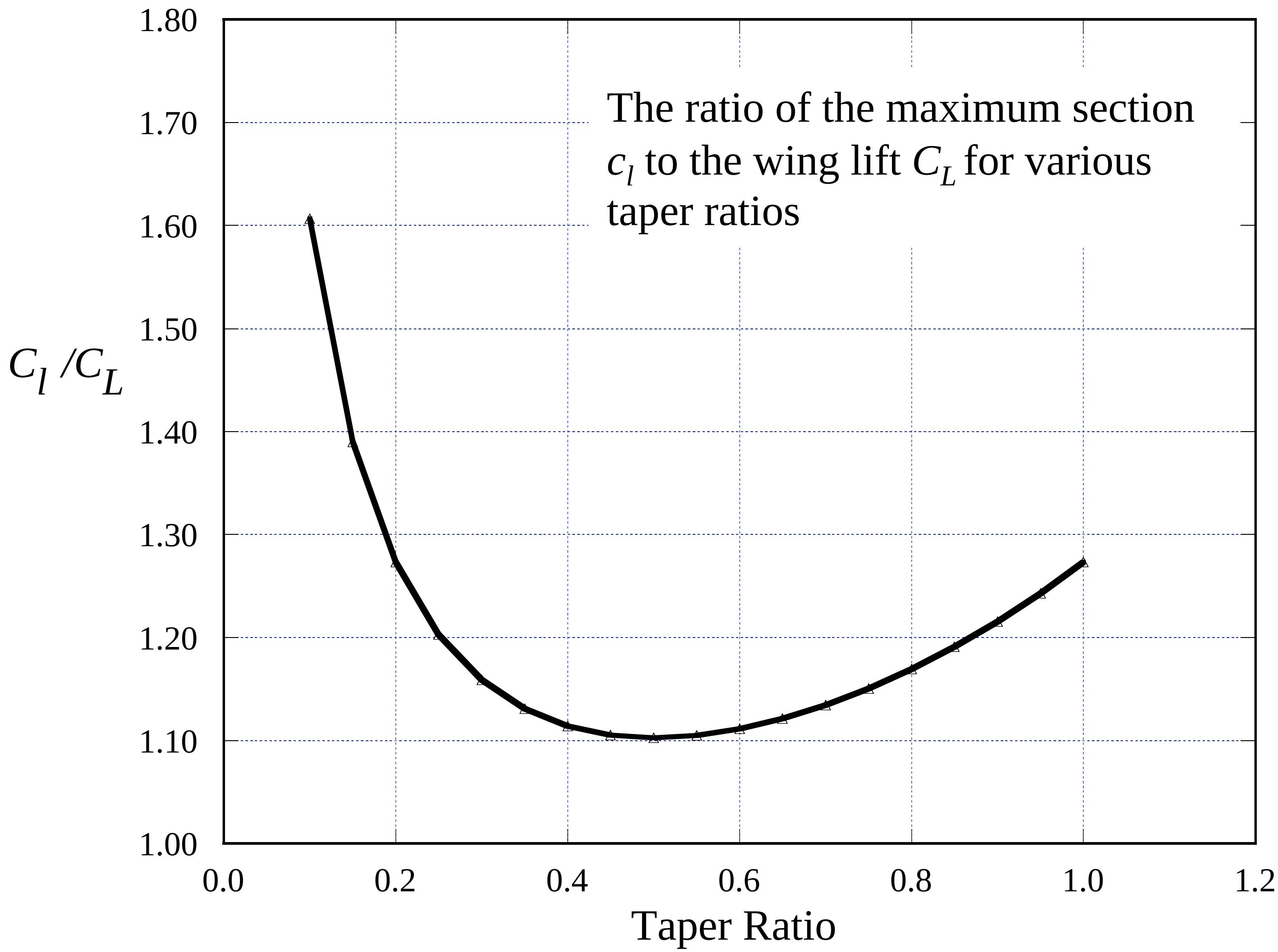
Spanloads
What's the best spanload?
and c_l/C_L distribution?

Today: Stories before break

- The homework
- The Vulcan Story
- The X-29 Story
- The Truth about Elliptic Spanloads
- A little more on flying wings: the BWB

