Aircraft Configuration Design

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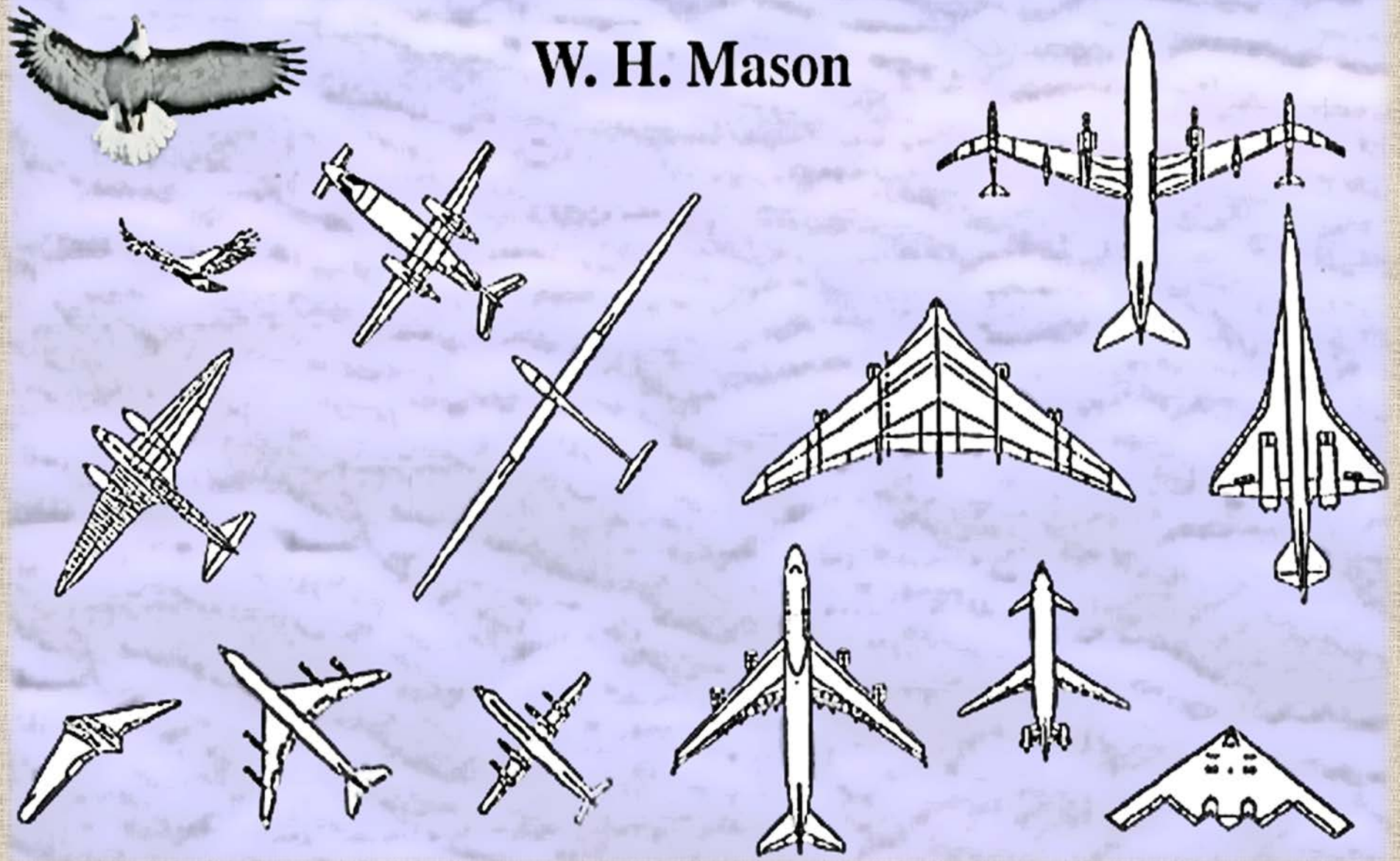
Why Airplanes Look Like They Do

W. H. Mason



About William *Bill* Mason

http://www.aoe.vt.edu/people/faculty/whmason.html

Designer

Technology advances?

A new capability someone might pay to have?

