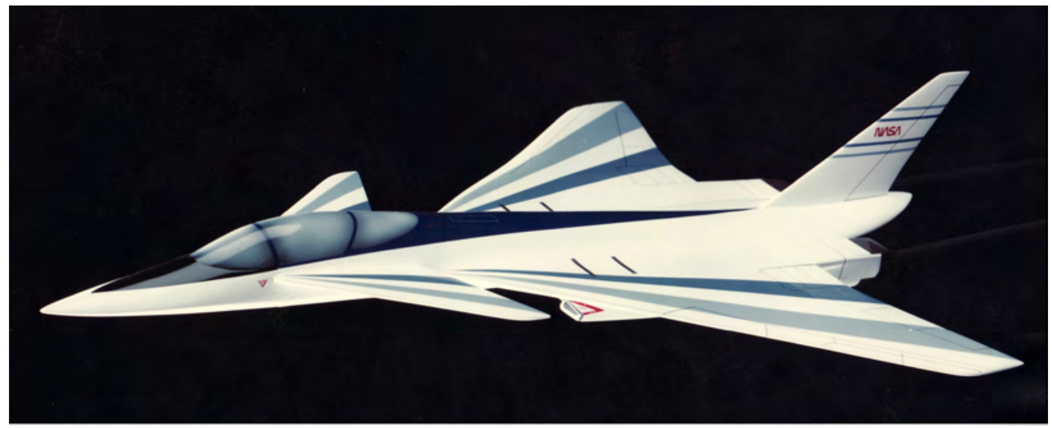
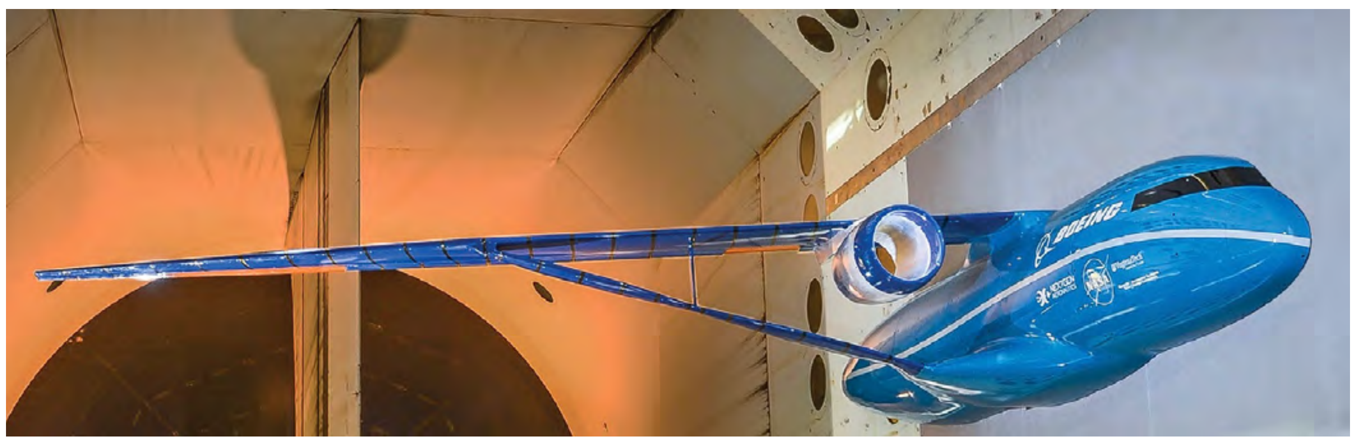
The Often Absent Academic Component of Engineering: ***Creativity***



W. H. Mason
2018



Motivated by

- John Anderson's *The Grand Designers*
  - Yes, by all means read it
  - His premise:
    - The aircraft design process hasn't changed
    - Technology is responsible for better airplanes
    - Creativity arising from understanding/exploiting aerodynamics is barely mentioned, essentially ignored
- The Science Channel: Engineering Catastrophes:
  - Doesn't capture what engineers do

Three Examples of Concepts Arising from *Creativity*

- The Forward Swept Wing X-29
- Supercritical Conical Camber (SC3)
- The Strut-Braced Wing

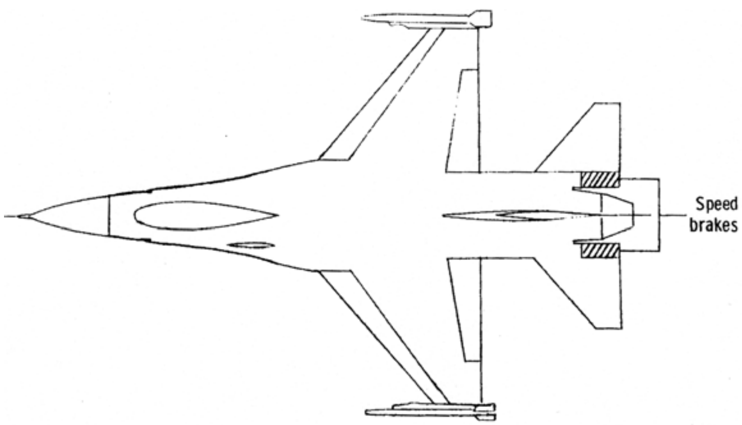
Glenn Spacht

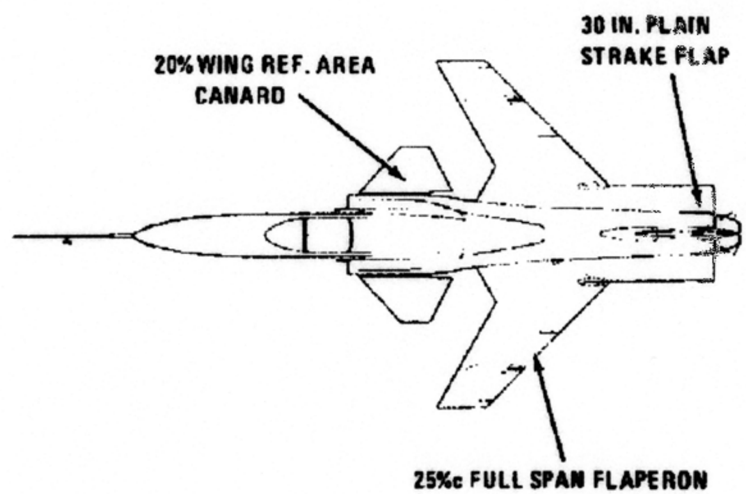
The Forward Swept Wing X-29

Concept: circa 1977, 1st flight: Dec. 1984, Last Flight: 1991

Why Forward Sweep?