Config Aero, March 5, 2010

First: the homework:
Elliptic Loading – Trapezoidal Wing



the Vulcan

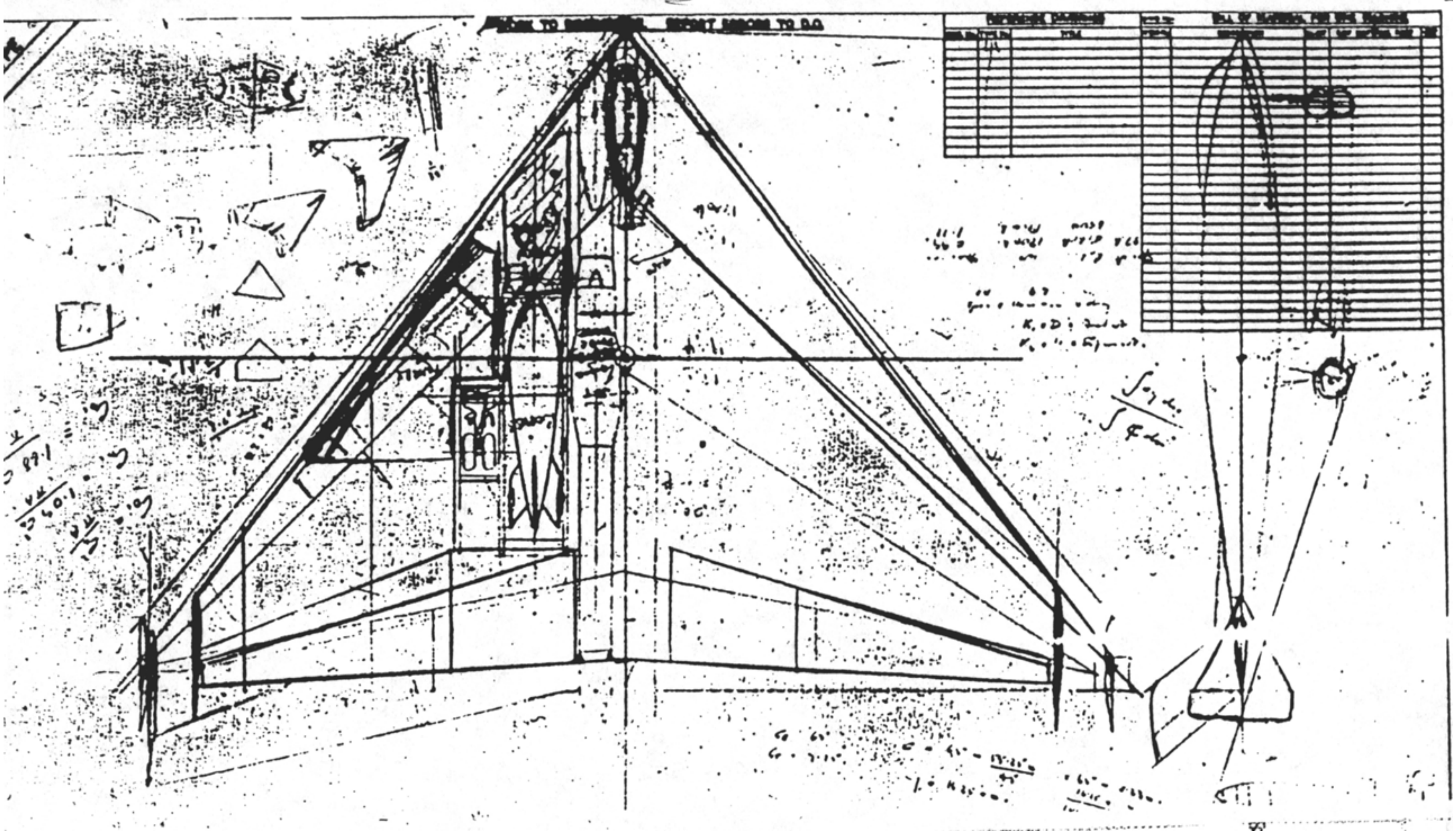
The Wing Configuration Evolution

Originally collected
By
Nathan Kirschbaum

A few more charts on the design class web page

Roy Chadwick’s initial concept

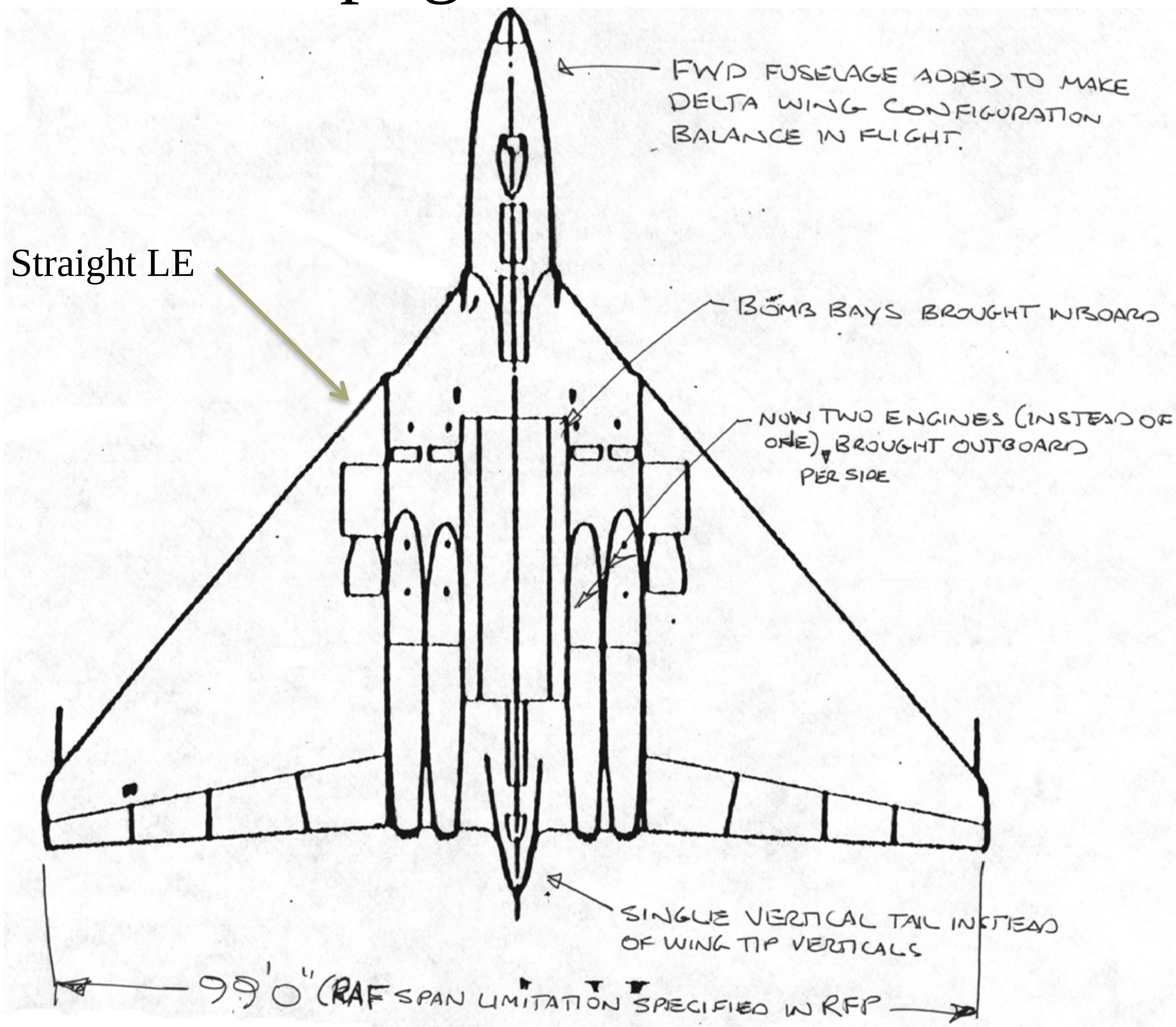
This historic sketch is believed to be the very first Avro 698 delta drawing. The “doodles” are by the late Roy Chadwick and his team.



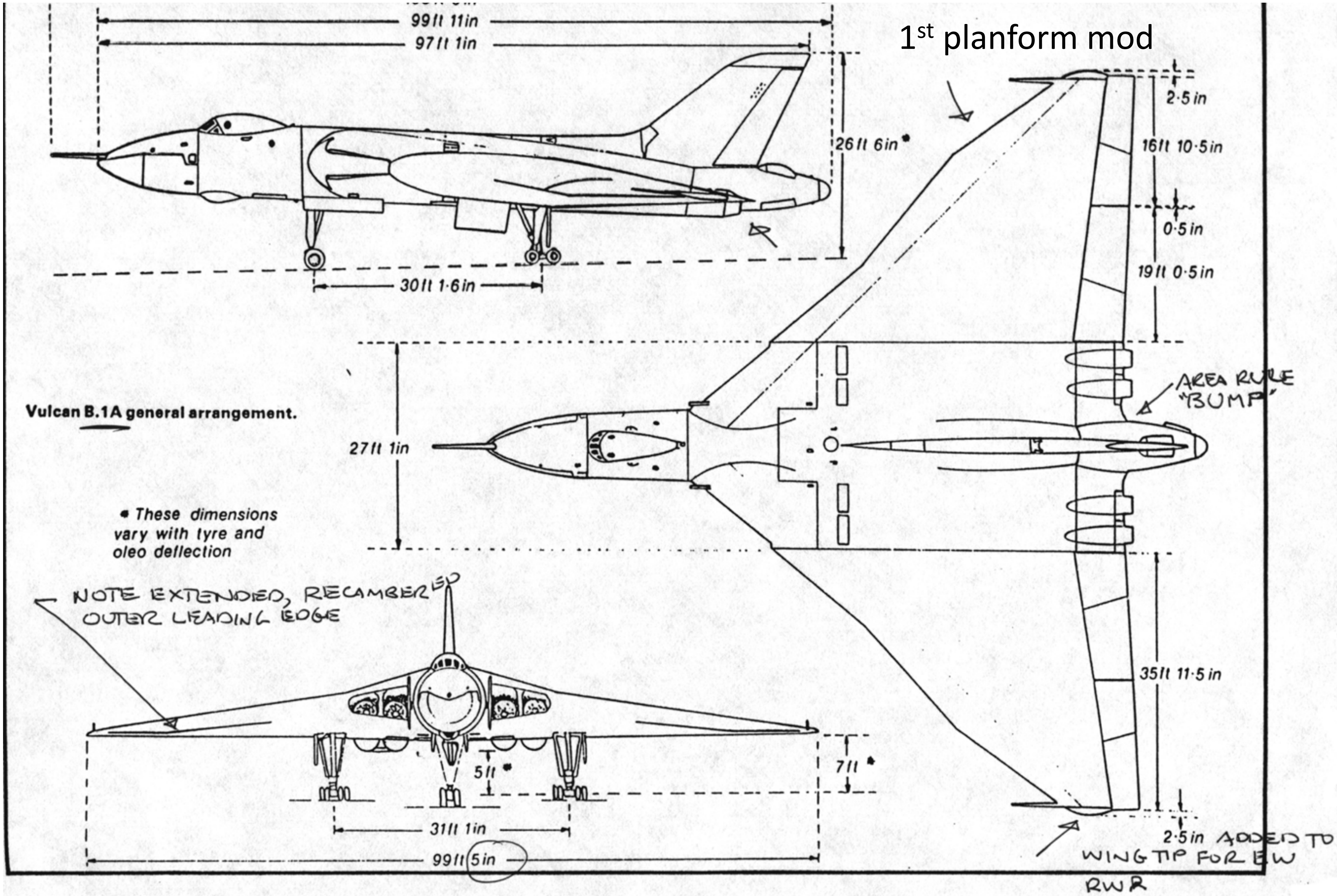
Chadwick had been known as the father of the Lancaster

