Geometry Challenges for Aero Design
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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

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

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

Example of CAD System Experience

Grumman/NASA RFC NTF WT Model

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

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

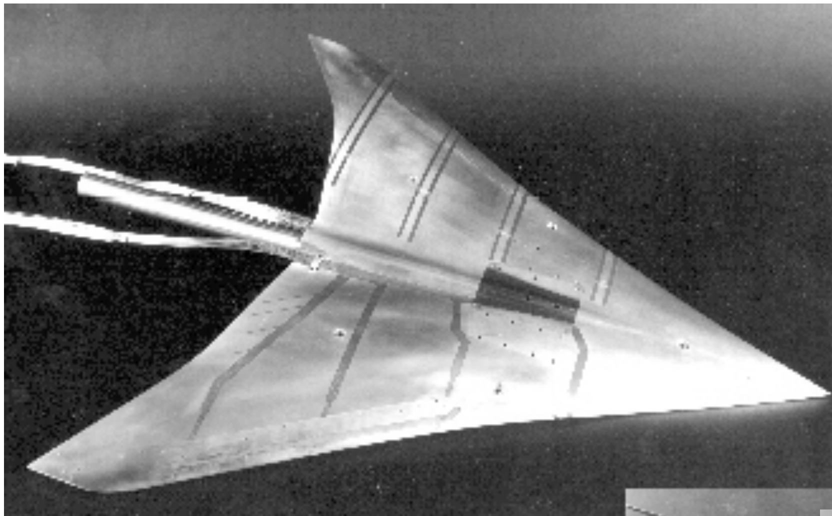
Geometry for Conceptual Design

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

- **QUICK** – for the Grumman Space Shuttle proposal, widely used, apparently even today (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 transport type aircraft
- **VSP**: Vehicle Sketch Pad, a *current* NASA conceptual design tool (we have it, 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) A student coded this up recently.
- 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.

