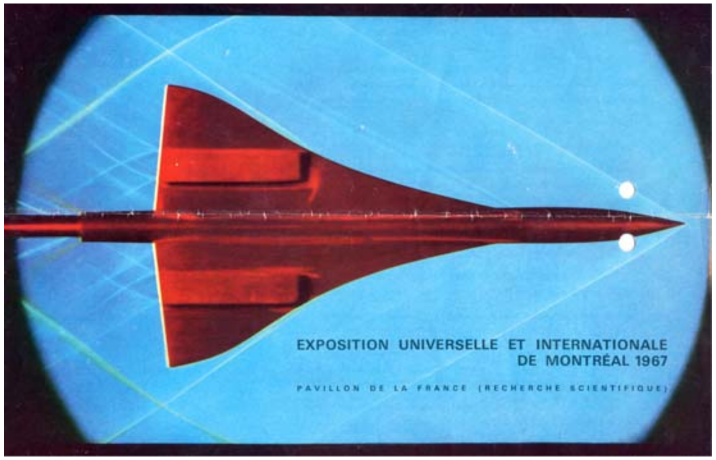

AOE 2104
A Lecture
on
Airplanes/Aerodynamics

W.H. Mason
October 31, 2006

Aerospace and
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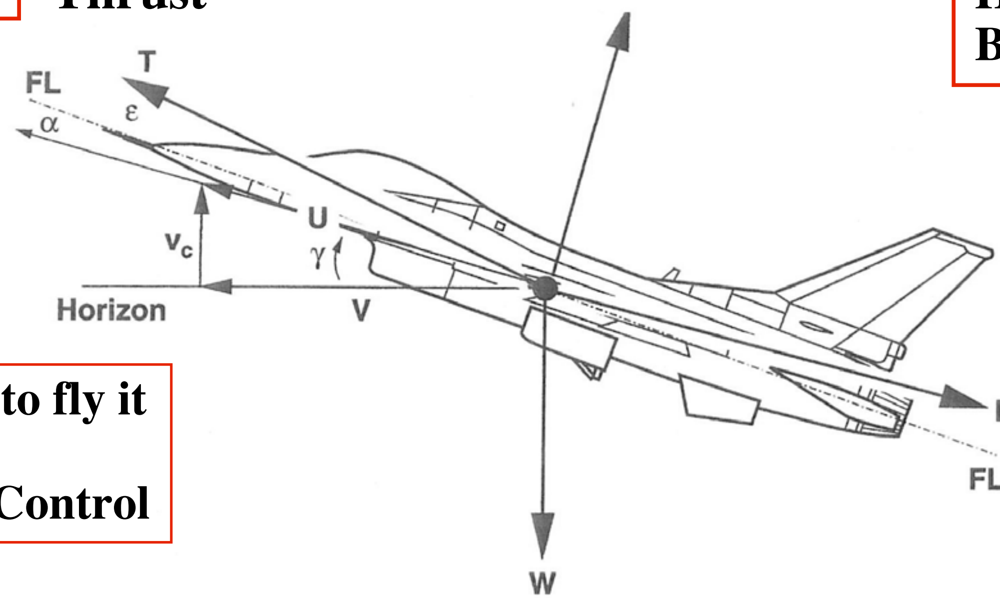
What's It all About?

Propulsion
(Thermo)

Thrust

Lift

Aerodynamics
High Speed Aero
Boundary Layer



Drag

And we need to fly it
- Dynamics
- Stability & Control

Weight

Materials
Structures

And make it green
- Noise
- Emissions

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Making it Quantitative

From *Performance Class*, the specific range:

$$\frac{mn\,range}{lb\,of\ fuel} = sr = \frac{V}{sfc}\left(\frac{L}{D}\right)\frac{1}{W}$$

V = velocity - speed!
sfc = lbs of fuel burned per lb of thrust - efficient propulsion!
L/D = Lift/Drag ratio - high L/D!
W = weight of the plane - low weight!

Putting it All Together

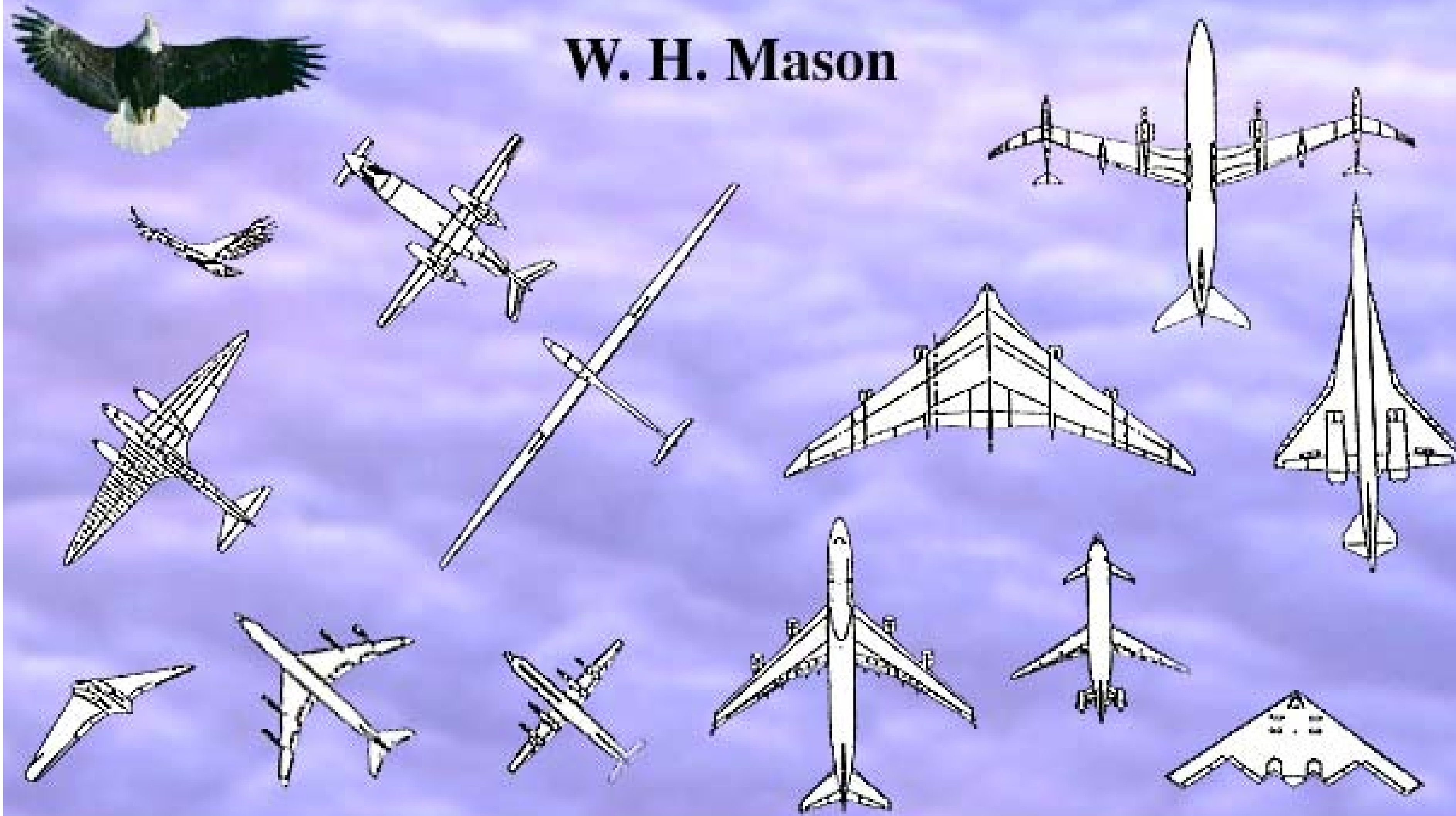
- First: ***Design the plane - Senior Design Class***
- Then ***Test the Concept - Aero Lab Classes***
  - Computational simulations
  - Wind tunnel testing for aerodynamics
  - Subscale flight tests
  - Full scale flight testing
- Note: Lots of other tests:
  - Systems
  - Structures
  - Flight Control: The Iron Bird

