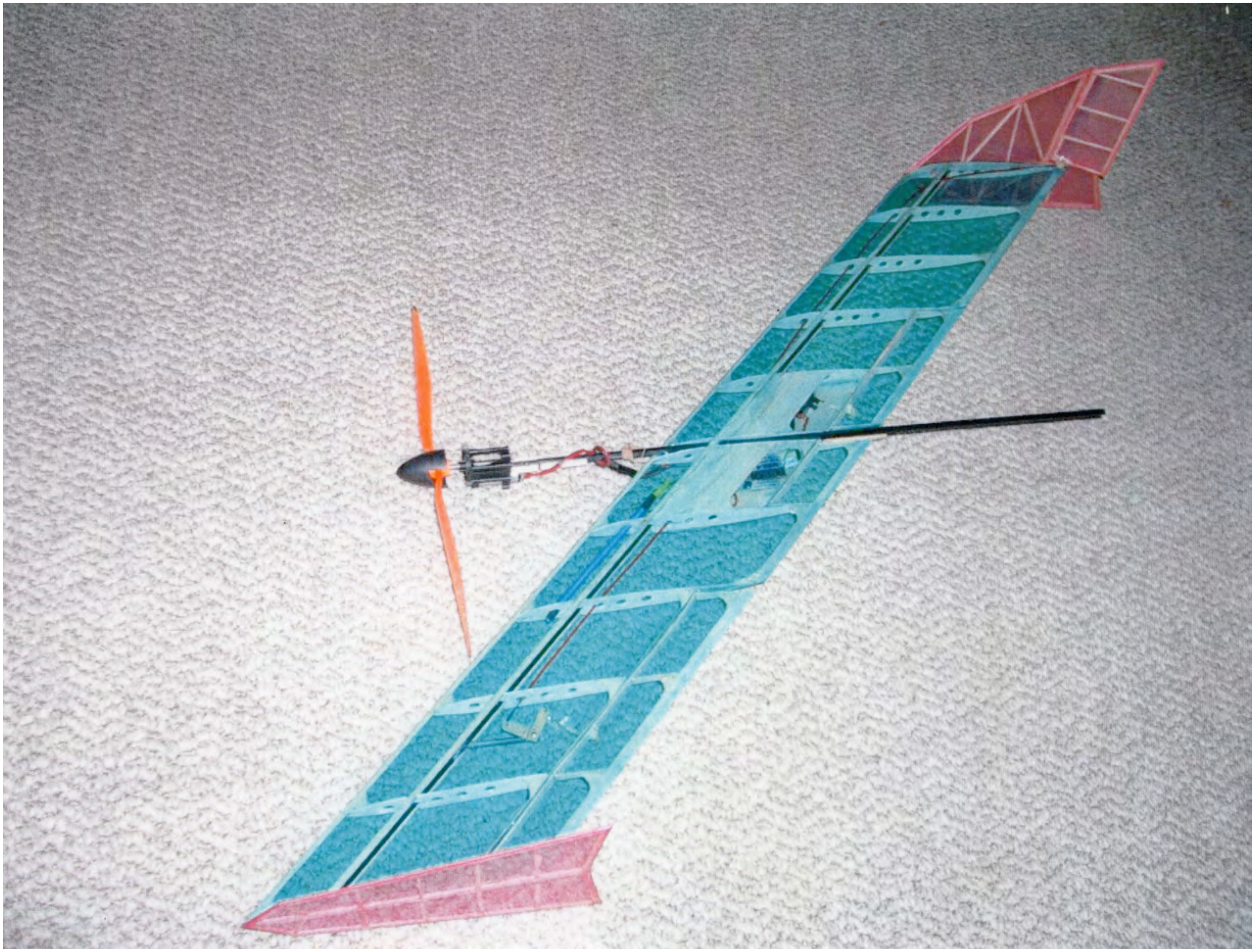
From R.T. Jones, *Wing Theory*, Princeton University Press, Princeton, NJ, 1990

# The AD-1 and a flying wing UAV

The NASA AD-1

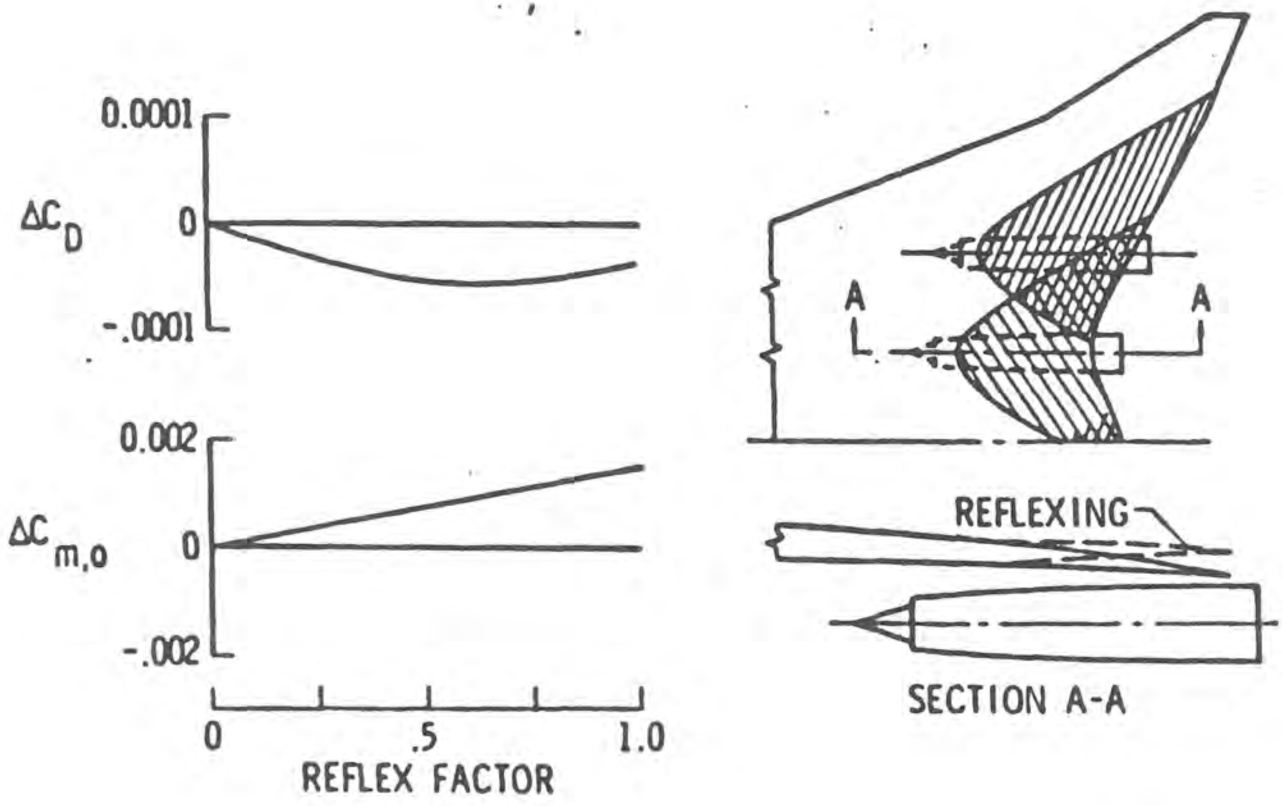
Stanford Flying Oblique

# Even Neblett made an RC model!



# Aero-Propulsion Integration becomes a critical consideration

*Example: details are critical to optimizing the design*



From Don Baals, Warner Robins and Roy Harris, "Aerodynamic Design Integration of Supersonic Aircraft," *Journal of Aircraft*, Sept-Oct 1970, Vol. 7, No. 5, pp. 385-394

# The computations story

*Linear Theory*

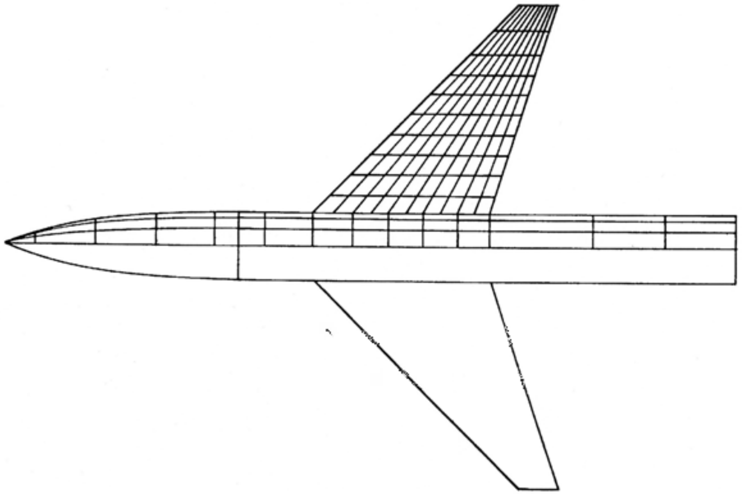
- For volumetric wave drag: The Harris Code, using the Eminton-Lord integral integration scheme
- The common input, the so-called Craidon input format
- Lifting surfaces panels:
  - For the US SST, The Boeing system of panel methods for both analysis and design
  - Later, Harry Carlson's Codes Aero2S and WINGDES
    - The concept of "attainable leading edge suction" introduced to include nonlinear aero in a "linear" methodology

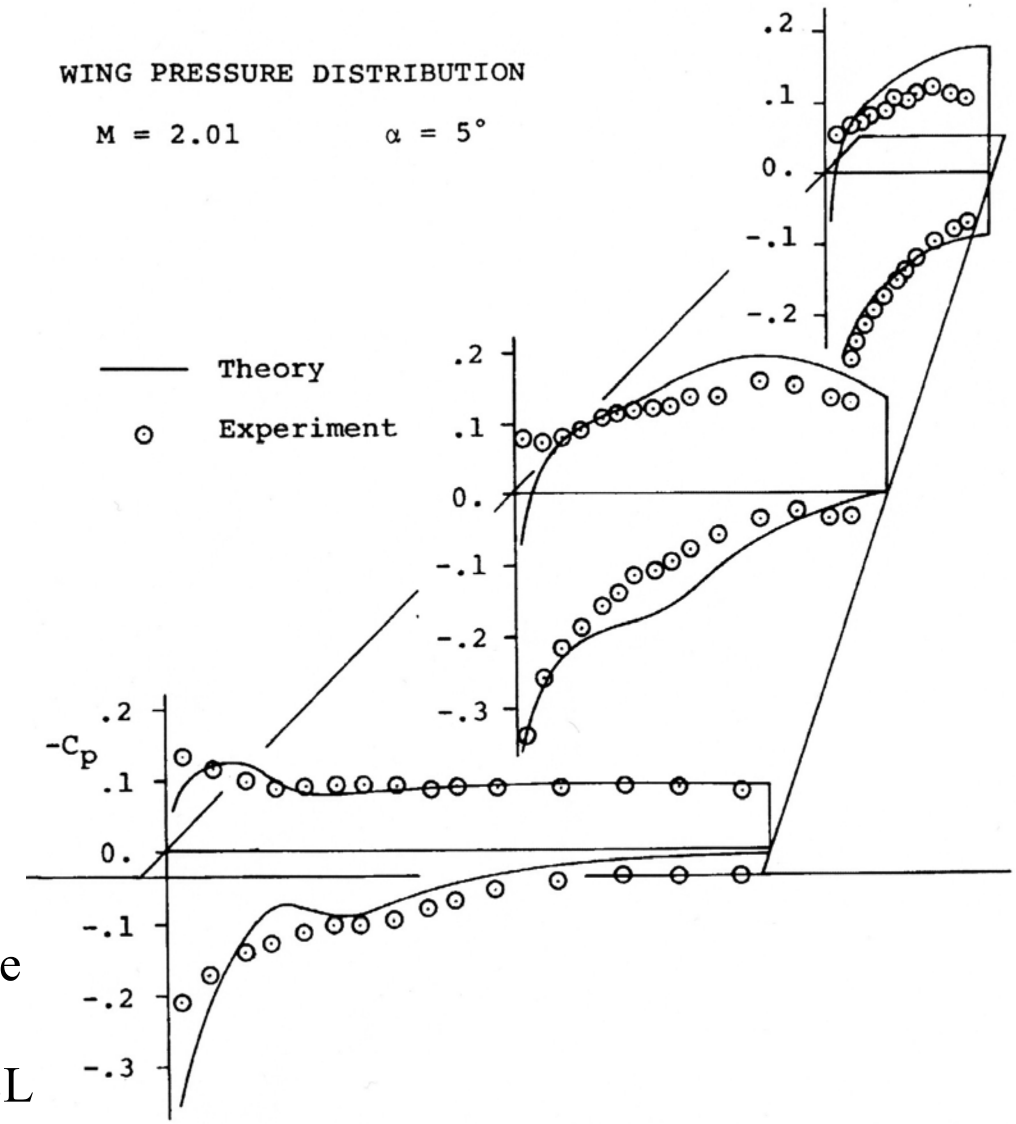
*Nonlinear Theory*

- Space marching Euler and PNS – finally RANS

**An irony: to a very good approximation a flat surface with 100% leading edge suction defines the minimum drag due to lift you can get.**

# Supersonic Wing Pressures
# Note the difference at the trailing edge



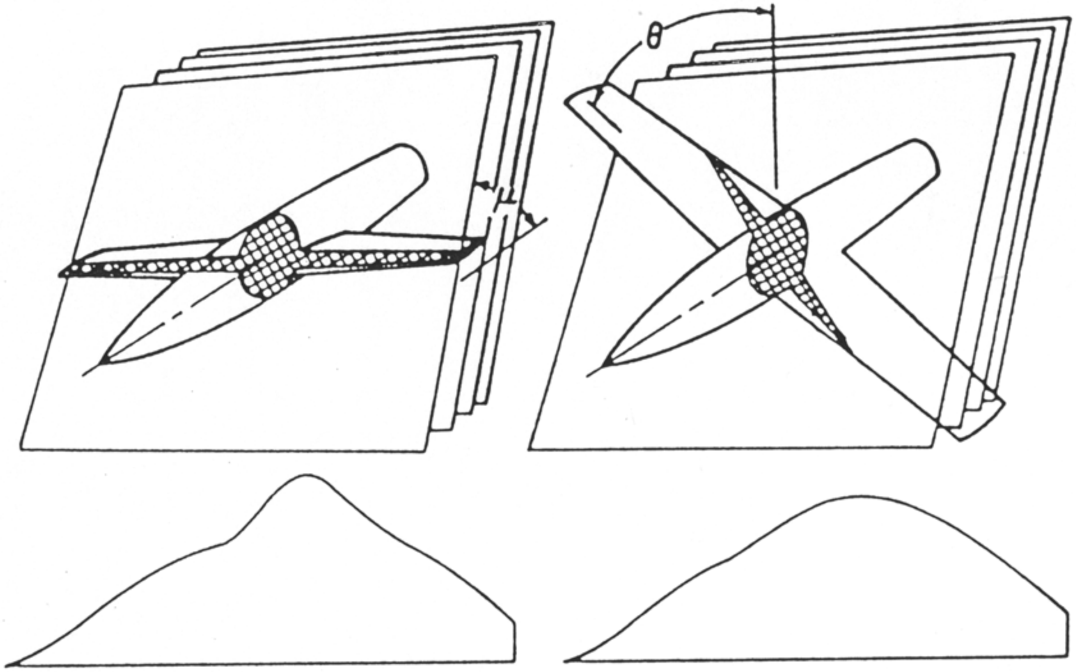


When the trailing edge is supersonic, the pressures don't have to come together at the trailing edge. A fundamental difference between subsonic and supersonic flow.