The concept gets defined in detail

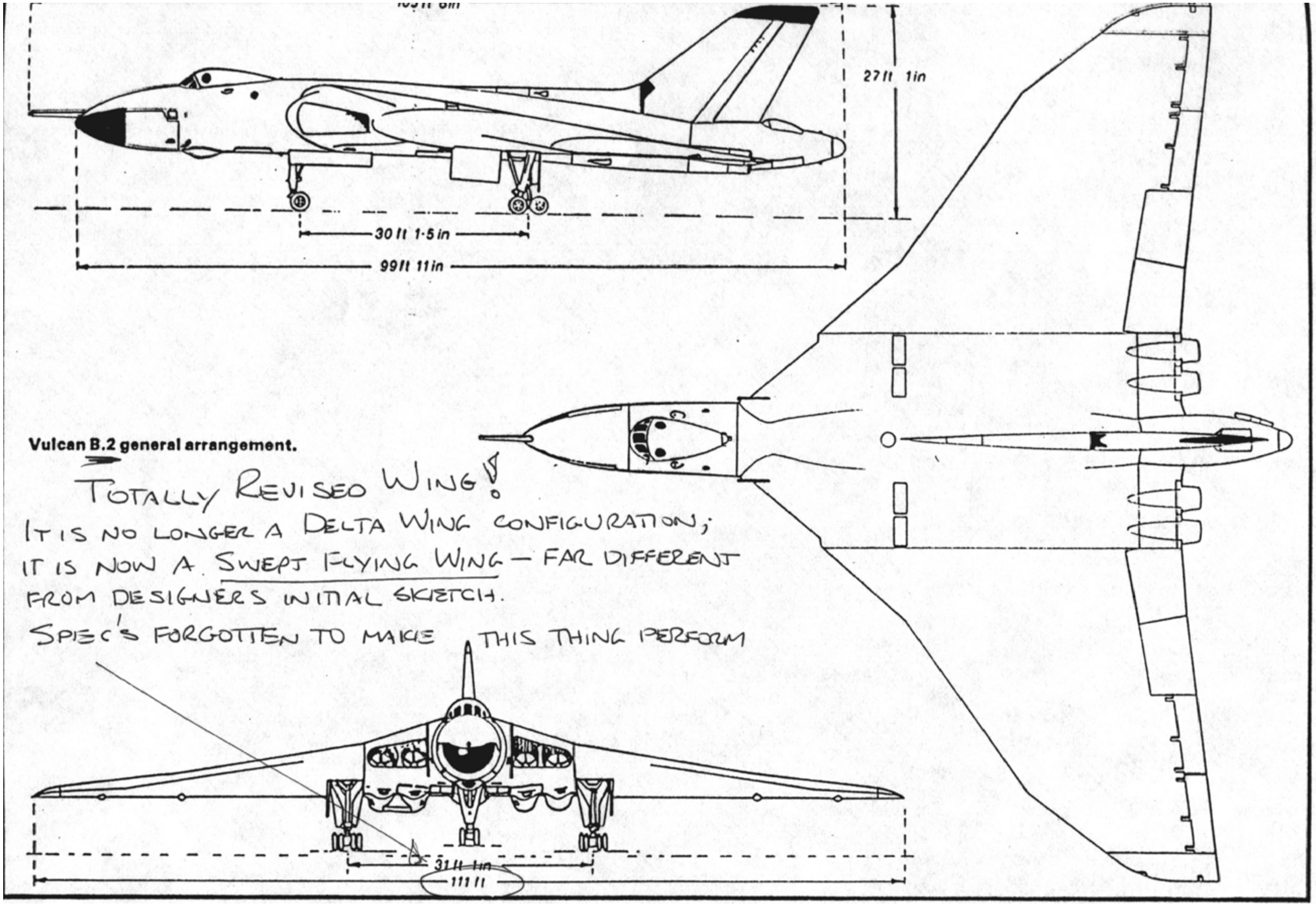
Note Straight LE



The first model: the B.1A



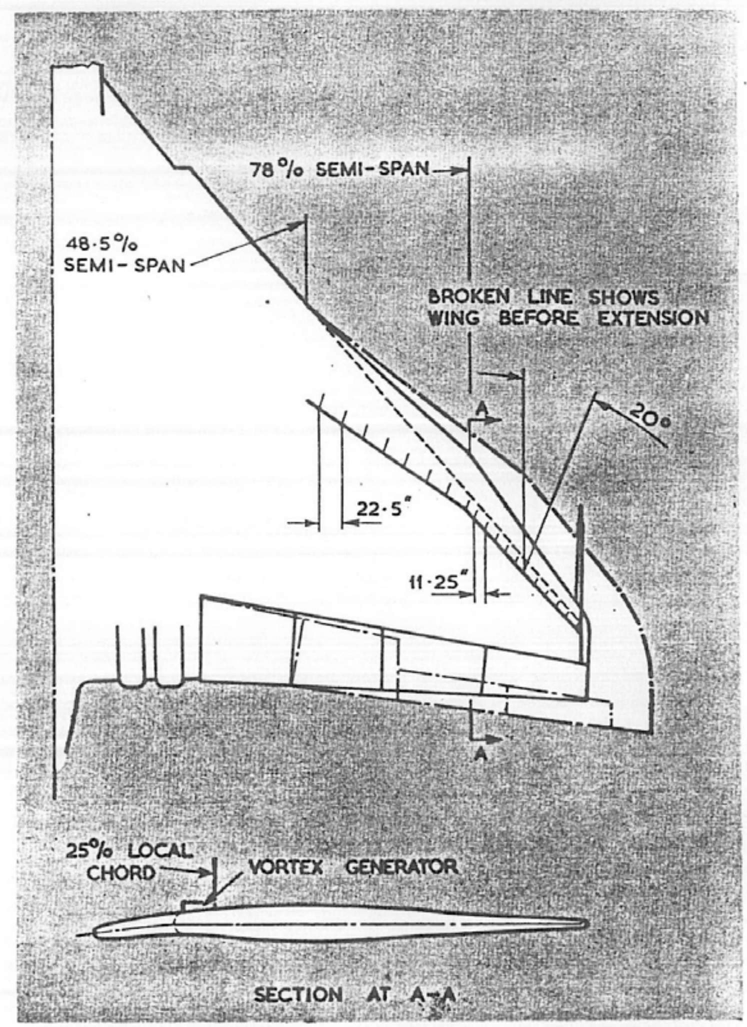
The final configuration: Model B.2



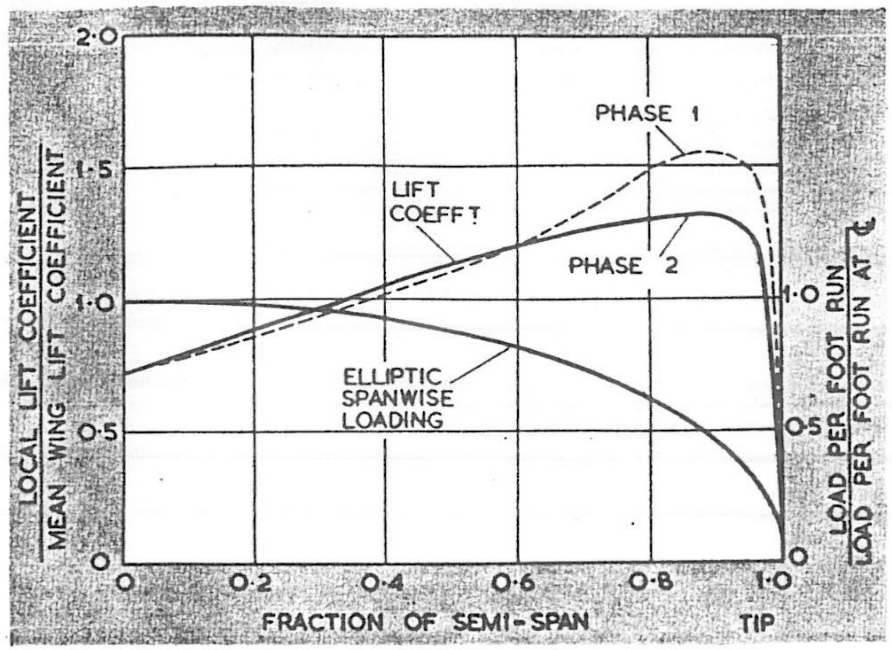
Vulcan B.2 general arrangement.

What Happened? Why?

Add chord outboard (twice!)



Reduce outboard section c_l



Flight, 31 Jan. 1958

The lessons?

- The concept needs to be continually revised as more understanding is gained: ***iteration***
  - *Hopefully: BEFORE the plane is made!*
- Understanding of the issues in terms of basic physics is key

In the cockpit of this very plane,
Nov. 1999
See Scott Bland in back

Note: This plane flew again in 2007!

X-29 and Aero Design
Computational Aero (circa 1977-78)
Needs a different concept/understanding

Dryden Flight Research Center EC87 0182-14 Photographed 1987
X-29

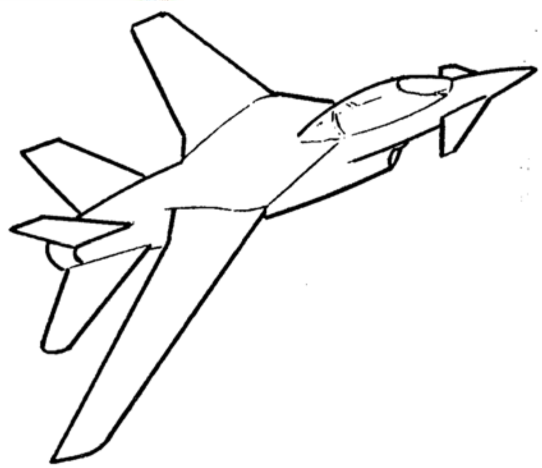
X-29 came out of a Grumman loss to Rockwell for the HiMat Program

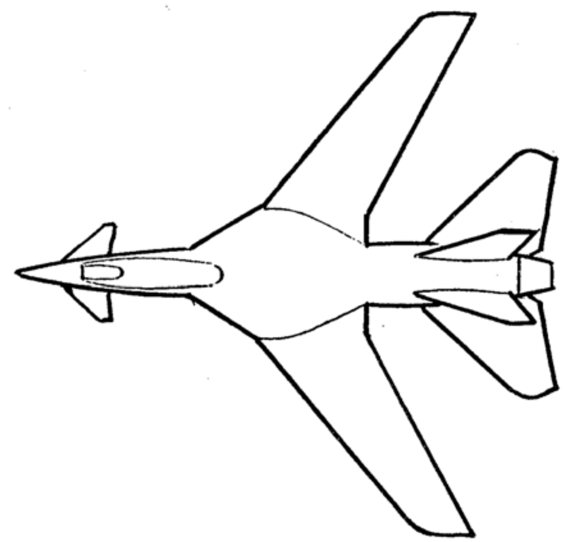
Dryden Flight Research Center ECN-14280 Photographed 1980
HiMat