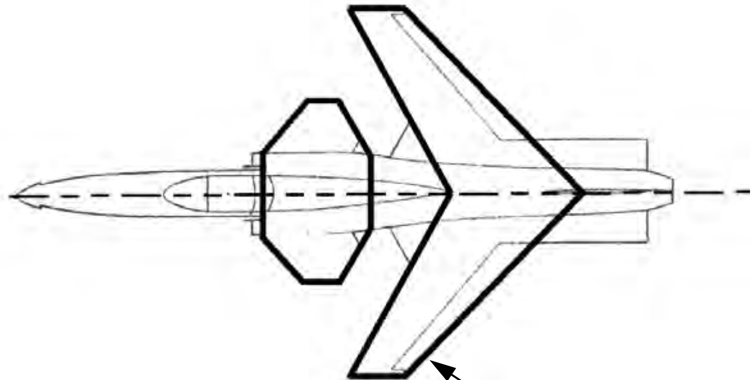
- Remember the idea of swept wings to reduce transonic drag?
- Fighters maneuvering at transonic speed
  - Strong aft shock, close to the trailing edge!
- Lets sweep the trailing edge to reduce shock wave drag
- Glenn realized that a forward swept wing would have high TE sweep – it's as simple as that
  - Aeroelastic tailoring overcame the divergence problem



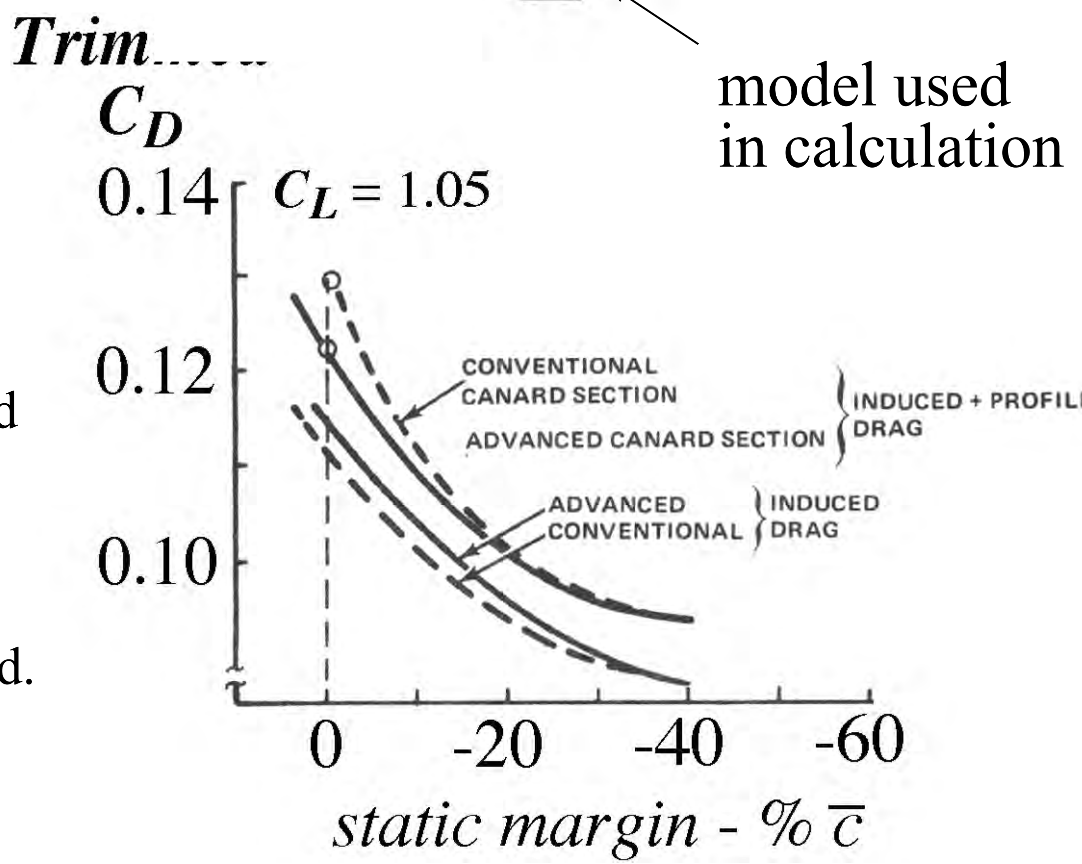


AIAA 83-1834, X-29 Forward Swept Wing Aerodynamic Overview

But: had to be 35% unstable



model used
in calculation



I found out that the plane had to be highly unstable to get the benefit of the forward swept wing/canard concept, and expected the study to end.

AIAA Paper 82-0097

Rudy Meyer's
SuperCritical Conical Camber (SC3)

Rudy (actually an ME, self-taught aero):
- Needed a supersonic maneuver wing design
- Insight from conical flow theory in Ferri's book

Gianky daForno
-Translated Rudy's idea into a development program

Bernie Grossman
-Funded by Rudy to create a CFD tool – COREL

Mason
-With NASA and Grumman IR&D support
- Use COREL to design and WT test SC3 wings
    - 1st a conical wing
    - 2nd a complete 3D demonstration wing