From Woodward's Panel Method Code
NASA CR-2228, Pt 1, 1973
Test data from NASA Memo 10-15-58L

# Wave Drag - The Harris Code

Needs the geometry to compute the integral.



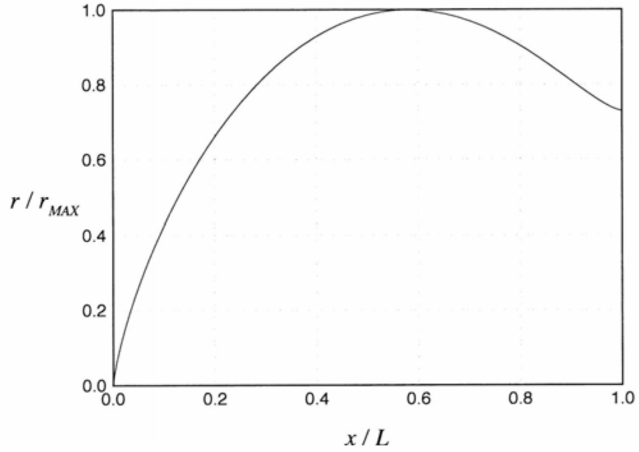
$$D(\theta) = -\frac{\rho V^2}{4\pi} \int_0^l \int_0^l A''(x_1)\, A''(x_2)\, \text{LOG}\left| x_1 - x_2 \right| dx_1 dx_2$$

$$D = \frac{1}{2\pi} \int_0^{2\pi} D(\theta)\, d\theta$$

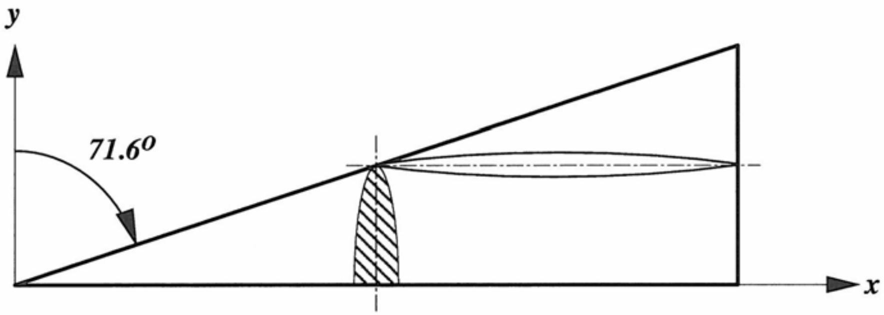
Harris, NASA TM X-947, 1964. Uses the Craidon Geometry
awaveFileMake.m by Prof. Lowe helps you make the input

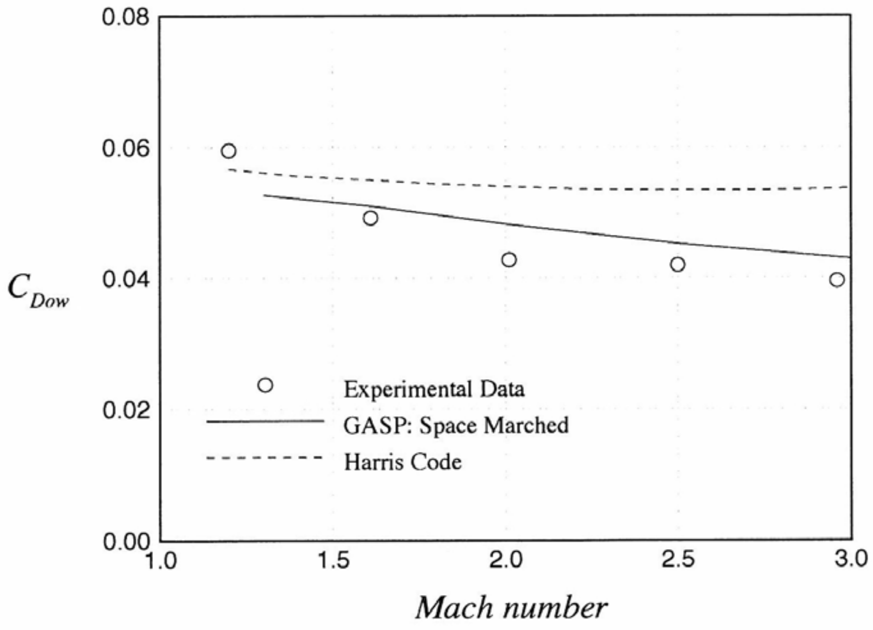
# Validation of the Harris Code

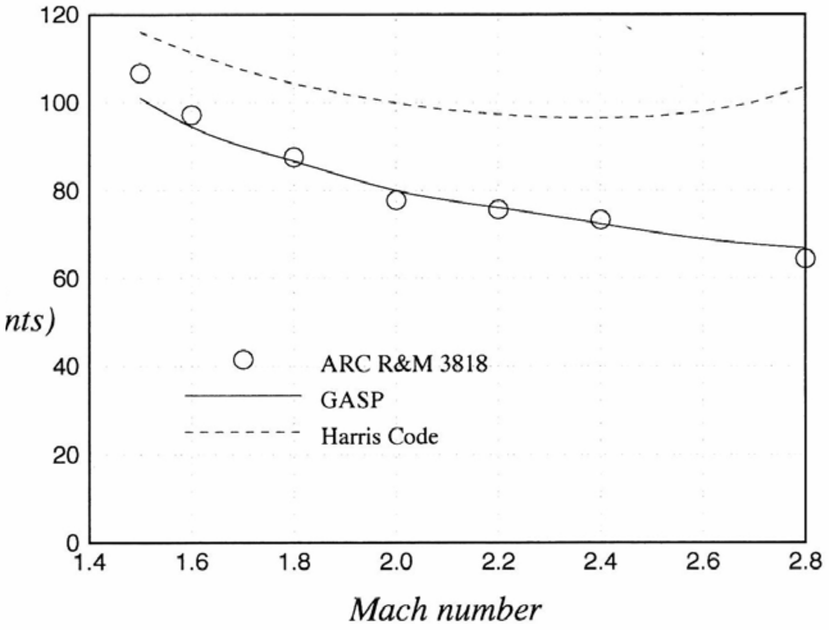
Haack Adams Body of Rev.



The Squire Wing

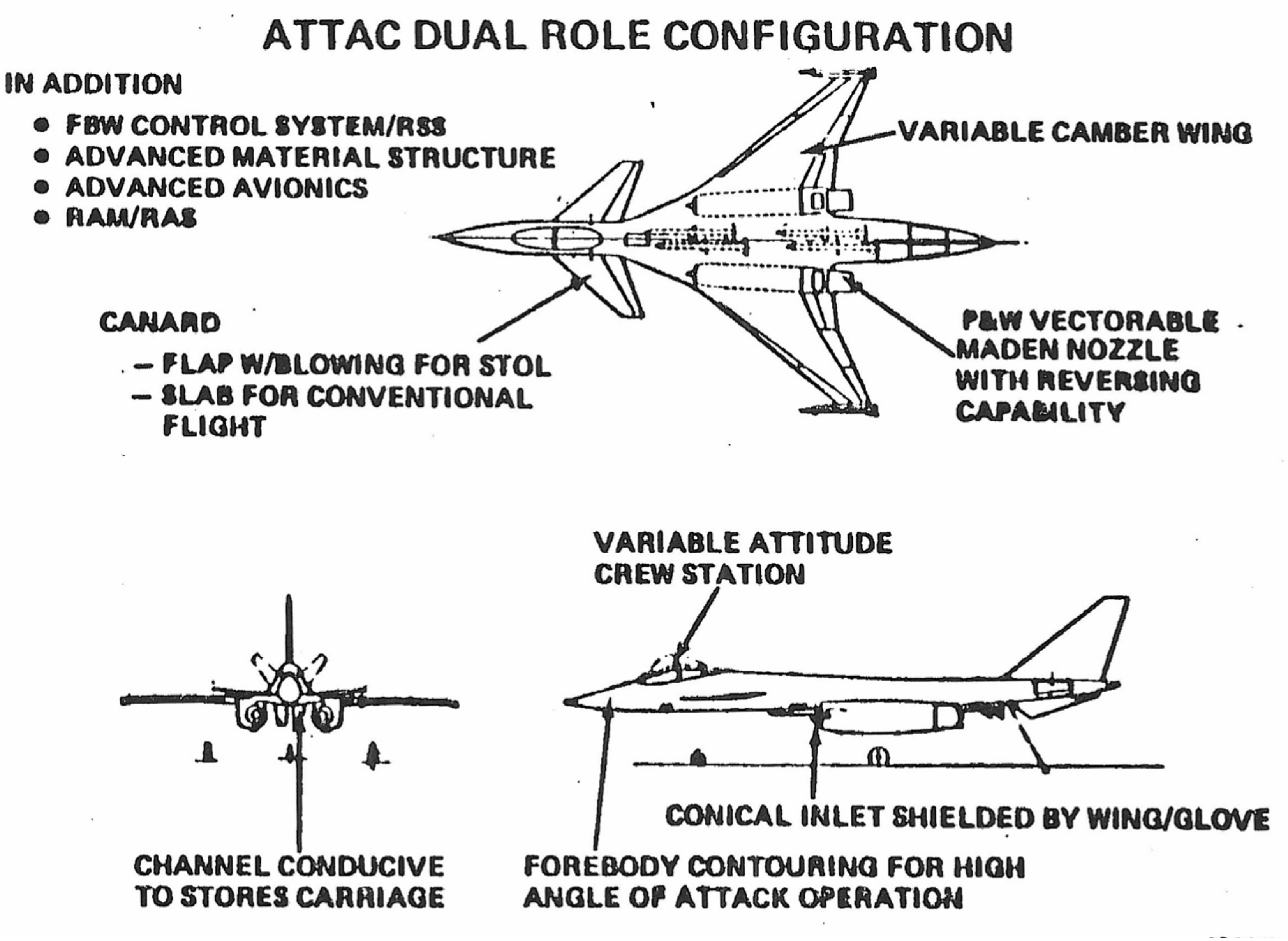






VT MAD Center Report 96-12-01 (on Mason's publications page)

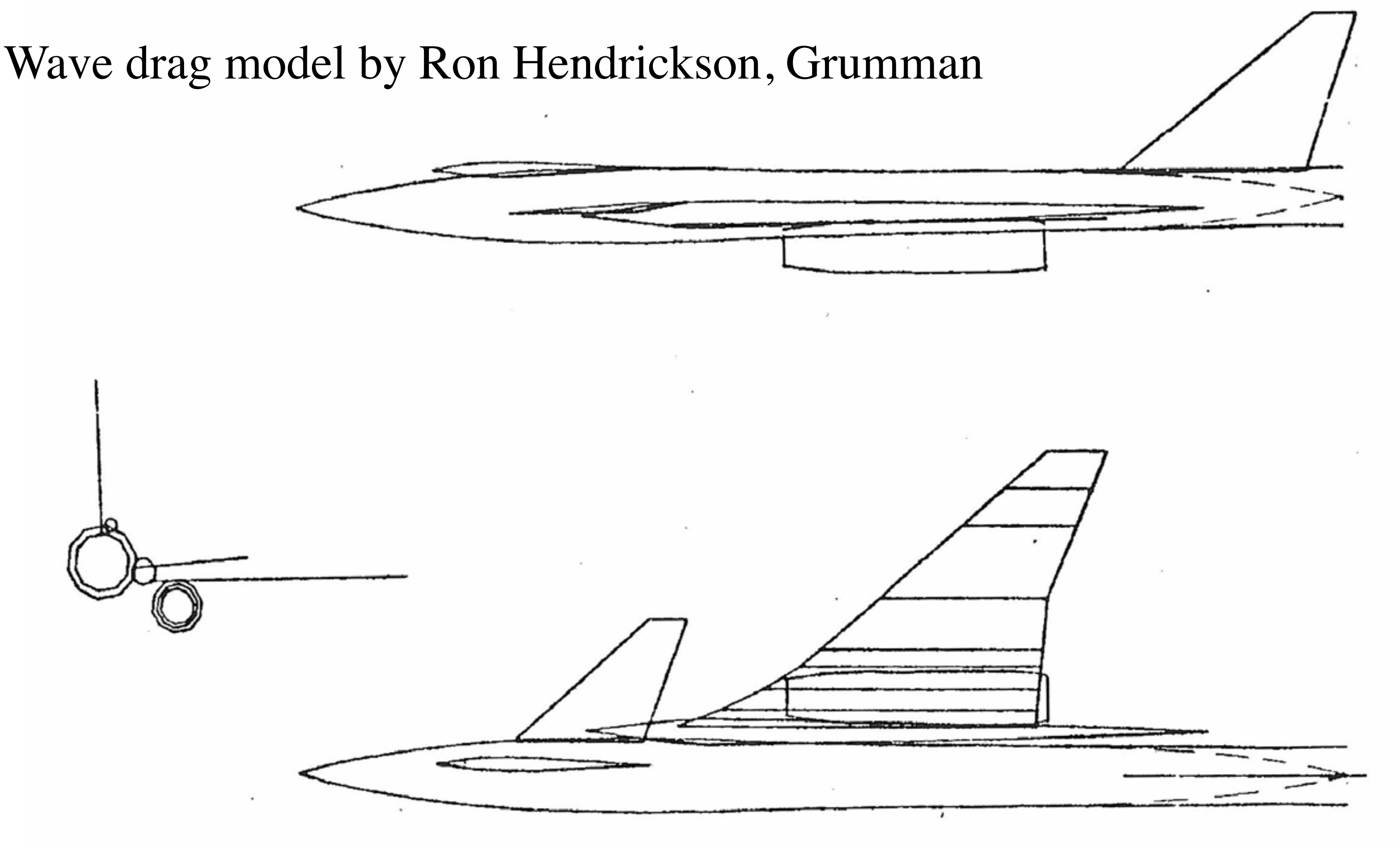
# Modeling a Configuration in the Harris Code