Some Connections: Mason's Classes

- Aircraft Design Class - 2 semester senior class
- Configuration Aerodynamics - a senior elective
- A Common Theme
  - Why are airplanes different shapes and sizes?

Why Airplanes Look Like They Do

W. H. Mason



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collage from John McMasters

Designer

Technology advances?

A new capability someone might pay to have?

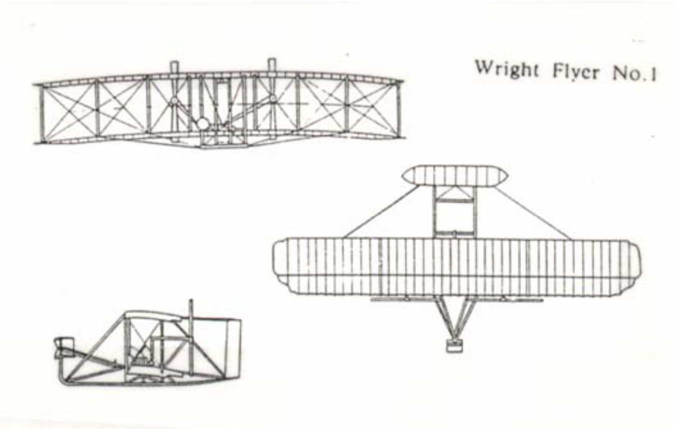
How to exploit technology for capability?

Configuration Concept

Airplane Shapes Have Changed to Exploit Advances in Technology

Configuration Concept:

- Payload
- Lifting surface arrangement
- Control surface(s) location
- Propulsion system selection
- Landing Gear



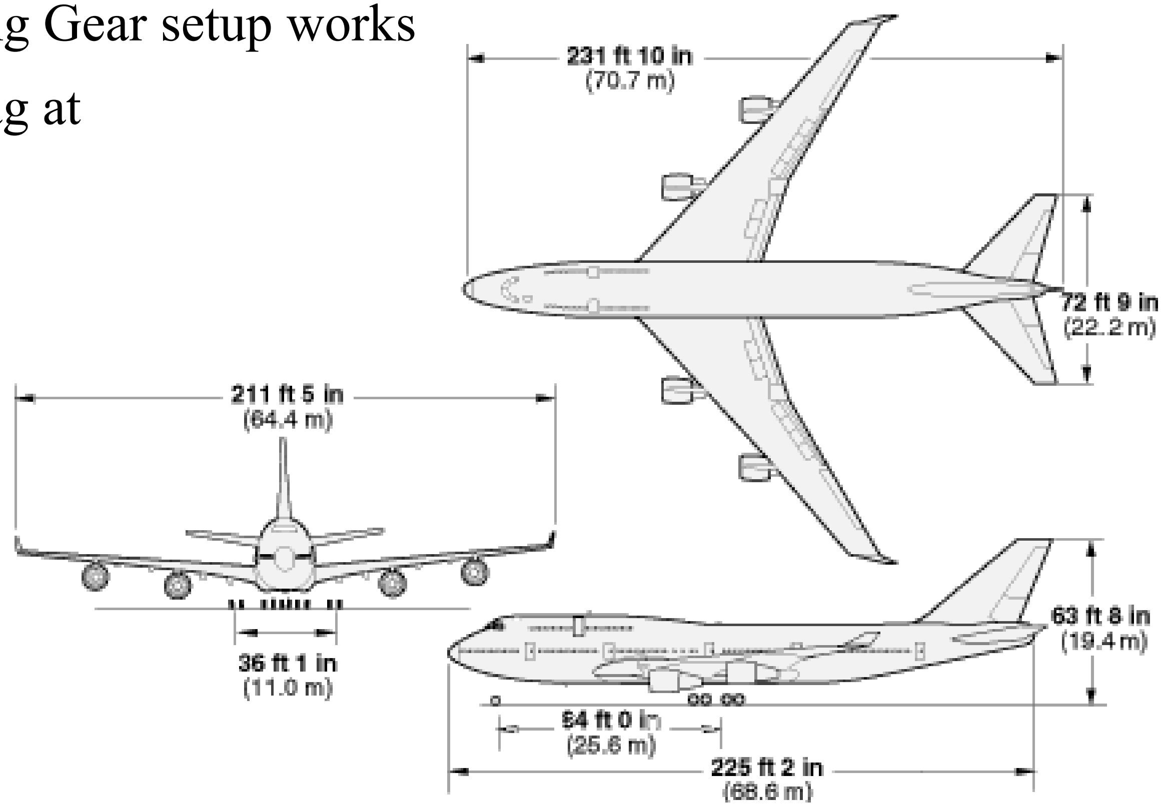
Wright Brothers:

- Innovative control concept (more important than stability)
- "Light weight" propulsion
- Continual design evolution/refinement

Amazingly Tricky to Integrate Advances in Each Technology

Conventional Subsonic - A Baseline

- Payload distributed around *cg* (center of gravity)
- Longitudinal control power from tail (with moment arm)
- Vertical Tail for directional stability, rudder for control
- Wing/Fuselage/Landing Gear setup works
- Minimum trimmed drag at near neutral stability



Boeing 747-400, source: www.boeing.com

Why Sweep the Wing?

Subsonic (usually small)

- Adjust wing aerodynamic center* relative to *cg*
- On flying wing, get moment arm length for control

Transonic (significant, 30°-35°)

- Delay drag rise Mach (compressibility effect)
  - definition of the drag divergence Mach no.?

Supersonic (large, 45°-70°)

- Wing concept changes,
  - must distribute load longitudinally as well as laterally
- reduce cross-sectional area and area variation

Wing sweep increases wing weight for fixed span

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*the aerodynamic center, *ac*, is the longitudinal station about which the pitching moment is constant as the lift changes.

The classic large airplane: The Boeing 747

source: www.boeing.com

Why Canards?