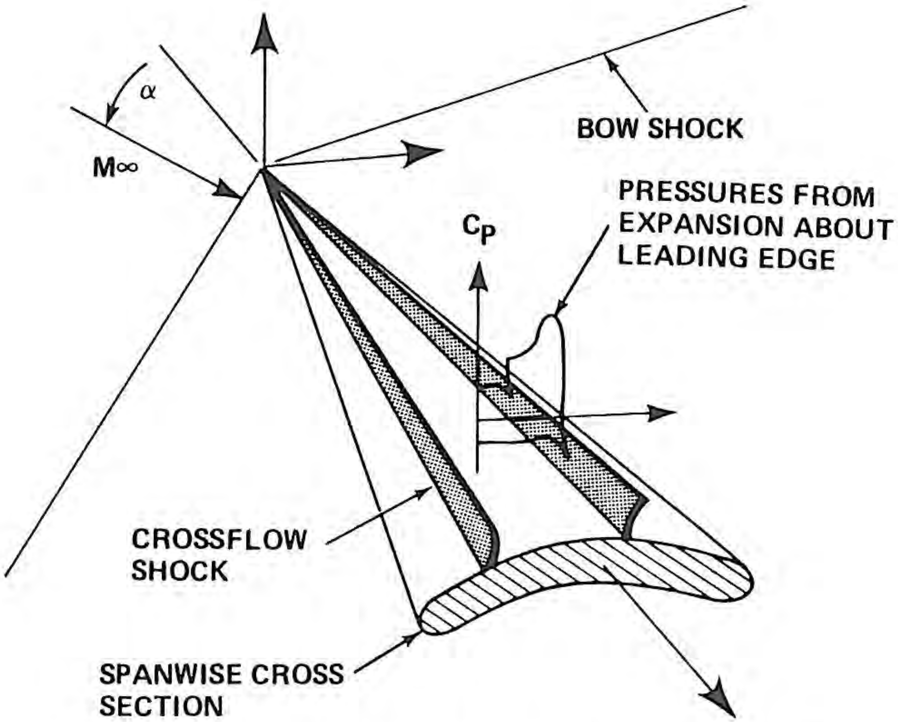
Conical Camber should have achieved the full LE Suction at Supersonic Speed – But Didn't!

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

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

The physics of the breakdown

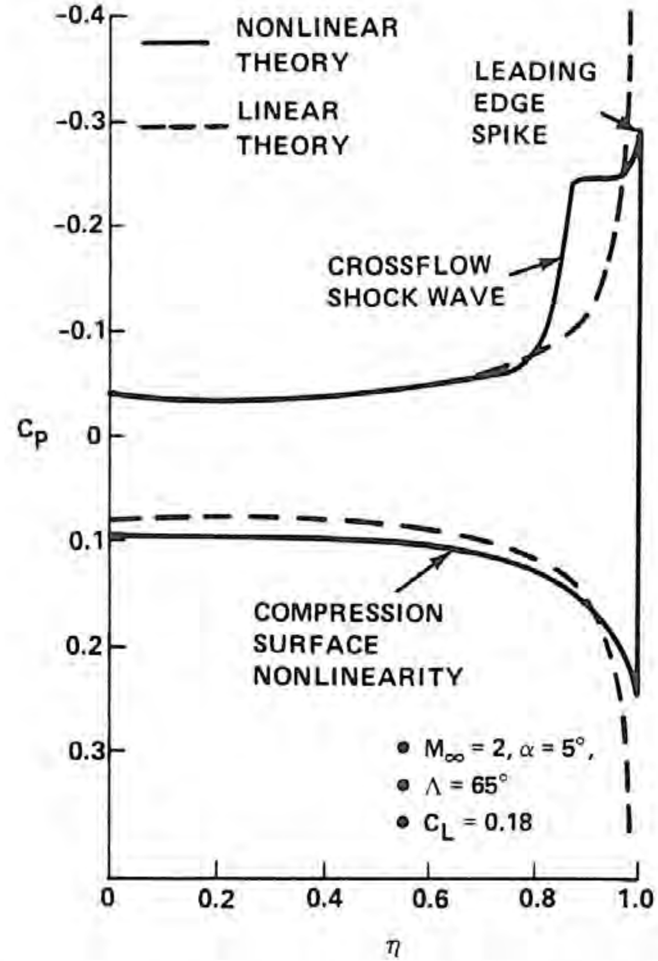
The physics



A. TYPICAL FLOW IN CROSSFLOW PLANE

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

The implications for theory



B. UNCAMBERED DELTA WING WITH ELLIPTIC THICKNESS DISTRIBUTION

NASA CR 3763, 1983

Rudy Connected the Dots I

In the early 1970s, Aero CFD centered on transonic flow

- full potential equation that changed math type, sub or supersonic

Shapiro, Vol. 1, ϕ is the potential, *c* is the speed of sound

Art. 9.8 DIFFERENTIAL EQUATIONS—VELOCITY POTENTIAL 289

PLANE, TWO-DIMENSIONAL FLOW. For plane, two-dimensional flow, Eqs. 9.32 and 9.33 are simplified to give

$$\left(1-\frac{\varphi_x{}^2}{c^2}\right)\varphi_{xx}+\left(1-\frac{\varphi_y{}^2}{c^2}\right)\varphi_{yy}-2\,\frac{\varphi_x\varphi_y}{c^2}\,\varphi_{xy}=0 \qquad (9.34)$$

$$c^2=c_0{}^2-\frac{k-1}{2}\left(\varphi_x{}^2+\varphi_y{}^2\right) \qquad (9.35)$$

- Change of math type easy to spot
- Nope, today we wouldn't solve this form
- Modern books no longer include this, *eliminating the insight*

Recent Amazon quote: from \$194.88 to \$7.95!

Rudy Connected the Dots II

Rudy connected the transonic numerical breakthrough to conical flow at supersonic speeds – use the same CFD methods to solve the conical flow equations. Bernie Grossman created COREL.

Antonio Ferri, *Elements of Aerodynamics of Supersonic Flows*, 1949.