Highly **M**aneuverable **a**ircraft **t**echnology

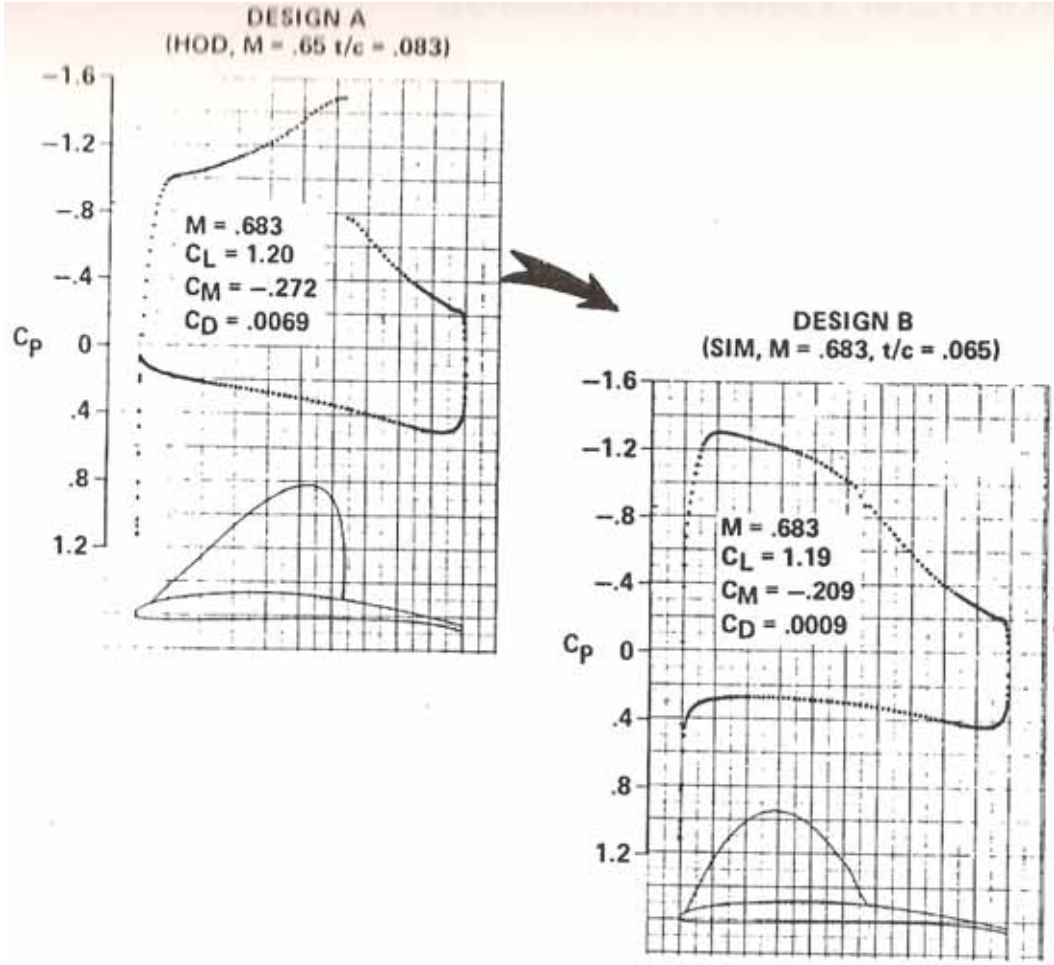
Won by Rockwell, Aug. 1975:
Canard Configuration
Flew from 1979 to 1983

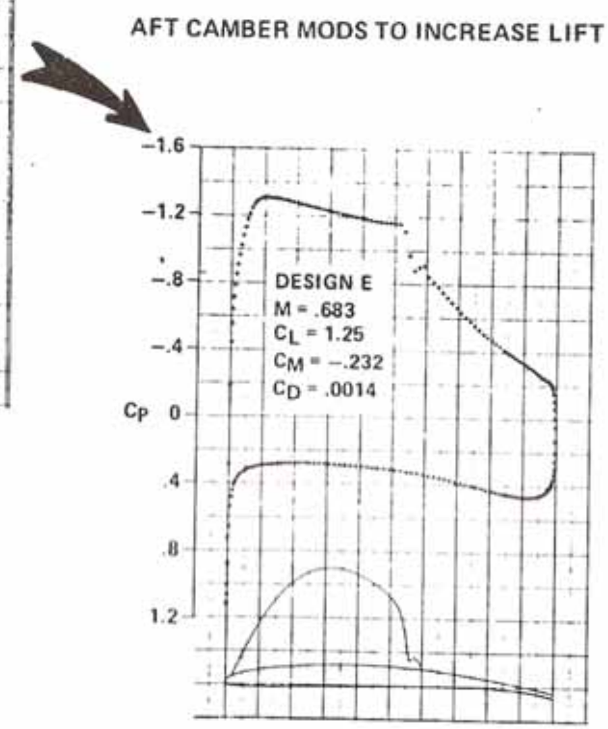
Grumman: variable sweep, w/attached flow and advanced supercritical airfoils (because of F-14 - "has to have a pin in it")





Airfoil Design: Full Potential + BL

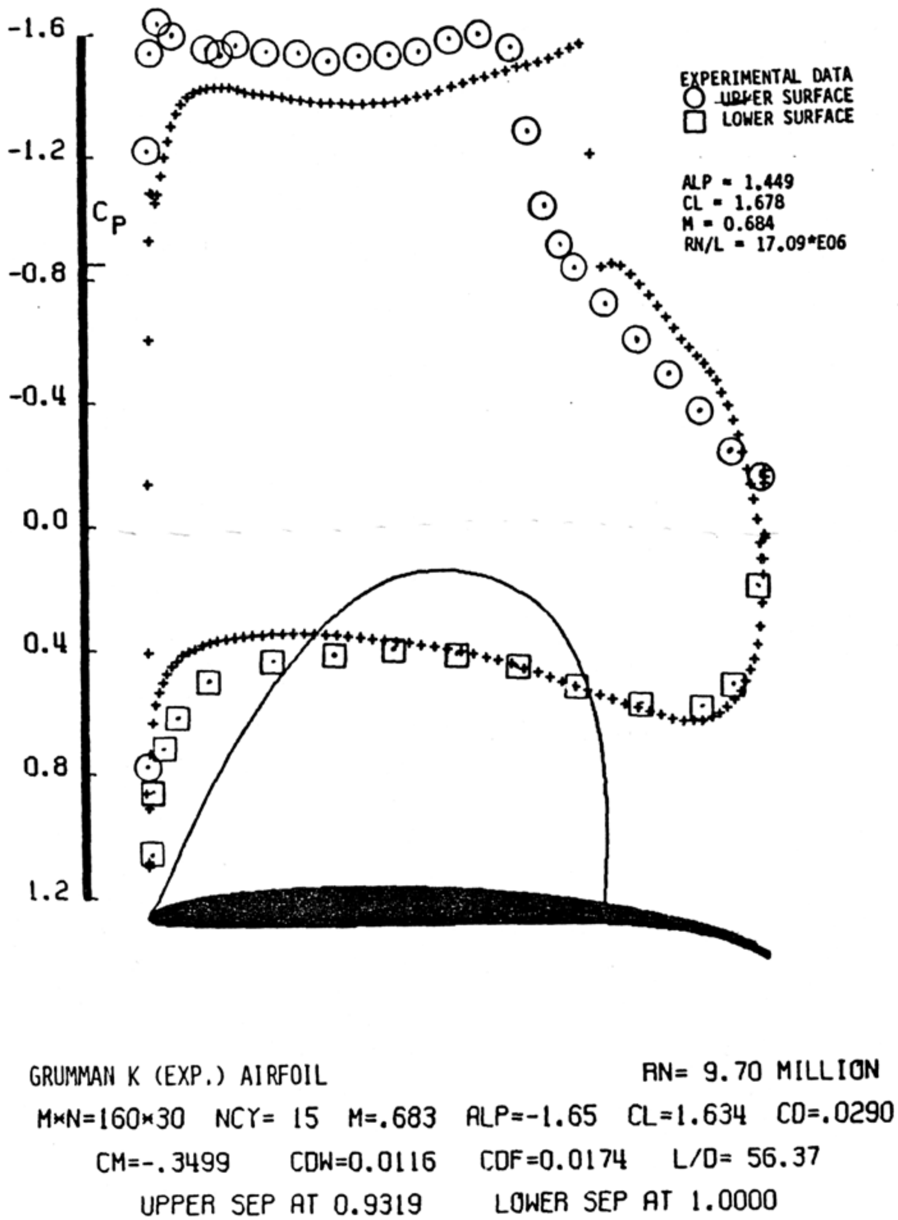




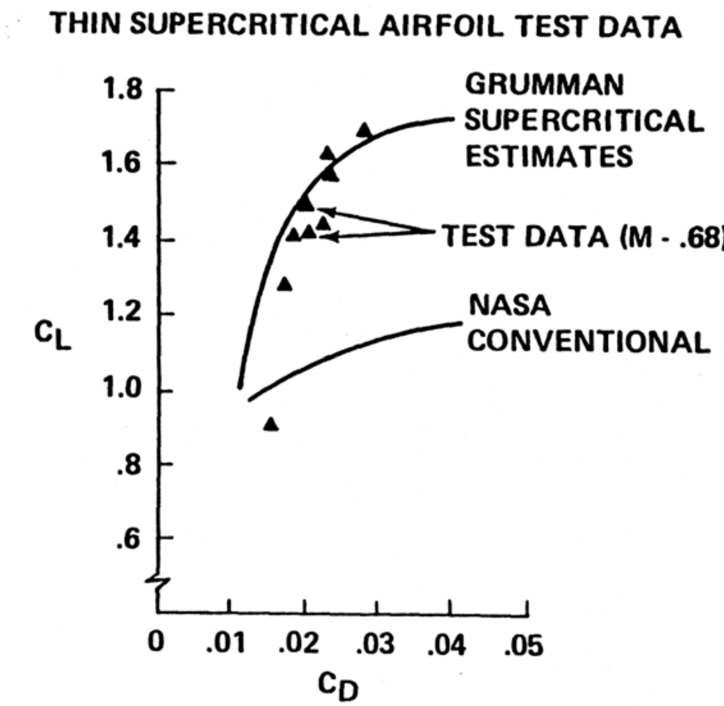
Very thin supercritical airfoils,
Design using the Hodograph Method, then scaled to meet requirements