- said that trim surface carries positive load for positive *g* maneuvers
- reduces subsonic-supersonic *ac* shift
- drawback: downwash from canard unloads wing
  (for forward swept wing this is good)
- if balanced stable,* C_L on canard is much higher than the wing
- balanced unstable, control system design very expensive
- acceptable high angle of attack lateral/directional characteristics hard to obtain
- When to use?
  - severe supersonic cruise/transonic maneuver requirement

*Stability is important. A stable airplane returns to its basic flight condition when disturbed, while an unstable airplane needs a flight computer, a so-called stability augmentation system, to fly well.

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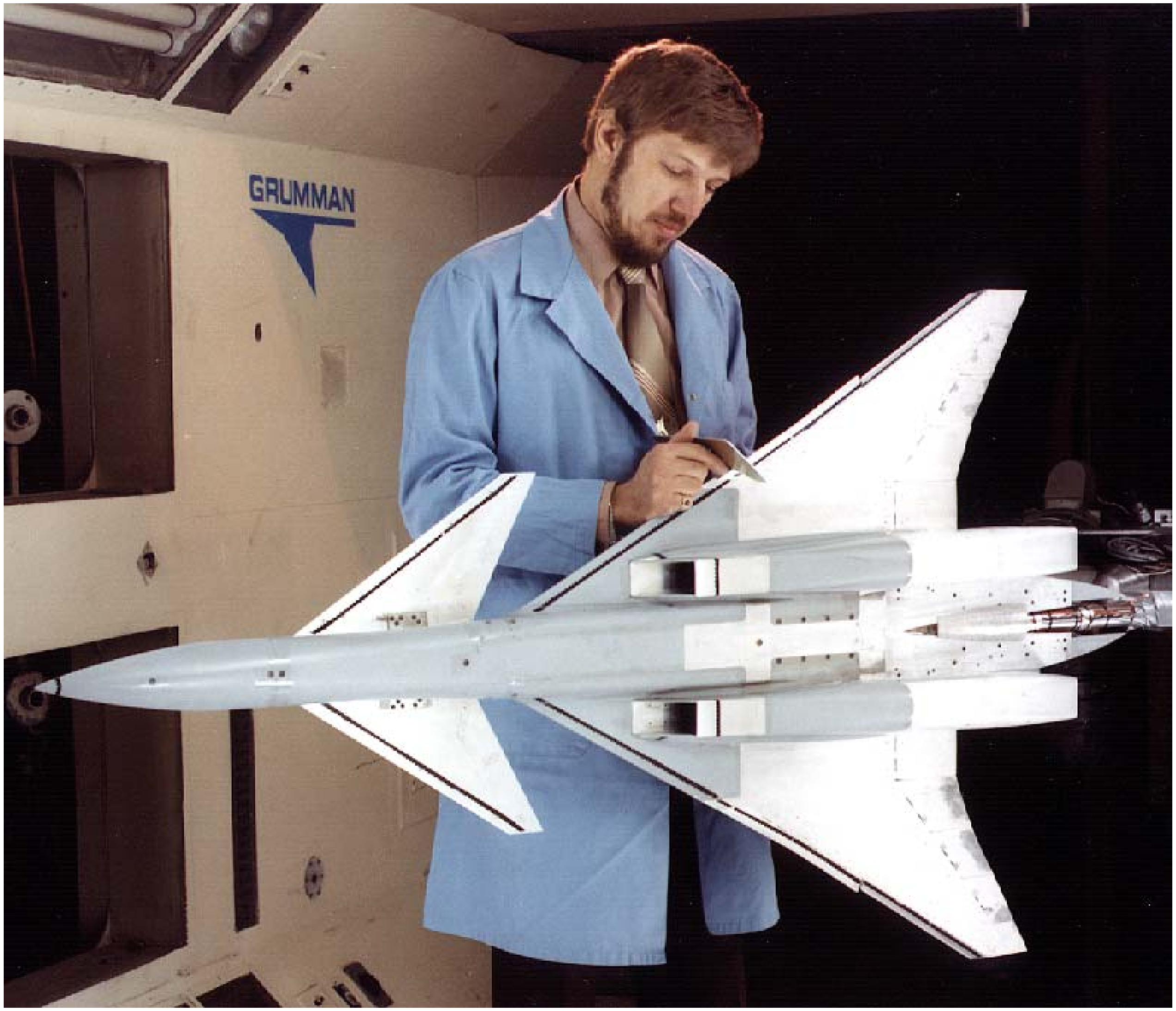
The Grumman Research Fighter



designed by Nathan Kirschbaum, Ron Hendrickson in pix

Why a Flying Wing?

- removing fuselage must improve aero efficiency
  - But, payload volume distribution is still an issue
- synergistic effect with relaxed static stability
- military: stealth
- commercial: distribute load, reduce weight

Example: XB-35, YB-49, B-2

The B-2 Stealth Bomber

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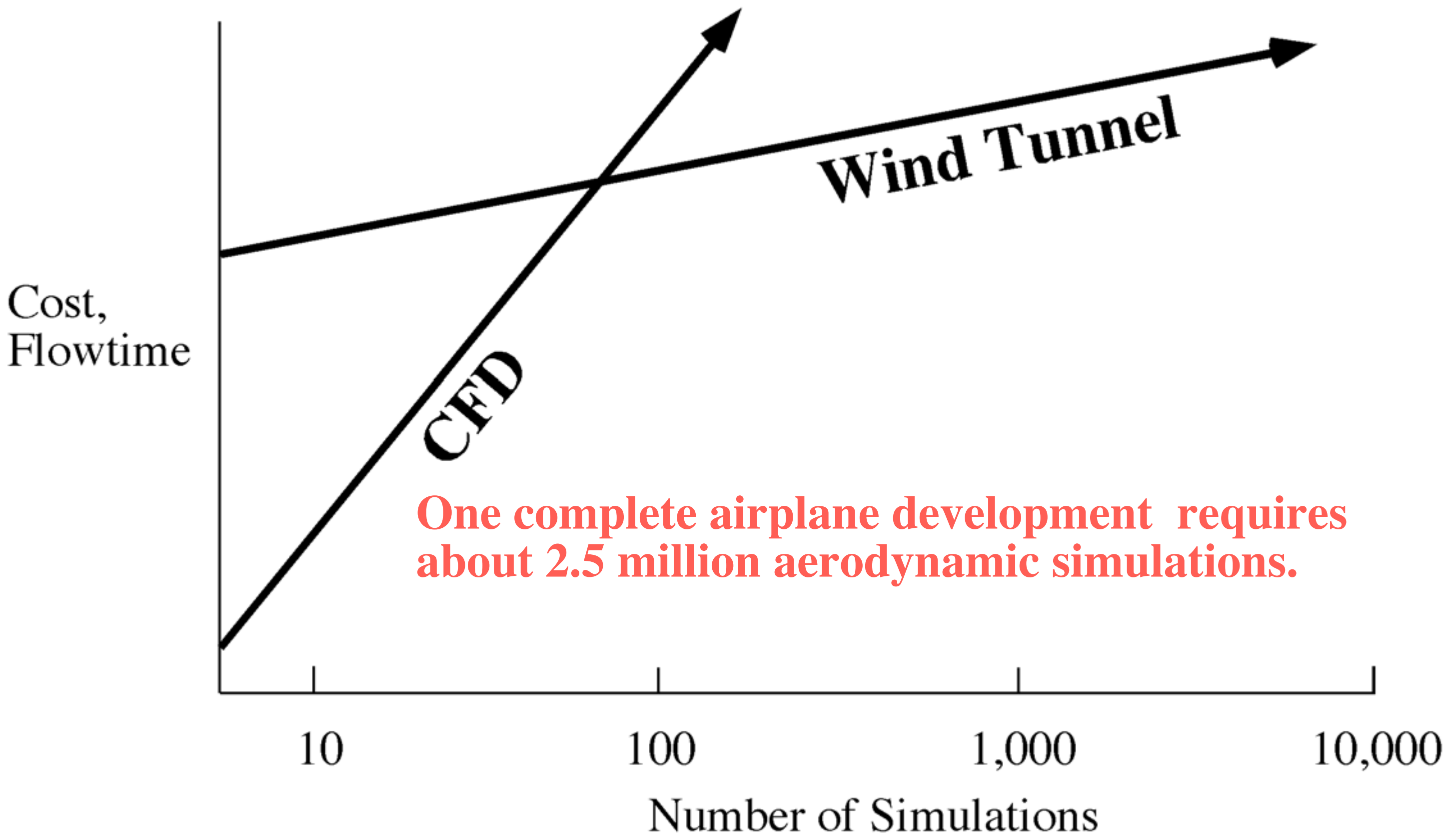
Computational Design Used Today