A Grumman Design Study w/WT Model for the Air Force

# The ATTAC Harris Wave Drag Model

Wave drag model by Ron Hendrickson, Grumman



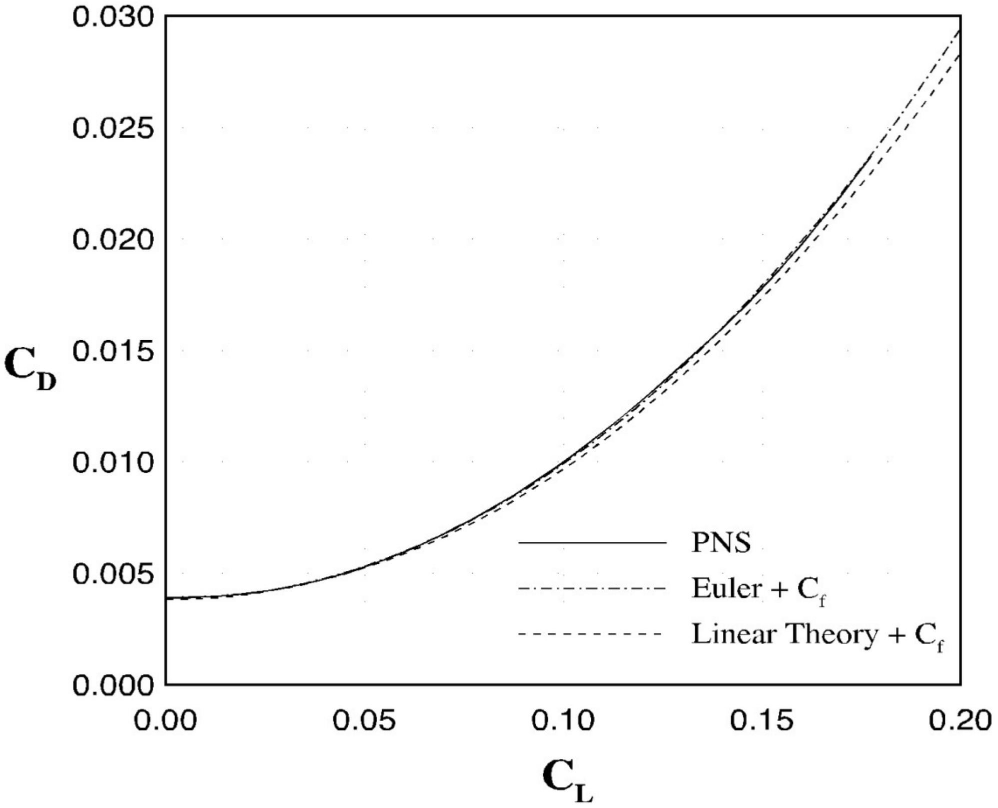
Use “pods” to represent area

# Comparison of Linear Theories with Euler and RANS for a supersonic transport

From VT Mad Ctr Report 96-12-01

- Linear theory induced drag consistently low
- Harris wave drag estimates within 2 counts of CFD value
- Skin friction estimate larger than PNS value (within 1 count)
- Addition / Cancellation of zero-lift drag and induced drag errors at cruise $C_L$
- Linear theory drag prediction typically 1-2 counts lower than PNS values
- 2 count drag underprediction results in 120 *n.mi.* overestimate of the range

Comparison made by Duane Knill



at $C_L = 0.082$

$C_D$ (PNS) = 0.00792

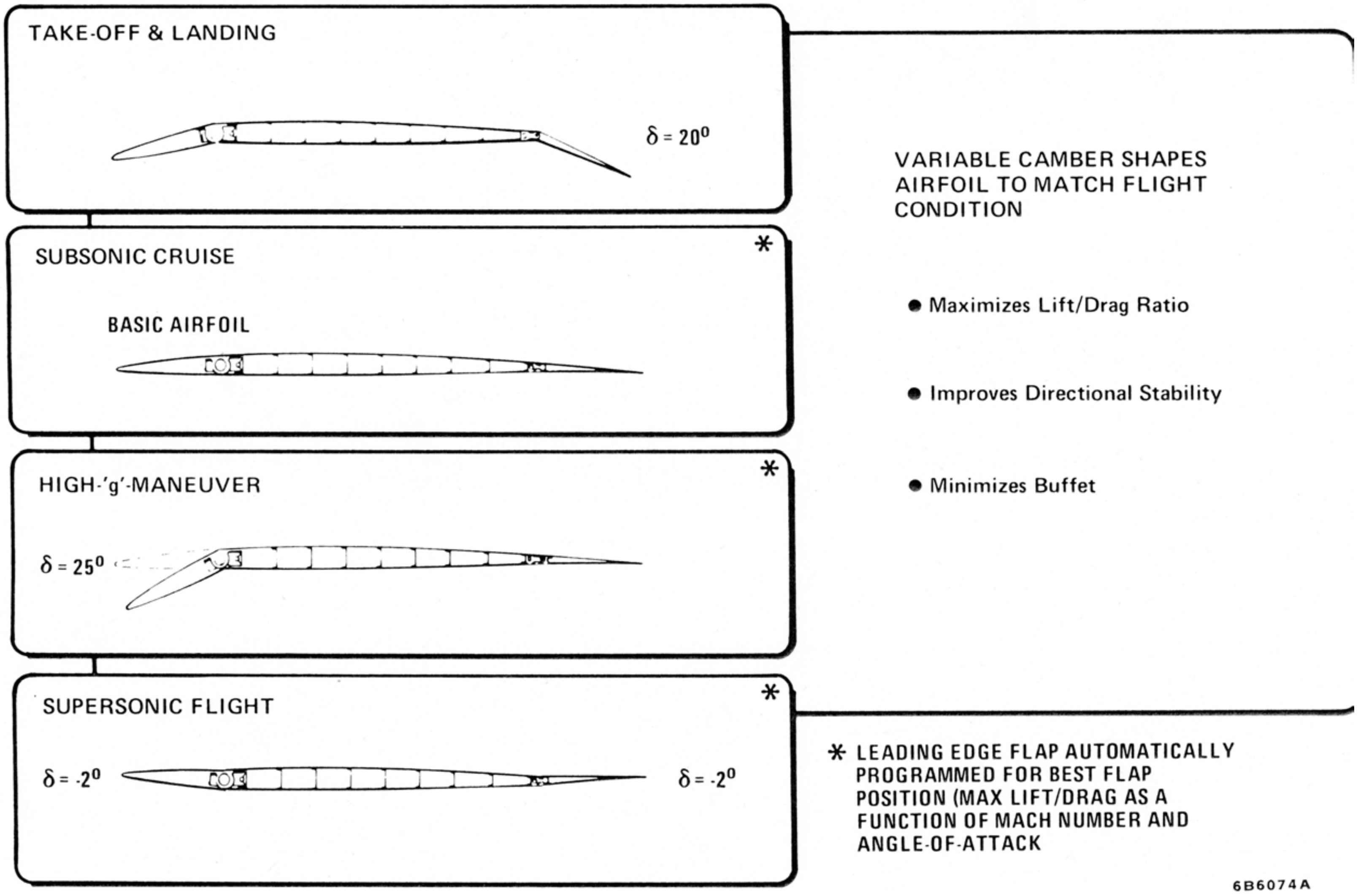
$C_D$ (Euler + $C_f$) = 0.00789

$C_D$ (L.T. + $C_f$) = 0.00771

Note: PNS stands for Parabolized Navier Stokes

# Supersonic wings – almost flat, in fact negative camber on the F-16

From AIAA Case Study on the F-16 flight control system



VARIABLE CAMBER SHAPES AIRFOIL TO MATCH FLIGHT CONDITION

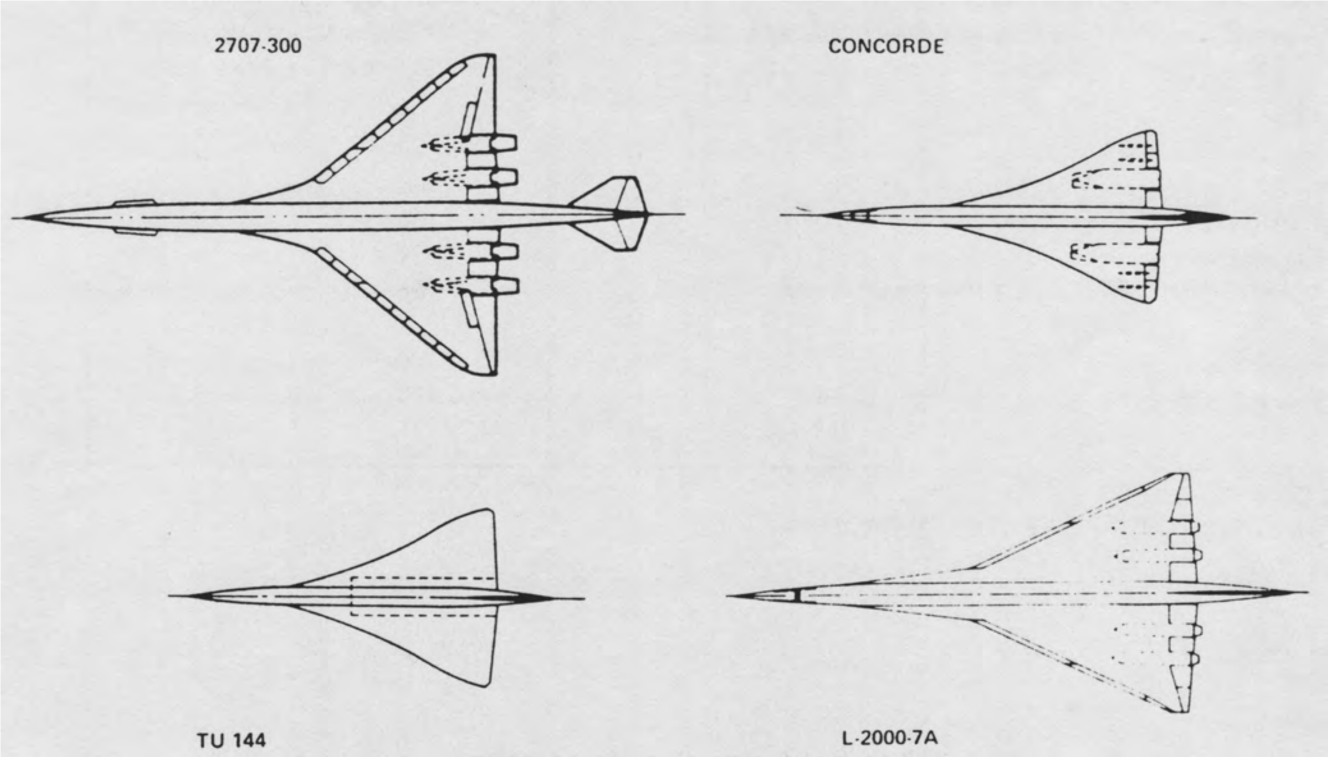
- Maximizes Lift/Drag Ratio
- Improves Directional Stability
- Minimizes Buffet

* LEADING EDGE FLAP AUTOMATICALLY PROGRAMMED FOR BEST FLAP POSITION (MAX LIFT/DRAG AS A FUNCTION OF MACH NUMBER AND ANGLE-OF-ATTACK

# The US SST Program

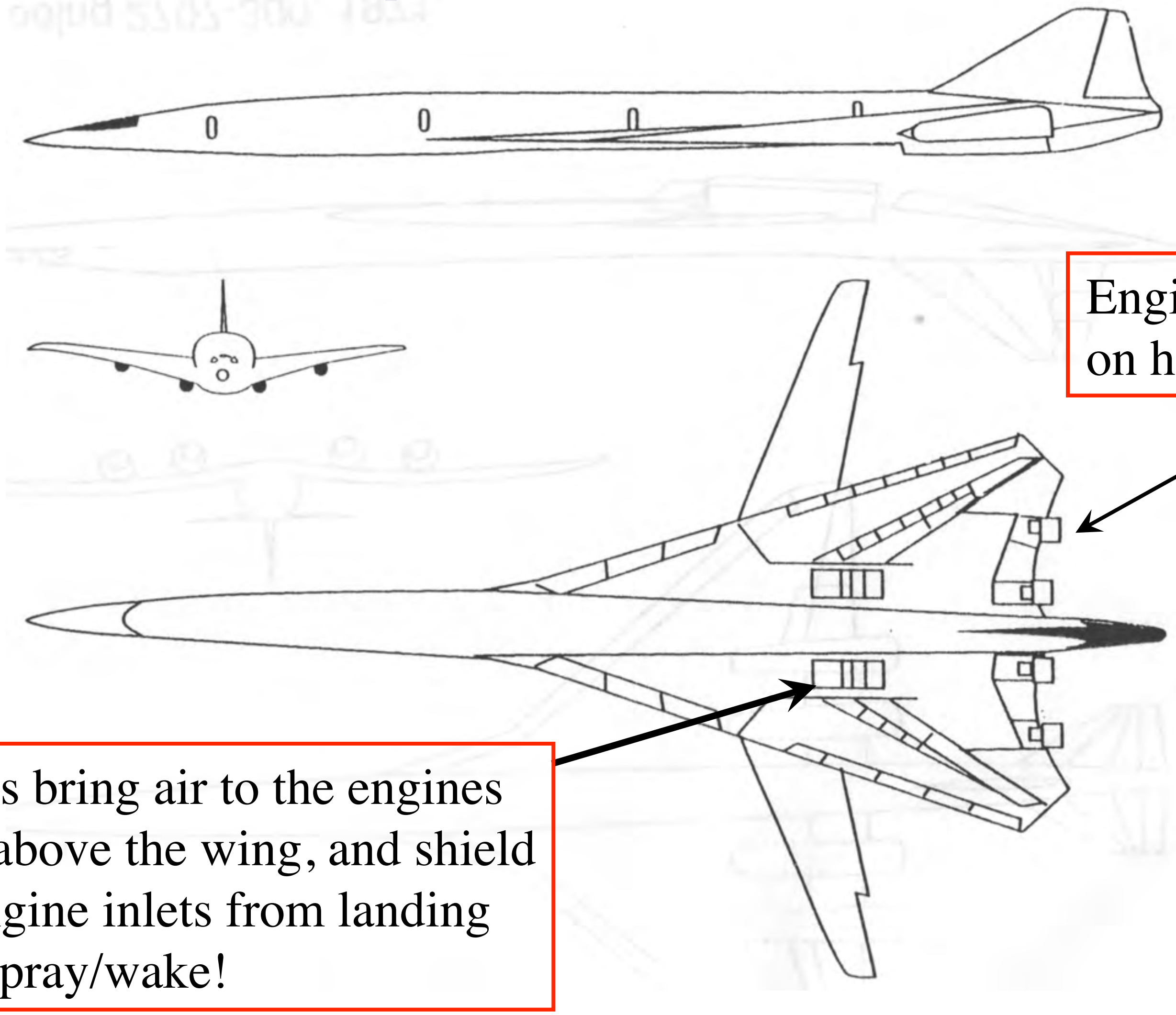
- Started in Response to British/French and USSR Supersonic Transport Programs
- Too big for one company, a national program funded by the US and administered mainly by the FAA!?
- Aug. 15, 1963: FAA Issues RFP
- May 15, 1964: Gov't selects Boeing and Lockheed and GE & P&W to compete for final concept
  - Lockheed proposes a double delta
  - Boeing proposes a variable sweep wing
- Dec. 31, 1966: Boeing & GE selected
- Oct. 21, 1968: Boeing abandons variable sweep
- March 24, 1971: Program cancelled

# Comparison of concepts



Walter C. Swan, “A Review of the Configuration Development of the U.S. Supersonic Transport,” 11th Anglo-American Aeronautical Conference, London, Sept., 1969.