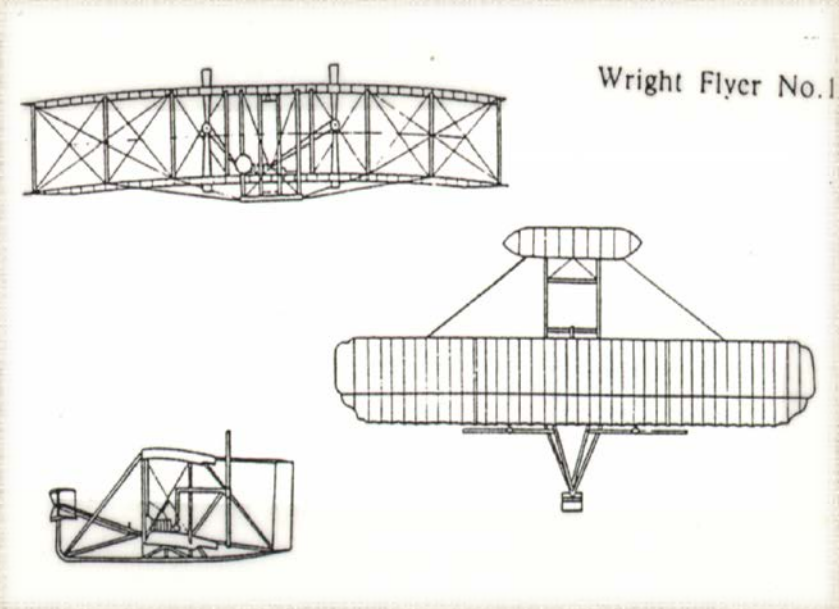
How to exploit technology for capability?

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:

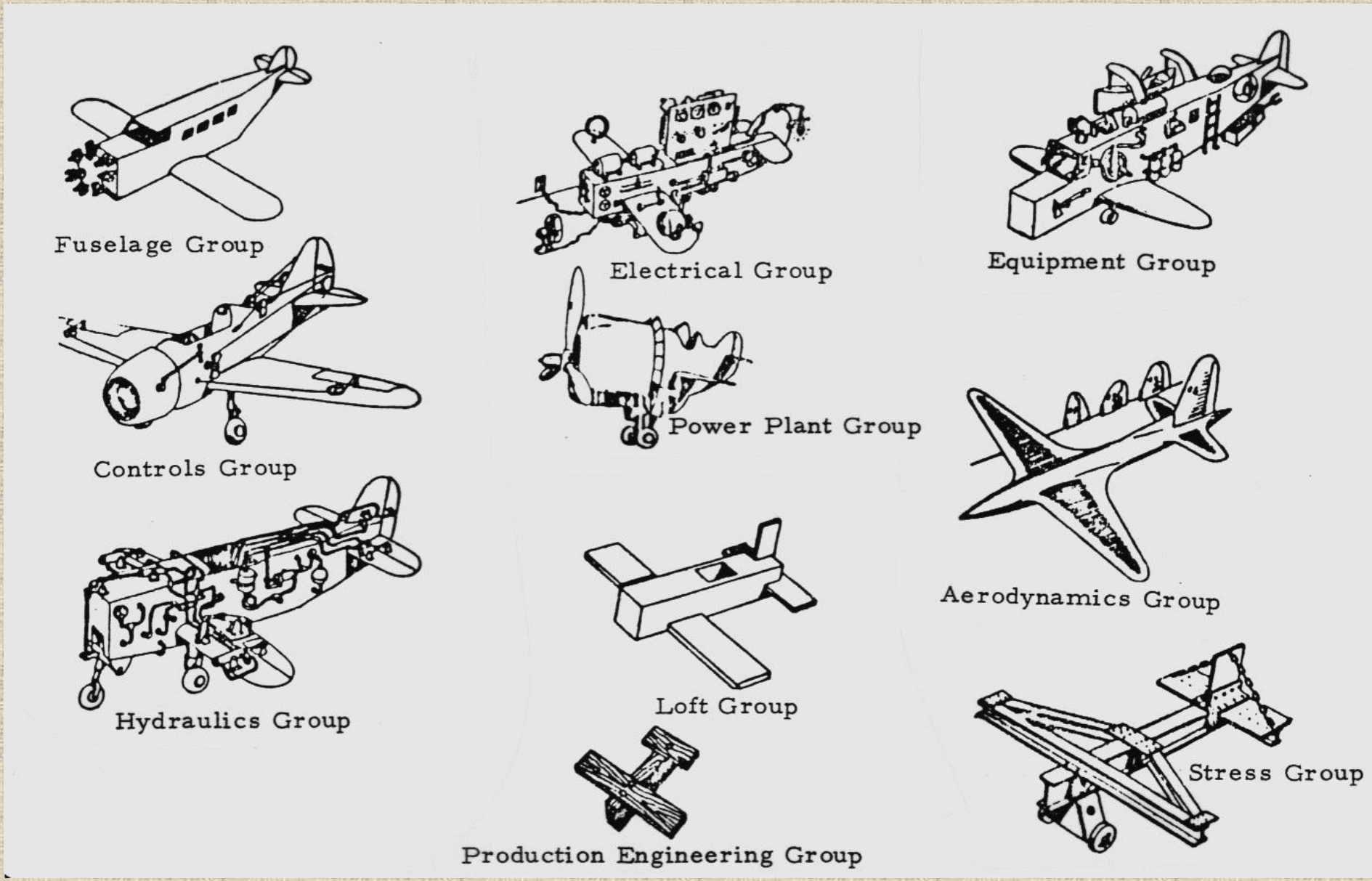
- Innovative control concept
  (more important than stability)
- “Light weight” propulsion
- Continual design evolution/refinement