- Disciplines integrated:
  - Not the optimum aerodynamic design
  - Not the optimum structural design
  - *The Best Total System Design*
- Known as MDO
  - Multidisciplinary Design Optimization

So Will the Computer Eliminate the WT?

E.N. Tinoco, (Boeing) “The Impact of CFD in Aircraft Design,”
Canadian Aeronautics and Space Journal, Sept., 1998, pp. 132-144



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Comptational Simulations and WT Testing are Complimentary

- Both have strengths and weaknesses
- Solving a real problem requires both

Key Idea of a Wind Tunnel Test

Simulate the full scale design at reduced scale, low cost, and controlled conditions

Key Concept:

- Model is fixed, air moves

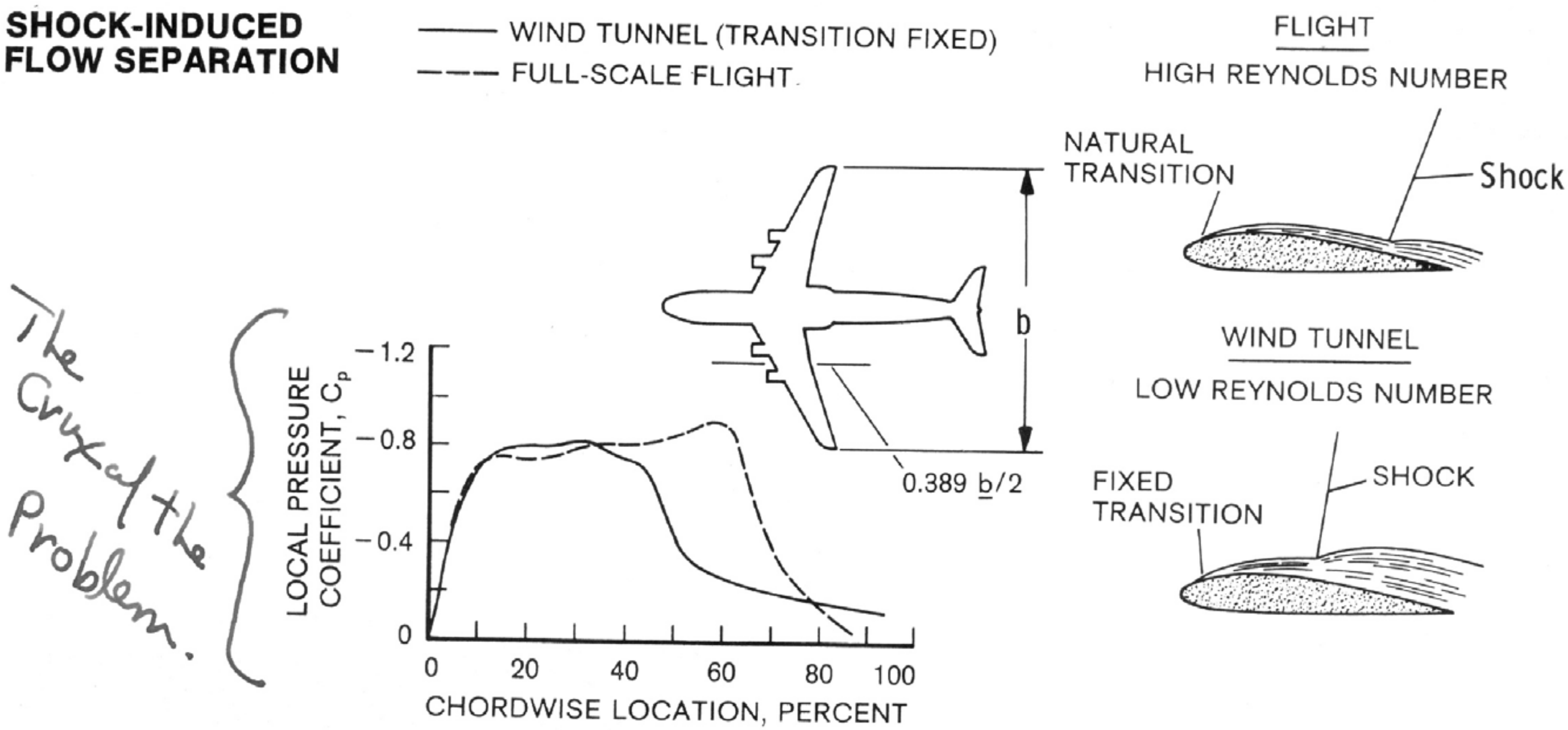
Same as?

- Air fixed, airplane moves

Similarity

- *Reynolds Number (Re)*
  - To simulate the viscous effects correctly, match the Reynolds Number
  - But you most likely can't match the Reynolds number, we'll show you why and what aeros do about the problem
- *Mach Number (M)*
  - You are not going to get accurate aero data for supersonic flight with a subsonic test!
  - To match model to full scale compressibility effects, test at the same Mach number, sub-scale and full scale

Example of the Re Issue



"The Need for developing a High Reynolds Number Transonic WT"
Astronautics and Aeronautics, April 1971, pp. 65-70

Matching the Reynold's Number?