NASA/Grumman SC^3 Wing Concept

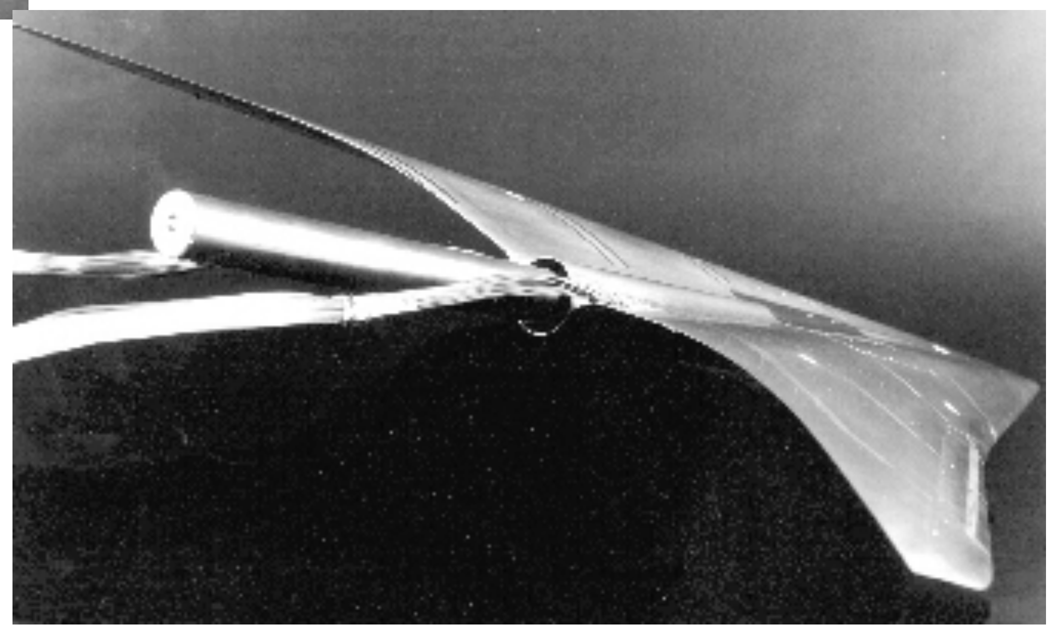


Supercritical Conical Camber, SC^3

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

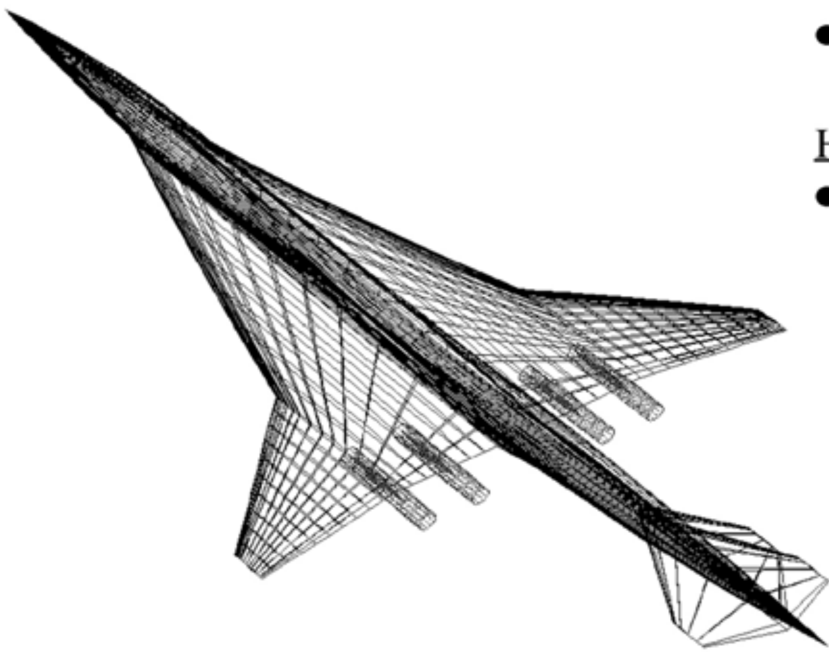
NASA CR 3763/AIAA 83-1858

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.



Need a “reasonable” number of geometric parameters

HSCT Optimization Problem



Design Requirements

- $Mach_{cruise} = 2.4$, 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

Optimization Problem

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

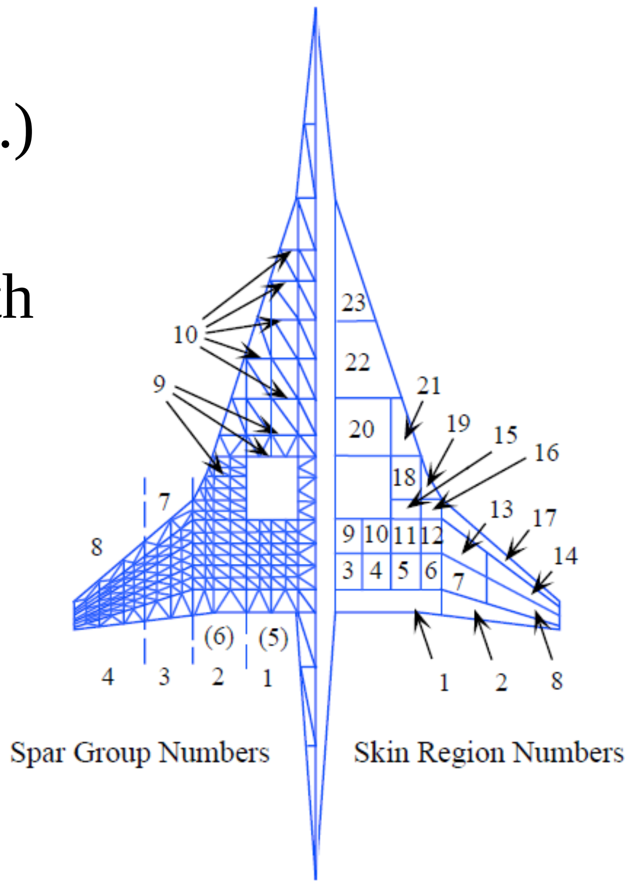
Journal of Aircraft, Vol. 39, No. 2, March-April 2002, pp. 215-220, among many others