Basic Laws of Airplane Design

- *Simplicity is the essence of true elegance—*
  - it can also save weight and/or reduce cost.
- *If you can't build it, you can't sell it.*

John McMasters
Boeing Commercial Airplane Company

Beauty lies in the Eye of the Beholder



"Dream Airplanes" by C.W. Miller,
as shown in *Fundamentals of Aircraft Design*, by L.M. Nicolai

Features of Good Aircraft

- Aerodynamically efficient, including propulsion integration (streamlining!)
- Must balance near stability level for minimum drag
- Landing gear must be located relative to *cg* to allow rotation at TO
- Adequate control authority must be available throughout flight envelope
- Design to build easily and have low maintenance costs
- Should be quiet, and have low emissions

Key Technologies

- Aerodynamics
- Propulsion
- Structures

in the late 70s:

- Flight controls

in the 80s and early 90s:

- Systems/avionics/observables & Manufacturing

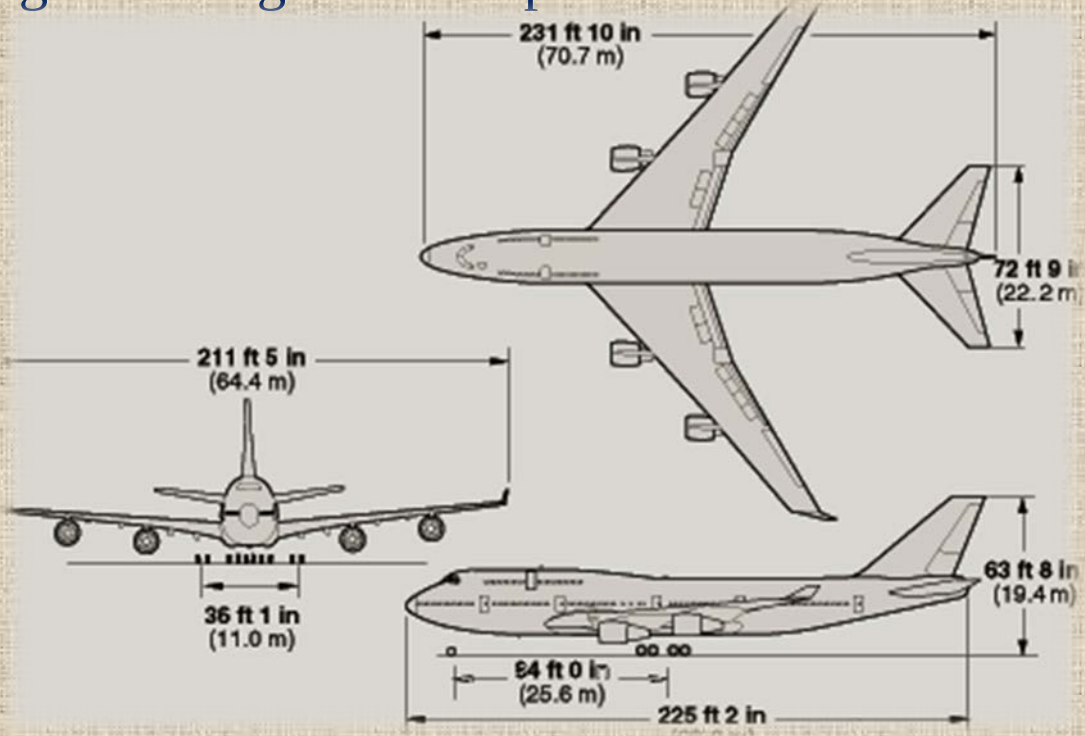
today:

- the design *process* - (includes MDO)

Amazingly Tricky to Integrate Advances in Each Technology

Conventional Subsonic: A Baseline

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



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

Layout Options

- Where do you put
  - the wings?
  - the engines (in fact, what kind?)
- Where do you put the control surfaces?
  - what options are available?
- Do you have room for the landing gear?
- Possible innovative designs?

A few WHYs ??

- *Why podded engines below wing ?*
- *Why Swept wing ?*
- *Why Forward Sweep ?*
- *Why Variable sweep ?*
- *Why Canards ?*
- *Why Flying Wing ?*
- *Why Three-surfaces ?*
- *Why Winglets ?*
- *Why Thrust Vectoring ?*
- *Why ? Why ? Why ? Why ? Why ?*

Why Put Engines in Pods on Wing?

- load relief on wing: weight savings
- access to work on engines (maybe)
- safety
- can be low drag

Original idea by the British – in wing!

If it's small, can't put them below wing

Boeing Made Wing Mounted Engines Work

Why Sweep the Wing?

Subsonic (usually small)

- Adjust wing aero 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

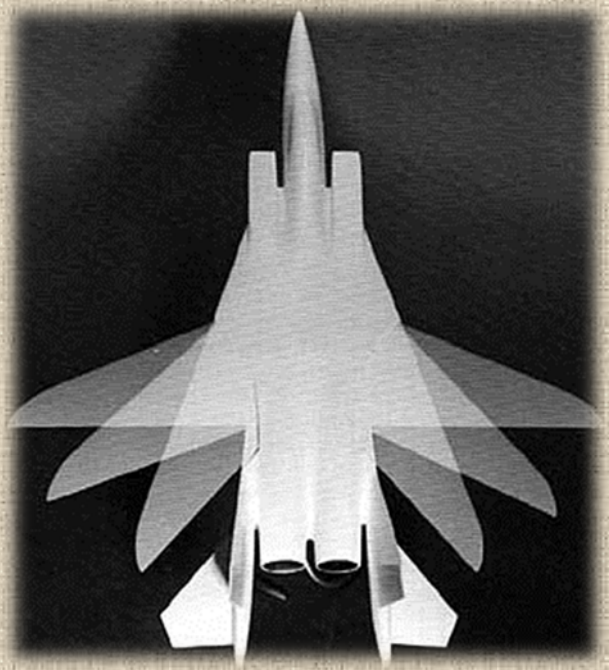
Why Sweep the Wing Forward?

X-29

SU-47

Why Variable Sweep?

The F-14 Tomcat



- Swept back: low supersonic drag
- Unswept position: low landing speed on carrier, *efficient loiter*
- Optimum sweep back available over transonic speed range
- But: adds weight/complexity, currently unfashionable

Why Canards?

- Trim surface carries + load for + '*g*' maneuvers
- Reduces subsonic-supersonic *ac* shift
  (for forward swept wing this is good)
- If balanced stable, C_L on canard is much higher than the wing

Drawback:

- downwash from canard unloads wing
- Acceptable high angle of attack lateral/directional characteristics hard to obtain

➢ When to use?

- severe supersonic cruise/transonic maneuver requirement
- Not Stealthy

Why a Flying Wing?

Flying Wing Testing

The B-2 Stealth Bomber

- Removing fuselage improves aero efficiency

  But, payload volume distribution is still an issue

- Synergistic effect with relaxed static stability

- Military:

  Stealth

- Commercial:

  distribute load, reduce weight

  but, limited *cg* range

Three-Surface Aircraft

Piaggio P-180 Avanti

- If you can make a design with two surfaces, why use three?