This chart came from a presentation by Charlie Boppe

Final “Ultimate” Airfoil: the K mod 2



Eventually used a viscous analysis code developed by Paul Bavitz



NASA Liked the Proposal Airfoils

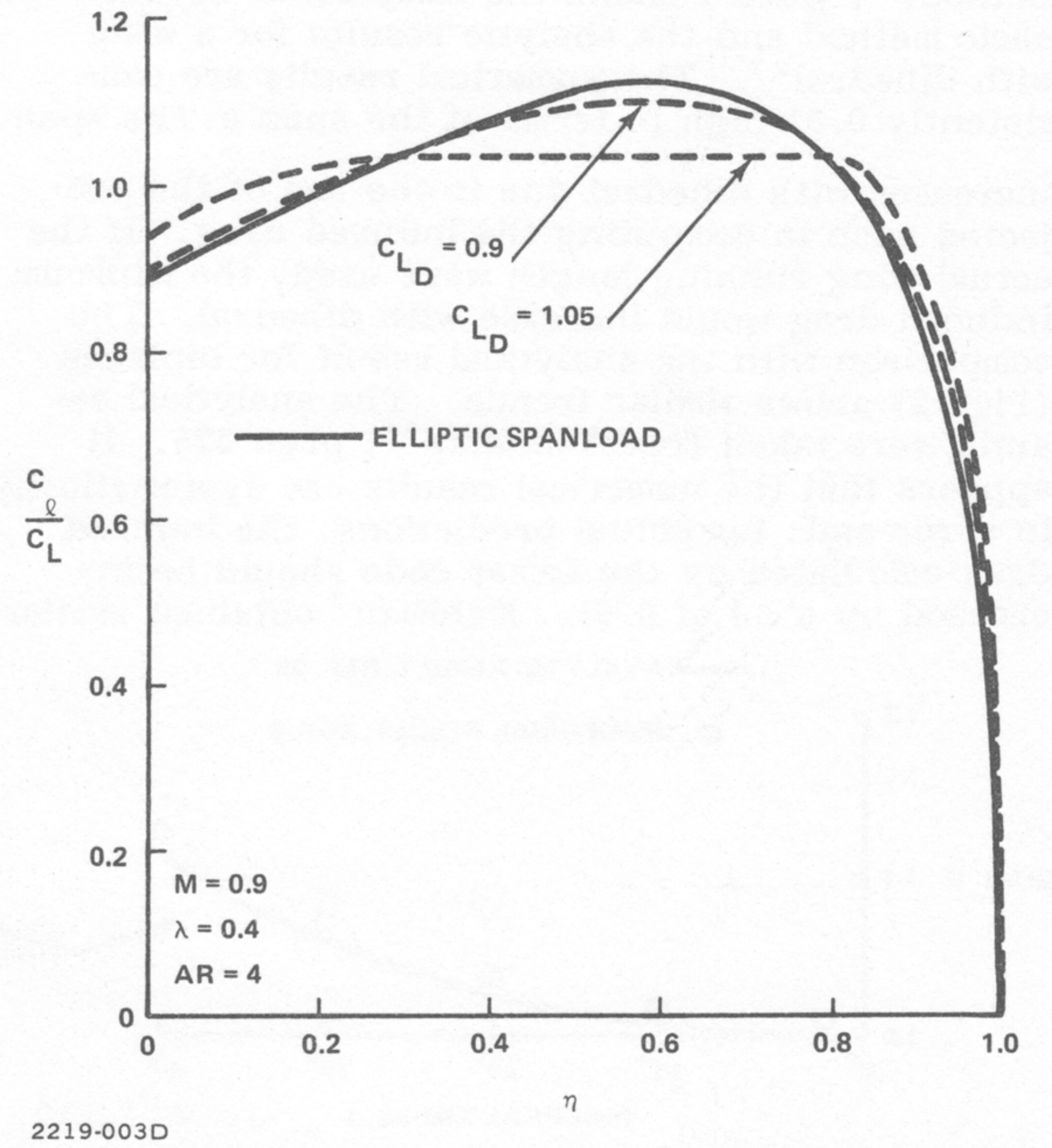
- Test the Grumman HiMat/Airfoils at Langley
- They worked - *but*
  - how do these airfoils best integrate into a wing planform?
    - Strong aft shock is on the lowest sweep part of the wing
    - To sweep the trailing edge to sweep the shock:
      - Inverse taper (XF-91, Thunderceptor – see last slide)
      - Forward swept wings?
    - Aeroelastically tailored composites were of current interest to suppress forward swept wing aeroelastic divergence
    - Norris Krone had an application for his PhD thesis!

Grumman (Glenn Spacht) starts looking at forward swept wings, DARPA gets interested (Norris Krone)

High C_L Maneuver section c_l distribution

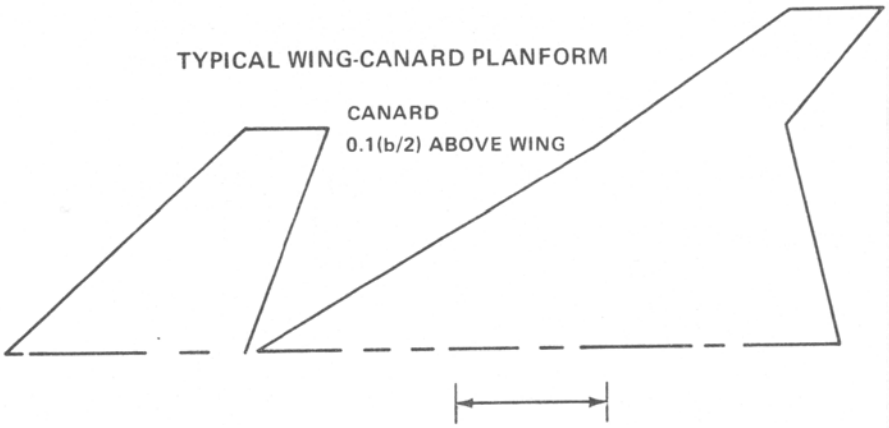
Note the transition from the normal elliptic spanload to a constant C_l spanload to squeeze the highest possible attached flow performance from the wing.

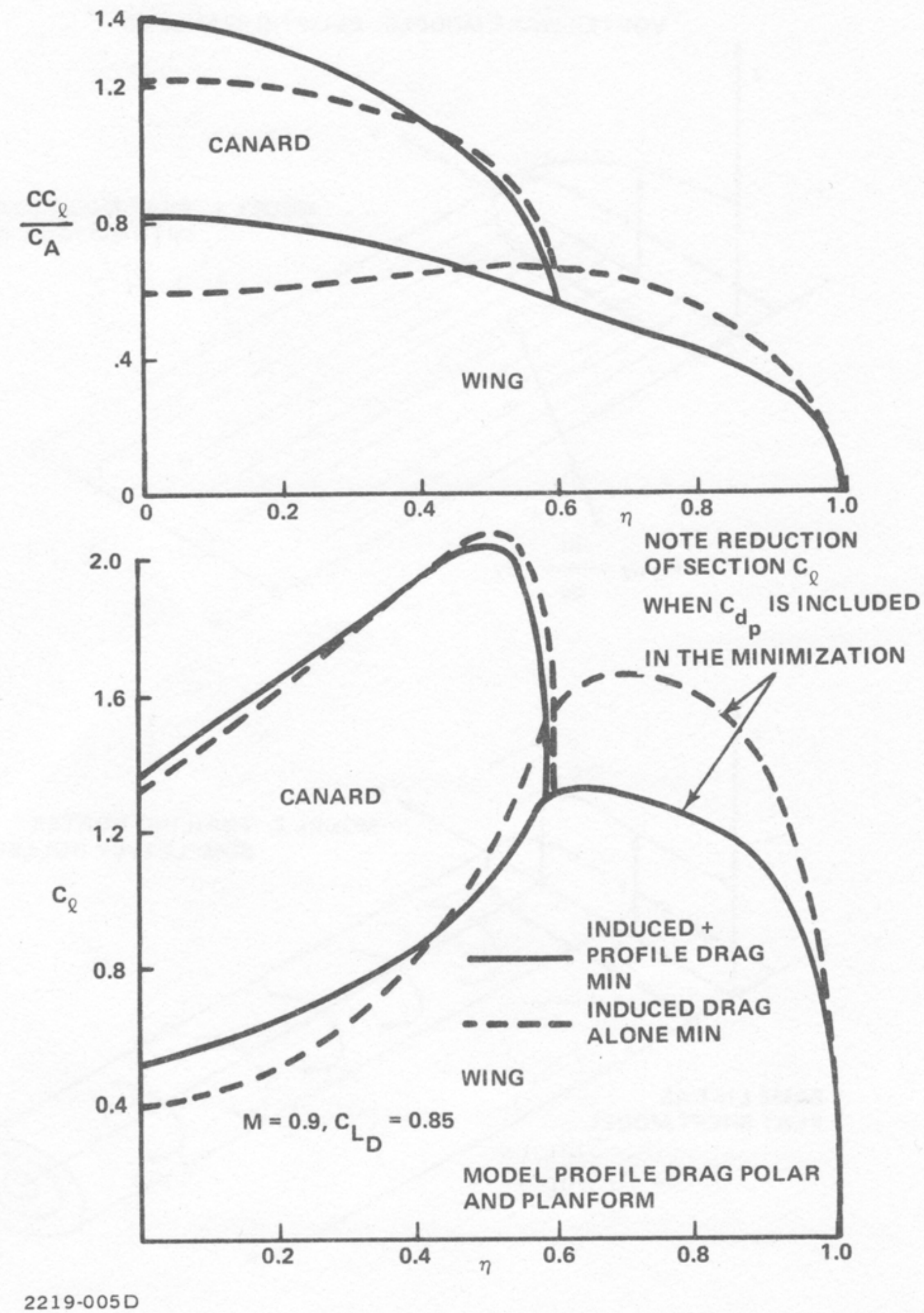
(Drag due to flow separation goes up way faster than non-ideal spanload induced drag)