The outside has to be bigger than the inside

- actually the title of a Dan Raymer paper -

- The finite element model has to respond to the external contour
- Fuel volume has to be found (leaving room for landing gear, *etc*.)
- For buried engines: inlets, nozzles and the required flow paths (smooth area distribution) are needed
- Payload and systems volumes.
- Room for *cg* management

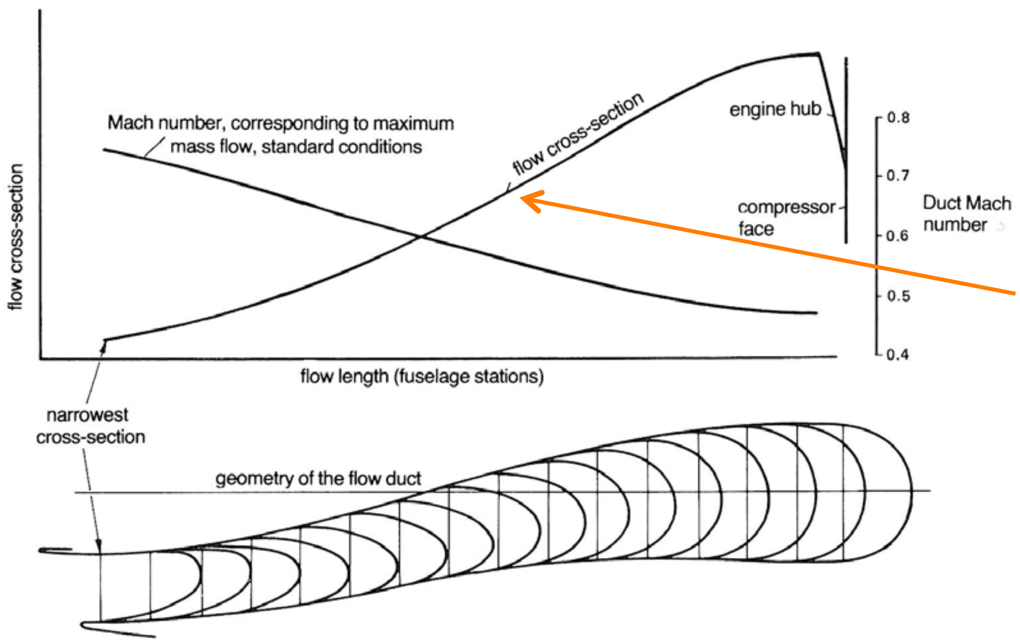
Fine HSCT FE Model



FEM from Vladimir Balabanov’s Dissertation, August 1997

Embedded engines require inlets!

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



Smooth cross-sectional area distribution required

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.