  -Adds cost, weight, wetted area

- Can trim with near minimum drag over wide *cg* range
- Sometimes, efficient component integration can save weight

Ferrari of the Skies ?

Design Features of P-180 *Avanti*

Anhedral in Canards

Delta Fins on Airfoil Shaped Fuselage

behind Passenger Cabin

Avanti *EVO*

P-180 Avanti

Avanti EVO

Why Winglets?

- Nearly equivalent to span extension *w/o* increased root bending moment
- Used where span limitations are important
- Good wingtip flow crucial to lower drag
- The local flow field is extremely non uniform:

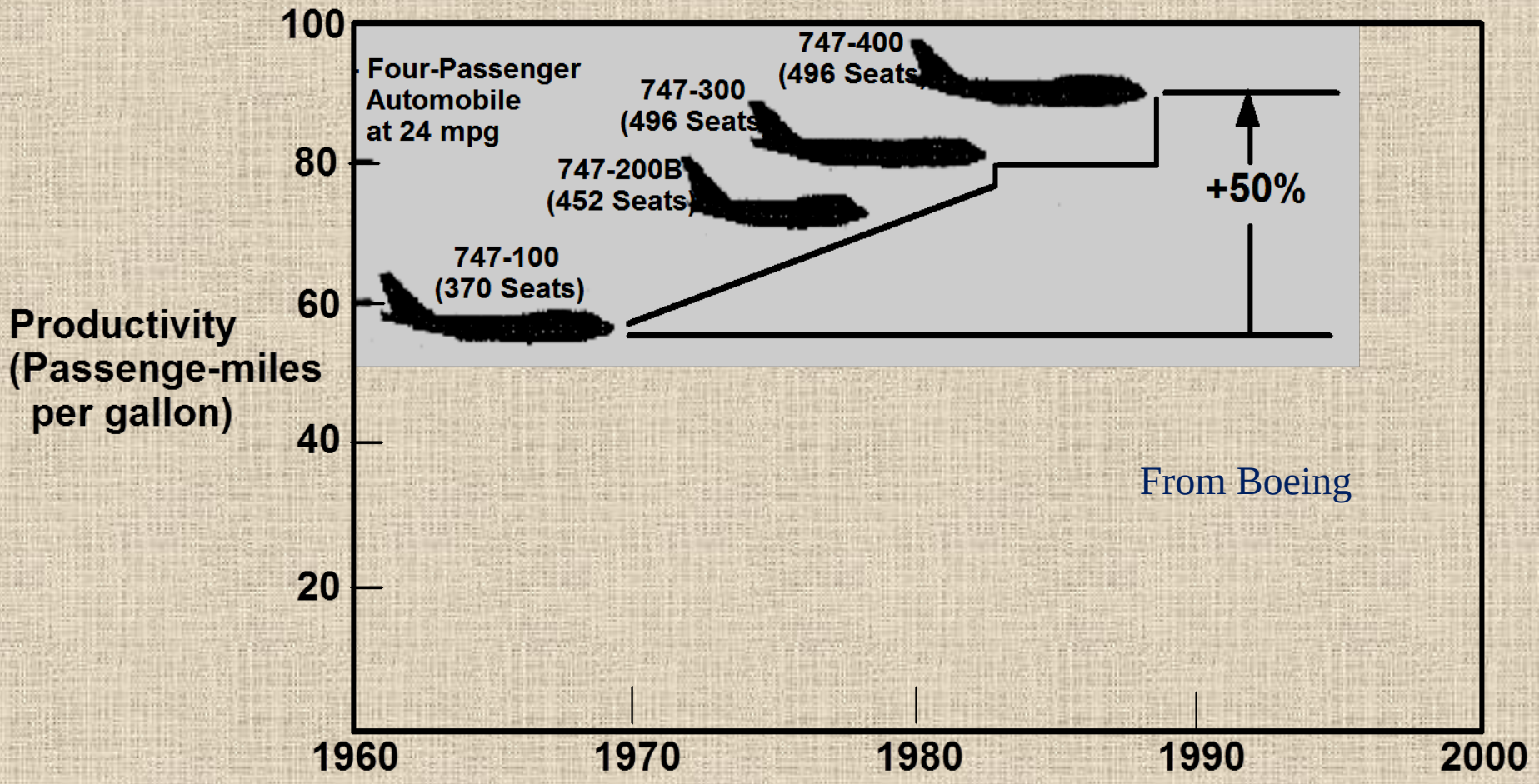
Requires advanced computational aerodynamics methods to design.