AIAA 82-0097

LamDES does this: see the software page



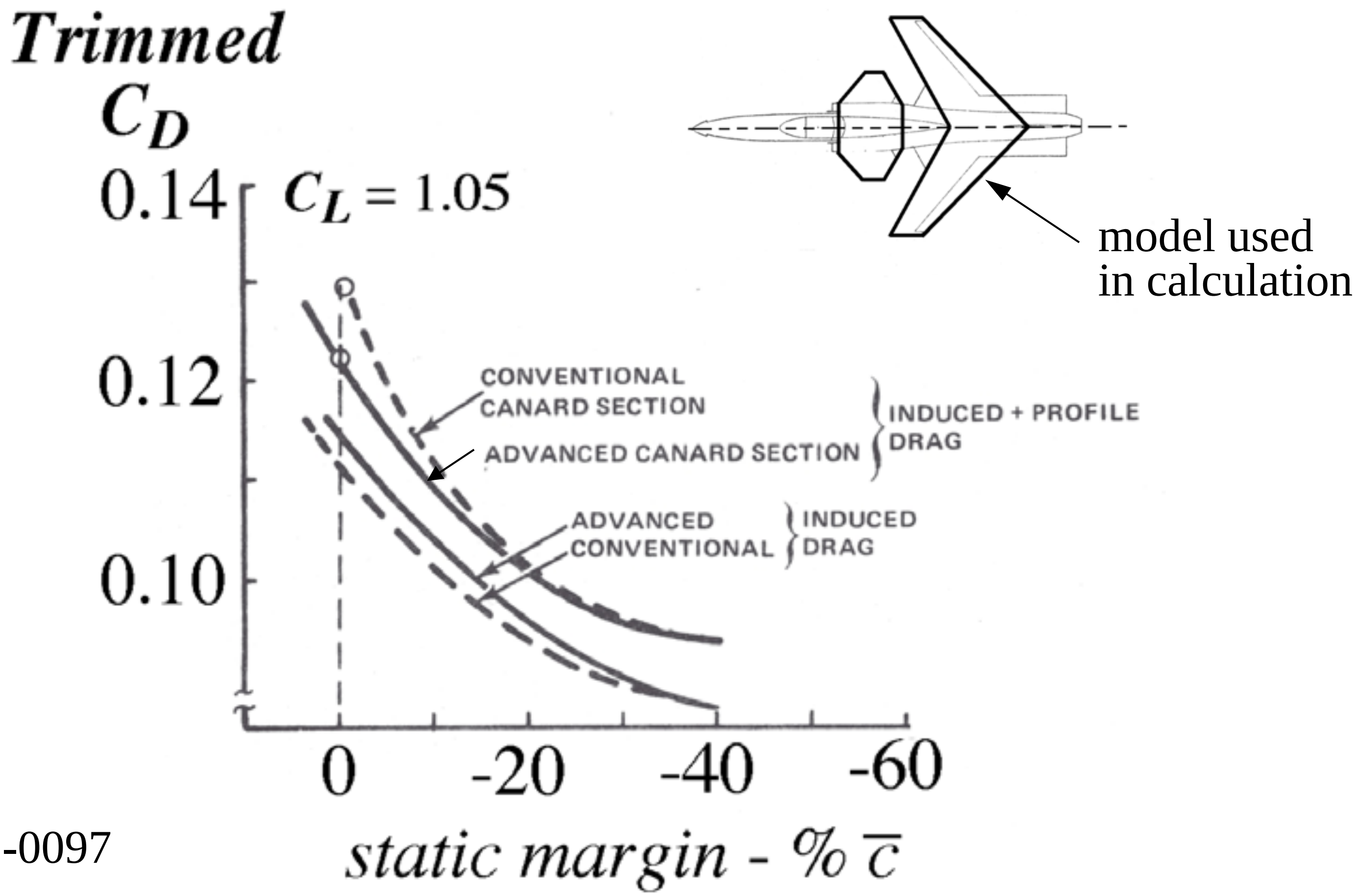


Typical combined wing-canard spanload, showing viscous drag minimized by reducing high section C_l's

AIAA 82-0097

"Linear" VLM finds stability level required for min trimmed drag

- Performance was strongly related to design static stability



AIAA 82-0097

What happened?

You *can* have an attached flow fighter that outperforms the F-16*

- The X-29 had to be 35% unstable
- It had
  - poor stealth characteristics
  - poor supersonic drag characteristics
- By the time it flew, the Air Force wanted
  - stealth
  - supercruise

The X-29 is now a museum piece

US Air Force Museum

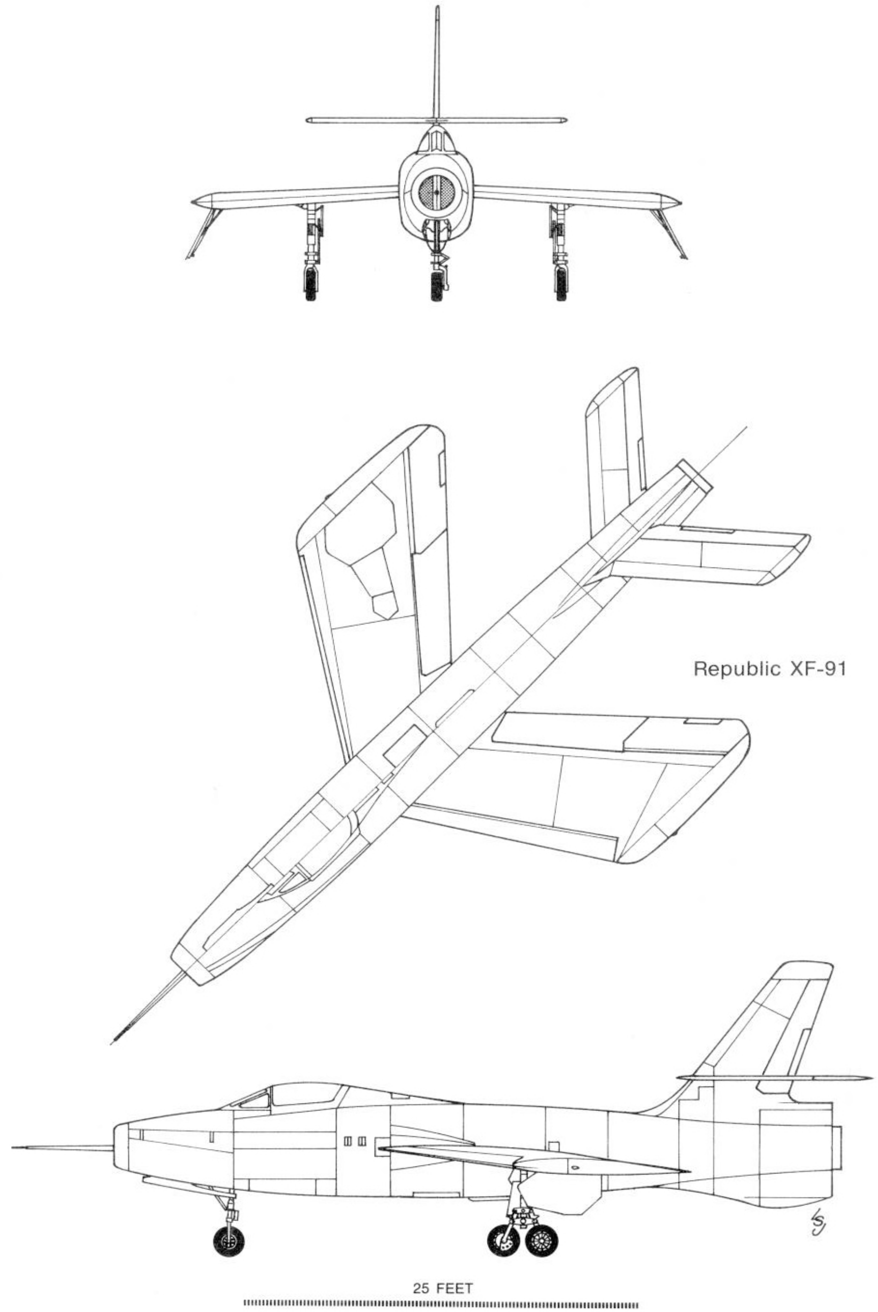
1st flight: Dec. 14, 1984

*Recall the F-16 gets its perf from vortex flow from the strakes

Just in case -
The XF-91 Thunderceptor

Rockets as well as a jet engine,
and a variable incidence wing!
1st flown: May 1949
Two were built by Republic

USAF Museum web site



Lloyd Jones, *U.S. Fighters*

Sergio Iglesias and W. H. Mason, AIAA Paper 2001-5234

The Truth About Elliptic Spanloads

or

Optimum Spanloads Incorporating Wing Structural Weight

The Issue:

- An Elliptic spanload is the best for planar aero
- Is it the best for the whole system?