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

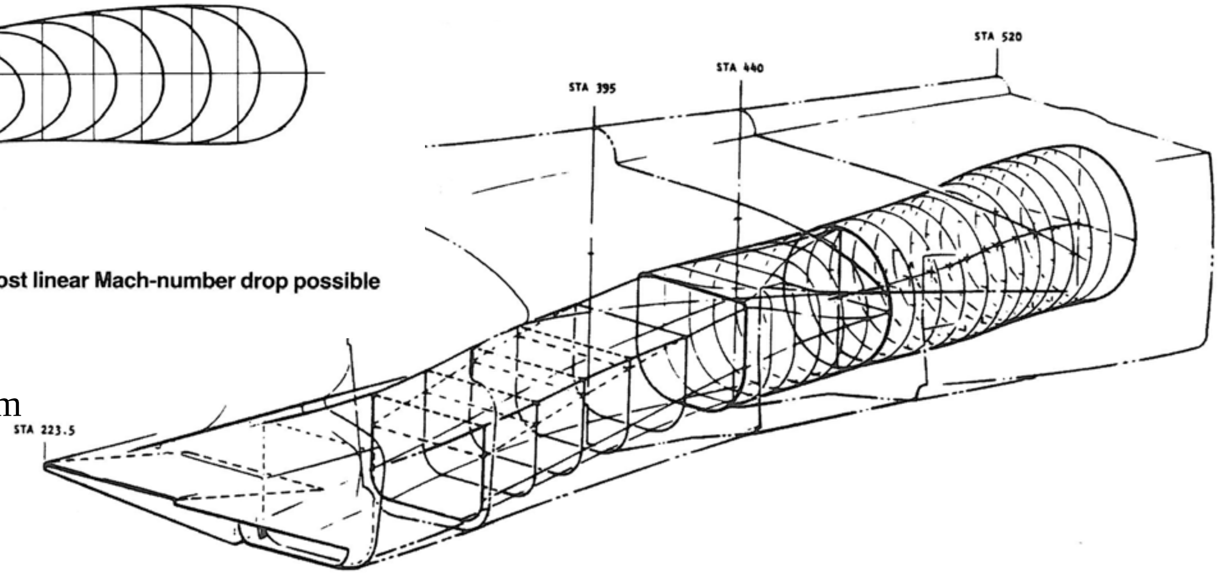
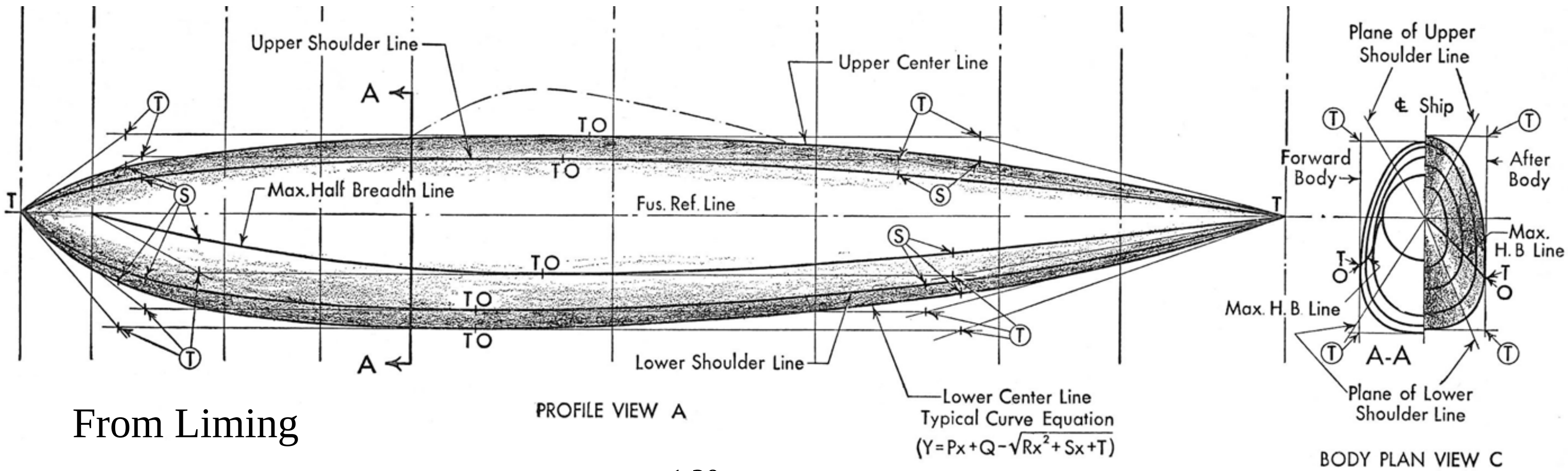


Fig. 10.12 Typical fighter inlet diffuser.