$$Re = \frac{\rho V L}{\mu}$$

ρ: density, V: velocity, L: length, μ: viscosity,

$$\frac{Re_{fs}}{Re_m} = \left(\frac{\rho_{fs}}{\rho_m}\right)\left|\frac{V_{fs}}{V_m}\right|\left|\frac{L_{fs}}{L_m}\right| \frac{1}{\left|\frac{\mu_{fs}}{\mu_m}\right|}$$

fs: full scale
m : model

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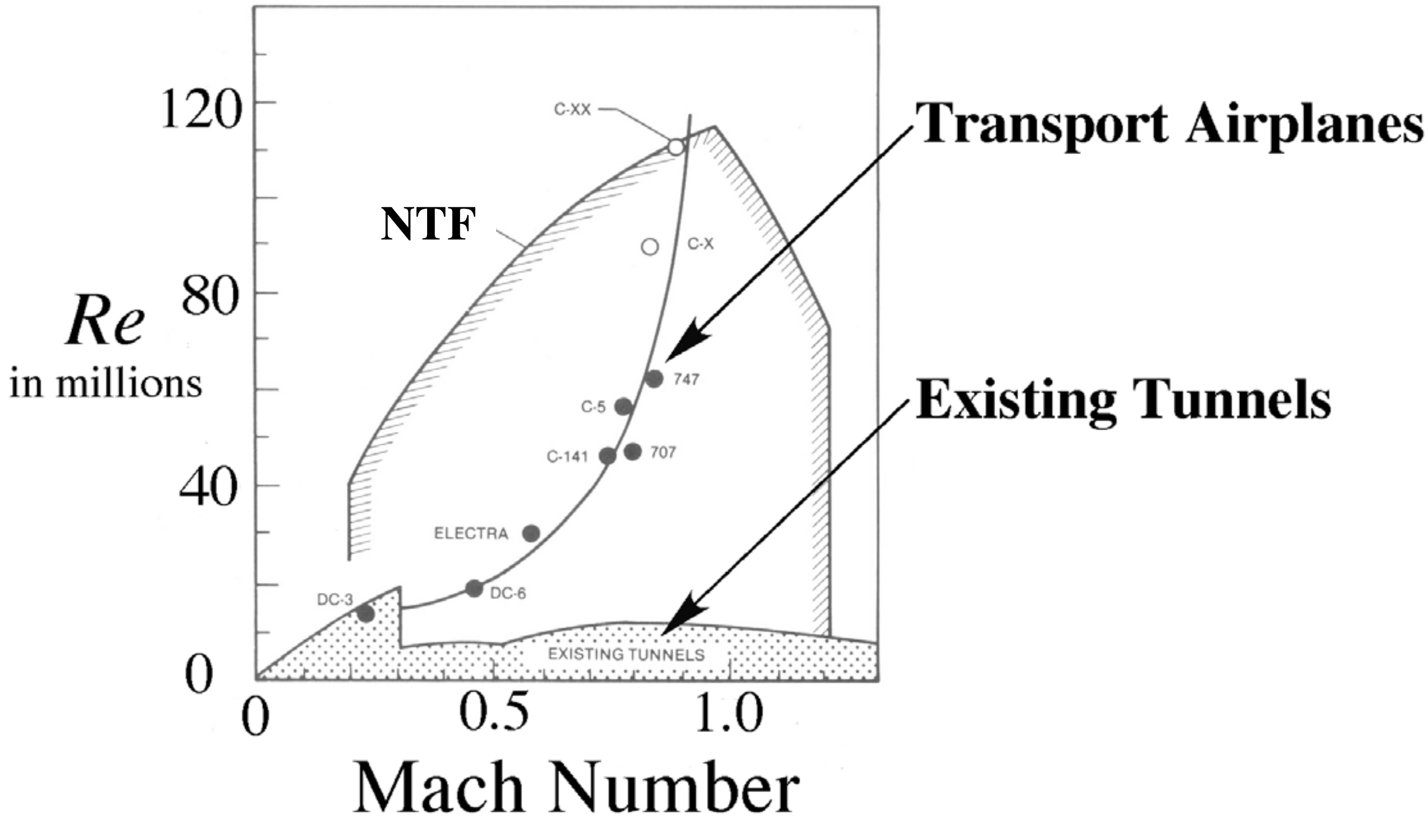
WT vs Flight
- why the NTF was built -

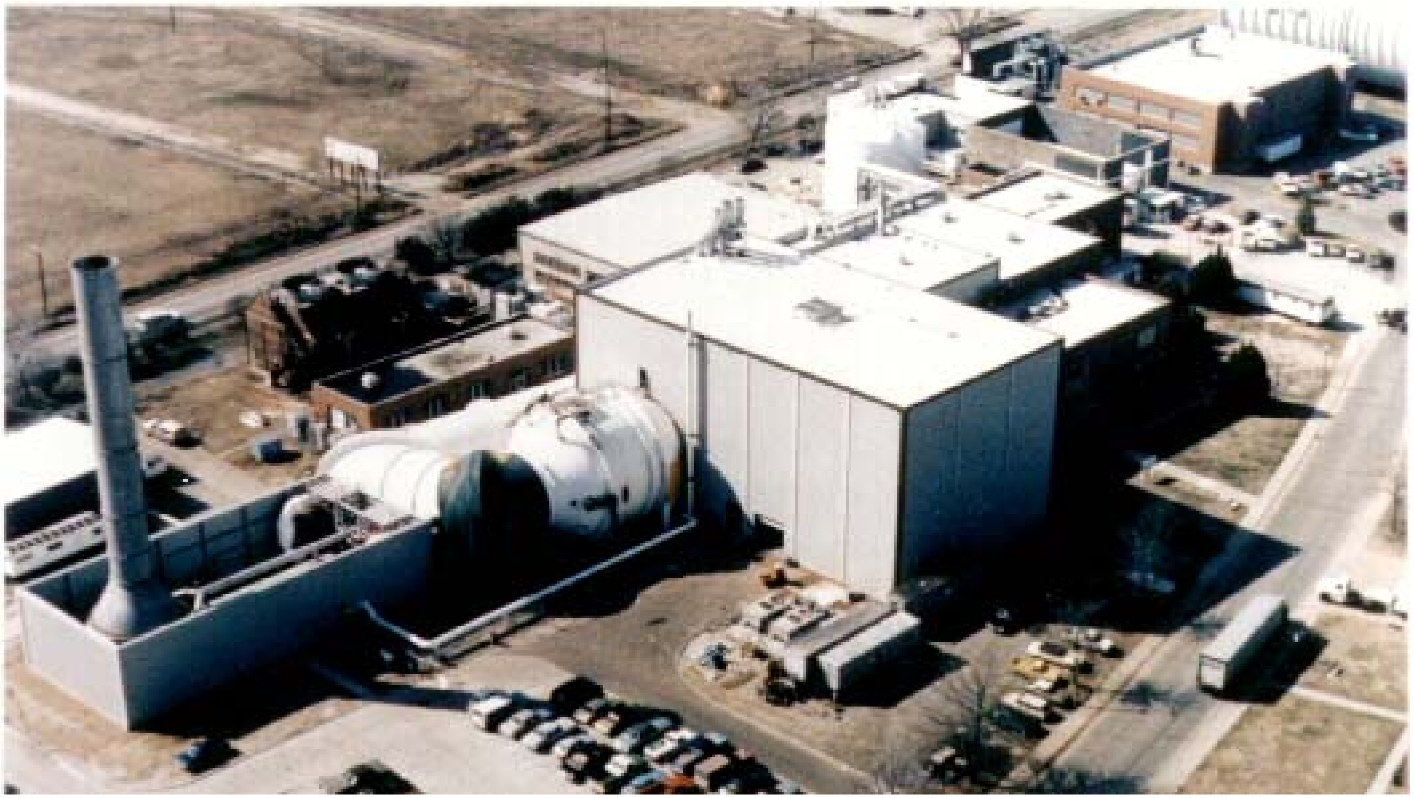


"The Large Second Generation of Cryogenic Tunnels"
Astronautics and Aeronautics, Octoberl 1971, pp. 38-51

What's the Problem?