Note:

- Lots of people have studied this in the past
- Tim Takahashi cautions that this is not always the right trade

Example: R.T. Jones among others let the span vary

TECHNICAL NOTE 2249

THE SPANWISE DISTRIBUTION OF LIFT FOR MINIMUM INDUCED DRAG OF WINGS HAVING A GIVEN LIFT AND A GIVEN BENDING MOMENT

Robert T. Jones

Ames Aeronautical Laboratory

December 1950

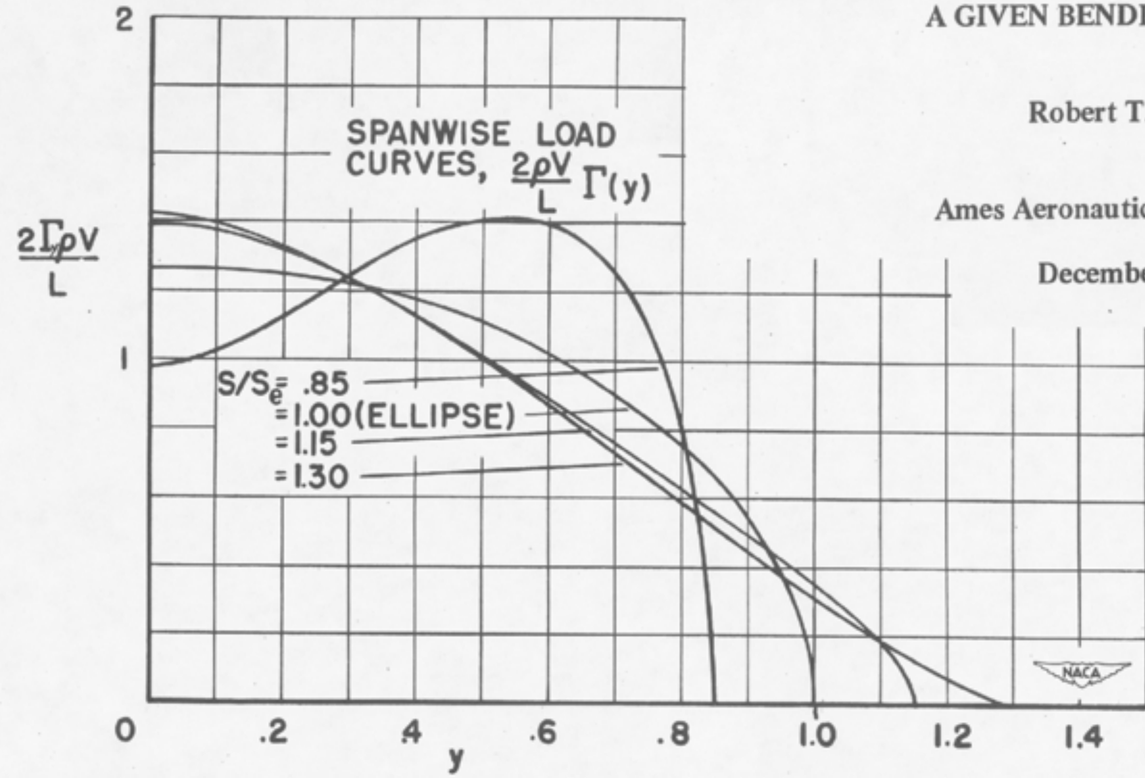


FIGURE 5.- VARIATION OF SHAPE OF THE SPANWISE LOADING CURVE WITH SEMISPAN RATIO S/S_e, FOR WINGS HAVING A FIXED TOTAL LIFT AND A FIXED BENDING MOMENT

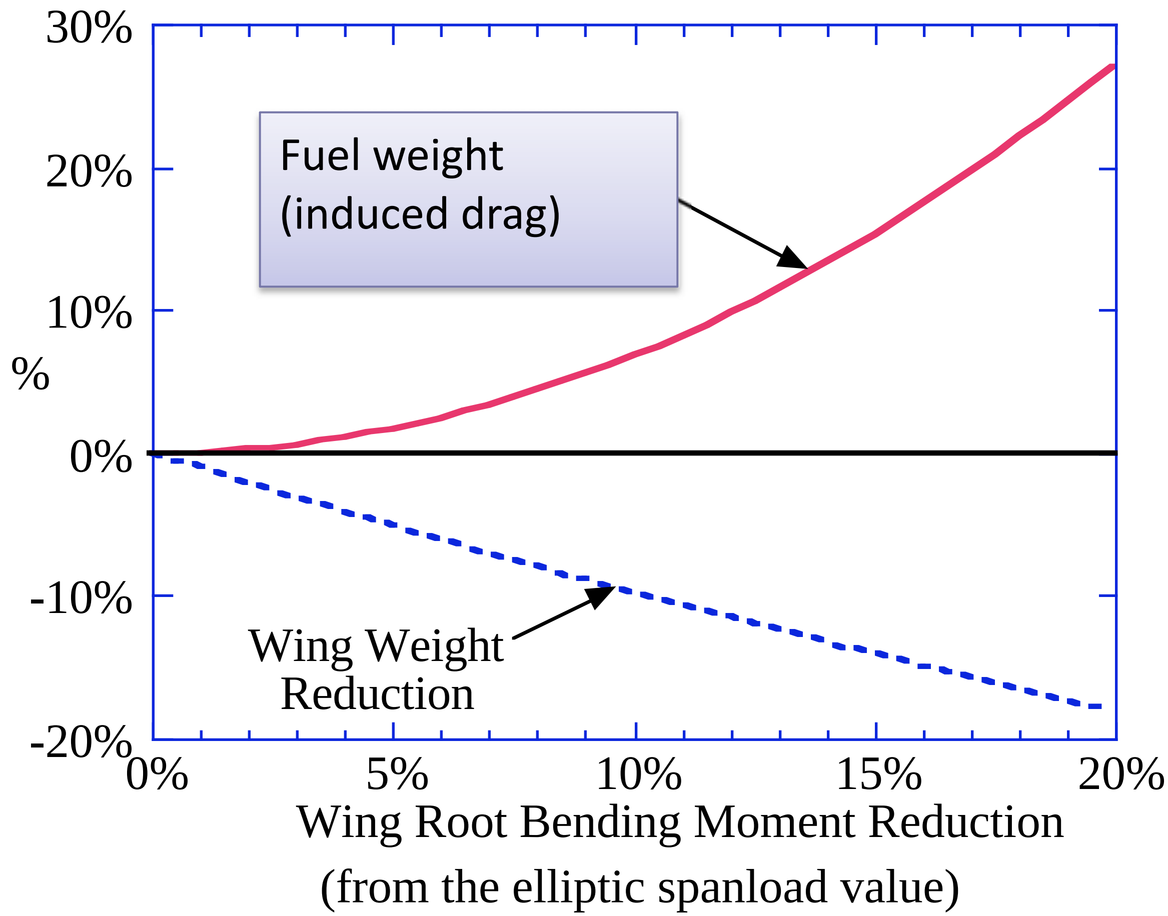
Note: span is a very powerful contributor to induced drag

The model problem

- Minimum induced drag spanloads subject to a wing root bending moment (WRBM) constraint are calculated.
- The wing planform and thickness are held constant (outer loop MDO will treat these).
- The structural constraint (WRBM) is only used to generate spanloads.
- The actual wing weight is calculated using a general structural model where the spanload is one of the inputs.
- Changes in induced drag and wing weight are related to changes in fuel and take-off weights with the help of the Breguet Range equation.

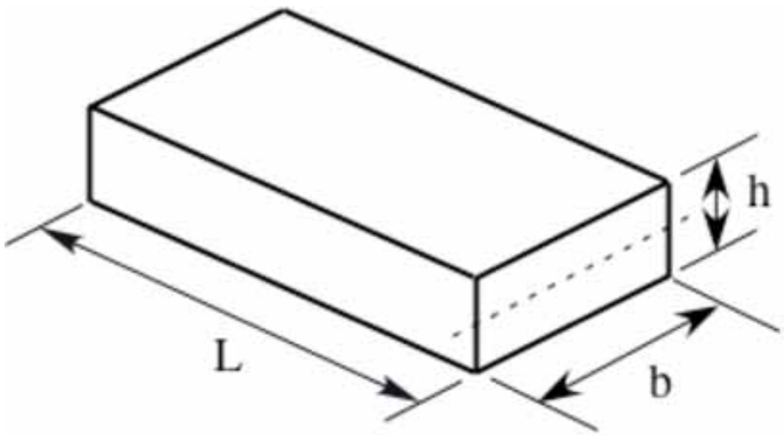
Wing Weight Reduction and Induced Drag Increase. B-777 type aircraft.

- Induced drag (hence fuel weight) increases parabolically from aero optimum.
- Wing weight decrease is nearly linear.
- ***Note!*** Therefore, a small root bending moment reduction will always be beneficial



Why is wing weight linearly proportional to the wing root bending moment?