From Raymer, *Aircraft Design*, AIAA, 2006

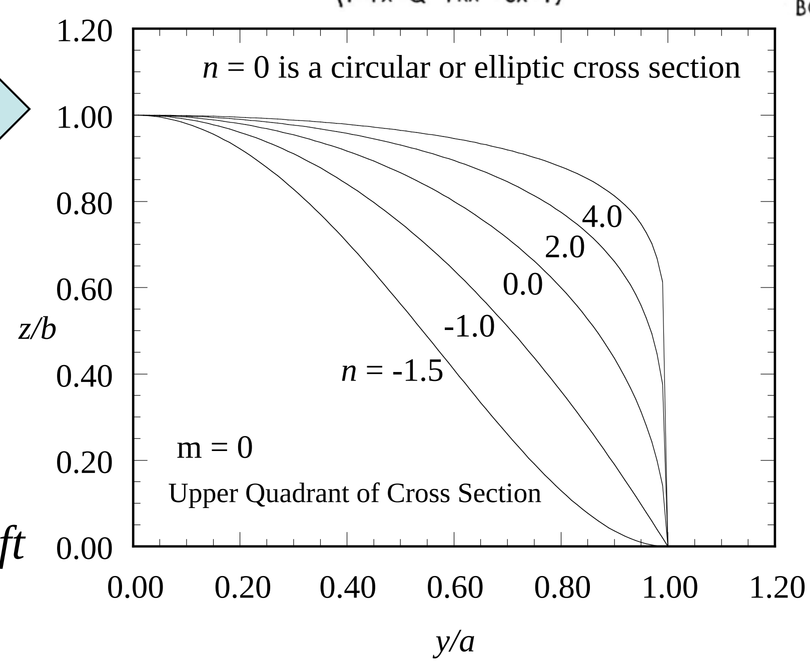
Traditional Fuselage Construction

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

Example from RAGE

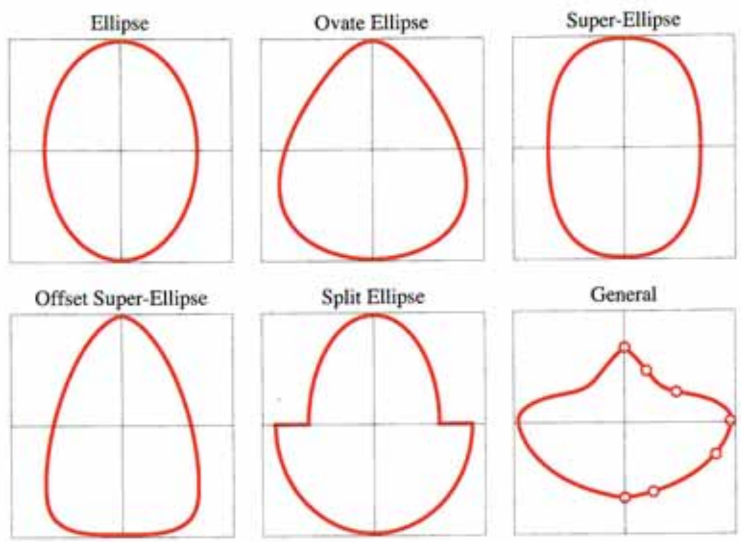
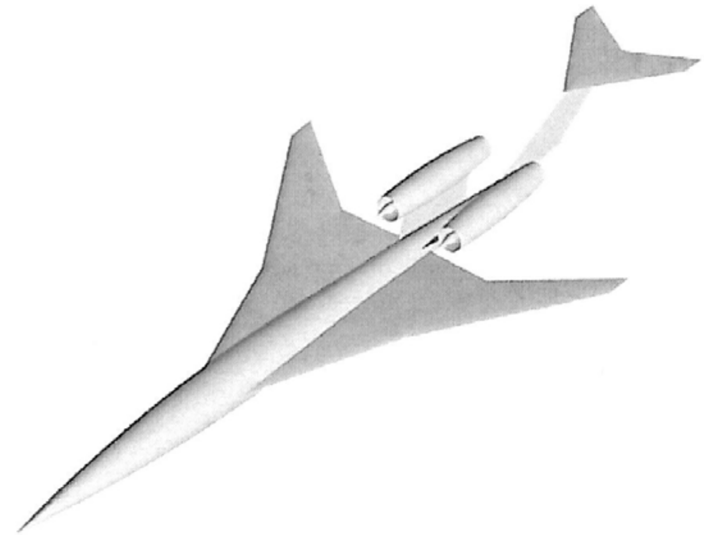


Figure 1. Example cross sections generated by RAGE.