# But first, a most bizarre variable sweep concept, the 2707-200!

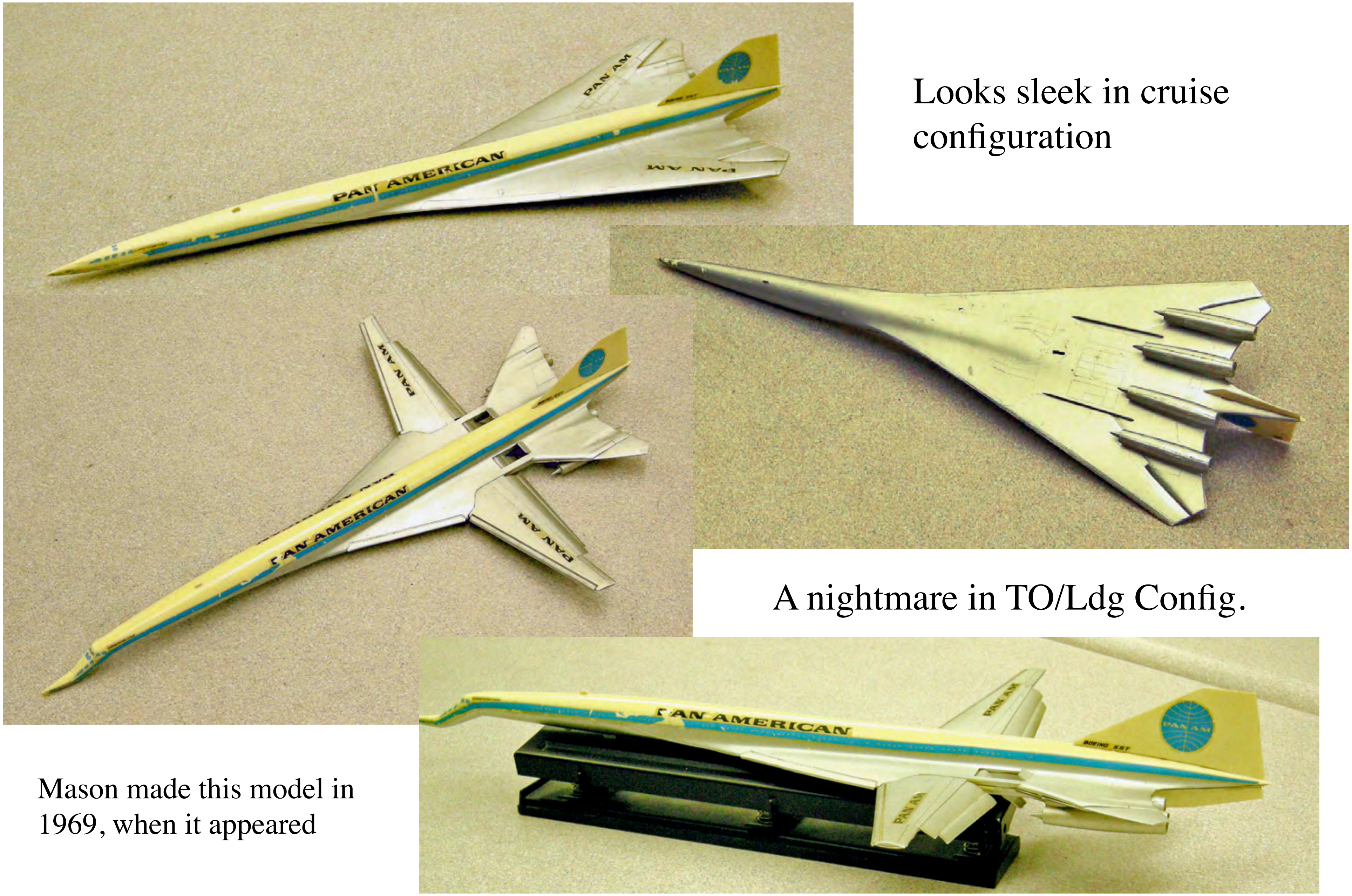


Engines mounted on horizontal tail!

Ramps bring air to the engines from above the wing, and shield the engine inlets from landing gear spray/wake!

M. Leroy Spearman, “The Evolution of the High-Speed Civil Transport,” NASA TM 109089, Feb., 1994

# That drawing does not do the 2707-200 justice!



Looks sleek in cruise configuration

A nightmare in TO/Ldg Config.

Mason made this model in 1969, when it appeared

# Aeroelasticity – can’t neglect!

Aeroelastic deformation lessons learned on Boeing’s 1960s/early 70s US SST design - from Kumar Bhatia AIAA Paper 93-1478

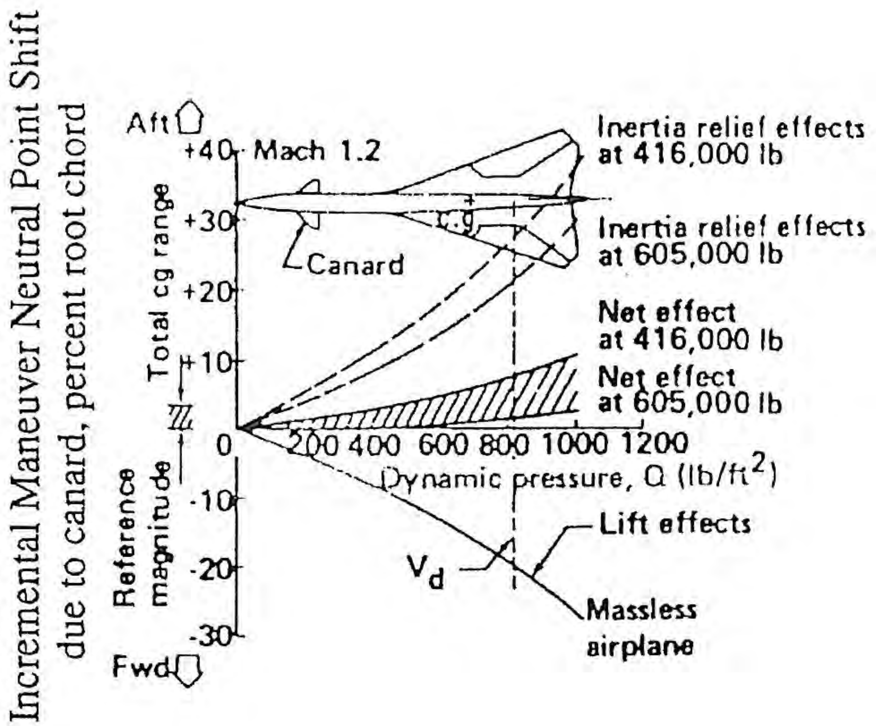


Fig 5. EFFECT OF AEROELASTICITY ON CANARD CONTRIBUTION TO LONGITUDINAL STABILITY IN MANEUVERING FLIGHT

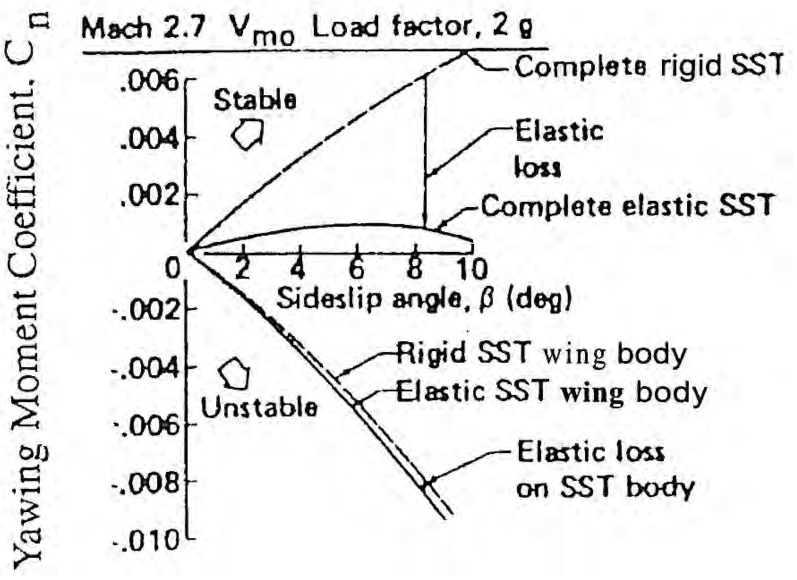


FIG 6. EFFECT OF AEROELASTICITY ON DIRECTIONAL STABILITY

# Final Design: The Boeing 2707-300

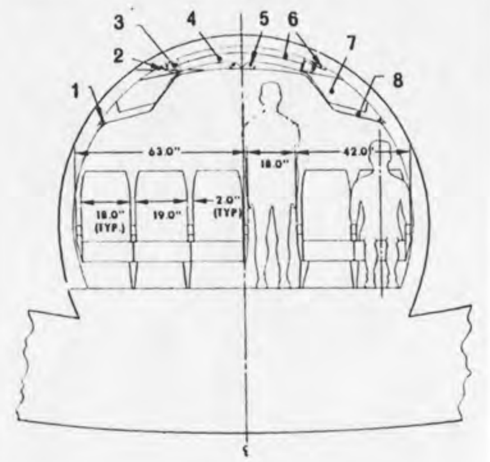
Still a tight fit,
only 5 cramped
seats abreast

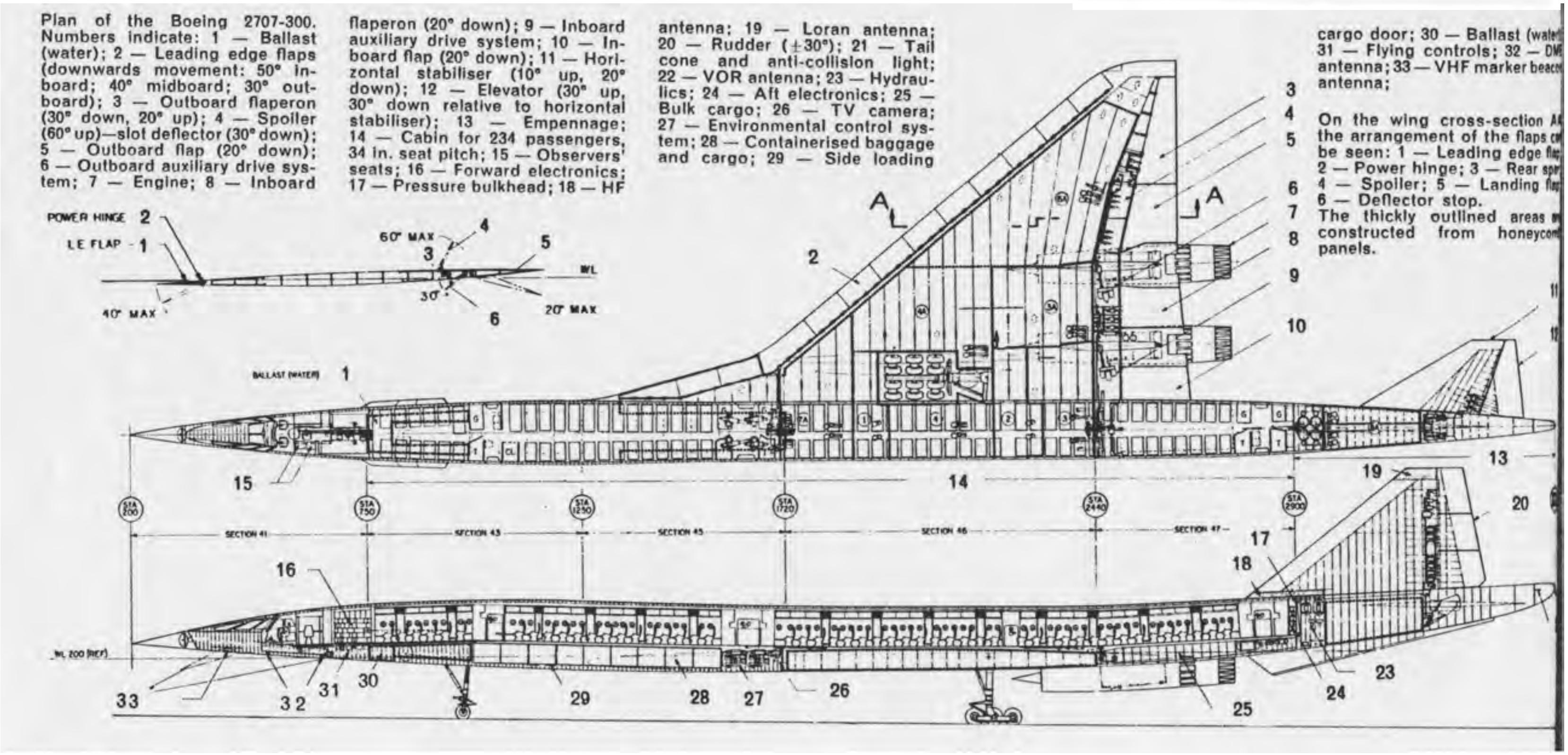
M = 2.7
Range: 3,500nm

200 passengers
TOGW: 750,000 lbs

*From Interavia*, Feb., 1969

Sectional view of Boeing 2707-300 main cabin at wings (234 tourist passenger arrangement). 1 — Sidewall light; 2 — Water pipe; 3 — Air duct; 4 — Air plenum; 5 — Ceiling light; 6 — Electrical wiring; 7 — Enclosed overhead rack; 8 — Passenger service unit.



