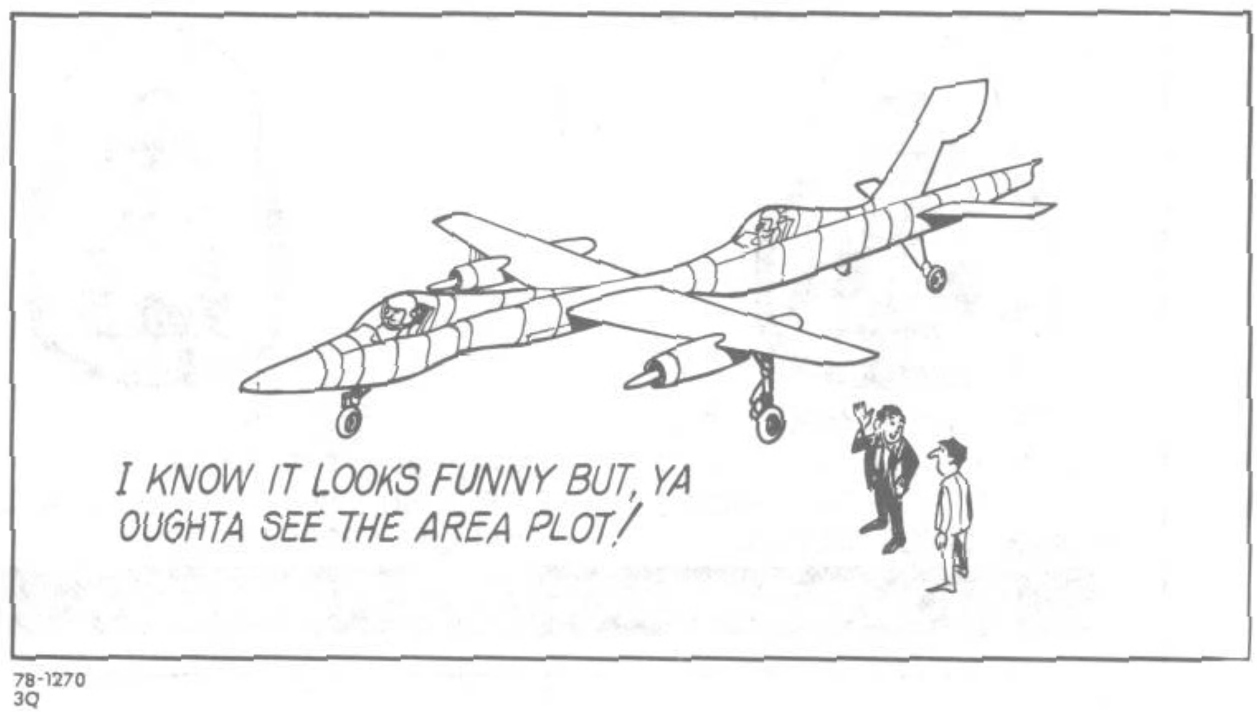
Aircraft Geometry

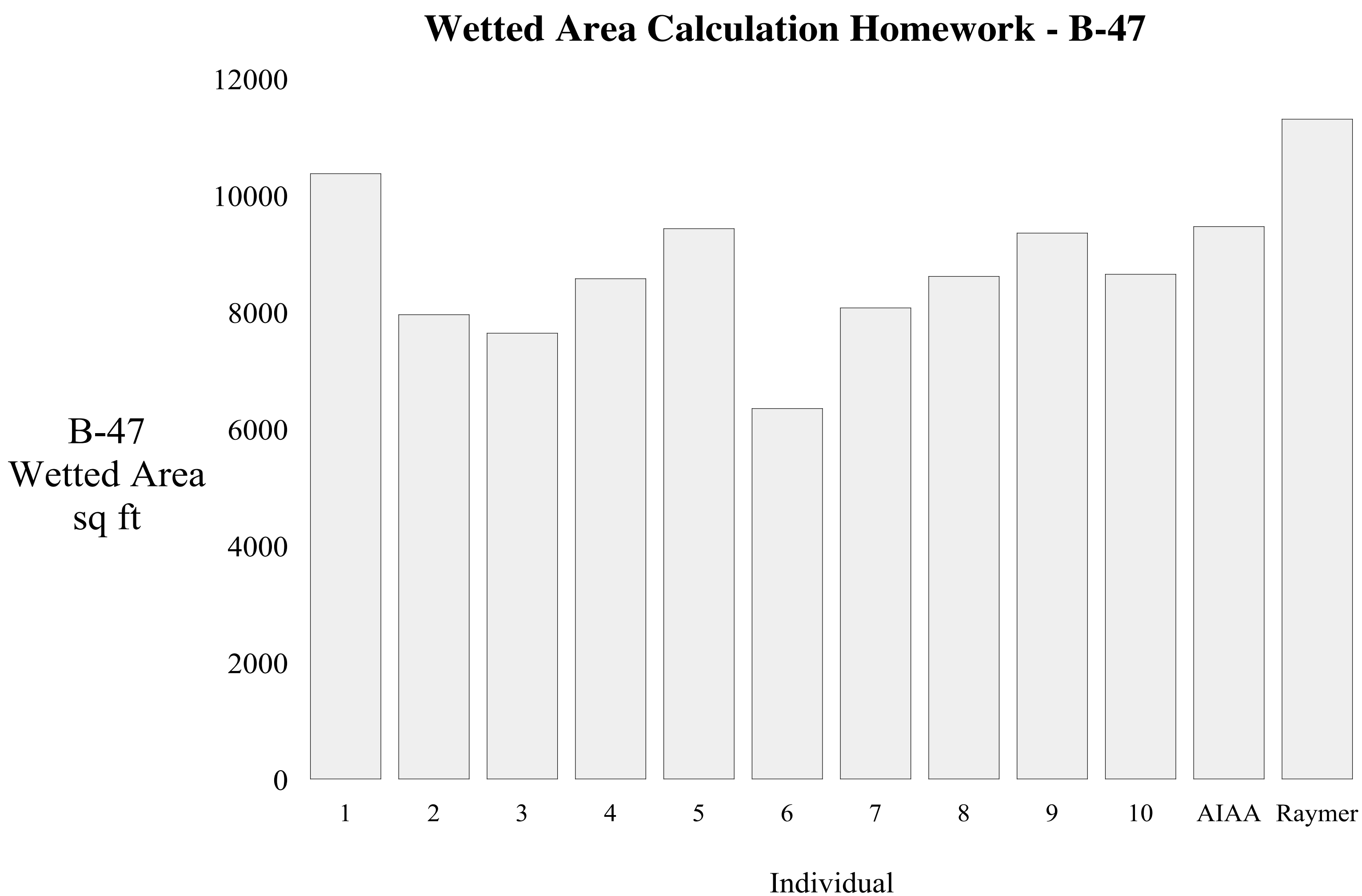
- There is a standard terminology
- We need to make sure we know it
- We can often work with analytically designed shapes
  - characterized by a small number of parameters
- Real airplanes don't have smooth analytic shapes
  - maybe partially, and maybe for stealth