(d) supersonic business jet

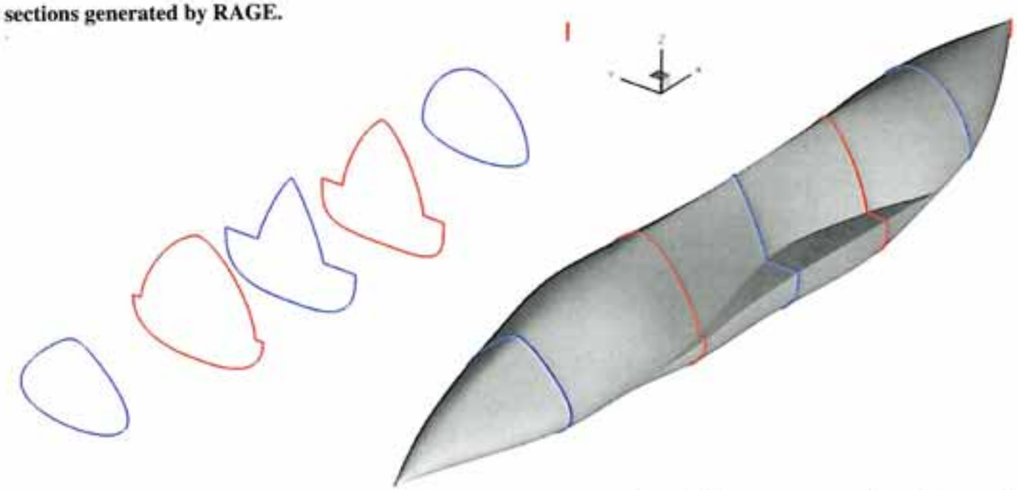
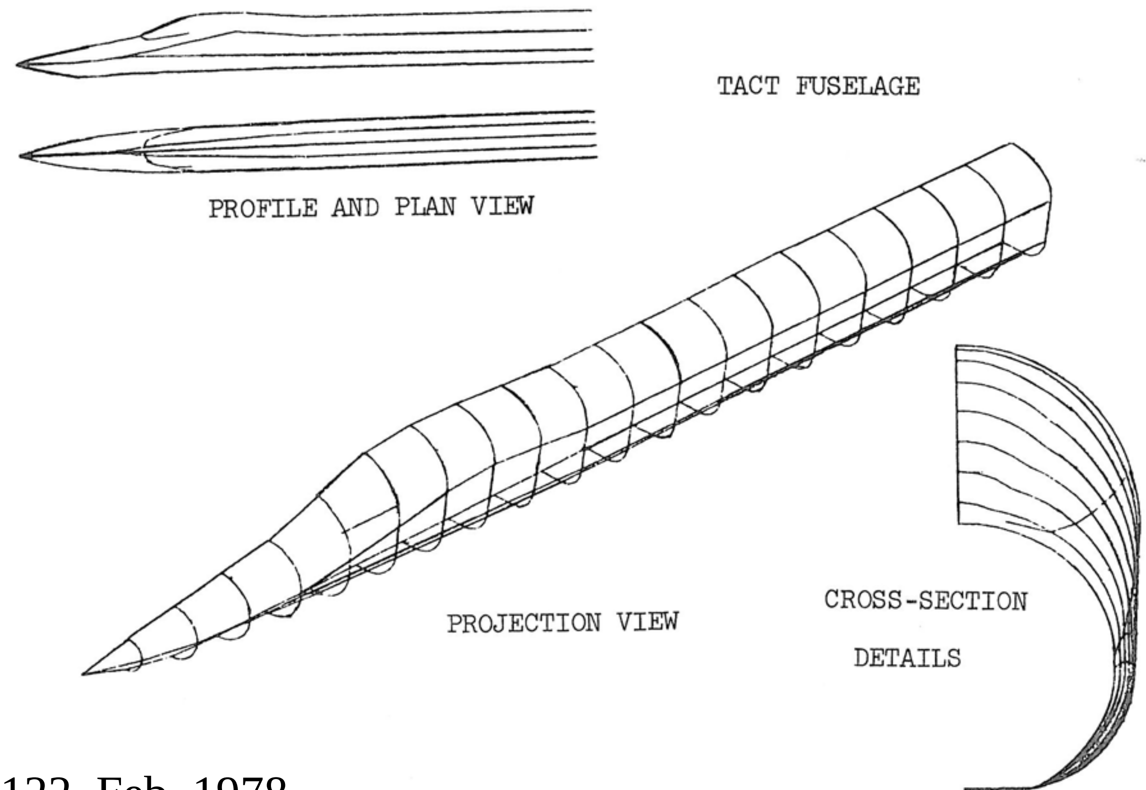