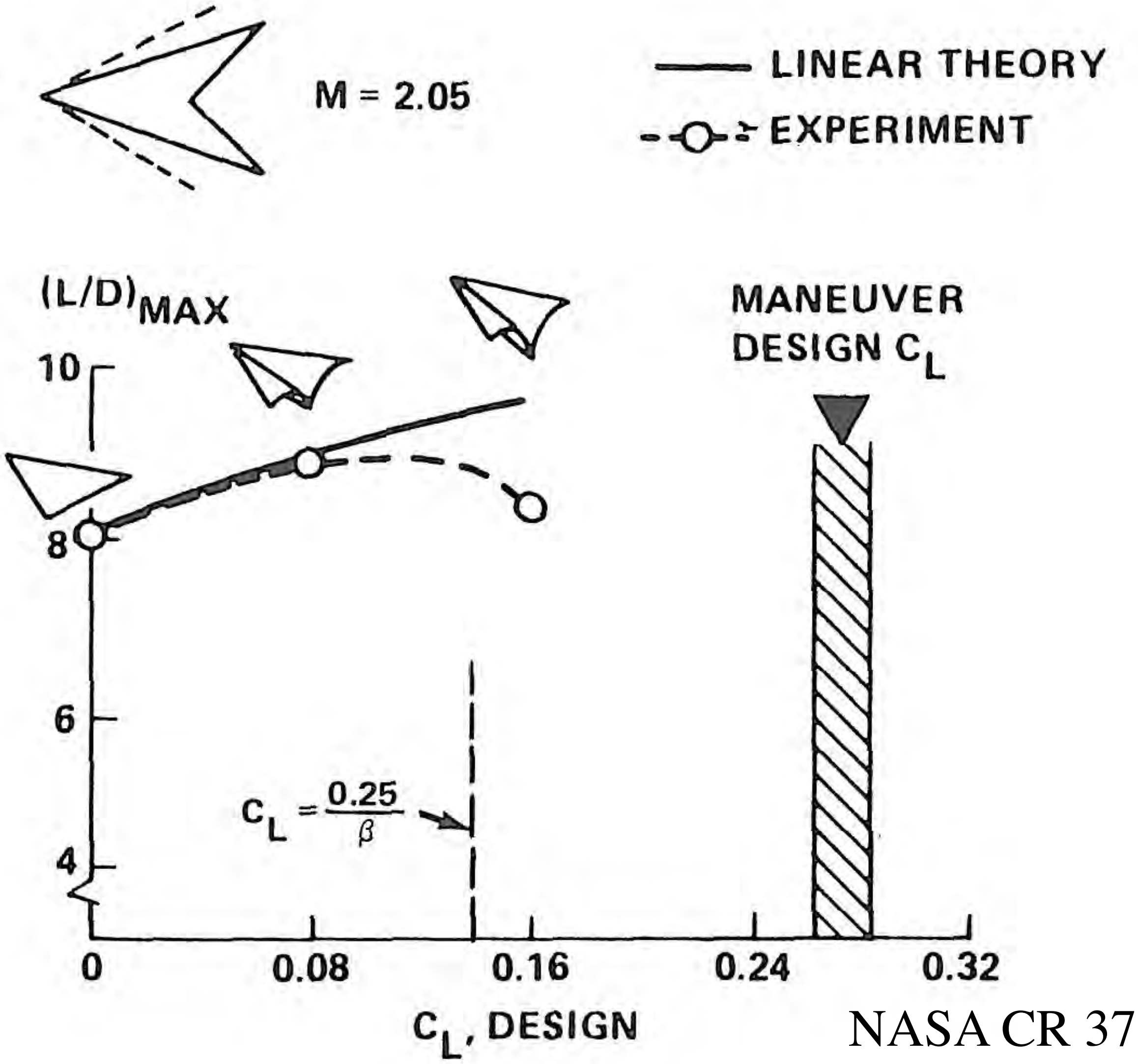


Plan of the Boeing 2707-300. Numbers indicate: 1 — Ballast (water); 2 — Leading edge flaps (downwards movement: 50° inboard; 40° midboard; 30° outboard); 3 — Outboard flaperon (30° down, 20° up); 4 — Spoiler (60° up)—slot deflector (30° down); 5 — Outboard flap (20° down); 6 — Outboard auxiliary drive system; 7 — Engine; 8 — Inboard flaperon (20° down); 9 — Inboard auxiliary drive system; 10 — Inboard flap (20° down); 11 — Horizontal stabiliser (10° up, 20° down); 12 — Elevator (30° up, 30° down relative to horizontal stabiliser); 13 — Empennage; 14 — Cabin for 234 passengers, 34 in. seat pitch; 15 — Observers' seats; 16 — Forward electronics; 17 — Pressure bulkhead; 18 — HF antenna; 19 — Loran antenna; 20 — Rudder (±30°); 21 — Tail cone and anti-collision light; 22 — VOR antenna; 23 — Hydraulics; 24 — Aft electronics; 25 — Bulk cargo; 26 — TV camera; 27 — Environmental control system; 28 — Containerised baggage and cargo; 29 — Side loading cargo door; 30 — Ballast (wate
31 — Flying controls; 32 — DM
antenna; 33 — VHF marker beac
antenna;

On the wing cross-section A
the arrangement of the flaps ca
be seen: 1 — Leading edge fl
2 — Power hinge; 3 — Rear sp
4 — Spoiler; 5 — Landing fl
6 — Deflector stop.
The thickly outlined areas w
constructed from honeycom
panels.

# Example: linear theory breakdown at "high" lift and a wing concept development program

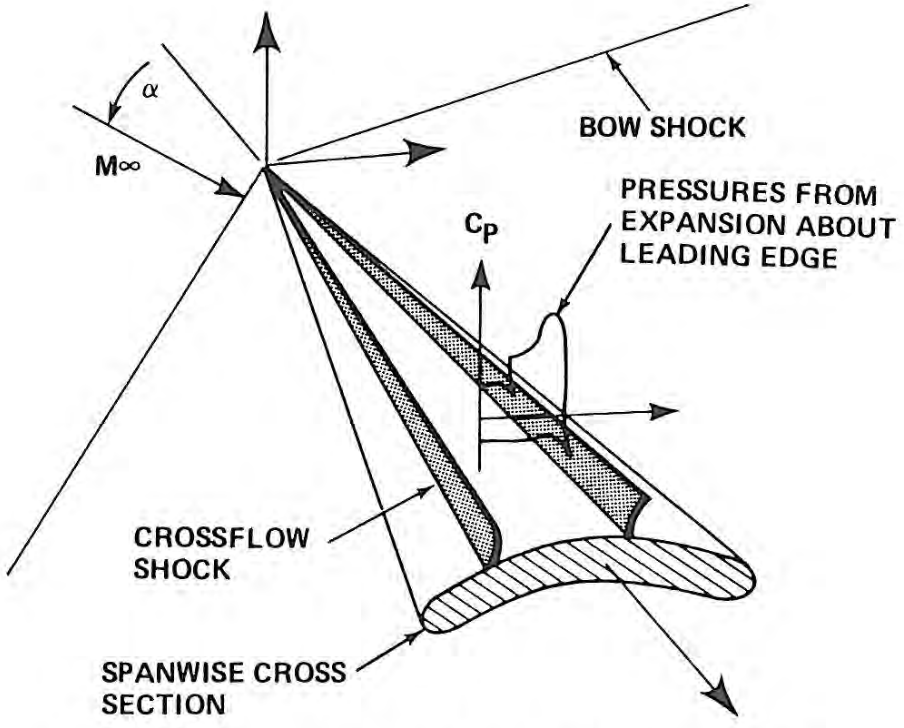
Rudy Meyer at Grumman identifies a problem (and a solution)



NASA CR 3763

# The physics of the breakdown

## The physics

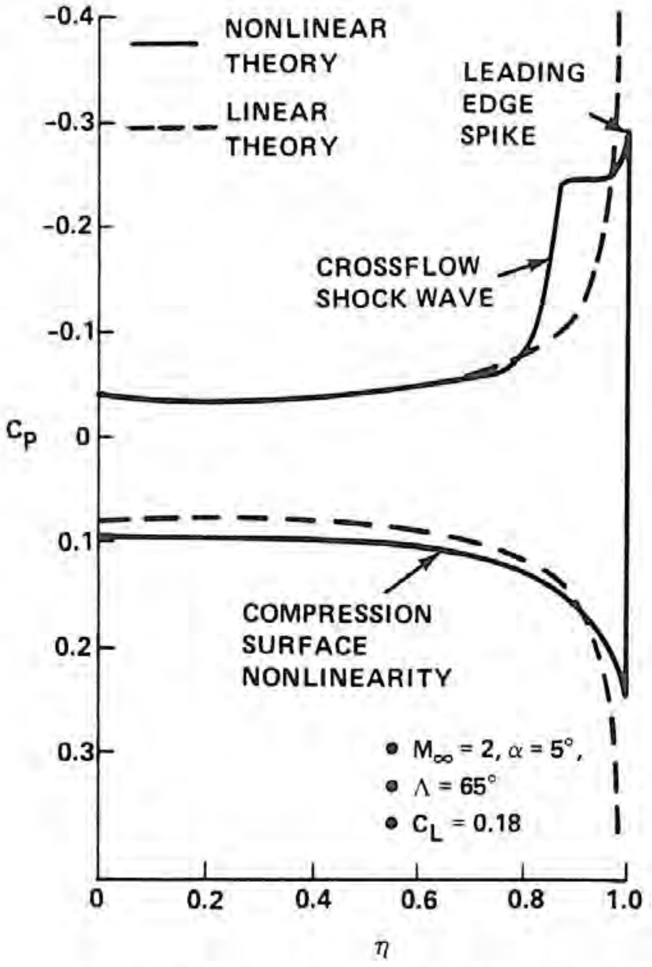


A. TYPICAL FLOW IN CROSSFLOW PLANE

If the crossflow is supercritical, need to address, just as for 2D transonic flow

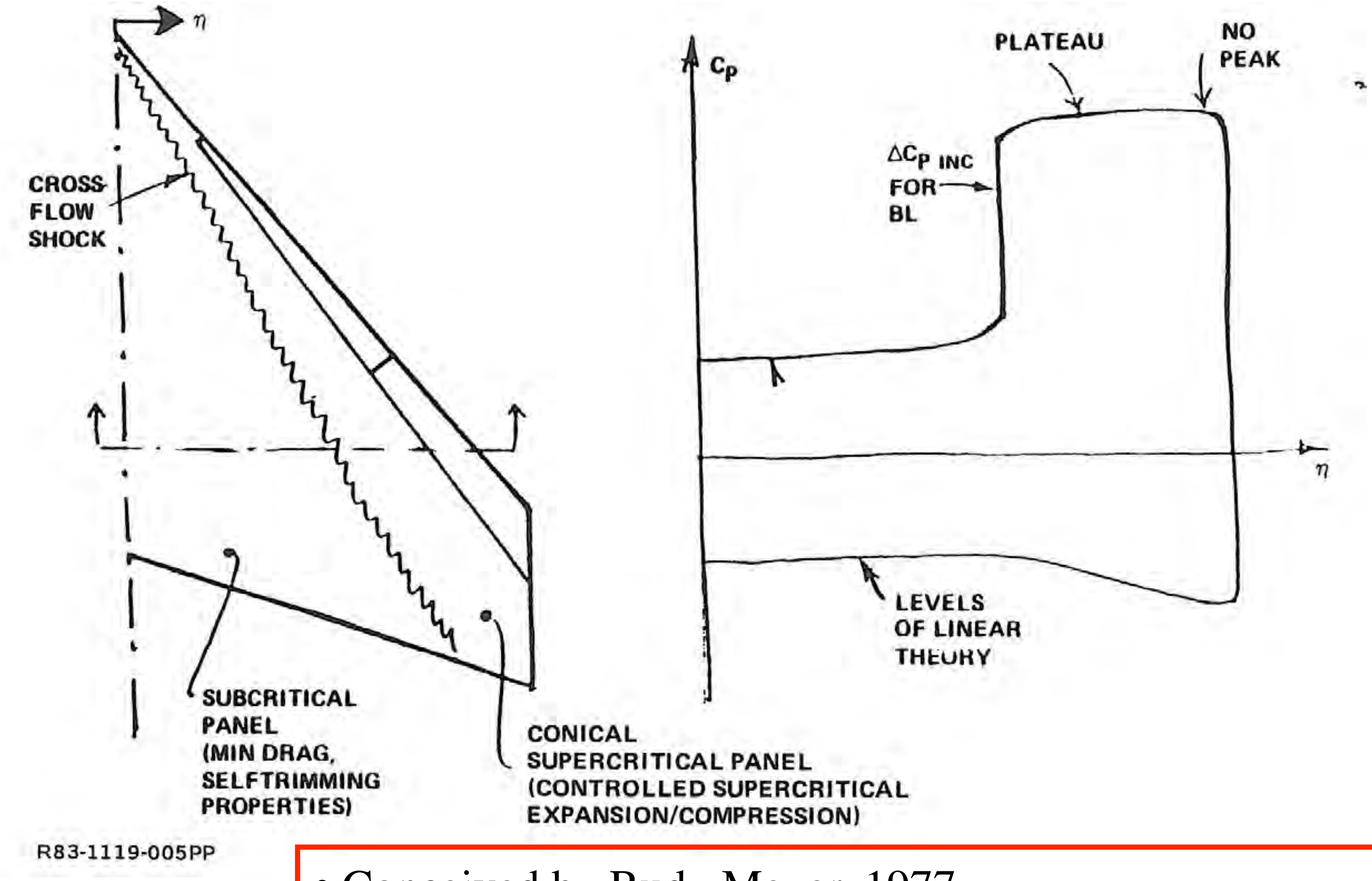
NASA CR 3763, 1983

## The implications for theory



B. UNCAMBERED DELTA WING WITH ELLIPTIC THICKNESS DISTRIBUTION

# The Super Critical Conical Camber Concept (SC3)



NASA CR 3763, 1983

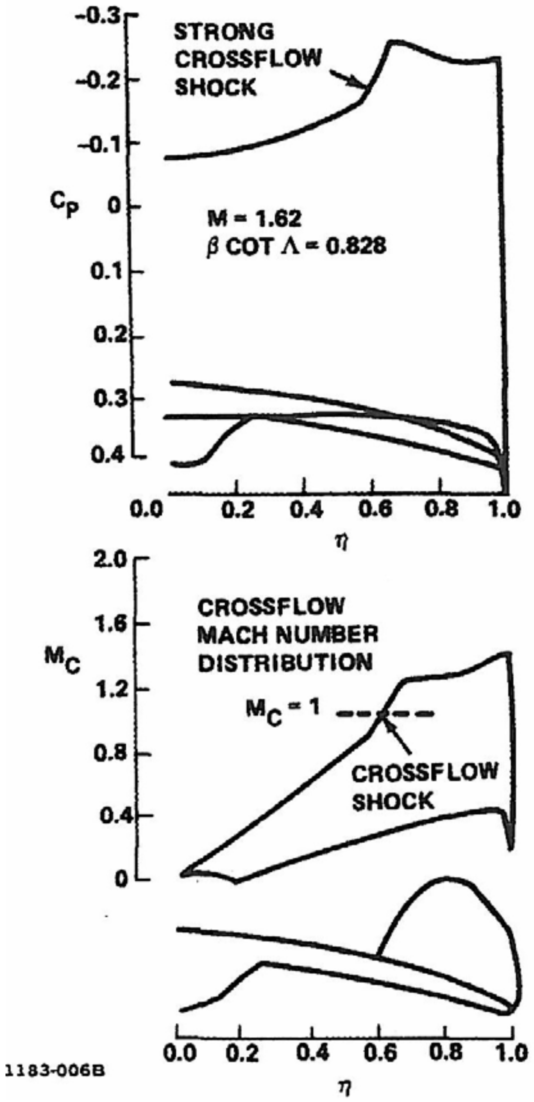
- Conceived by Rudy Meyer, 1977
- Concept drawn by Gianky daForno, 1977
- Computational Method by Bernie Grossman, 1978: COREL
- Aerodynamic design by W.H. Mason. 1978-82

# Steps to the “Demo” Wing

- Start with a “Conceptual” Conical Wing
- Design the spanwise “airfoil” section
- Build and Test the Conceptual Wing
  - This test mainly looked at the wing pressures
- We added a body and canard to understand interference
- Extend the design to a true 3D Wing
- Build and test the “Demo” wing
- Success!