Cartoon from the AIAA Northrop F-5 Case Study

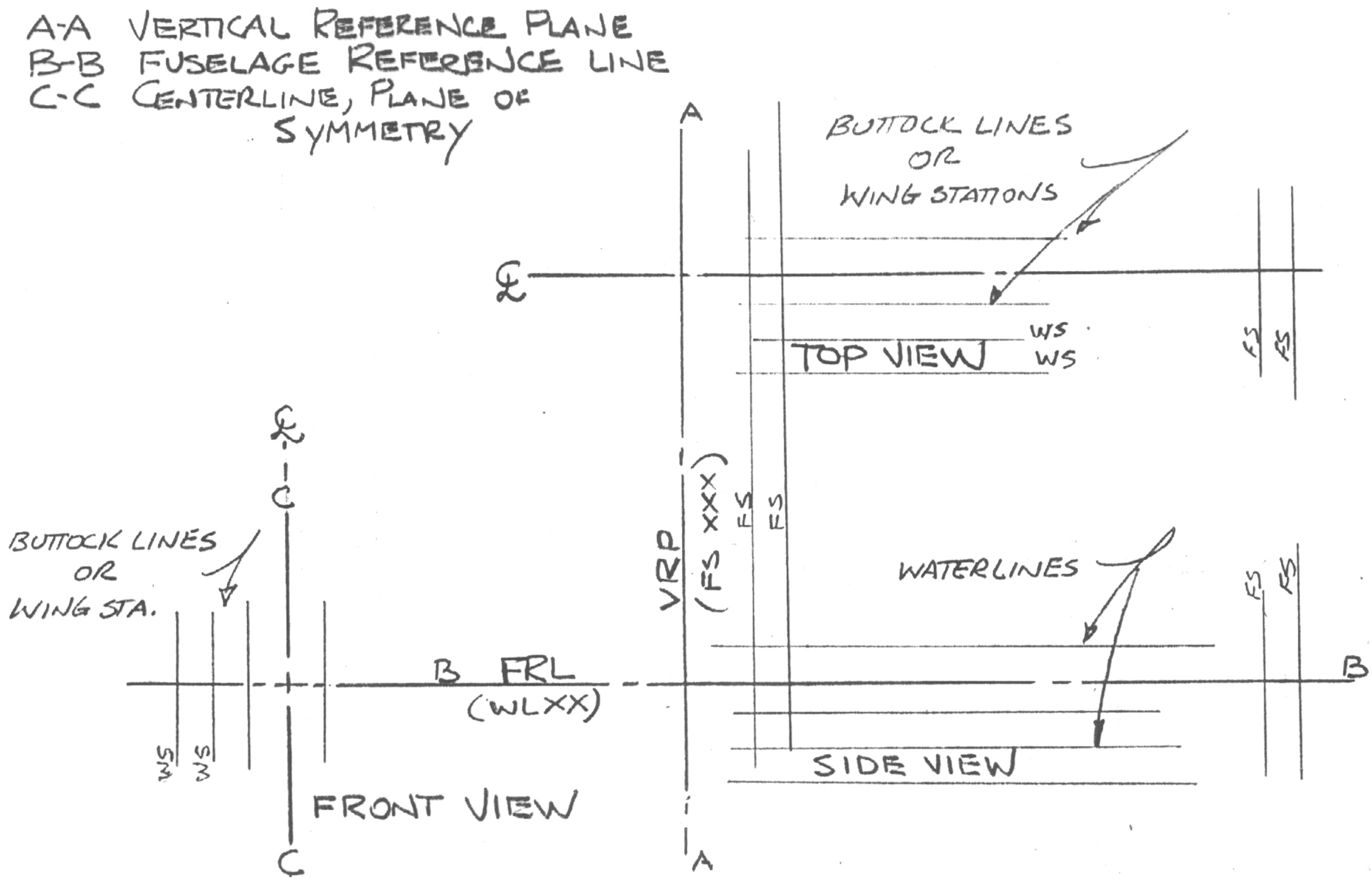


First: the Wetted Area – be able to calculate!
From a paper by Phillip van Seeters, AIAA 2009-6998