Figure 2. Example smooth fuselage surface generated from a stack of rather different cross section shapes. Note the axially smooth discontinuity boundary created by the split sections where the wing (not shown) intersects.

Example of QUICK-Based Geometry delivered to AFFDL in 1977

F-111 TACT Aircraft Fuselage



AFFDL-TR-77-122, Feb. 1978

LRS is a *spanwise* geometry concept

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

Where's the Physics in NURBS?

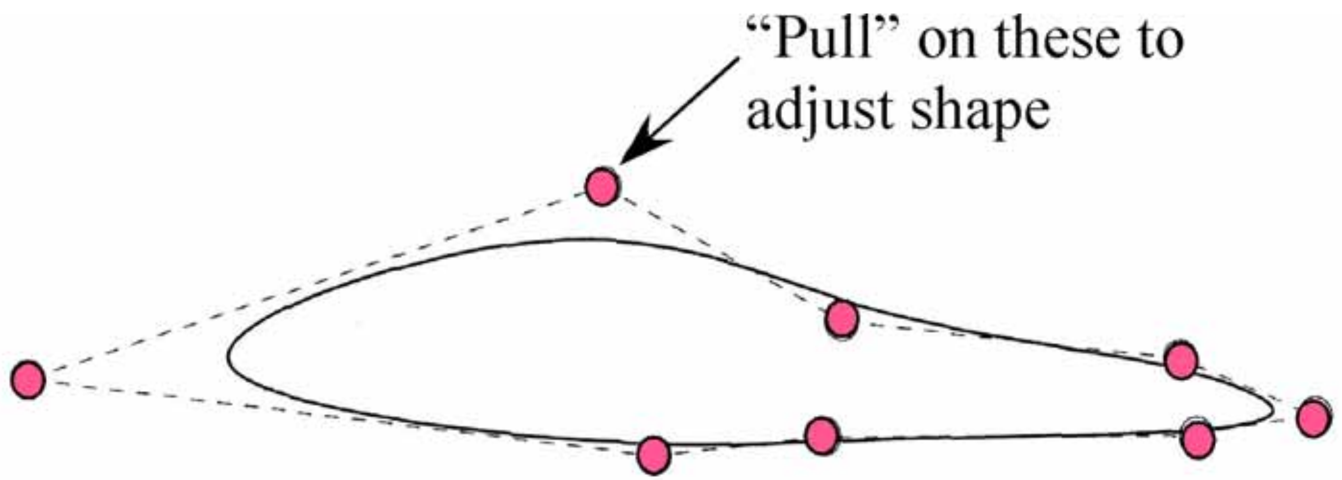