- Suppose we have a 20th scale model: $L_m/L_{fs} = 0.05$
  - Can we make $V_m = 20V_{fs}$? - Mach number would be different!
  - Can we change ρ? μ? - yes: make air cold or high pressure
- **Ways to help Reynolds number match:**
  - ***Cold*** Wind Tunnels
    - » Also keeps dynamic pressure "reasonable"
    - » Also reduces power requirements
  - ***Big*** Wind Tunnels
  - Games with the boundary layer
    - » Force transition from laminar to turbulent flow: "trips"

Trying to match flight Re using cryogenic nitrogen: The NTF at NASA Langley, Hampton, VA

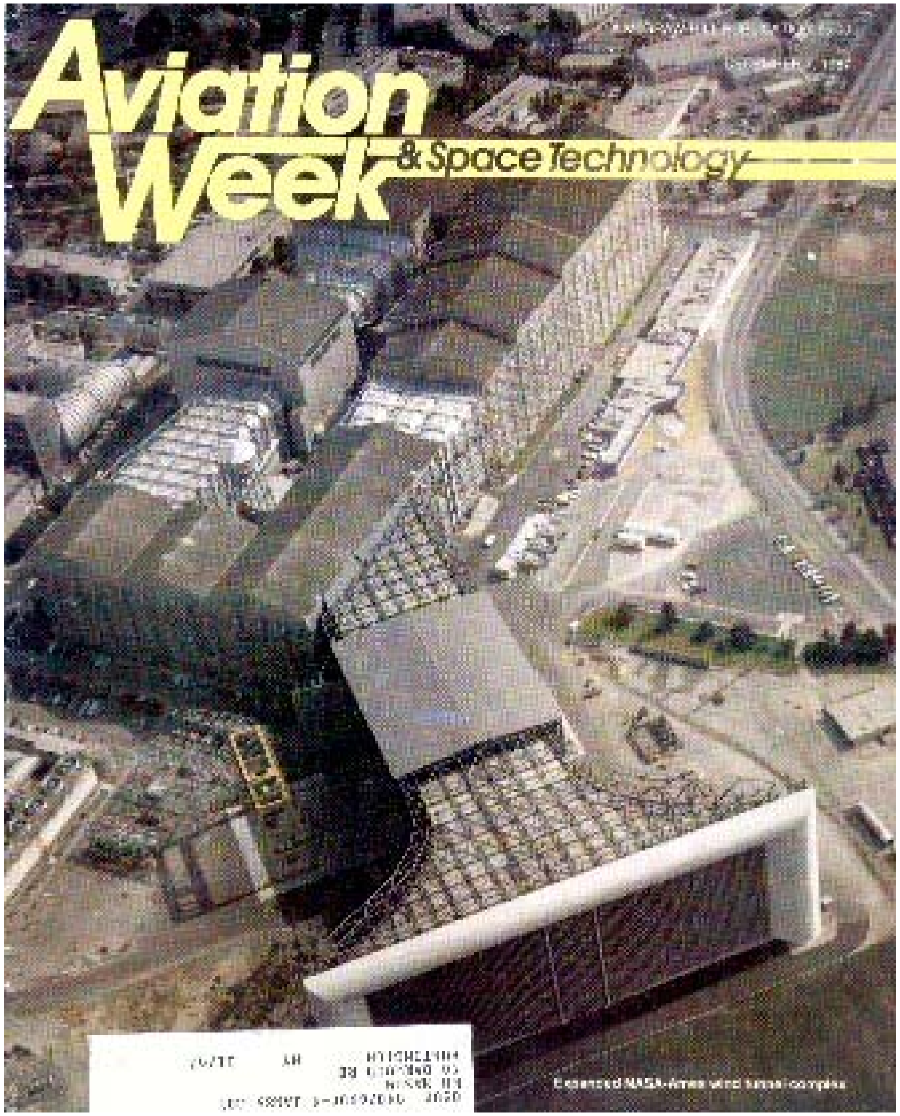


Feb. 1982

Performance: $M = 0.2$ to 1.20
$P_T = 1$ to 9 atm
$T_T = 77°$ to $350°$ Kelvin

Big Models: Full Scale WT at NASA Ames

40x80 Foot
Test Section



80x120 Foot
Test Section

Aviation Week & Space Technology, Dec. 7, 1987

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Sue Grafton with RFC at NASA Langley

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RFC in the 30x60 at Langley: static tests

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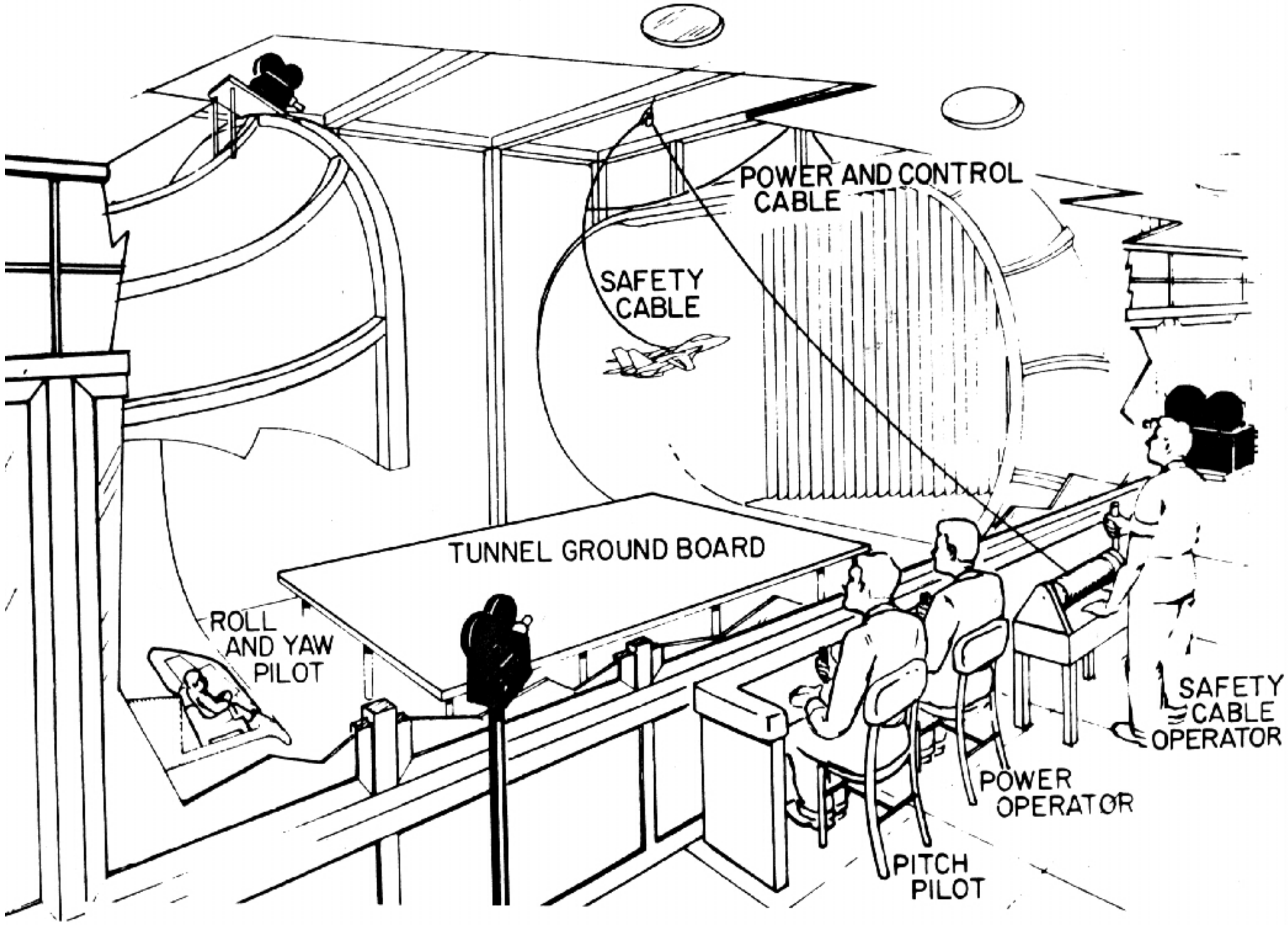
Free Flight Setup: A complicated activity