Note: done because there was an AIAA paper that said Raymer's value was wrong



Airplane Layout - Reference lines



FS: fuselage station

drawn by Nathan Kirschbaum

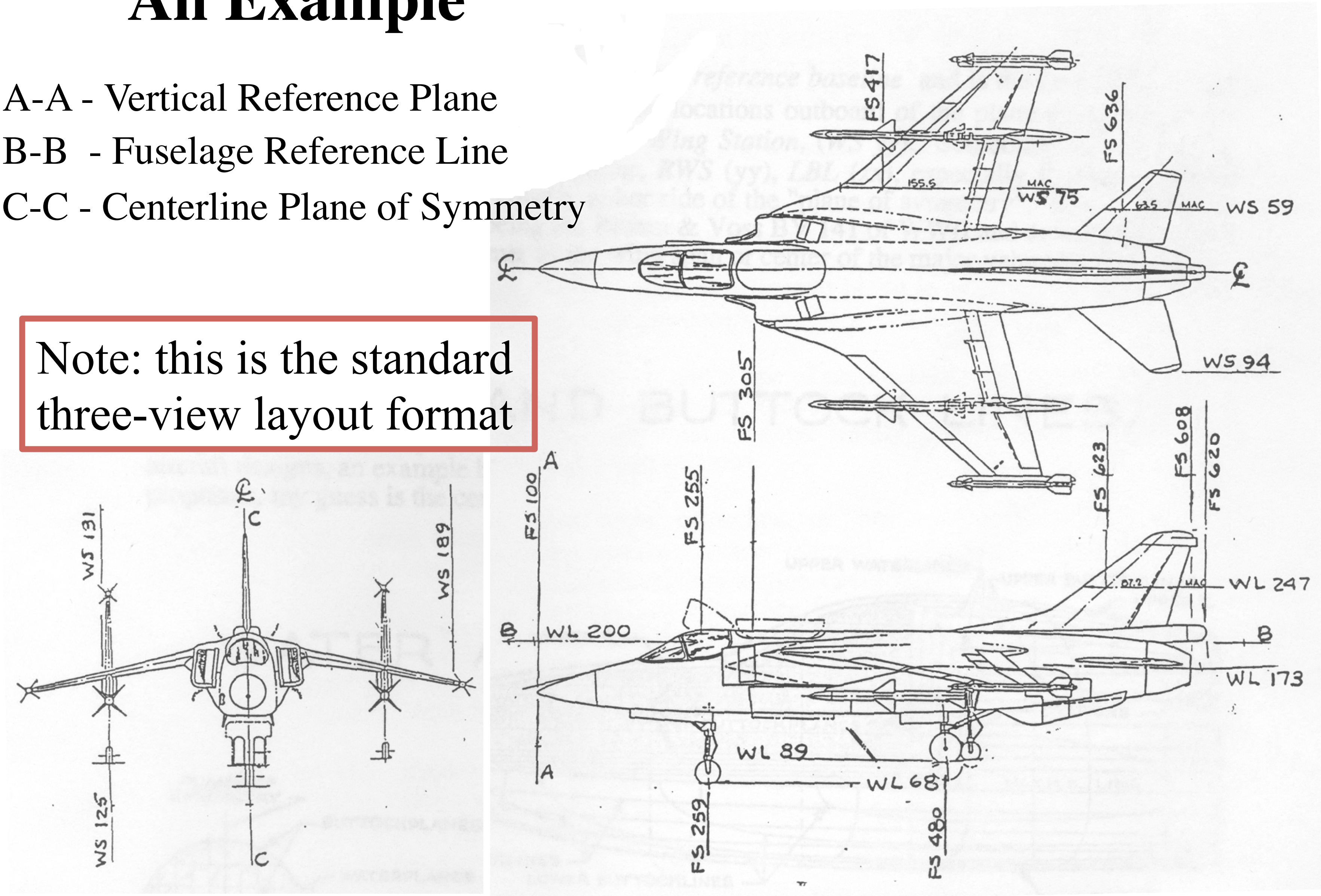
An Example

A-A - Vertical Reference Plane

B-B - Fuselage Reference Line

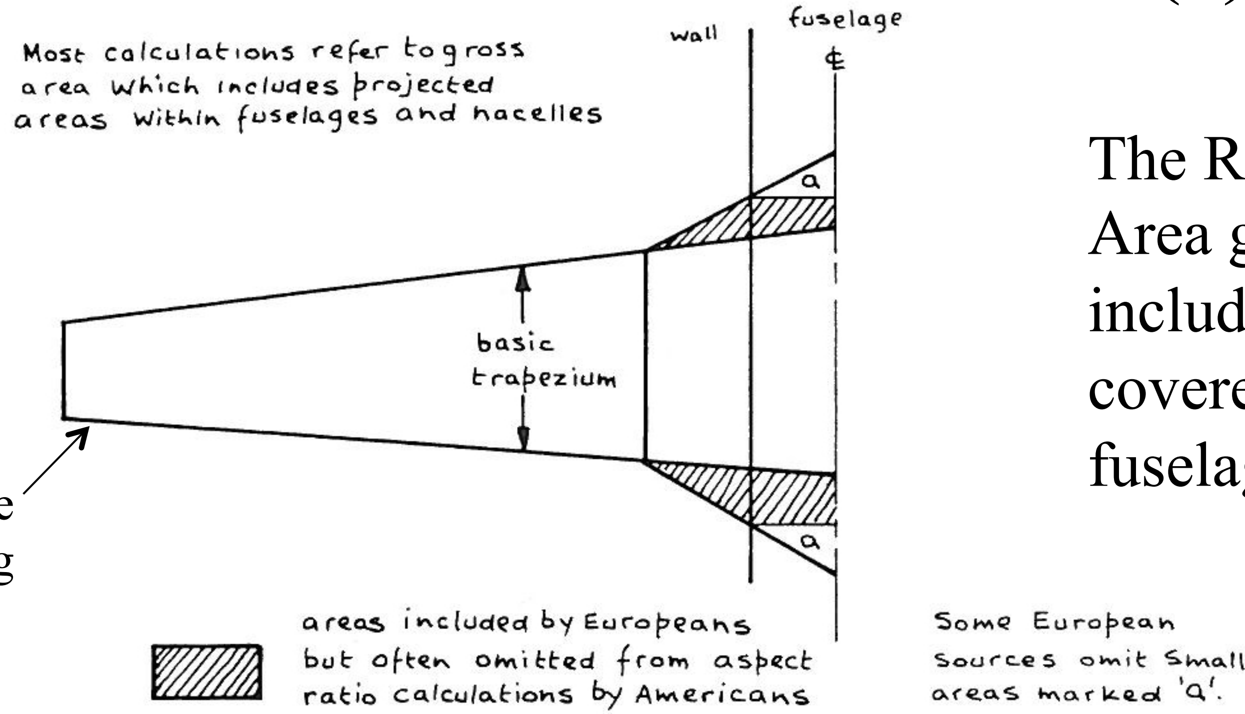
C-C - Centerline Plane of Symmetry

Note: this is the standard three-view layout format



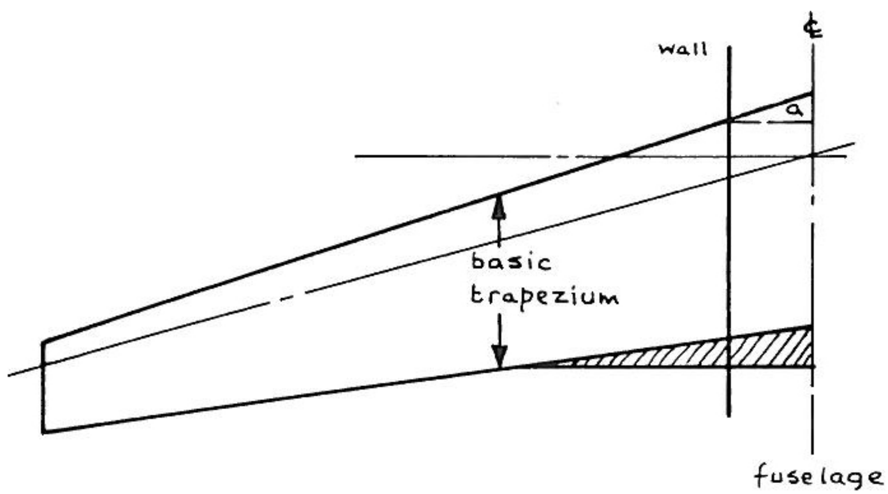
drawn by Nathan Kirschbaum

Comment: Reference Area(s)



The reference trap wing

The Reference Area generally includes the area covered by the fuselage



The main takeaway, Define the reference area for others!

Source: Stinton, (1927 – 2012), *Design of the Airplane*

Did you ponder the B-757 in Roanoke?

NASA CR 4746

M cruise = 0.8

Sweep = 25°

AR = 7.8

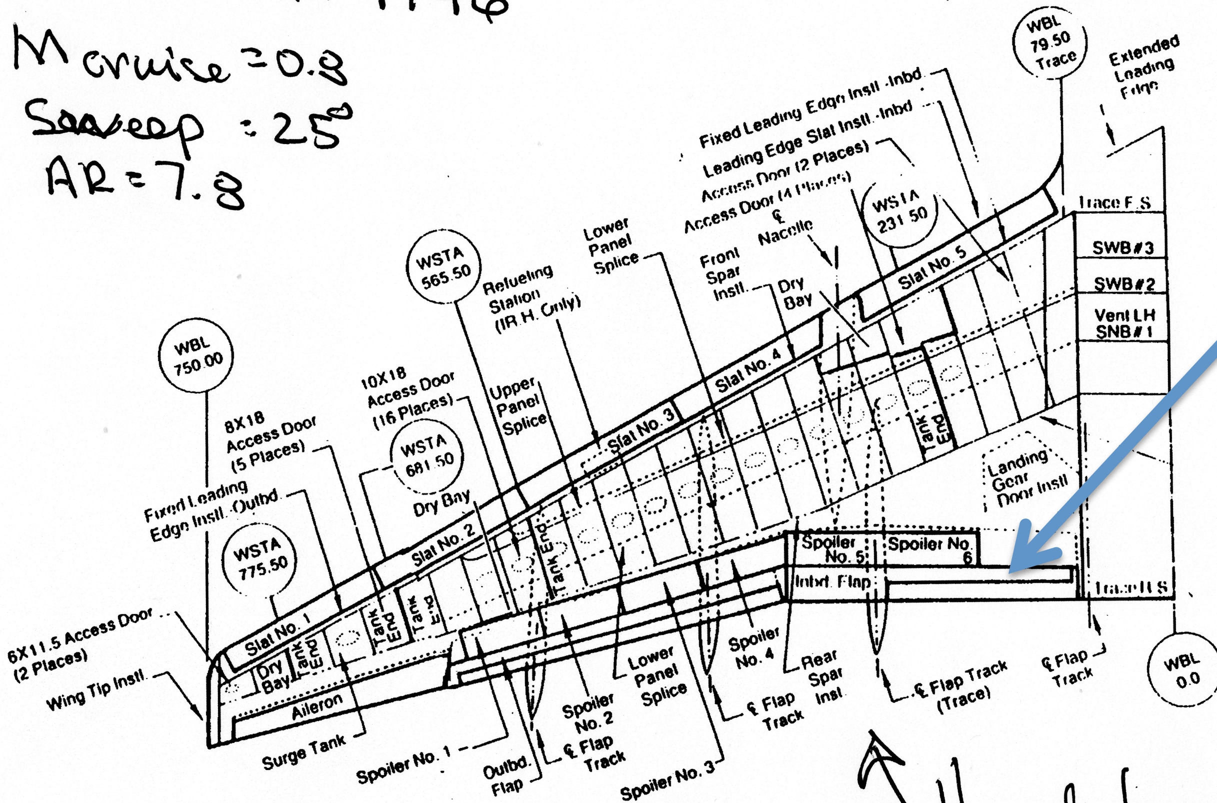


Figure 2.10. Boeing 757-200 wing.

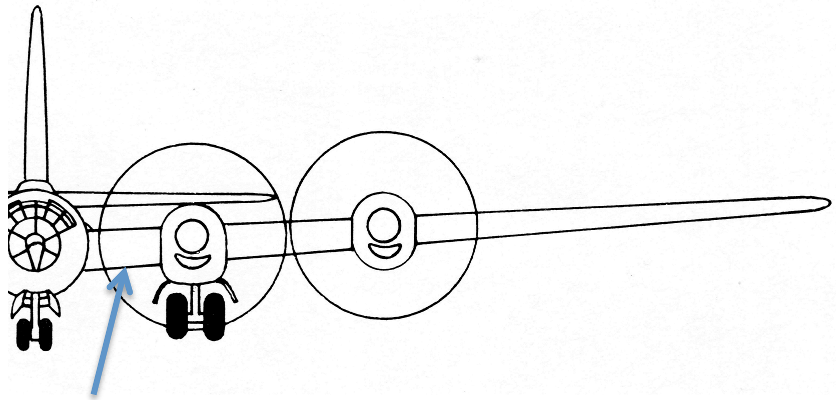
The Yehudi

Hard to see this TE break walking around the Alerc

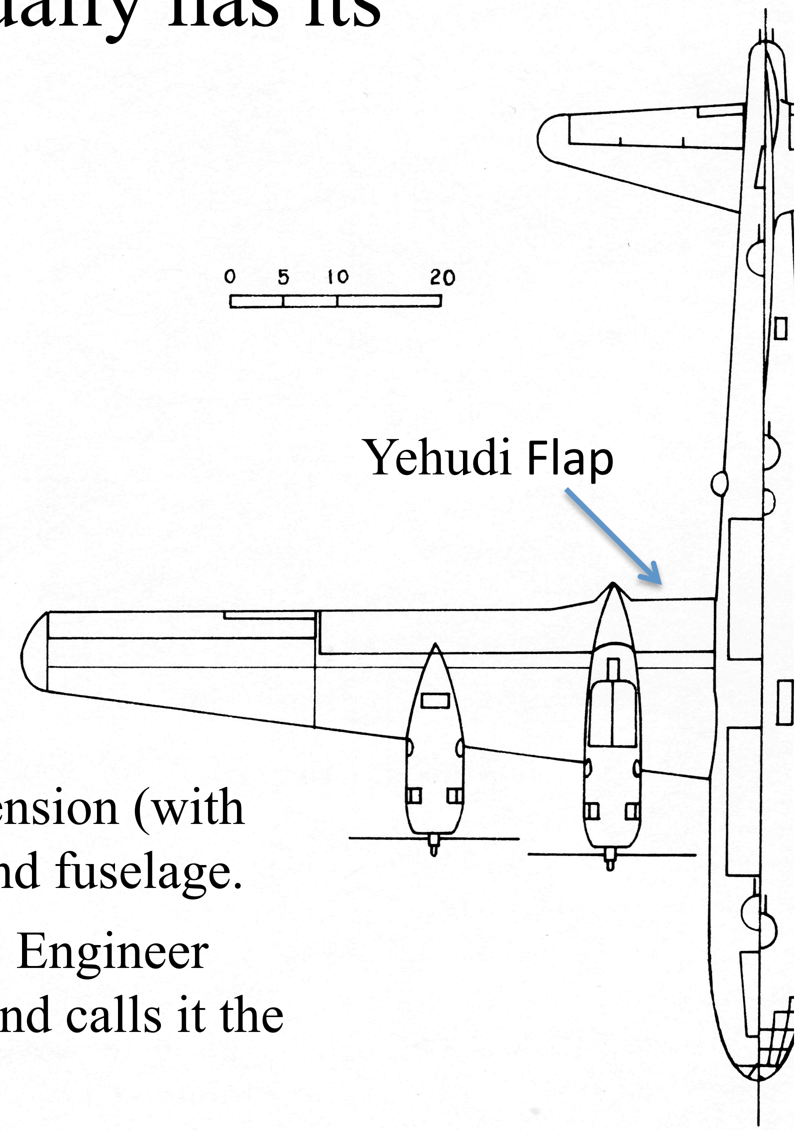
No Krueger

No Inbd Aileron

The “Yehudi Flap” story actually has its origin with the B-29:



Channel accelerates
Lower surface flow

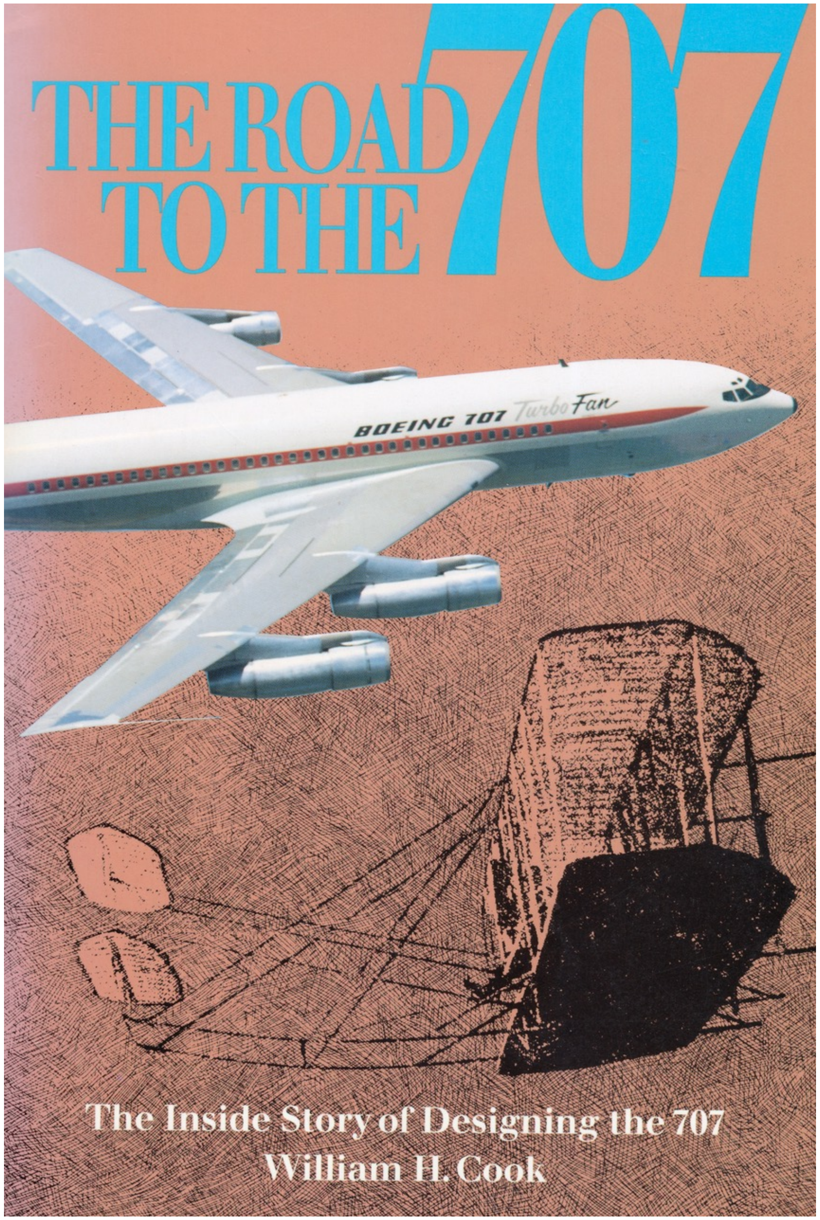


1. To get lower surface lift back, add chord extension (with slight camber) between the inboard nacelle and fuselage.
2. Have to give a name to each new model part: Engineer thinks of “Where’s Yehudi” on radio show, and calls it the “Yehudi Flap”.

William H. Cook, *The Road to the 707*, 1991, and letter from 1994.

3 Vu: Lloyd Jones *U.S. Bombers*

Letter from Bill Cook, March 16, 1994:

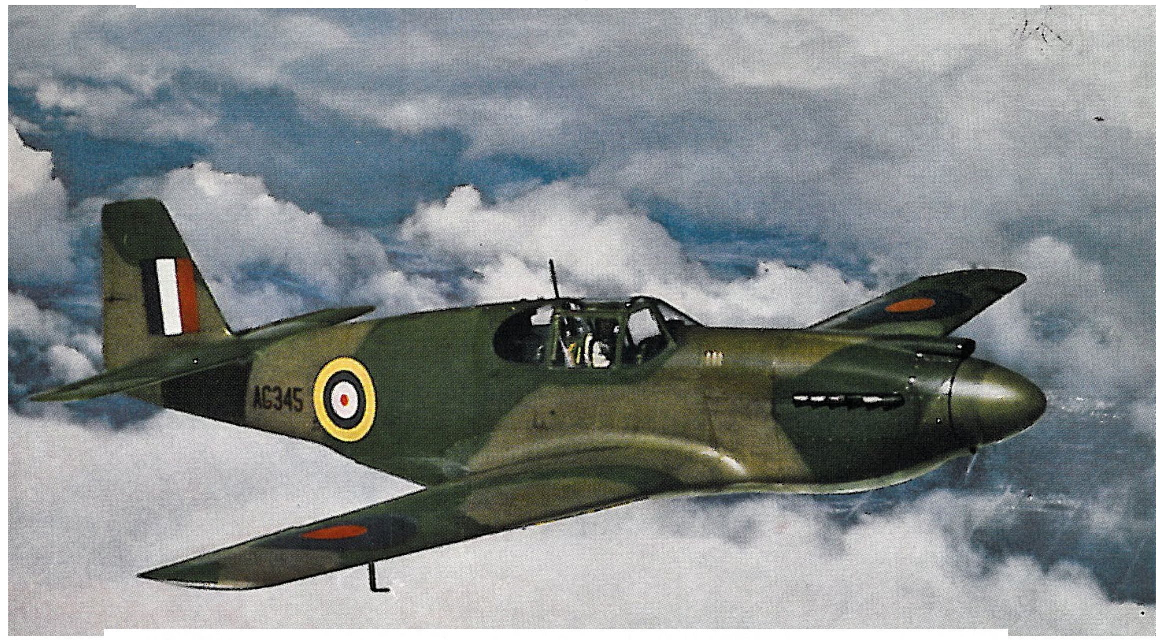


" It is too bad that all such experiences can not be related to engineering students, to show that ***thinking***, as contrasted to computer outputs, are very worthwhile"

Classic Aircraft Lofting

- Roots in ship hull development (in the lofts)
- Liming often said to have produced the first analytic description of an airplane
- Based on conic sections
- Farin: Close connection between conics and NURBS
- Raymer discusses lofting

PRACTICAL ANALYTIC GEOMETRY WITH APPLICATIONS TO AIRCRAFT



ROY A. LIMING

Head of Engineering Loft Mathematics
North American Aviation, Inc.

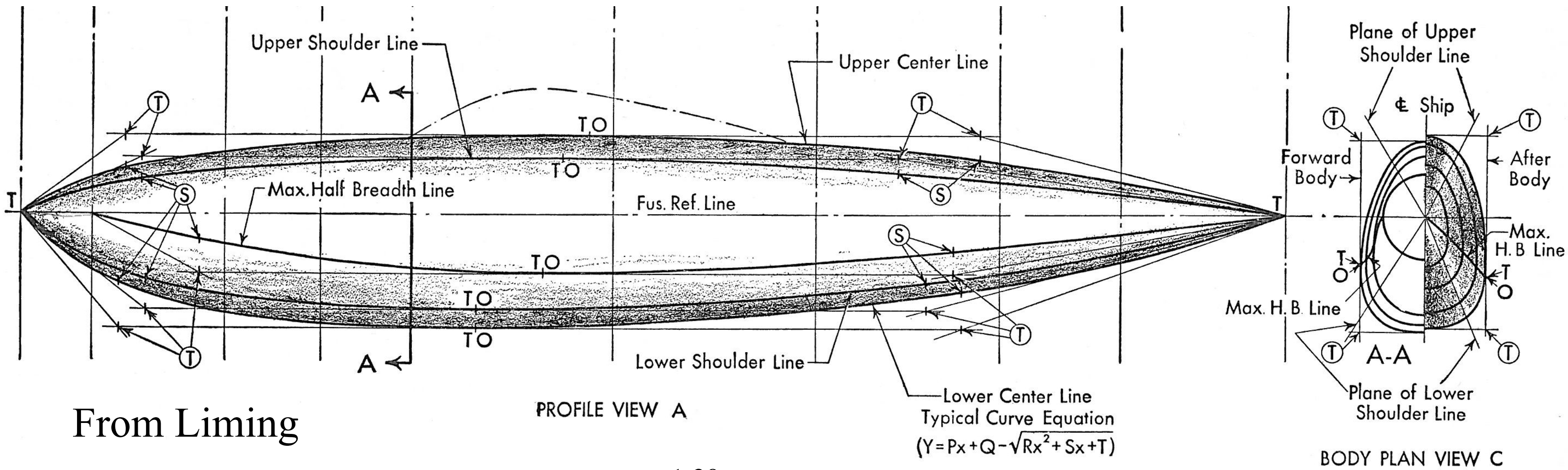
Special Lecturer in Engineering Mathematics
University of Southern California