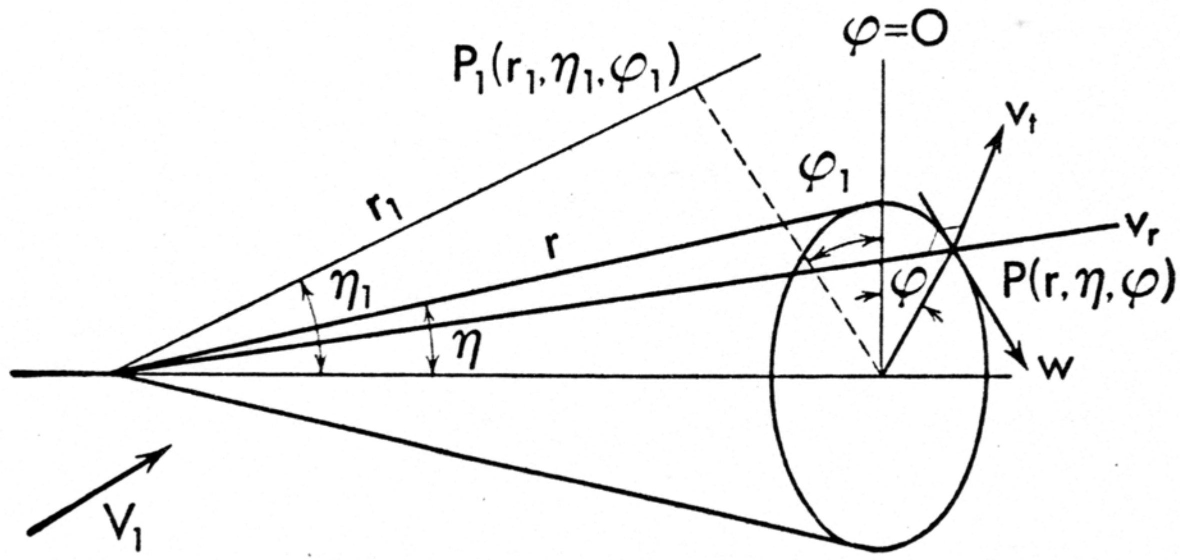


Fig. 160. *Velocity components in conical coordinates.*

Conical Flow Form of the (Full) Potential Equation:

- allows the use of the same numerics developed for transonics

$$\phi = rF(\eta, \varphi) \tag{444}$$

The components of the velocity along the radius r, (v_r), normal to the radius r in the meridian plane φ = constant, (v_t), and normal to the meridian plane (w), (Figure 160) are

$$v_r = \frac{\partial \phi}{\partial r} = F; \qquad v_t = \frac{\partial \phi}{r \partial \eta} = \frac{\partial F}{\partial \eta}; \qquad w = \frac{\partial \phi}{r \sin \eta \partial \varphi} = \frac{1}{\sin \eta} \frac{\partial F}{\partial \varphi} \tag{445}$$

In the equation of potential flow in polar coordinates (equation 333), because F is not a function of r, the terms

$$\frac{\partial v_r}{\partial r}, \quad \frac{\partial v_t}{\partial r}, \quad \frac{\partial w}{\partial r}$$

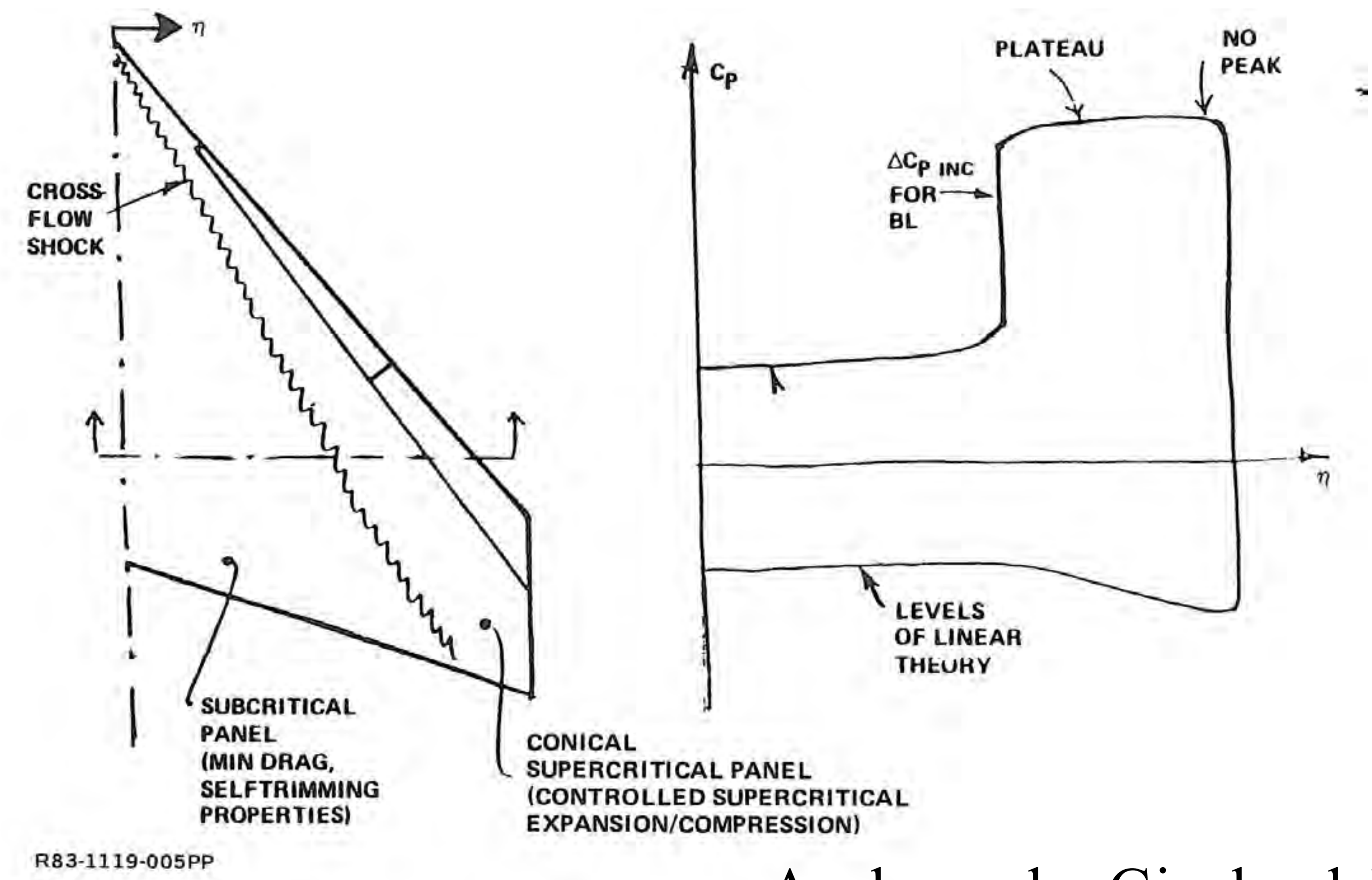
are equal to zero; therefore equation (333) becomes

$$\sin^2 \eta \left(1 - \frac{v_t^2}{a^2}\right) \frac{\partial^2 F}{\partial \eta^2} - \frac{2wv_t}{a^2} \sin \eta \frac{\partial^2 F}{\partial \eta \partial \varphi} + \left(1 - \frac{w^2}{a^2}\right) \frac{\partial^2 F}{\partial \varphi^2}$$
$$+ \sin^2 \eta F \left(2 - \frac{w^2 + v_t^2}{a^2}\right) + \frac{1}{2} \sin 2\eta \frac{\partial F}{\partial \eta} \left(1 + \frac{w^2}{a^2}\right) = 0 \tag{446}$$

See Grossman, *AIAA Journal*, Vol. 17, No. 8, Aug. 1979, pp. 828-837.