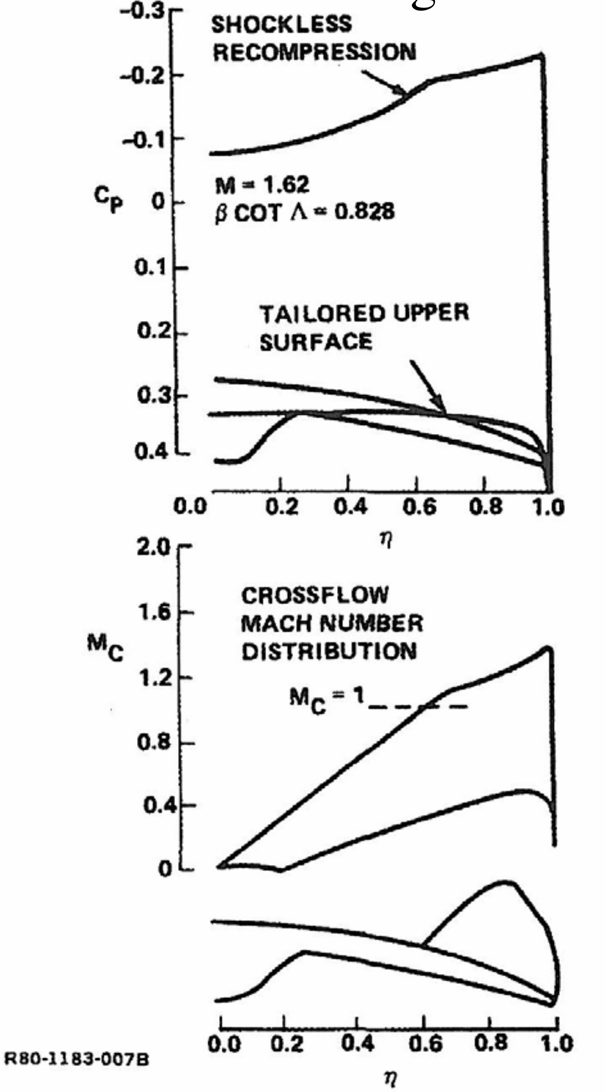
# Computational Design Spanwise Pressures

Initial Camber Studies



1183-006B

Final Design



R80-1183-007B

AIAA-1980-1421 “Controlled Supercritical Crossflow on Supersonic Wings”

# A WT Model to see if the CFD is valid

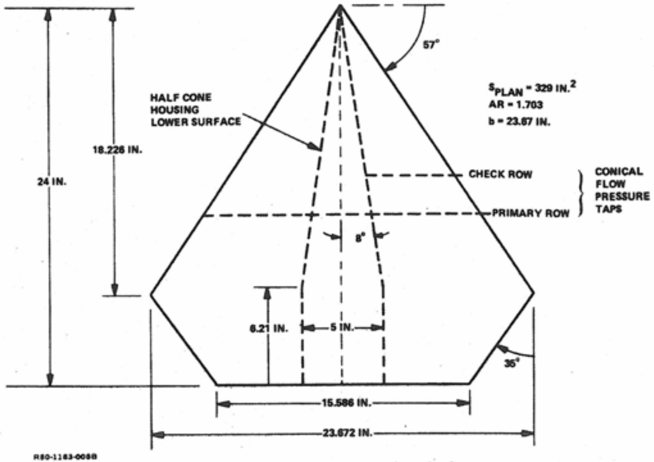
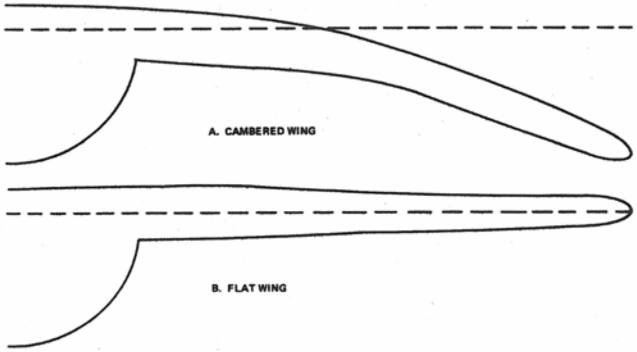
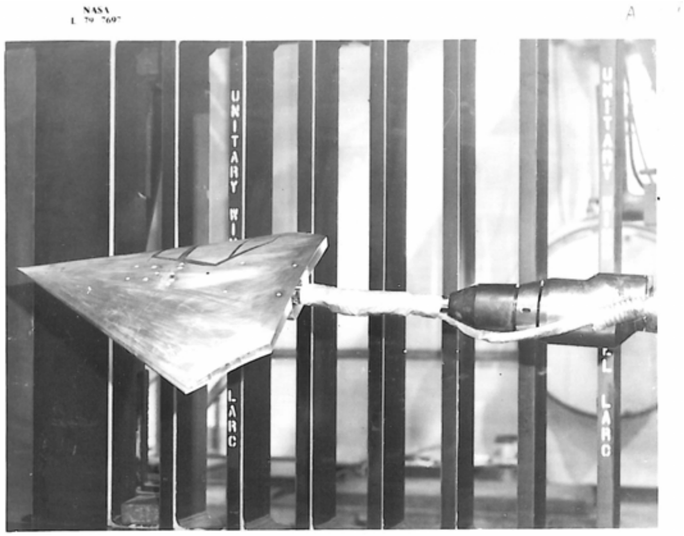
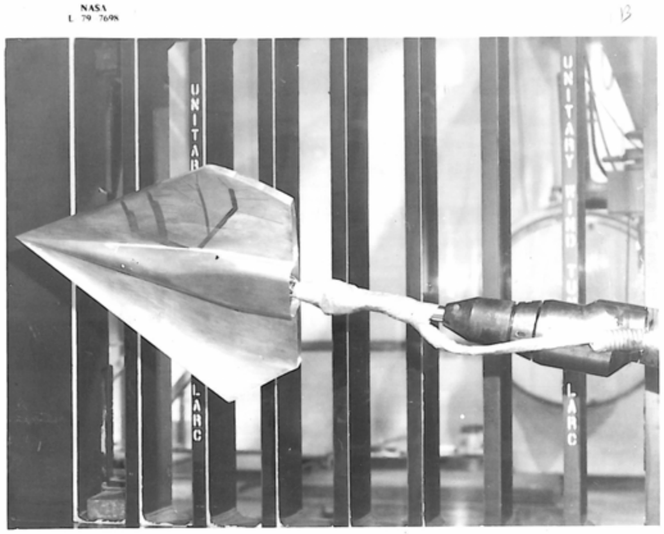


Fig. 8 Conceptual-maneuver-wing planform.

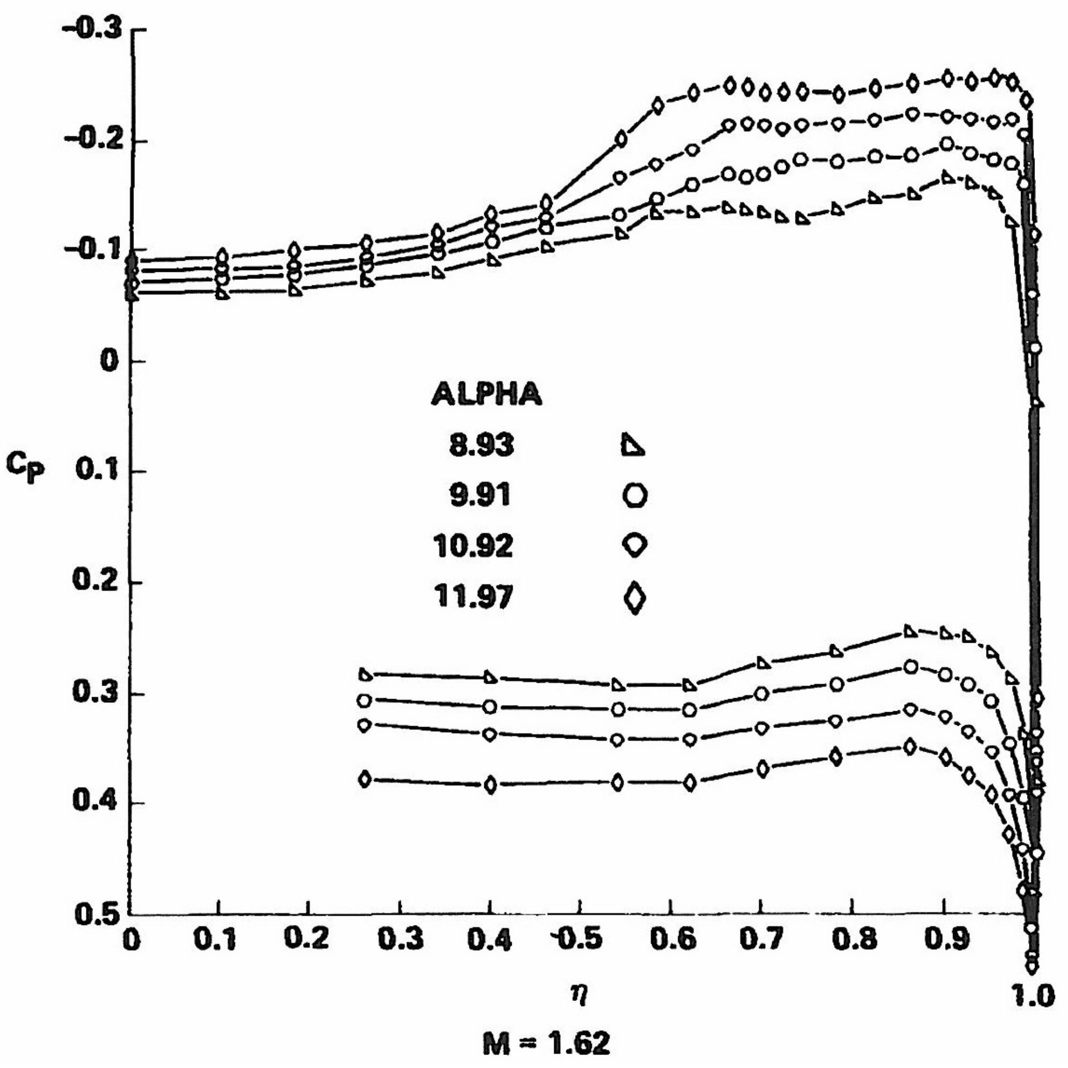






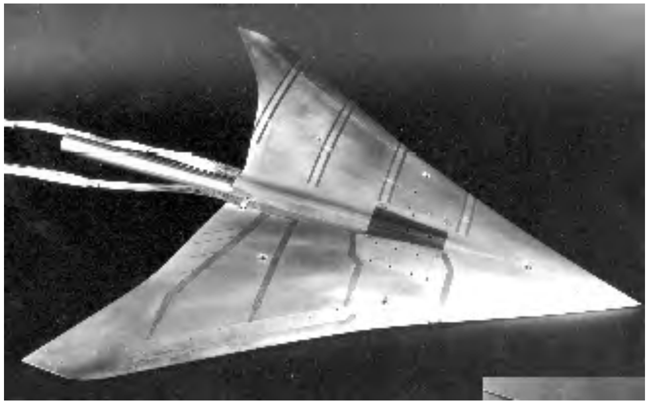
AIAA-1980-1421 “Controlled Supercritical Crossflow on Supersonic Wings”

# Pressure from WT Test
# - Just Like the CFD Predicted -



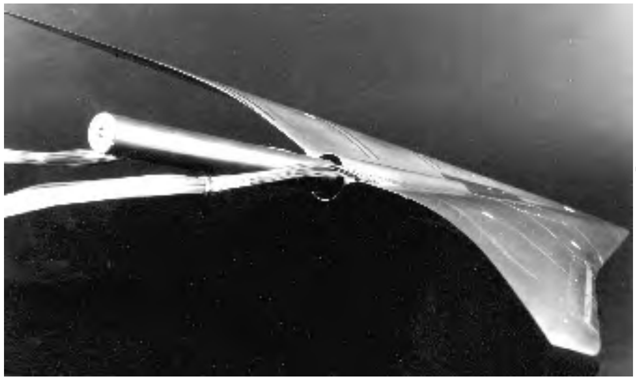
AIAA-1980-1421 “Controlled Supercritical Crossflow on Supersonic Wings”