THE MACMILLAN COMPANY · NEW YORK

1944

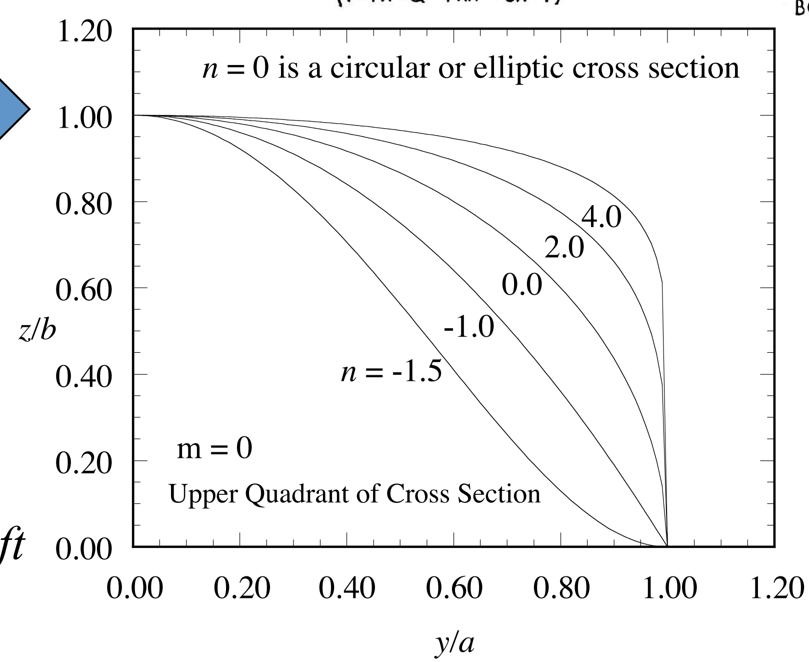
Traditional Fuselage Construction

Longitudinal lines: upper/lower centerline, max half-breadth line, etc.



From Liming

Example – one quadrant of fuselage

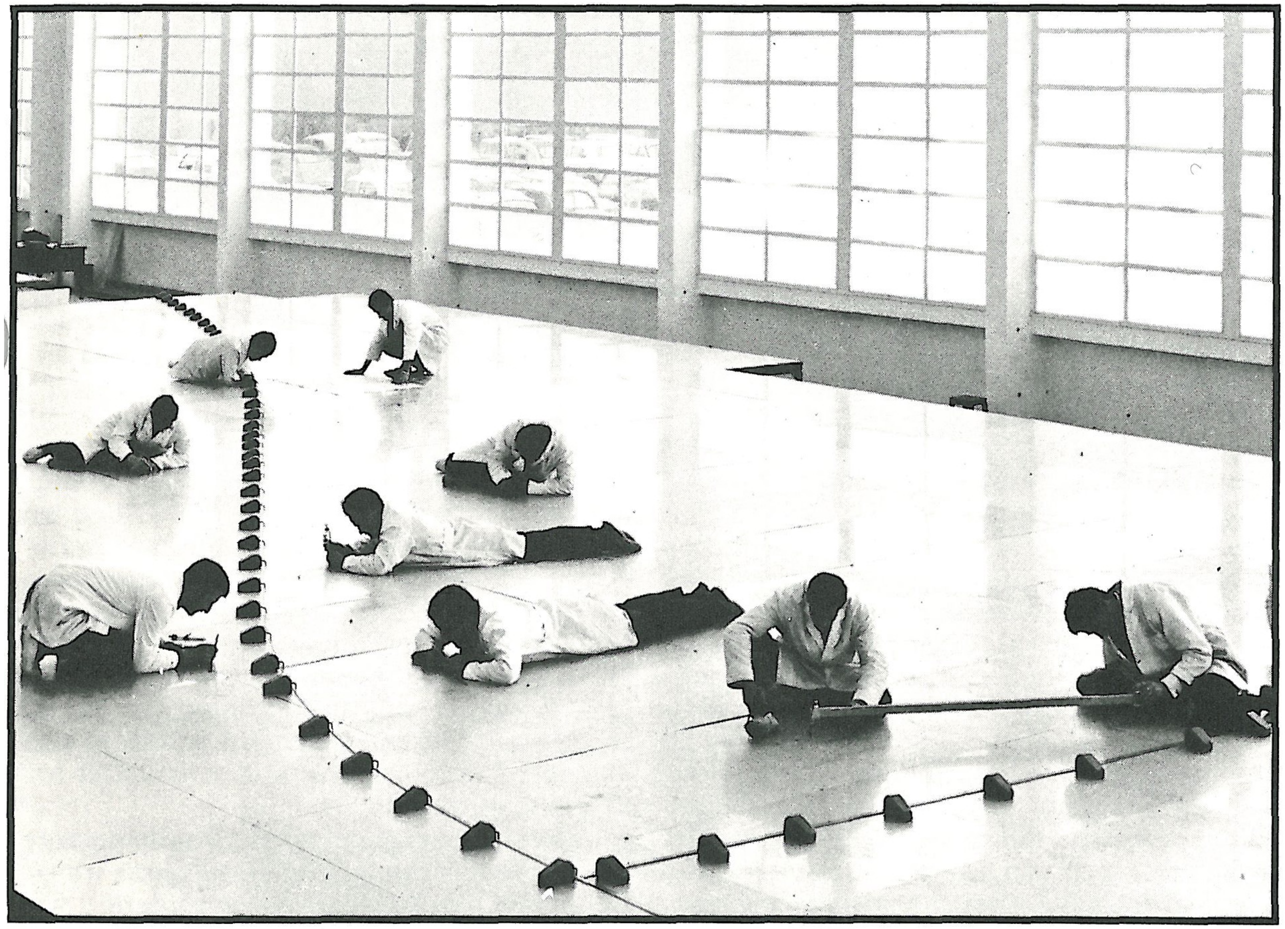


Use whatever you want for a cross-section, super-ellipses are good choices for a wide range of shapes from rectangles to chines.

NASA CR 4465, or *Journal of Aircraft* May-June 1994, pp. 480-487

See App A for the equation of a super ellipse

Lofting and Ducks!



Brits laying out the Concorde Wing!

From *Concorde*, by K.G. Clark and Arthur Gibson, Paradise Press

Example of CAD System Experience

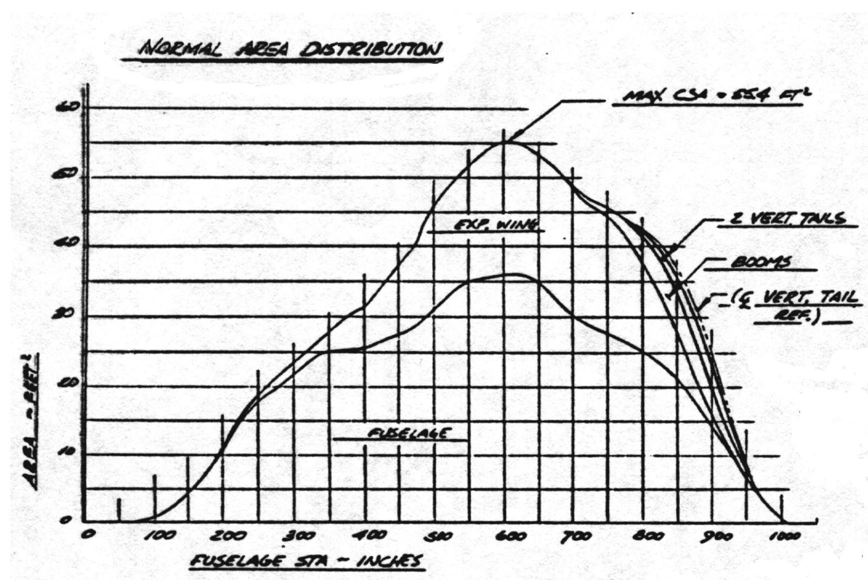
Grumman/NASA RFC NTF WT Model

CATIA was used. It was way, way too complicated to use in aerodynamic design work.

The number of patches, and fillets used for the contours was complicated and I was charged hundreds of man-hours.