Rudy Meyer: Use Conical CFD to Design Supersonic Maneuver Wings

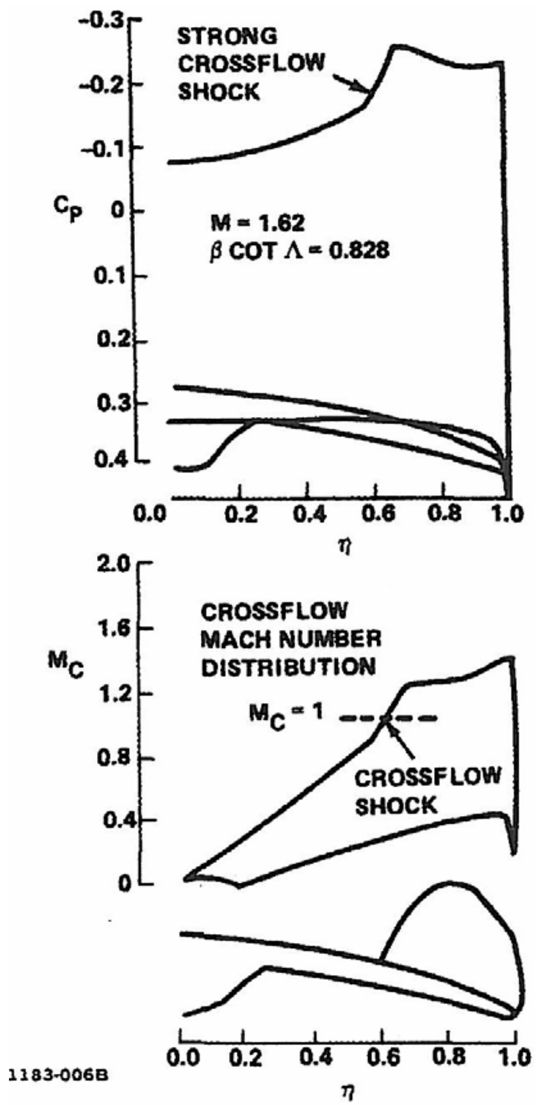
- Supercritical Conical Camber (SC3) -



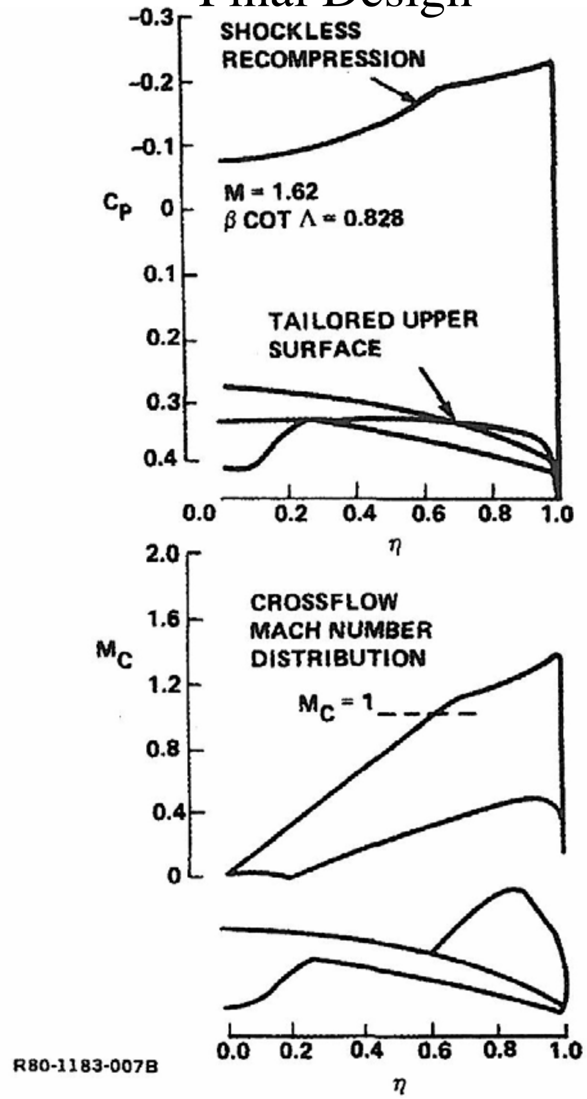
As drawn by Gianky daForno

Computational Design: Spanwise Pressures

Initial Camber Studies



Final Design



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

A WT Model to validate concept

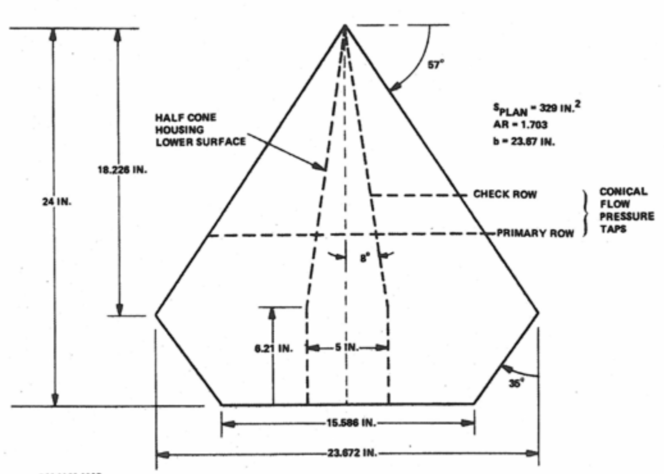
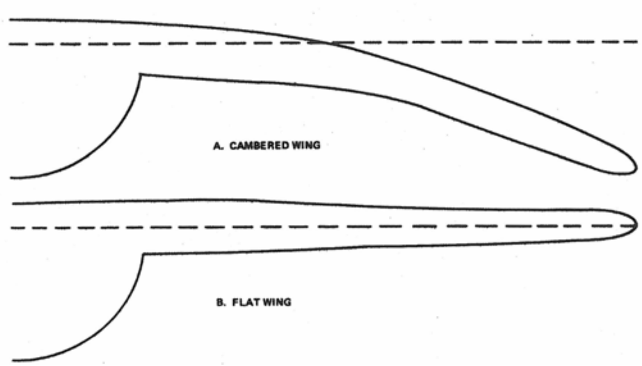
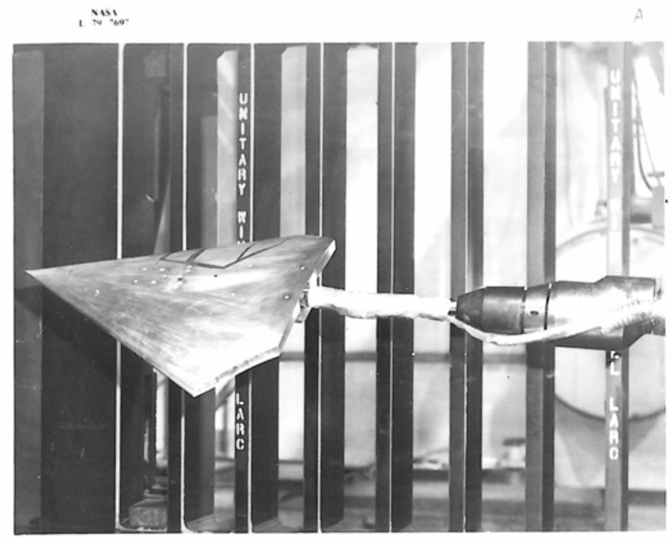
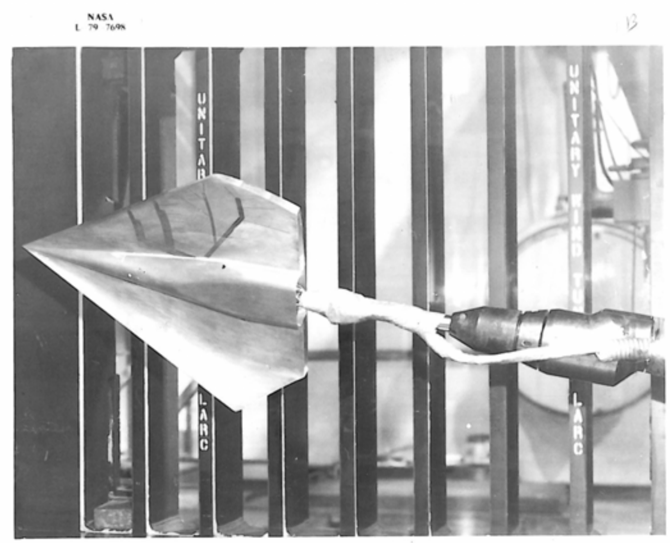


Fig. 8 Conceptual-maneuver-wing planform.