# The Outcome: NASA/Grumman Demo Wing

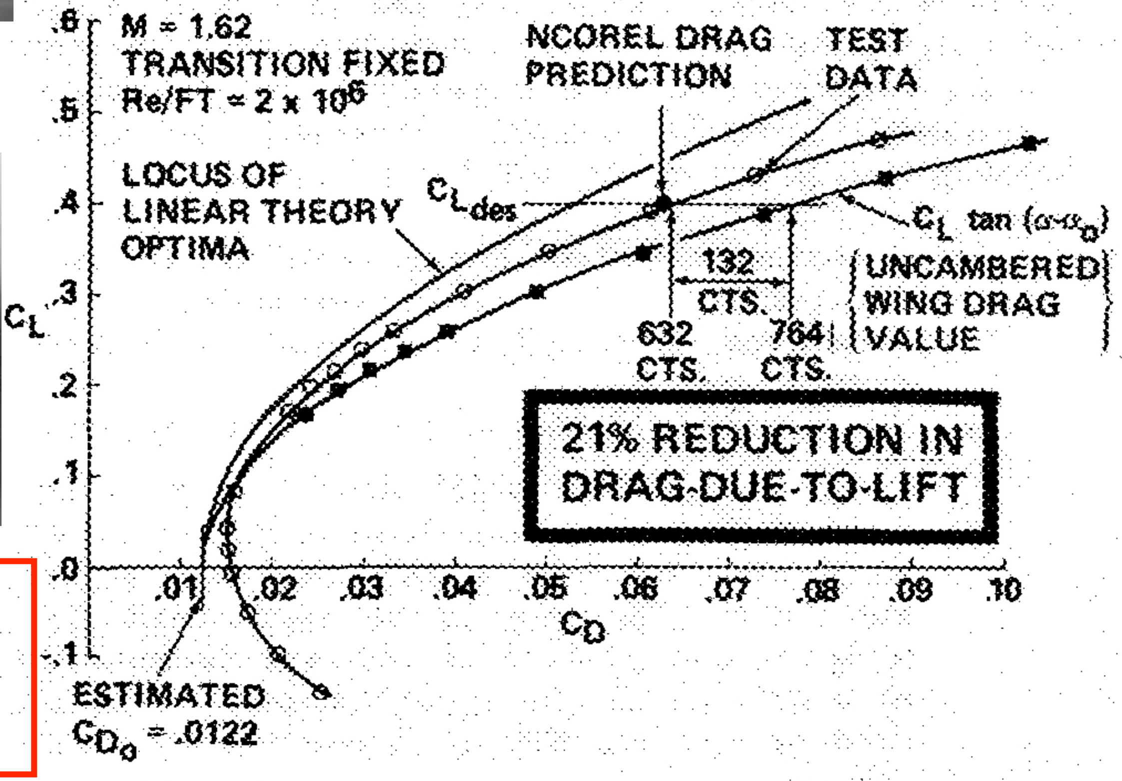


Supercritical Conical Camber, SC$^3$

An attached flow maneuver wing with controlled supercritical crossflow



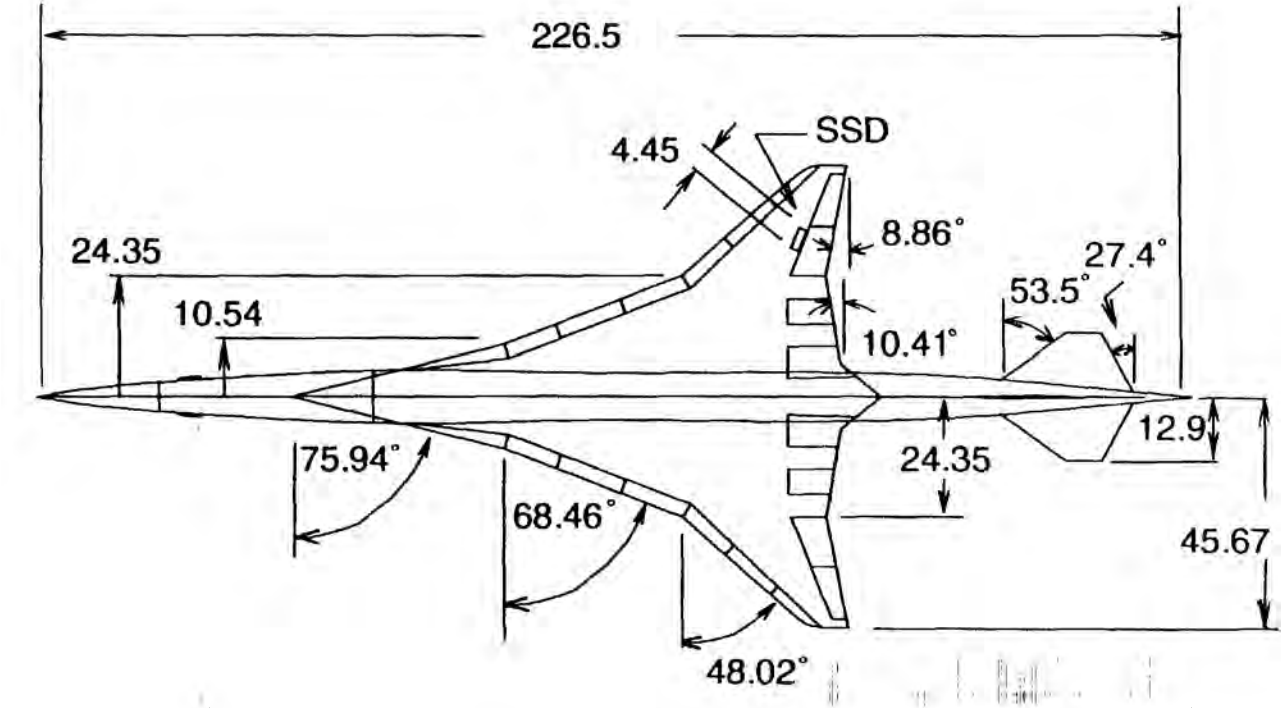
This wing set a record at NASA LaRC for low drag at high lift supersonic performance.



NASA CR 3763/AIAA 83-1858

# Through the 90s: The HSR Studies - the HSCT -

The Reference H public study configuration



WT Model (inches), NASA/TM-1999-209702, Kemmerly, et al

| | |
|---|---|
| M = 2.4 | 250 – 300 passengers |
| Range: 5,000 – 6,500 nm | TOGW: 700,000 lbs |

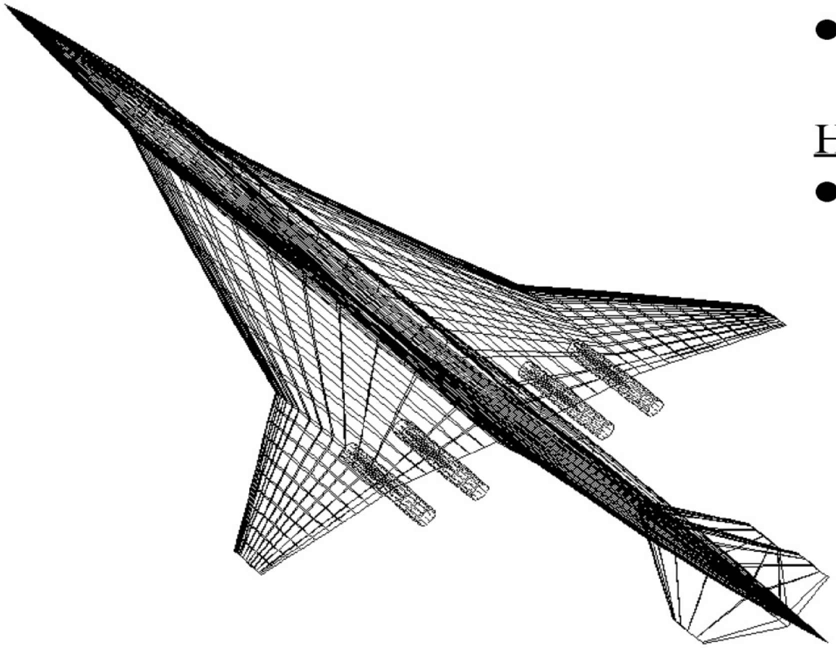
***Brenda Kulfan quotes sensitivity of 10,400 lbs/drag count***

**In the end, too tough for now.**

Erik M. Conway, *High Speed Dreams*, Johns Hopkins Univ. Press, 2005

# In the 90s At Virginia Tech: HSCT MDO

## HSCT Optimization Problem



Design Requirements

- $\text{Mach}_{\text{cruise}} = 2.4$, Range = 5500 n.mi.,
  Payload = 250 passengers
- Objective: minimize takeoff gross weight (TOGW)

HSCT Model Parameterization

- 29 variables:
  - 8 - wing planform
  - 8 - fuselage
  - 5 - airfoil section
  - 2 - nacelle location
  - 2 - vertical and horizontal tail areas
  - 1 - engine thrust
  - 3 - mission variables:
    fuel weight, initial cruise altitude, rate of climb

Knill, D.L., Giunta, A.A., Baker, C.A., Grossman, B., Mason, W.H., Haftka, R.T. and Watson, L.T., "Response Surface Models Combining Linear and Euler Aerodynamics for Supersonic Transport Design," *Journal of Aircraft*, Vol. 36, No. 1, Jan-Feb 1999, pp. 75-86.

Optimization Problem

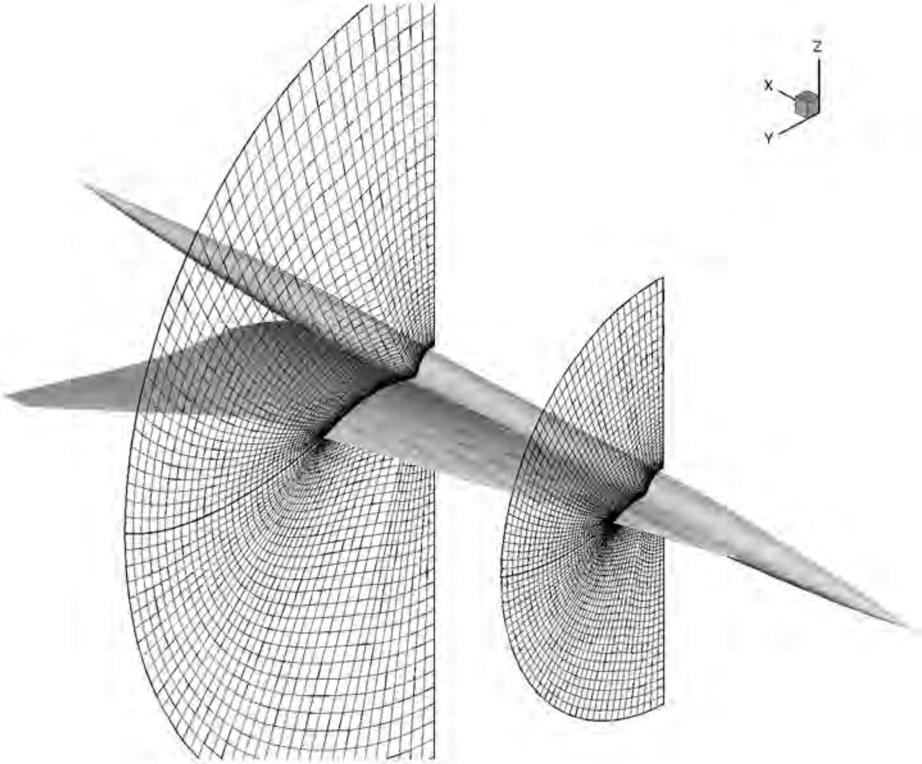
$$\underset{\boldsymbol{x} \varepsilon R^{29}}{\text{minimize}}\ TOGW(\boldsymbol{x}), \quad \text{subject to } g_i(\boldsymbol{x}) \le 0,\ i = 1,\ldots,70$$

# Lucky Break in Grid Generation

Grid generator for space marching calculations originally developed by Ray Barger at NASA Langley

Features of code

- Uses as input the aircraft configuration written in Craidon format
- Robust for large planform changes
- Measures are employed to reduce grid skewness
- Hands-off grid generation

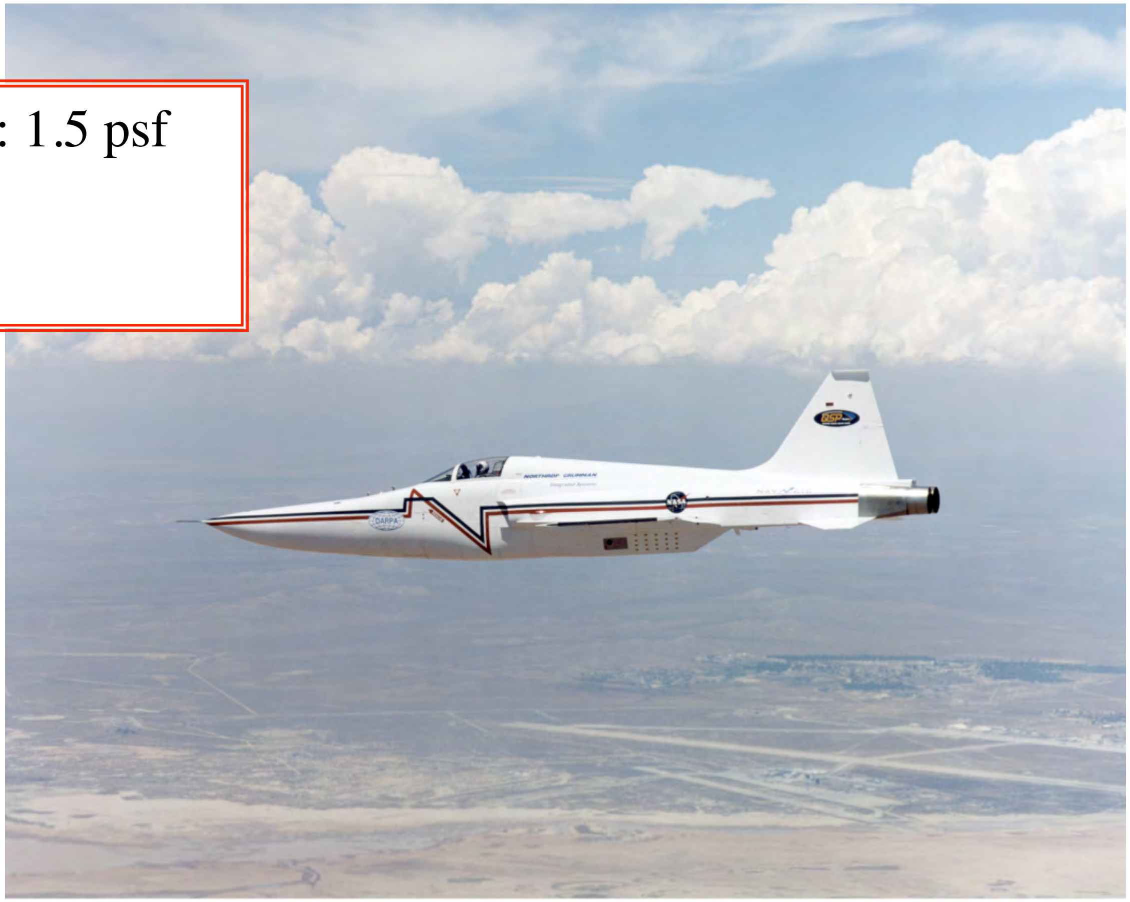


# The key to the next step: sonic boom - can we reduce the strength?

- Typical boom overpressure: 1.5 psf
- Would 0.3 psf be OK?
- Need new FAA rule

An F-5E modified to demonstrate “shaping” of the sonic boom signature, success achieved in 2003