Aerodynamic Design Requires Knowing Geometry

- See App. A: Geometry for Aerodynamics
  - Many classic shapes have analytic definitions
  - Includes airfoils
  - And classic bodies of revolution
  - You will need the area diagram, and wetted area



Parametric Geometry for Conceptual Design

Because of the ***huge mismatch*** between normal CAD and the needs of the aerodynamic designer, many systems have been and are still being developed:

- **QUICK** – for the Grumman Space Shuttle proposal, widely used, apparently even today – Al Vachris contributed (Larry Yeager took it to Hollywood), eventually morphed into **Leonardo**.
- Ray Barger's NASA TPs, a wealth of of aero-oriented analytic geometry modeling/lofting methods for the supersonic airplanes
- **VSP**: Vehicle Sketch Pad, **the *current* NASA conceptual design tool**
  - it came from **RAM,** continuing to be developed
- AVID's **PAGE** (parametric aircraft geometry engine)
- Desktop Aero's **RAGE** (rapid geometry engine, AIAA 2006-0929)
- Brenda Kulfan's **CST** (class shape function transformation, *JA* 2008)
  - Craig Morris at VT has coded this up already.
- etc. (I have a large folder, Kyle Anderson: Geometry for MDO, 2009)

Need to be able to connect aero thinking to geometry, a missing link in many CAD systems – the number of efforts illustrates the frustration and needs.

A growing number of sessions at AIAA Meetings on Geometry for Design

Example from RAGE

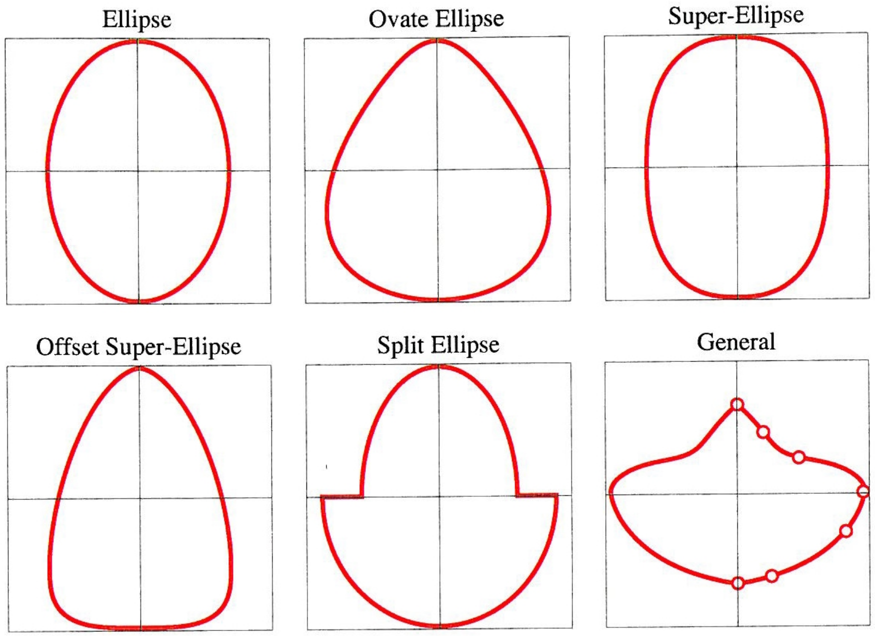
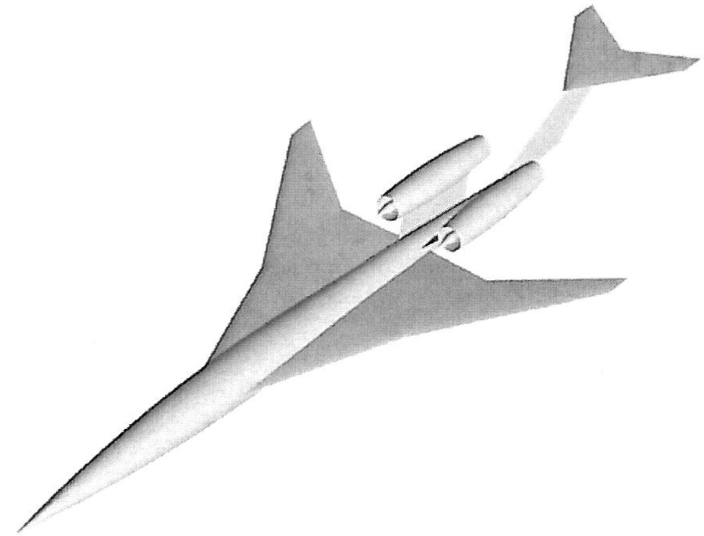


Figure 1. Example cross sections generated by RAGE.



(d) supersonic business jet

AIAA 2006-929

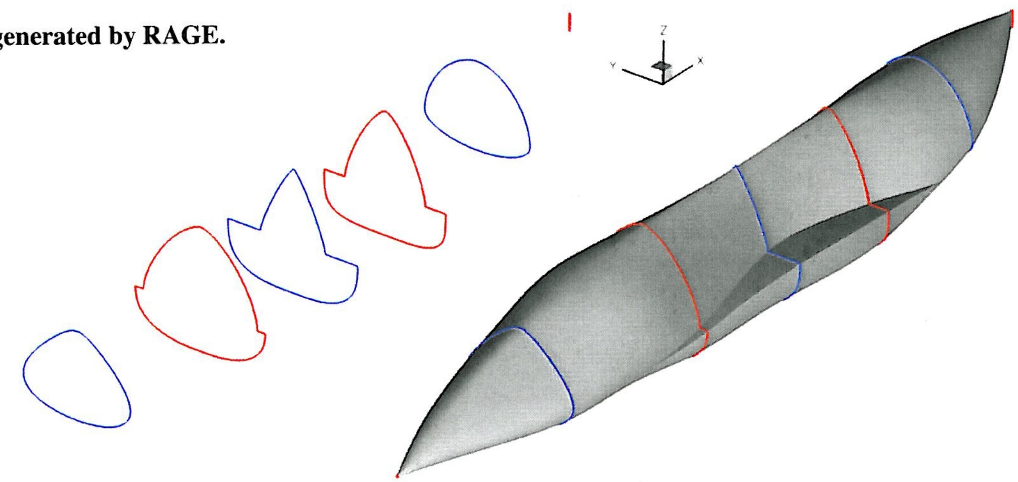
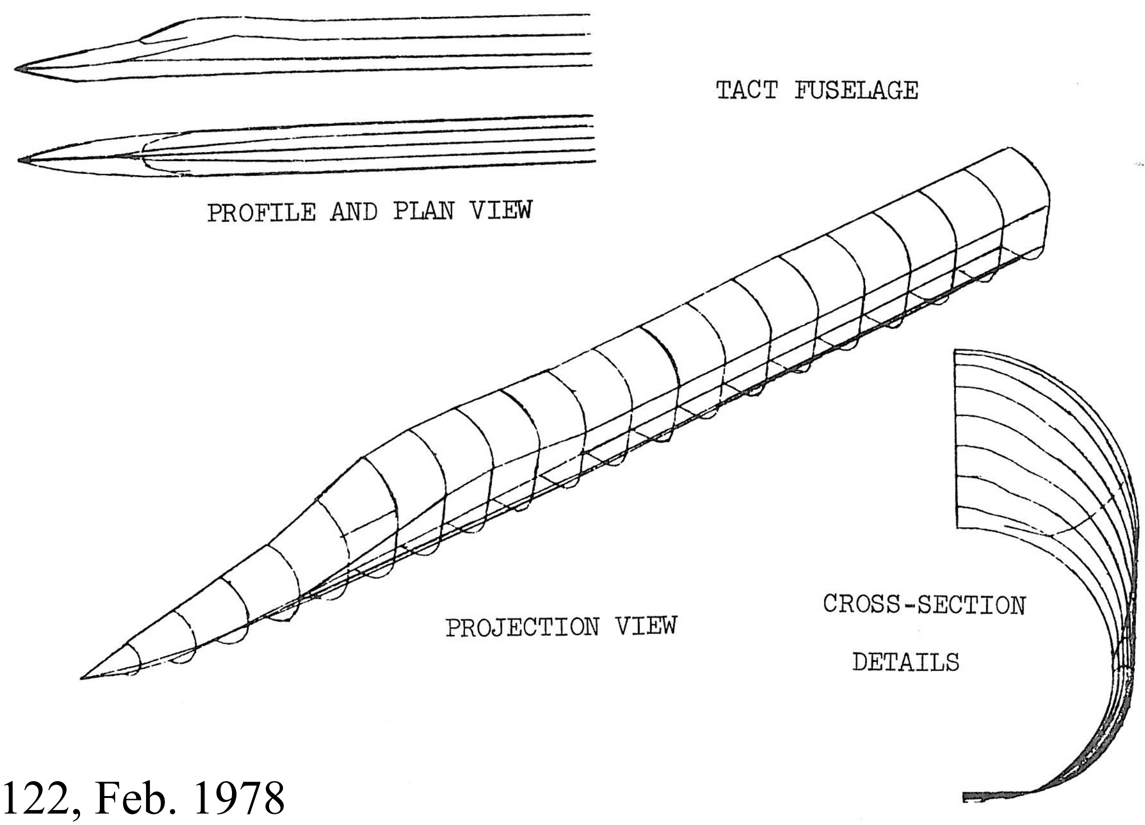


Figure 2. Example smooth fuselage surface generated from a stack of rather different cross section shapes. Note the axially smooth discontinuity boundary created by the split sections where the wing (not shown) intersects.