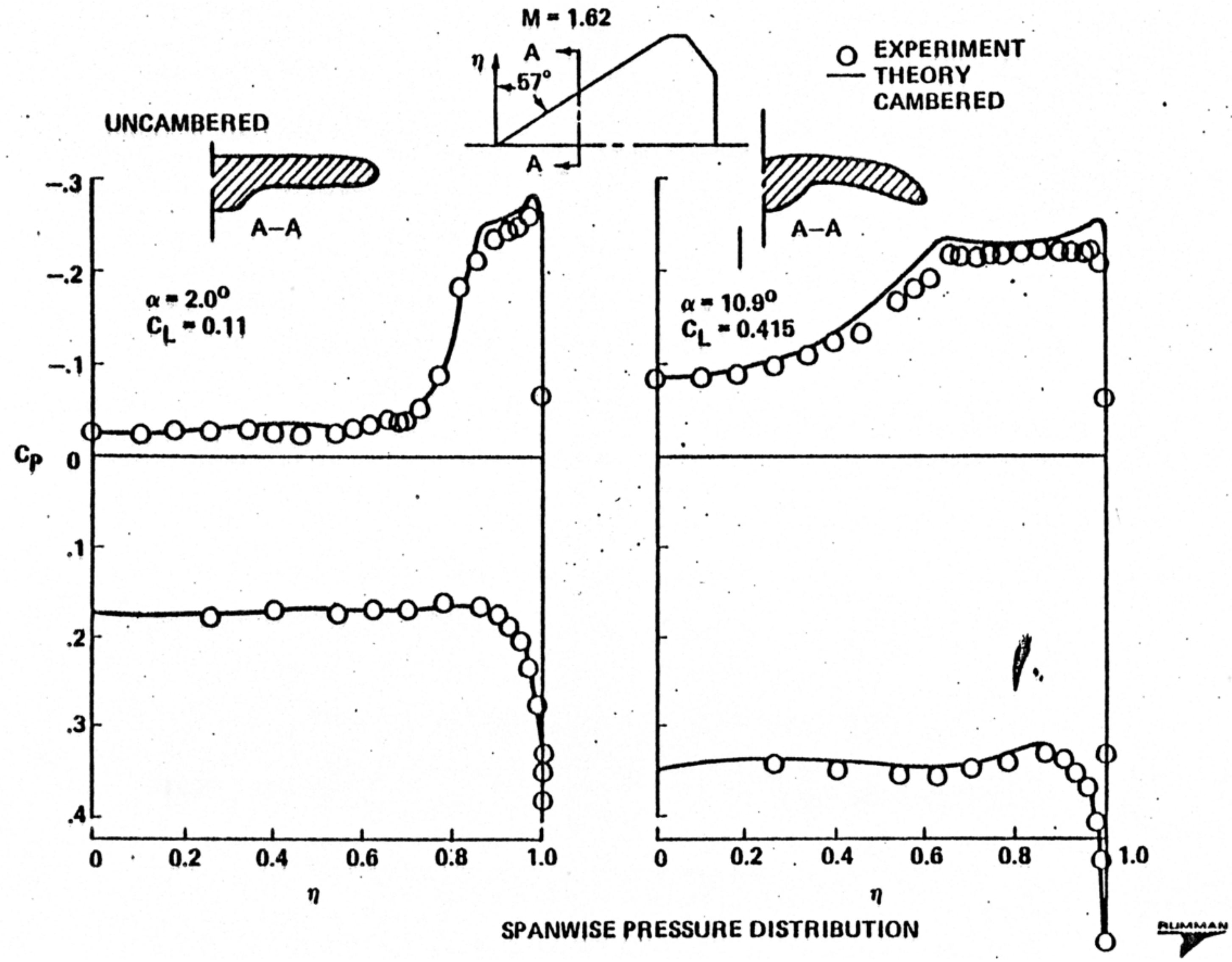






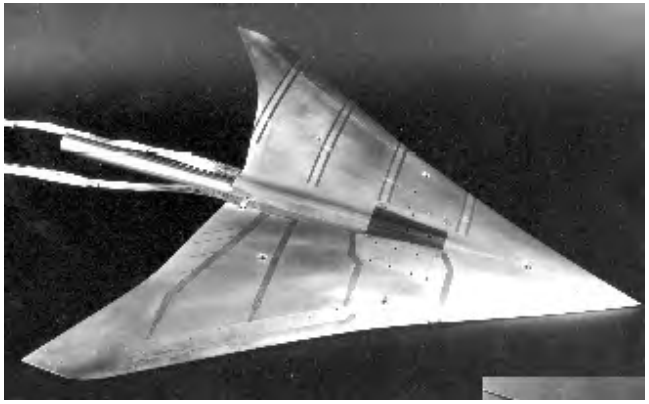
AIAA-1980-1421 “Controlled Supercritical Crossflow on Supersonic Wings”

Results Validate SC3 Design Concept!



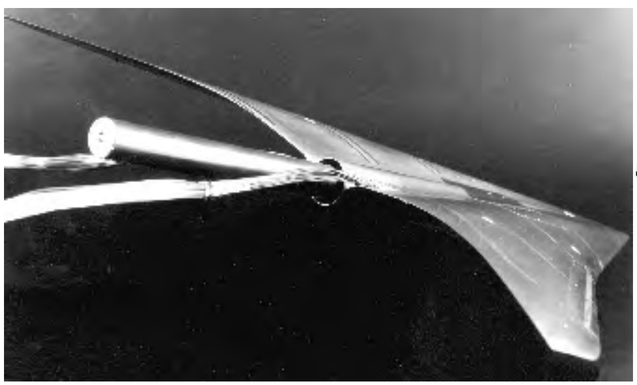