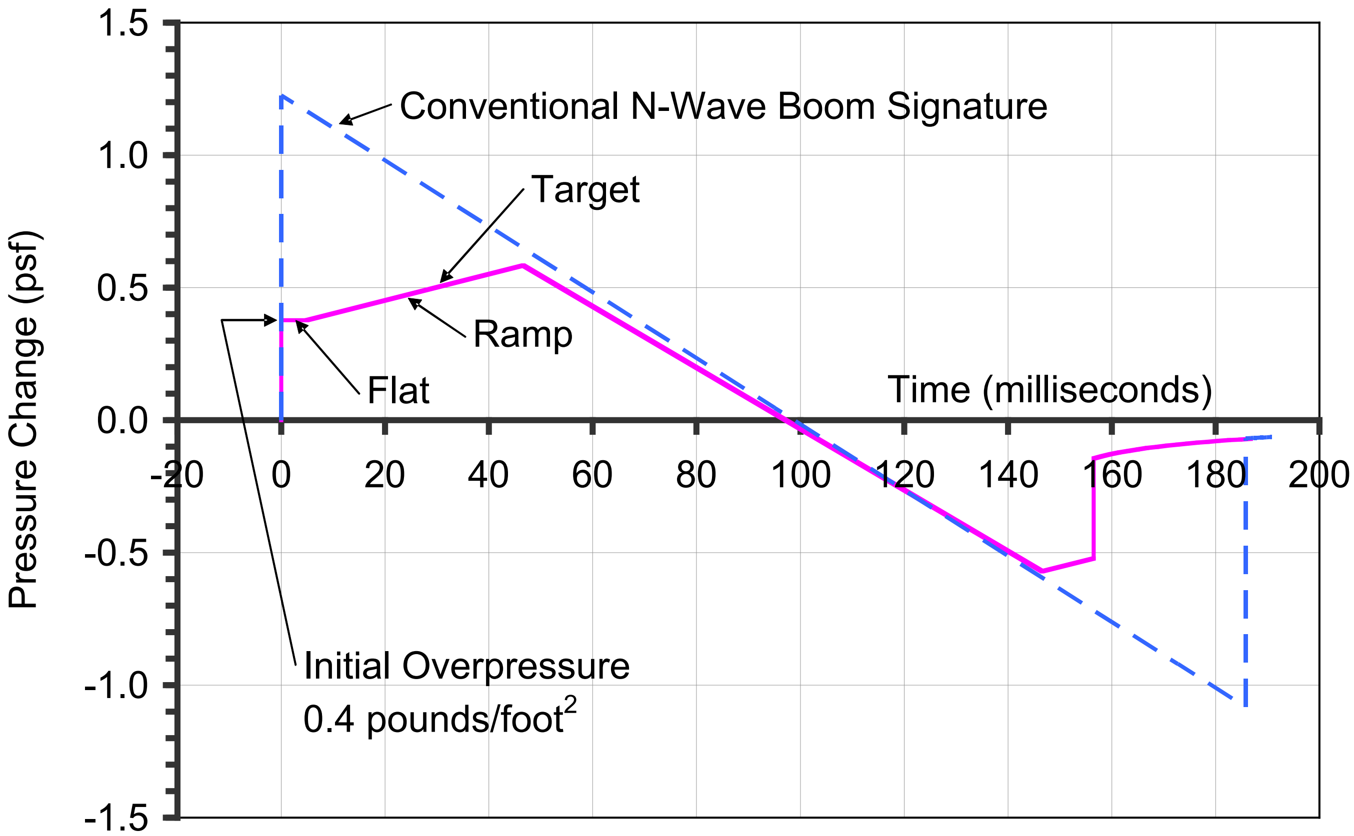
The heritage here is the DARPA Quiet Supersonic Platform (QSP) program, that kicked off in late 2000



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC03–0210–1   Date: August 2, 2003   Photo By: Carla Thomas

Northrop–Grumman Corporation’s modified U.S. Navy F–5E Shaped Sonic Boom Demonstration (SSBD) aircraft.

# Conventional N-wave, and future target for the “sonic boom”



From “Conceptual Design of a Sonic Boom Constrained Supersonic Business Aircraft” by David C. Aronstein and Kurt L. Schueler, AIAA Paper 2004-0697

# Keys to Reducing Boom Strength

- Extending the configuration length
- Low Aircraft weight
- Careful shaping of volume and lift distribution

**X-54 X-plane designation obtained by Gulfstream for a low boom strength demonstrator**

# One way to increase length: The Quiet Spike

“Spike” extends in flight, see AIAA Paper 2008-123, Jan. 2008 for overview

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED06–0187–12 Date: October 3, 2006 Photo By: Jim Ross

NASA F–15B #836 in flight with Quiet Spike attached.

# The hope is for Supersonic Biz Jets

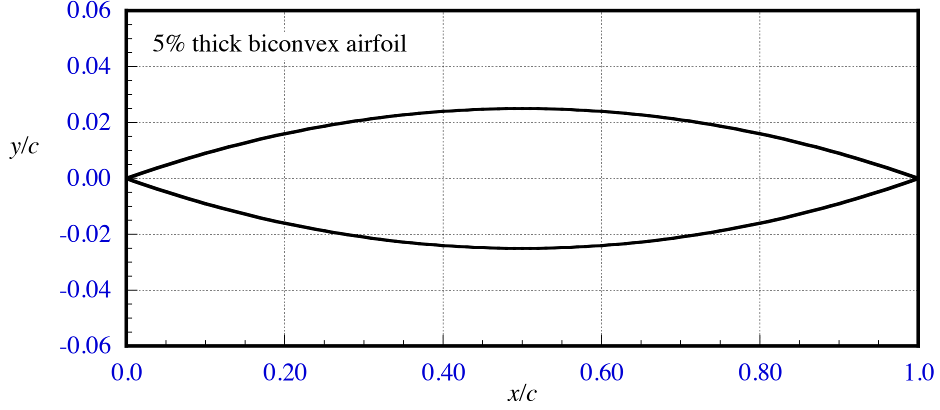
One concept from Aerion, depends also on obtaining laminar flow

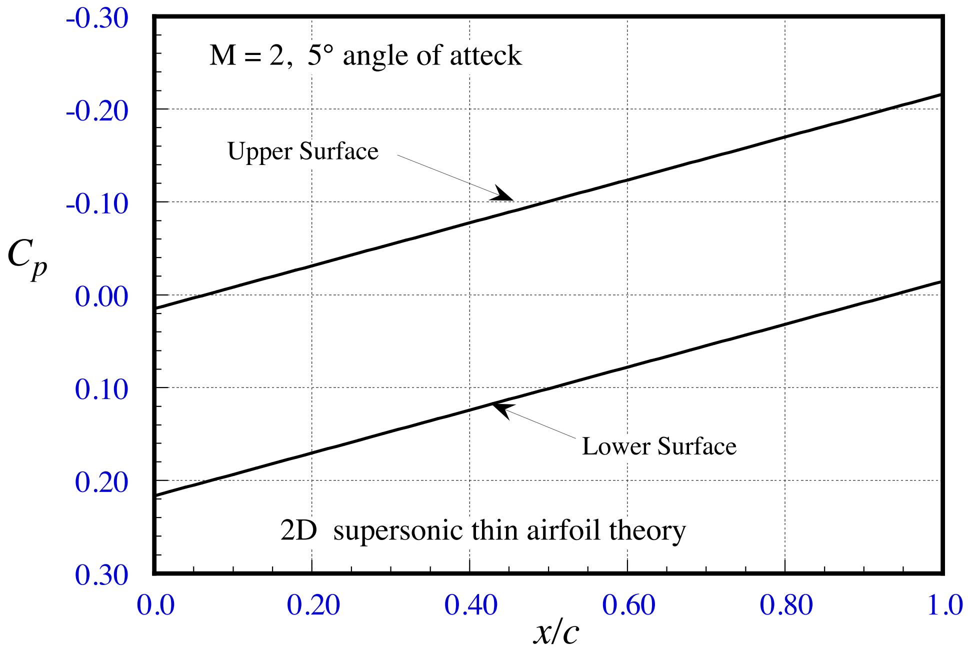
Now teamed with Airbus and a 3-engine design!

From the Aerion web site: http://www.aerioncorp.com/

# What’ s the *Aerion* Idea?

This *is* a case where 2D supersonic airfoil theory is interesting





2D supersonic airfoil pressures look nothing like the subsonic pressures

A favorable pressure gradient all the way to the trailing edge means that you might be able to get laminar flow!

-Small chord

-High altitudes

Implies a relatively low Re

Also observe that the upper and lower surface pressures don’ t have to be equal at the TE when it’ s a supersonic TE edge

# Today's Aerion Concept

Revised Design, with Airbus – Nov., 2013?

http://www.aerionsupersonic.com/as2.aspx

# A Breakthrough?

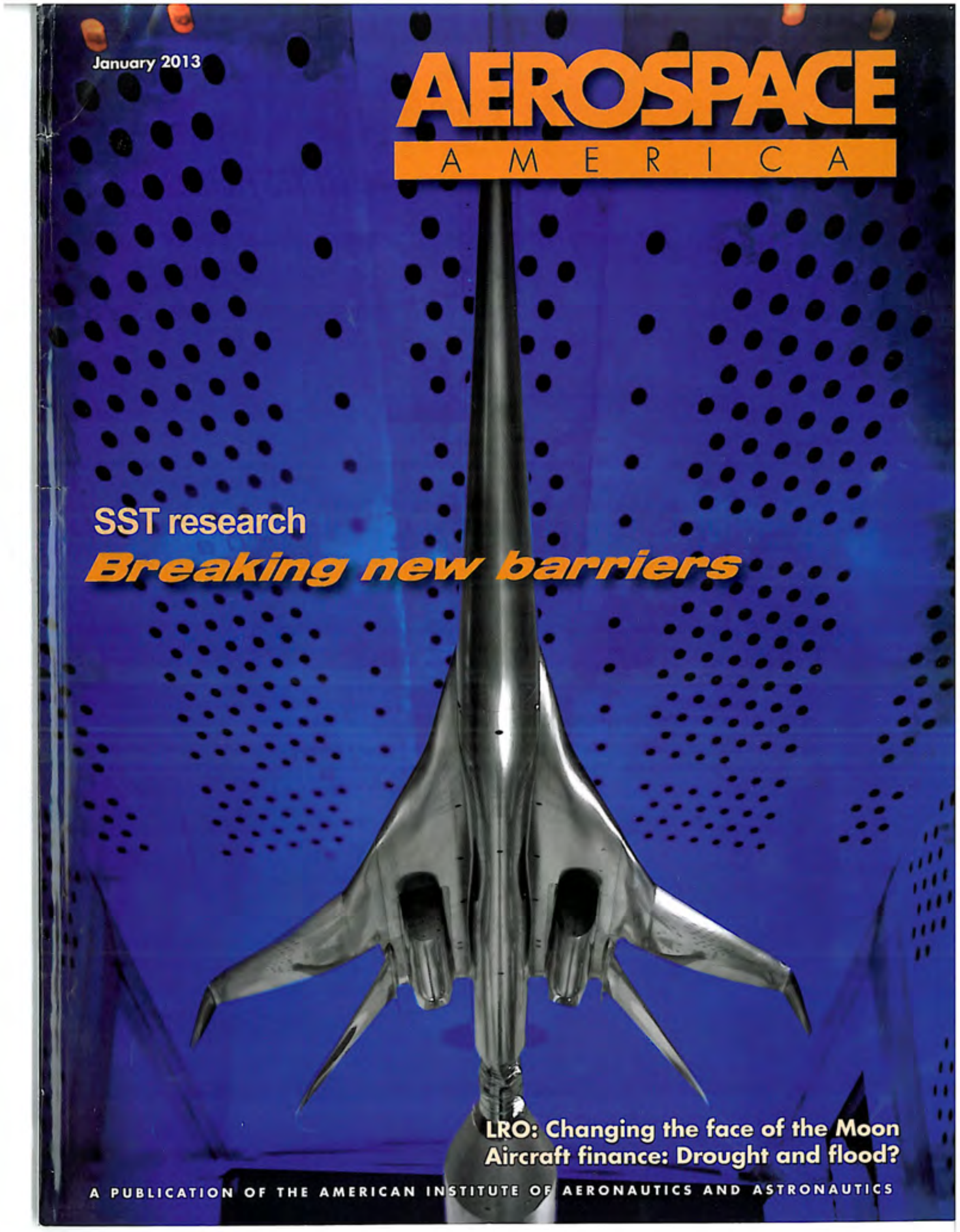
## AIAA Daily Launch, April 3, 2012

### NASA Claims Supersonic Aircraft Breakthrough.

Aviation Daily (4/2, Warwick) reported, "NASA is claiming a breakthrough in the design of supersonic aircraft, with wind-tunnel tests proving it is possible to design configurations that combine low sonic boom with low cruise drag, characteristics once thought to be mutually exclusive." Testing of scale models designed by Boeing and Lockheed Martin that could be available by 2025 showed that "design tools could produce a supersonic business jet capable of unrestricted overland flight," says Peter Coen, NASA's Supersonic Fixed-Wing project manager. Coen added, "It's the first time we have taken a design representative of a small supersonic airliner and shown we can change the configuration in a way that is compatible with high efficiency and have a sonic signature than is not a boom." Both companies are now trying to "refine" the designs.

# And we keep hoping

The cover of *Aerospace America*, Jan. 2013



January 2013

AEROSPACE
AMERICA

SST research
Breaking new barriers

LRO: Changing the face of the Moon
Aircraft finance: Drought and flood?

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

# Current Programs – Spring 2016

- NASA Low Boom Supersonic Demonstrator

- QueSST Program, 20M to Lockheed Martin

Spike Aerospace

Boom Technology

In the next few years we’ll see how these programs turn out.

# To conclude

- Today “we” can supercruise with the F-22
- There is a possibility of lowering the sonic boom overpressure, and a new FAA rule allowing supersonic flight over land.
- We may see supersonic business jets in the “not too distant” future, especially if the FAA allows supersonic flight over land.

I have Brenda Kulfan’s Supersonic Aerodynamics Lecture Series, given at UVA in November 2008, for any student that wants it.