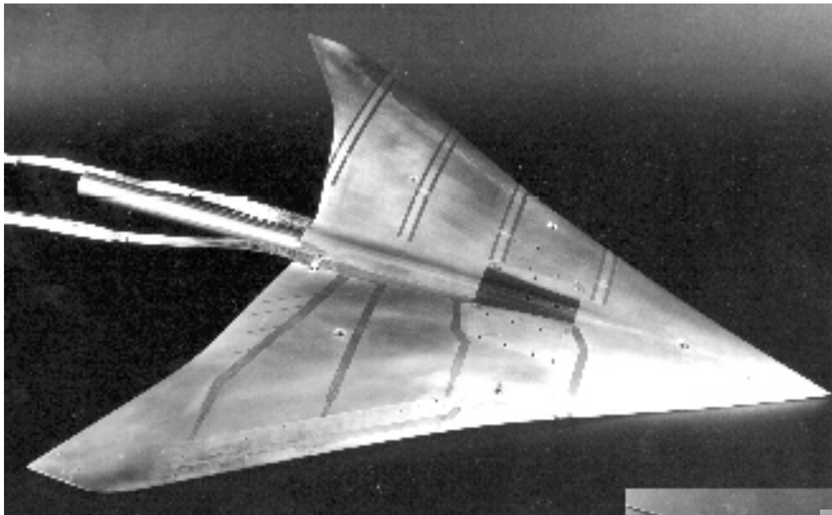
Example of QUICK-Based Geometry delivered to AFFDL in 1977

F-111 TACT Aircraft Fuselage



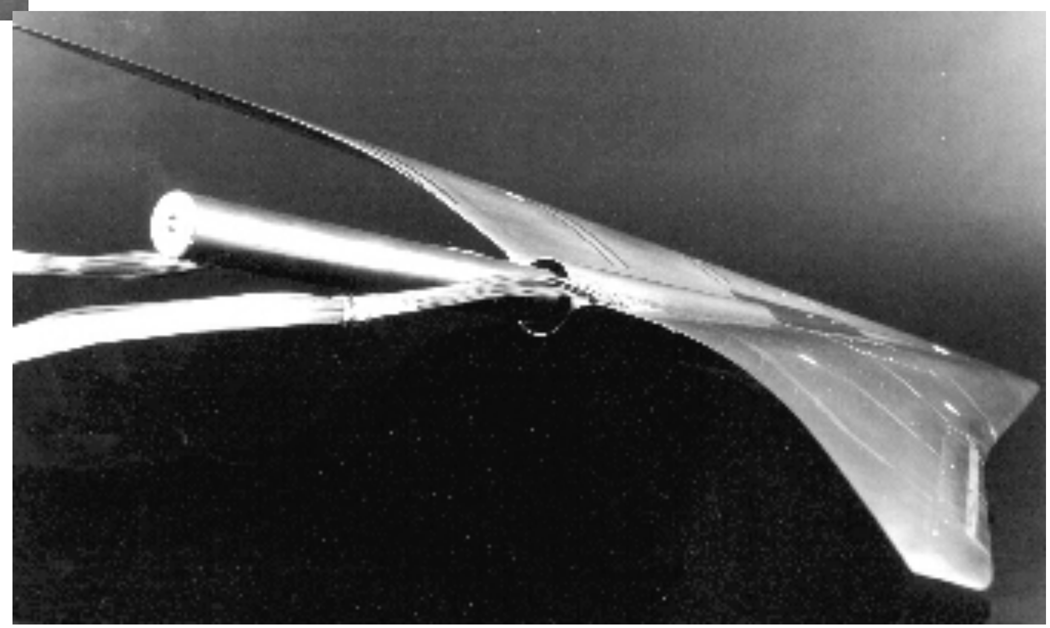
AFFDL-TR-77-122, Feb. 1978

NASA/Grumman SC^3 Wing Concept



Supercritical Conical Camber, SC^3

An analytically defined wing with a small number of design parameters. Perfectly suited for computational design

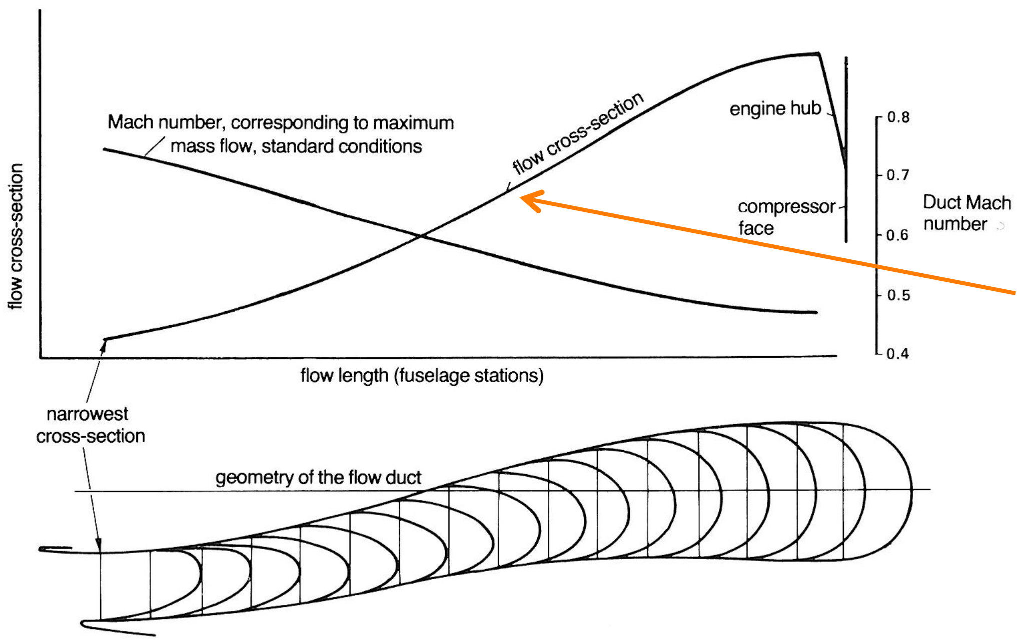


NASA CR 3763/AIAA 83-1858

This wing would have gone on the NASA/Grumman Research Fighter Configuration. It set a record at NASA LaRC for low drag at high lift supersonic performance.

Loft the inside too: inlets!

Internal volume for intake cross-sectional area distribution has to be provided: smoothly varying (and monotonic)



7-35 **Geometry of the F-16 duct.**
The gradual increase in cross-section makes an almost linear Mach-number drop possible between throat and compressor face.

Smooth cross-sectional area distribution required

YF-16 Inlet, Originally appeared in AIAA Paper 74-1062, this is a figure from Huenecke, *Modern Combat Aircraft Design*, Naval Institute Press, 1984

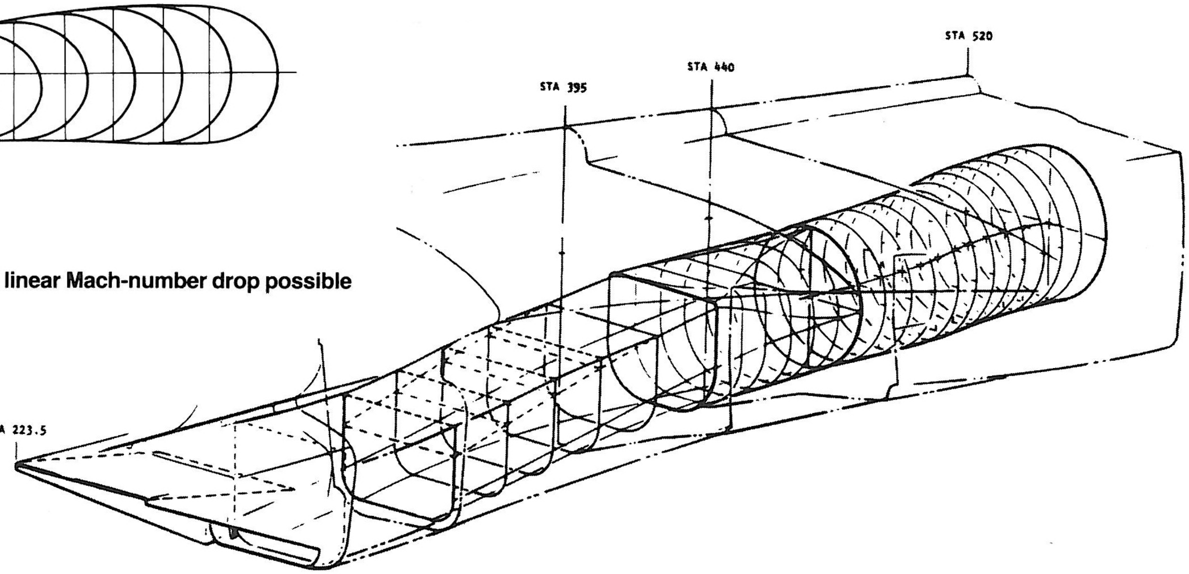


Fig. 10.12 Typical fighter inlet diffuser.