Why Thrust Vectoring ?

- Improved performance
- Vertical Takeoff and Landing Capability

F-35 Lightening-II
perhaps USA's last manned fighter aircraft ??

So Where Have We Come So Far?
747 Productivity improvement



From Boeing

FEW NOVEL CONCEPTS

Blended Wing Body

- Concept from Bob Liebeck (Douglas A/C)
- Less wetted area (no fuselage as such)
- Possibly more efficient structure
- This is now the X-48 series of planes

Oblique Wing Supersonic Transport

- Concept by R.T. Jones of NASA
- Fore-aft symmetry of lift
- Better area distribution
- Possibly only “practical” SST
- Flying wing version also

Mother-Daughter Configuration

Burt Rutan: Still imagineering!

SpaceShipOne

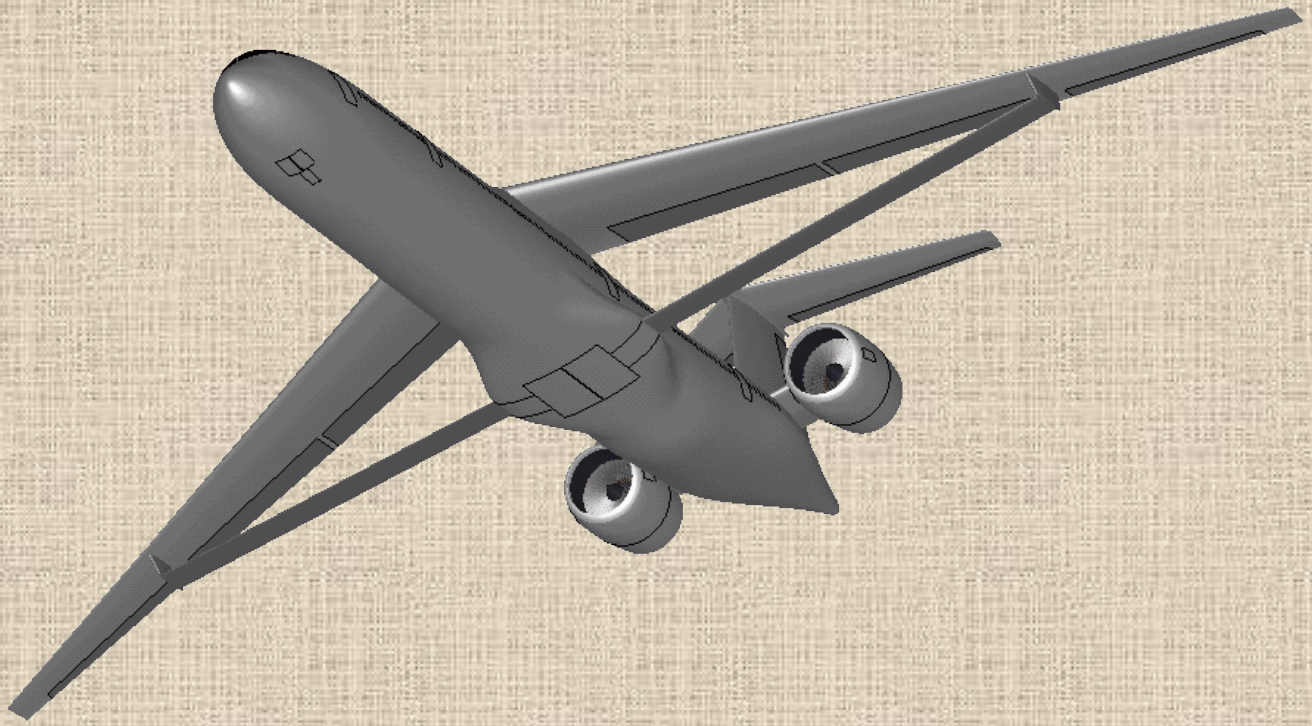
The White Knight

Pictures from the
Scaled Composites web site

Strut Braced Wing

- Werner Pfenninger's strut-braced wing concept from 1954
- The strut allows a thinner wing without a weight penalty
- Also a higher aspect ratio (span), 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
- Need MDO to make it work