SPANWISE PRESSURE DISTRIBUTION

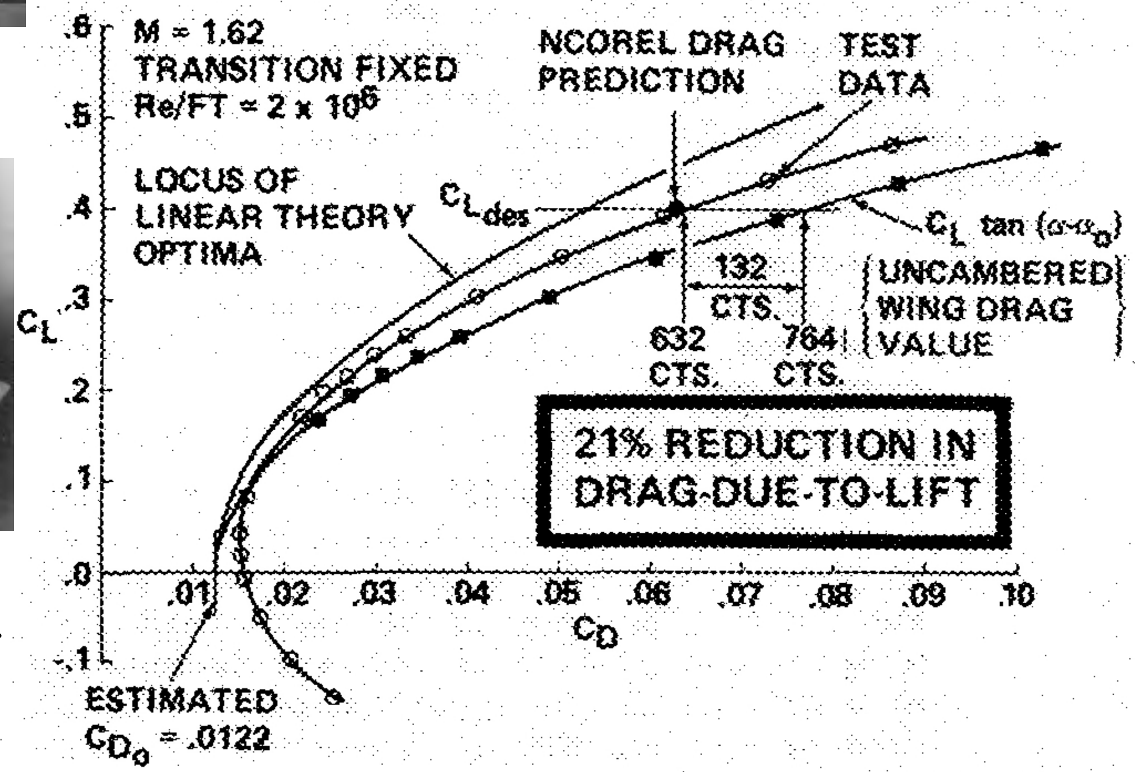
NASA/Grumman SC3 Wing Concept



Supercritical Conical Camber, SC^3

An attached flow maneuver wing with controlled supercritical crossflow





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.