From Raymer, *Aircraft Design*, AIAA, 2006

The Transonic Strut Braced Wing
- slightly connected to the sensorcraft complexity -

Example from VSP, NASA's Vehicle Sketch Pad

See AIAA Papers 2005-4667, 2009-7114

Today, NURBS Often Used

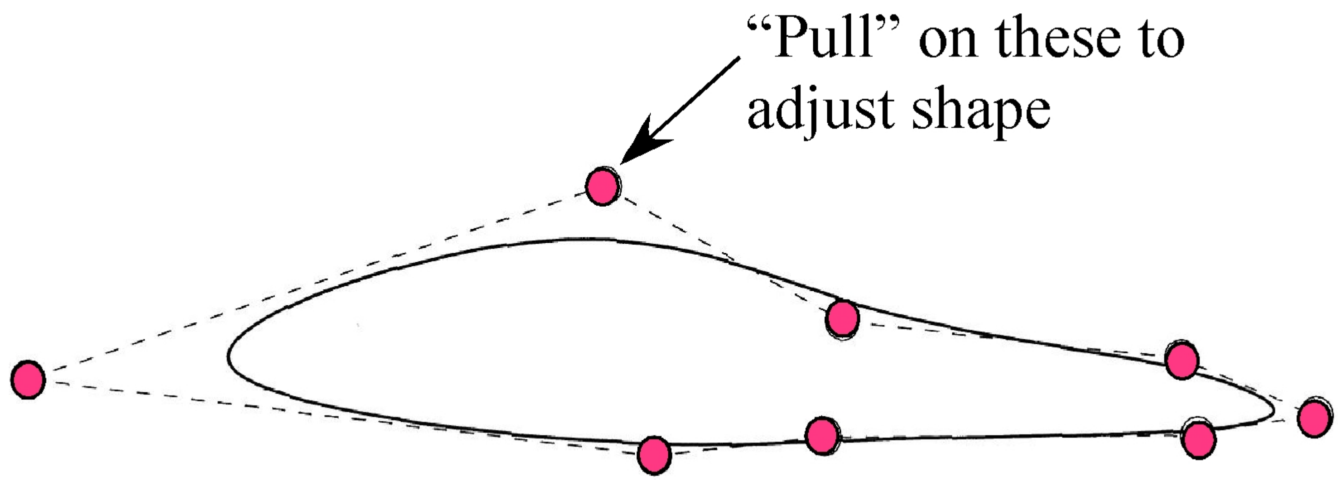


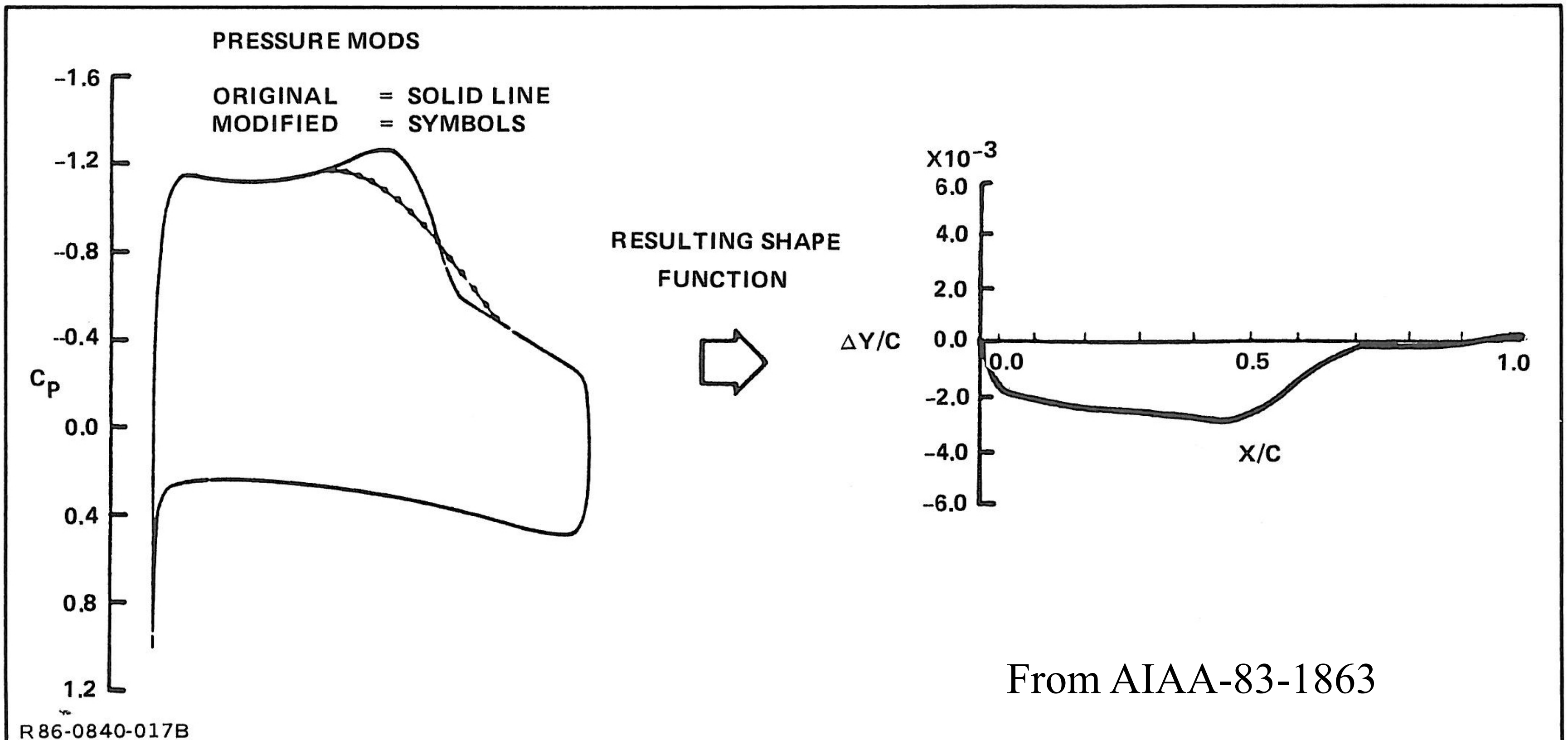
Figure 2.5 Airfoil defined by NURBS curves using control points.

From Keane and Nair,
Computational Approaches for Aerospace Design, Wiley, 2005

It's hard to relate to usual aero thinking in this approach.
3-D surfaces using this approach are even more obscure

Physics-based shapes: Transonic Airfoil Design

- Transonic airfoils generally defined by computational methods, and are not readily described by simple analytic curves
- ***Surface curvature distribution is critical***
- Pressures can be modified by physically meaningful aerodynamic shape functions, a random "bump" is a last resort
- Example: the Grumman E airfoil modified to remove the shock



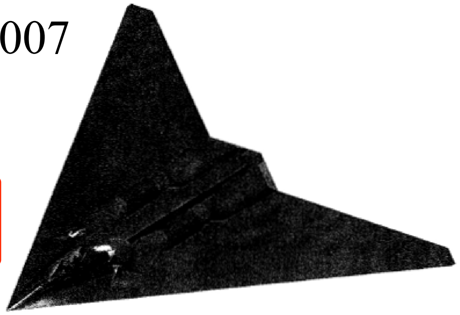
From AIAA-83-1863

Challenges for Aerodynamicists

Northrop Grumman notional concept that Brady White was allowed to show in his MS Thesis

From something that I was shown in the last week:
"The definition of the external aerodynamic shape (i.e., geometry) of the airframe lies at the heart of the aircraft design process"

All moving tip control
Brady White, MS 2007
(Techsburg)



None of these concepts are *airfoil* based, also minimal fuselages

Phil Beran Charts

Bottom line: Aero Design means manipulating geometry

- Beware of attempting to develop a single monolithic scheme, the TBW and the Concorde are very different geometric concepts: *flexibility* is crucial.
- Use a small number of parameters
- Don't ignore the existing body of work and knowledge – build on it.
- Aerodynamic designers need to think in terms of physically-based vehicle characteristics: airfoil thickness envelopes, camber, wing twist, straight hinge lines, manufacturing issues (ruled or straightline wrap surfaces), etc.

Switchblade Assessment,
Ryan Plumley, MS 2008

Asymmetric configurations are more common then you think, anticipate needing this capability.

Note: formulas and discussion of classic aerodynamic airfoils and bodies are available.
See Appendix A, a pdf file, on my Configuration Aerodynamics Web Page:
http://www.aoe.vt.edu/~mason/Mason_f/ConfigAero.html