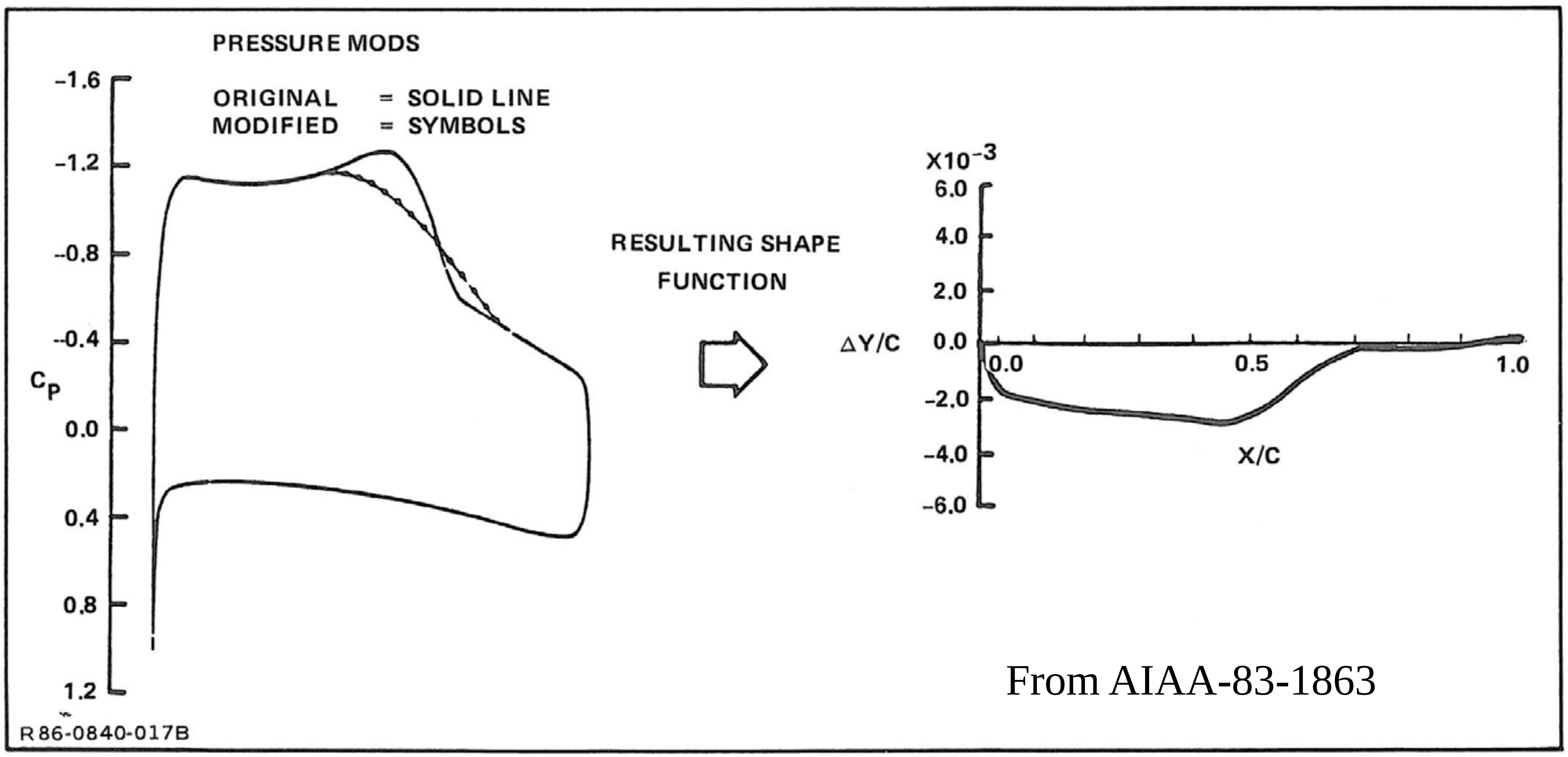
Figure 2.5 Airfoil defined by NURBS curves using control points.

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

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

Bottom line from my perspective

- Beware of attempting to develop a single monolithic scheme, a sensorcraft and a Long Range Strike plane are very different geometric concepts: *flexibility* is crucial.
- 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, curvature, 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