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RFC Model in Free Flight at Langley

Flight Test

Subscale demonstration of an oblique wing airplane

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Flight Test

- *The X-45A from last November*

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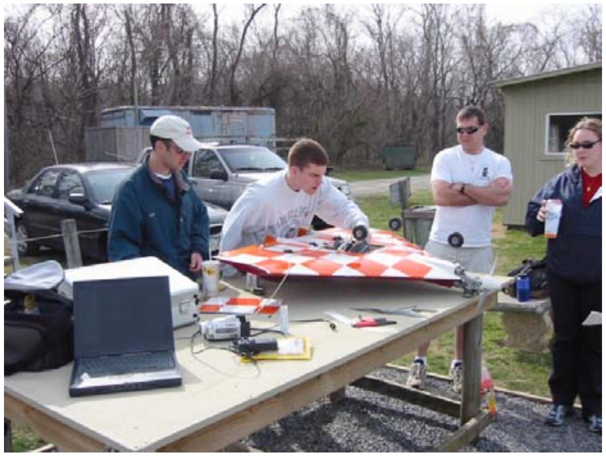
Find movies on the NASA Dryden web site:
http://www.dfrc.nasa.gov/gallery/Movie/index.html

Flight Test at VT: March 14, 2003



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A senior ME/AE Design Team

Full scale flight test the X-29

X-35 Flight Test Leading to the F-35!

Tech's Human Powered Airplane Model

October 26, 2006

http://www.aoe.vt.edu/design/hpa/video.php

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And A Few Novel Concepts

- **Blended Wing-Body Concept**
  - Concept from Bob Liebeck (Douglas A/C)
  - Less wetted area (no fuselage)
  - Possibly more efficient structure

- **Oblique Wing Supersonic Transport**
  - concept by R.T. Jones
  - fore-aft symmetry of lift/better area distribution
  - possibly only "practical" SST
  - flying wing version also

AD-1, Circa 1980

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SpaceShipOne

Burt Rutan: Still imagineering!

SpaceShipOne

The White Knight

Pictures from the
Scaled Composites web site

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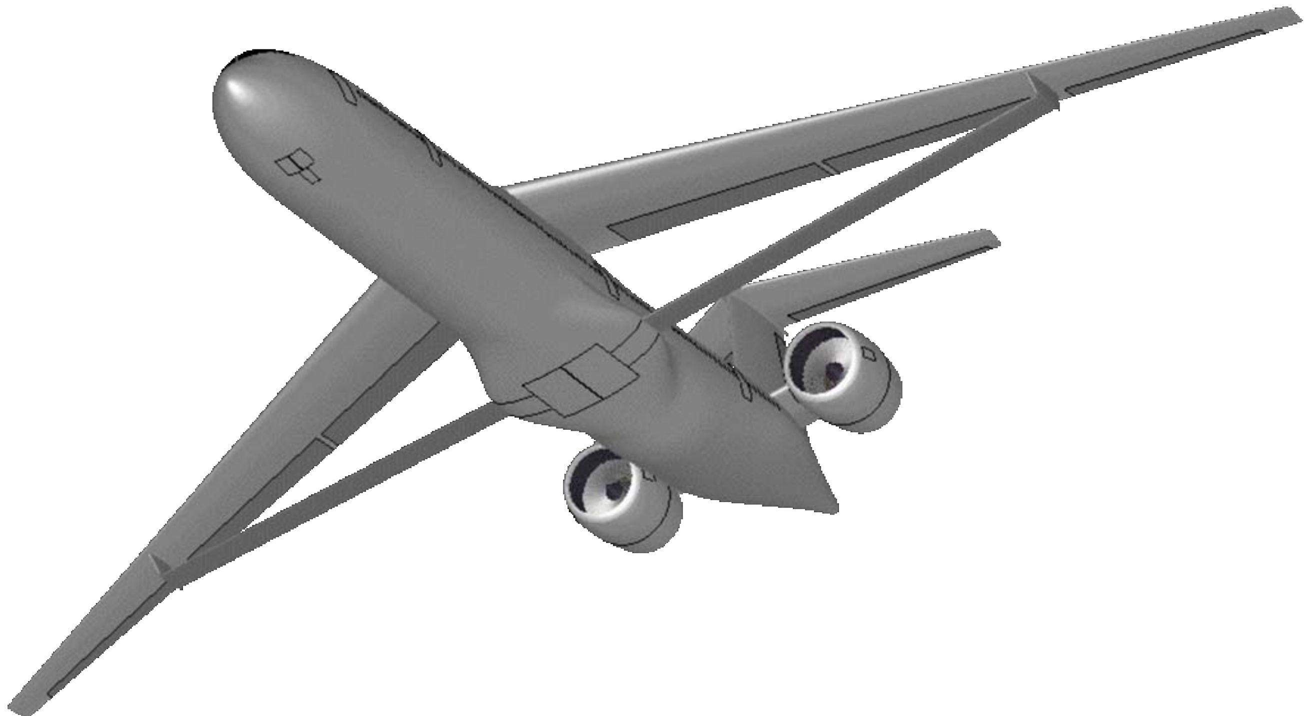
Our Current Favorite: the Strut Braced Wing

- Werner Pfenninger's strut-braced wing concept from 1954
- We need MDO to make it work

- The strut allows a thinner wing without a weight penalty
  - and also a higher aspect ratio, 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

Was proposed as an X-plane

Lockheed, Virginia Tech, NASA Team



Compared to a conventional cantilever design:

- 12-15% less takeoff weight
- 20-29% less fuel
- less noise and emissions

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And Hope for Low-Sonic Boom Noise Flight

A modified F-5E demonstrated a low-noise boom on Aug. 27, 2003

So-called "boom shaping" can be used to reduce the part of the boom that hits the ground.