M is the bending moment, *L* is the span and *h* is *t/c*



$$\sigma = \frac{My}{I}, \quad I = \frac{bh^3}{12}$$

$$\sigma_{allowable} = \frac{M\frac{h}{2}}{\frac{bh^3}{12}} = \frac{6M}{bh^2}$$

$$W \approx bhL \Rightarrow bh \approx \frac{W}{L}$$

$$or \quad bhh = \frac{6M}{\sigma_{allowable}}$$

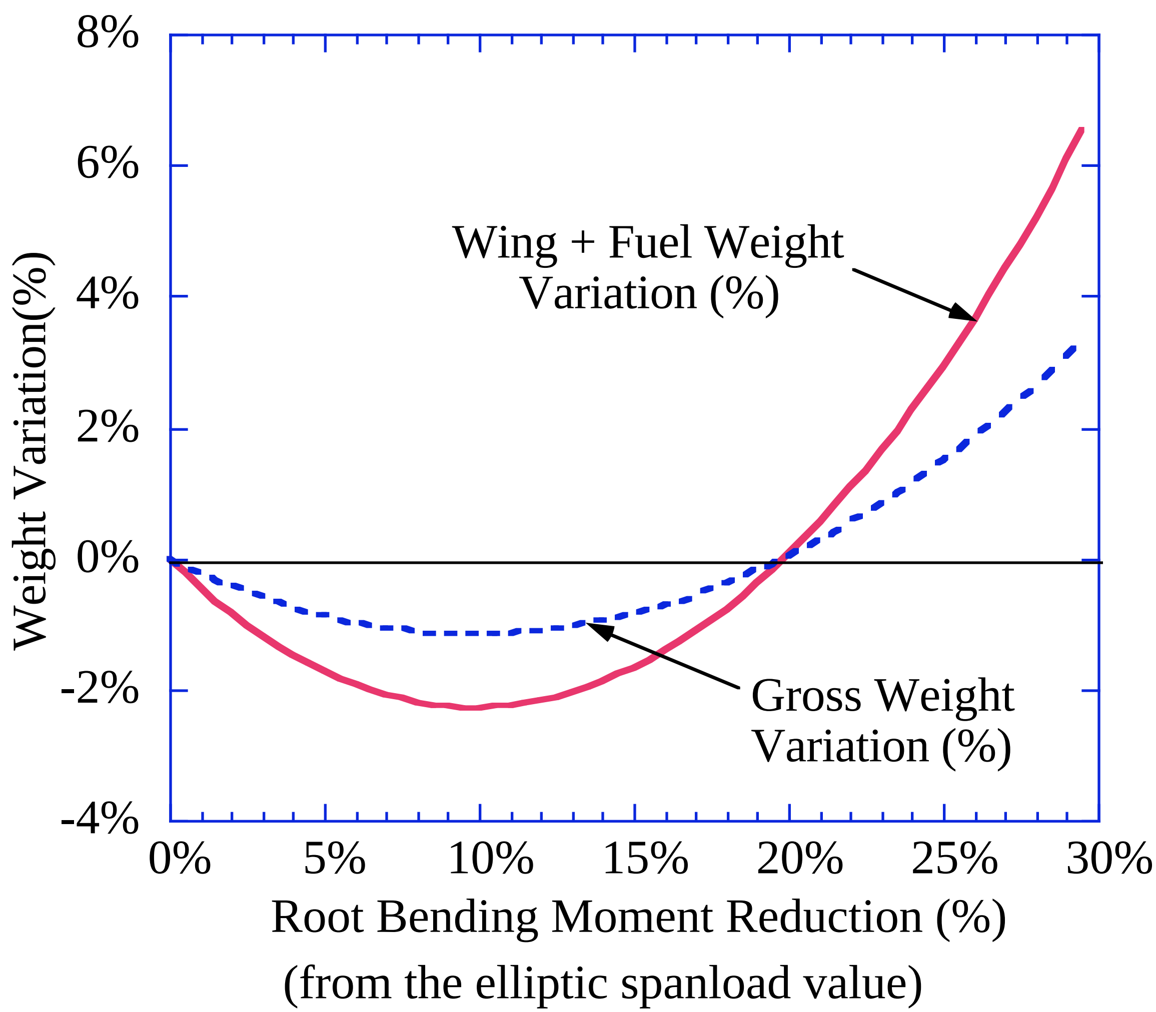
And combining yields:

$$W \approx \frac{L}{h}\frac{M}{\sigma_{allowable}}$$

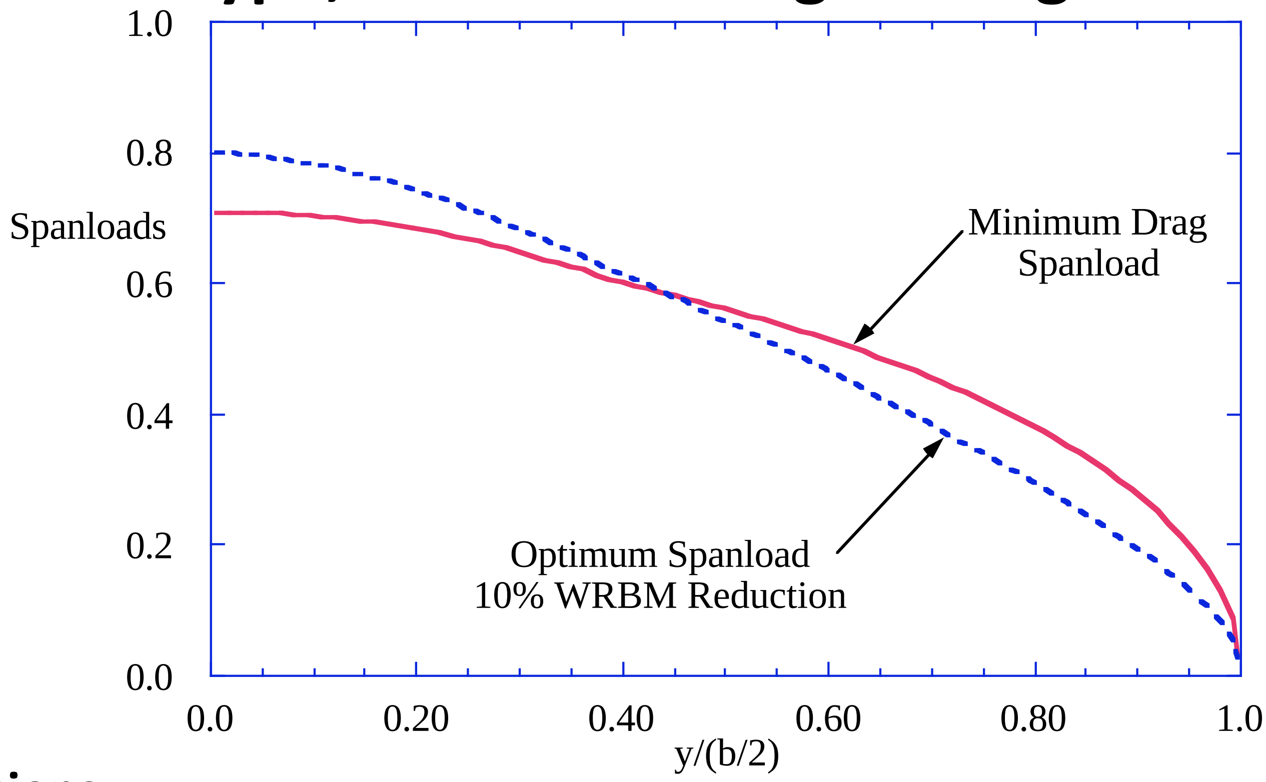
Thanks to Prof. Eric Johnson!

Wing+Fuel and Gross Weight Variation. B-777 type, maximum range configuration.

- Maximum gross weight reductions of about 1% can be obtained.
- Minimum gross weight found for a root bending moment reduction of 10%.
- Shorter range aircraft are expected to experience higher benefits since they are more driven by structures than by aerodynamics.



Spanload for Max TOGW Reduction
B-777 type, maximum range configuration.



Conclusions

- The system minimum will always occur for a spanload with a lower wing root bending moment than the aerodynamic optimum.
- Larger take-off weight reductions can be achieved for reduced mission ranges (structural weight dominated case)
- The actual optimum spanoad depends on the specific mission.

Flying Wings Have Their Own Issues

To read in detail, see Bob Liebeck, *Journal of Aircraft*, Jan-Feb. 2004

The “now-Boeing” BWB concept

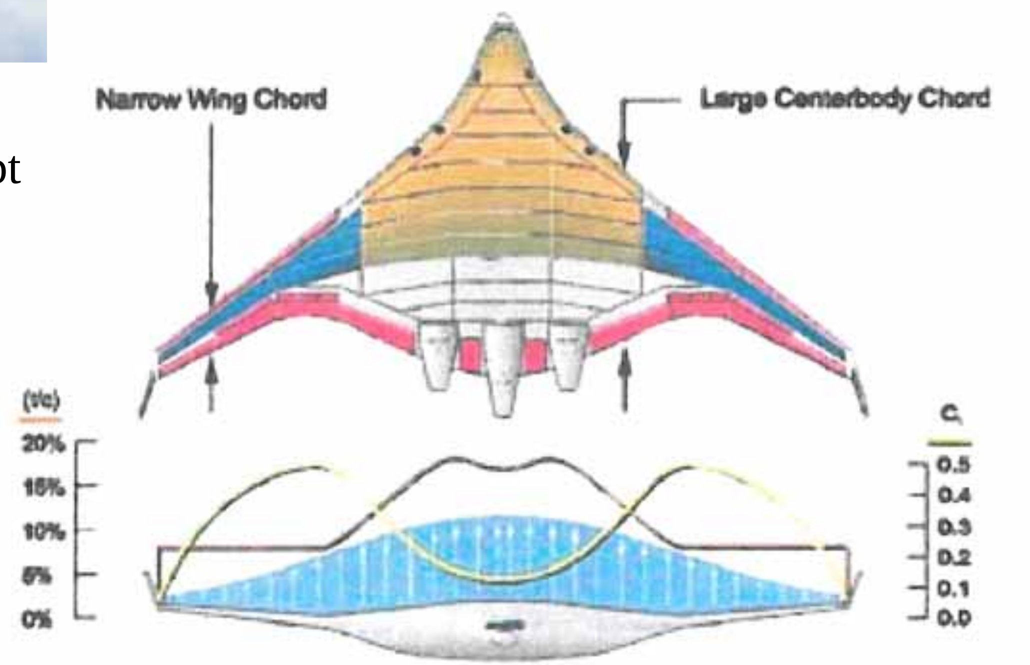


Fig. 11 Section lift coefficient and thickness-to-chord ratio variation with span.

Note: many stable flying wings actually have a negative lift outboard, see the AIAA book on Tailless Aircraft, Karl Nickel and Michael Wohfahrt, *Tailless Aircraft in Theory and Practice*, AIAA, Washington, 1994

To Conclude
What did we learn?

- The concept dictates how to think about spanloads
- Understanding dictates the aero targets
- Think!