NASA CR 3763/AIAA Paper 83-1858

Werner Pfenninger

Swiss born Aero Innovator

Best known for laminar flow

Northrop X-21: April 1963 - 1968

Courtesy Tony Landis, personal collection

Active Laminar Flow Control via wing slots
Major re-work of
Douglas WB-66D
AR = 7, LE Sweep = 30°
t/c = 0.10
Ultimately successful.
M = 0.745, Flights 120 and 121

Pfenninger: the Idea – to Max Laminar Flow Benefit

- Exploiting laminar flow requires complete configuration integration
- Can drive down parasite drag, so:
- Maximizing *L/D* requires parasite *and* induced drag reduction:

$$C_{D_i} = C_{D_0}$$

- Need a low C_{D_i}

$$D_i = \frac{1}{\pi q E}\left(\frac{W}{b}\right)^2$$

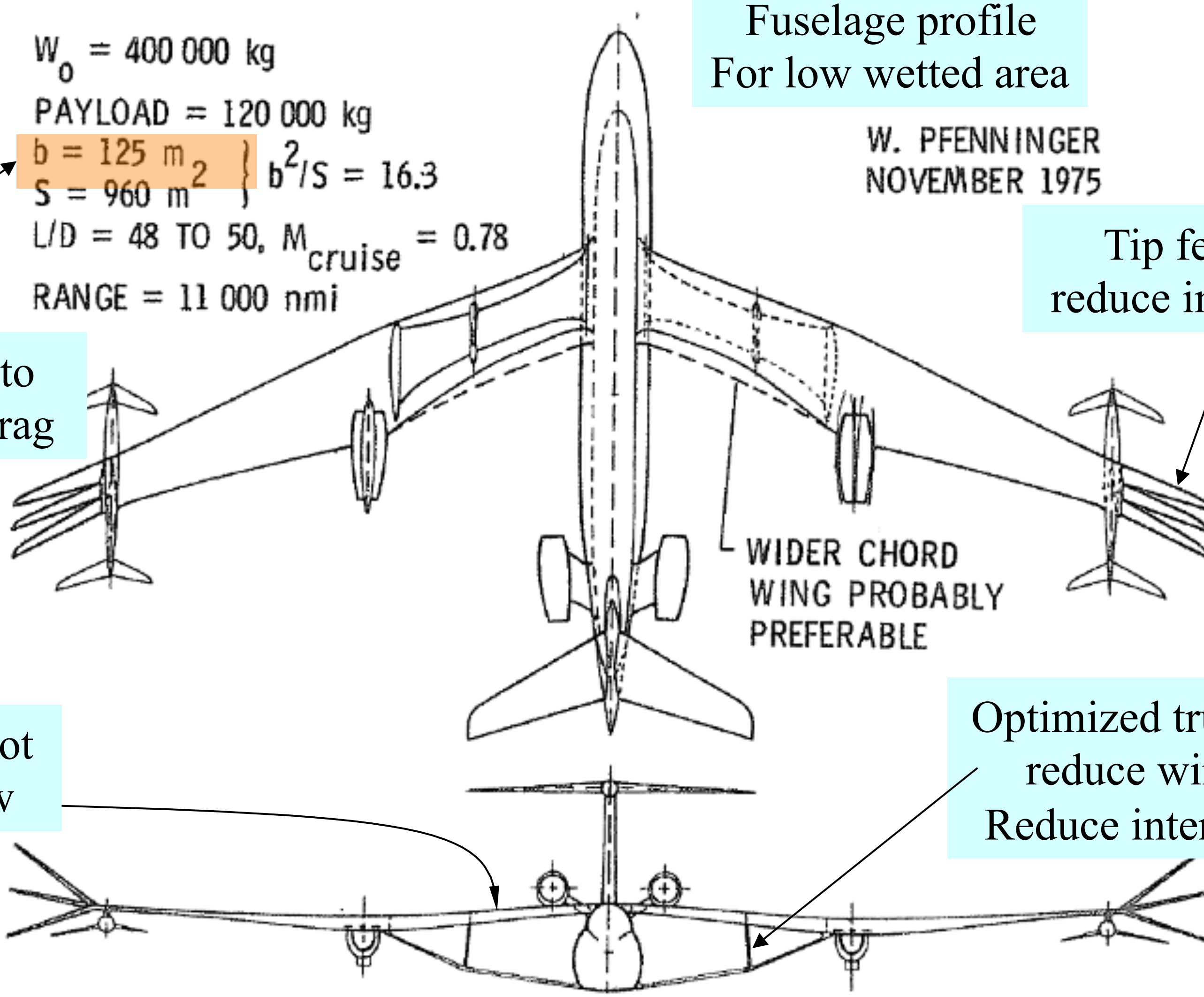
Span NOT Aspect Ratio drives induced drag

$$\left.\frac{L}{D}\right|_{\max} = \frac{1}{2}\sqrt{\frac{\pi AR E}{C_{D_0}}}$$

Note: Pfenninger started this line of thinking in the early 1950s at the latest

Werner Pfenninger - The Strut-Braced Wing

Pfenninger was assuming *active* laminar flow control



Fuselage profile
For low wetted area

Tip feathers to
reduce induced drag

Large span wing to
reduce induced drag

Thin wing at root
for laminar flow

Optimized truss support to
reduce wing weight-
Reduce interference drag

To realize the concept: use MDO

See our AIAA Paper 2005-4667

Compared to a conventional cantilever design for a B-777 mission:

- 12-15% less takeoff weight
- 20-29% less fuel

- The strut allows a lower *t/c* without a weight penalty
- A higher span leads to less induced drag
- Reduced *t/c* allows less sweep without a wave drag penalty
- Reduced sweep leads to *even lower* wing weight
- Reduced sweep allows for some natural laminar flow
  - reduced skin friction drag

Still being studied (2014 cover):

But:

- The High-Aspect-Ratio description is wrong
- No dogleg at wing-strut intersection
- Short range mission is wrong application

Managers must have gotten involved

Eventually the SBW will prevail

The Theme?

- *Understanding*, often through approximate aero models, provides the insight into the physics that leads to important concepts
- *Then* cut lose the big codes!
  - See Pradeep Raj, "Applied Computational Aerodynamics: An Unending Quest for Effectiveness," The Royal Aeronautical Society 2018 Applied Aerodynamics Conference, *The Future of Aerodynamics*, July 2018
  - Requires MDO

The Takeaway

- Theodore Von Kármán:
  - The scientist discovers that which exists. An Engineer creates that which never was.