NASA Press Release, Sept. 4, 2003

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.

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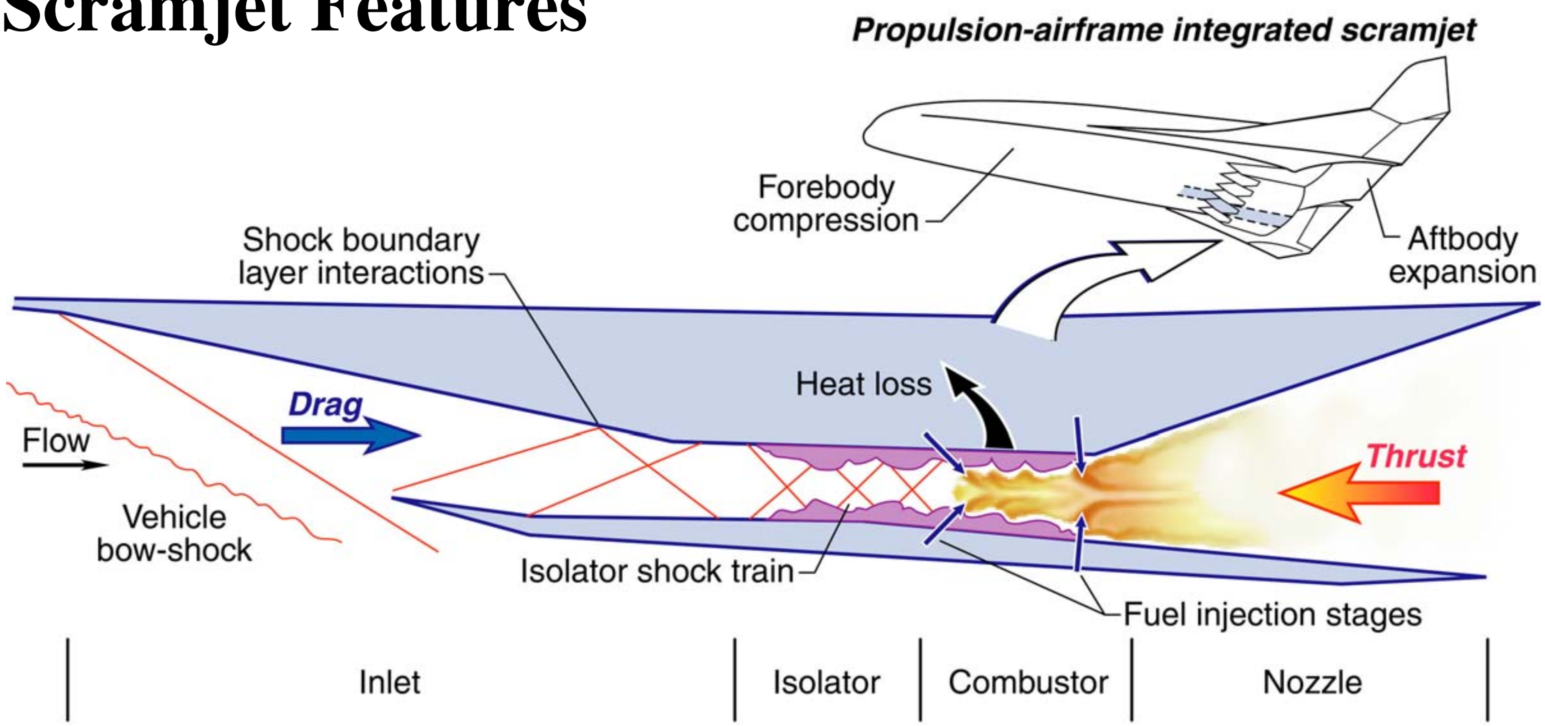
And Hypersonics - The X-43

Scramjet Features



Important Terms/Concepts for the X-43 Experiment

Inlet starting

Ignition/Flameout/Flameholding

Combustor/isolator interaction

Fuel equivalence ratio/Φ

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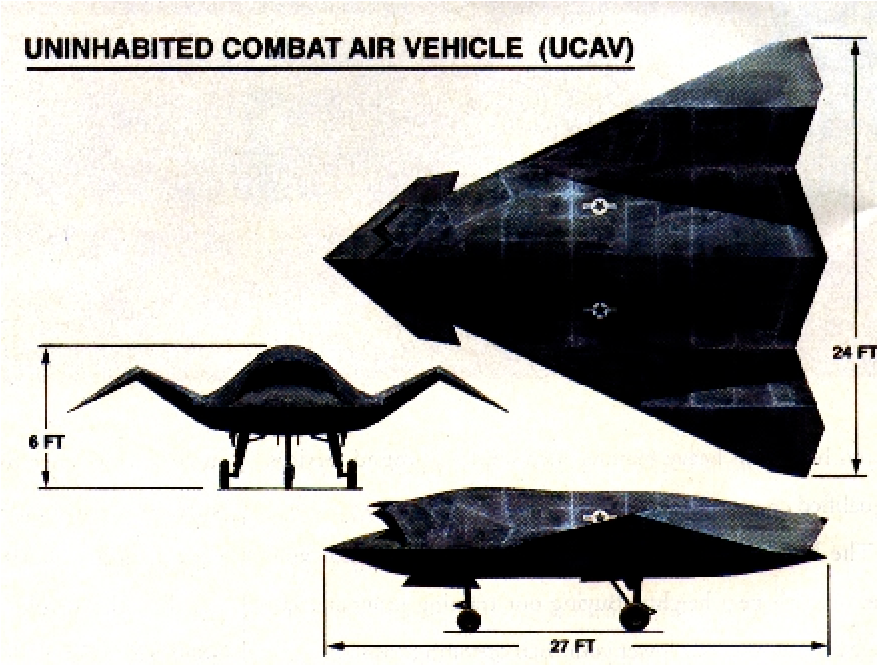
The Latest: UCAVs

This one is based on
Nastasi/Kirschbaum/Burhans Patent 5,542,625



Northrop Grumman Corporation, reprinted by *Aviation Week*, June 16, 1997

The vertical tail is eliminated for stealth, directional control comes from specially coordinated trailing edge deflections

And finally, Micro AVs!

Black Widow
AeroVironment, Inc.

- 6-inch span fixed-wing aircraft
- Live video downlink
- Portable launch/control box
- Pneumatic launcher
- 60 gram mass
- 22-minute endurance
- Estimated 10 km range
- Electric propulsion

Achievements

- World MAV endurance record of 22 minutes
- Smallest video camera ever flown on a UAV: 2 grams
- Smallest live video downlink ever flown on a UAV
- World's smallest, lightest multi-function, fully proportional radio control system: 3 grams
- First aircraft to be flown "heads-down" indoors

Joel Grasmeyer, MS VT 1998 - team member!

To Conclude: There is Still Room for Dreamers

We don't yet know what the ultimate airplane concept is.