Lockheed, Virginia Tech, NASA Team



Compared to a conventional cantilever design:

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

Recent Configuration (2010)

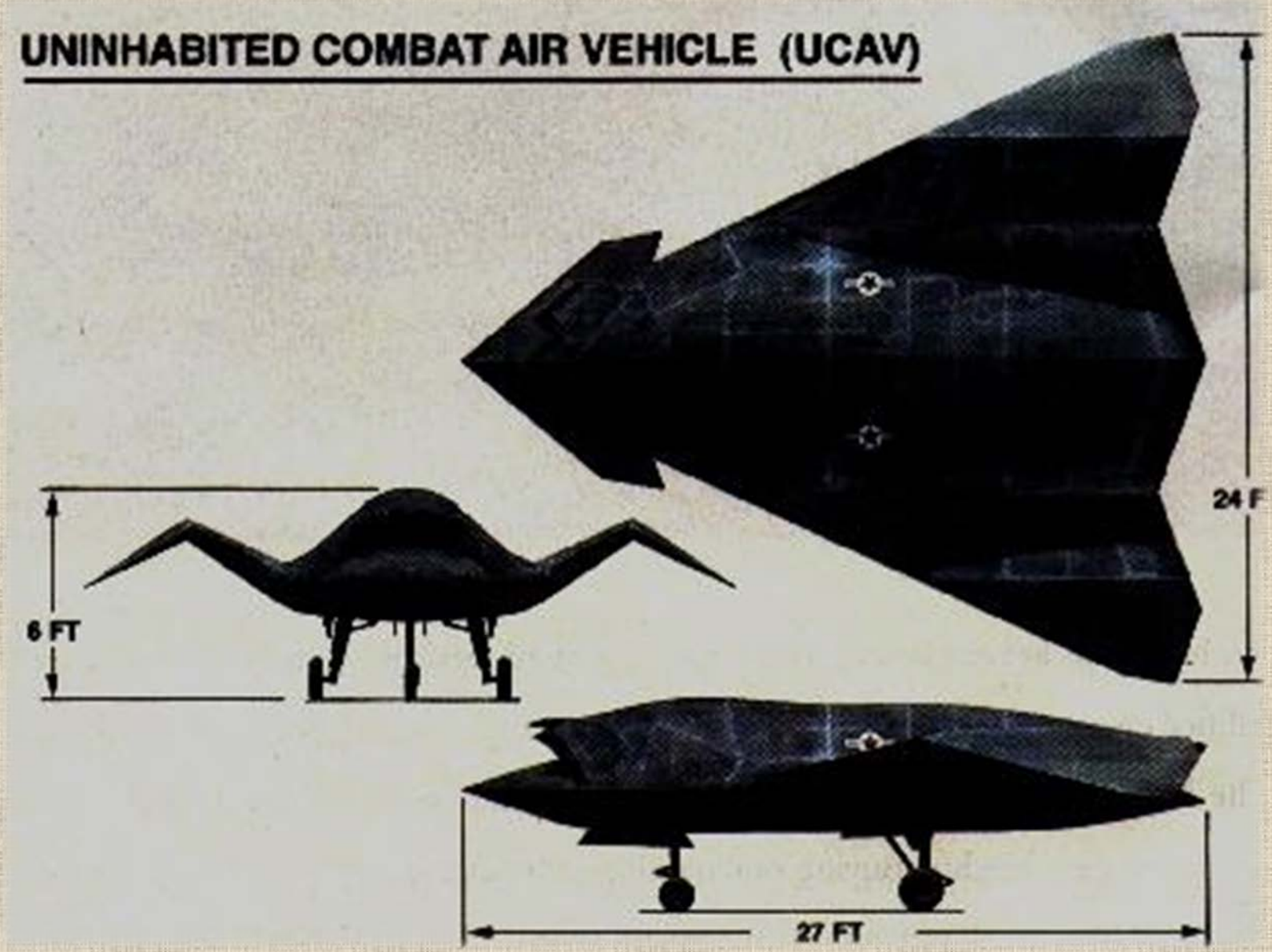
Courtesy Ohad Gur

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



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

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

To Learn More, Read These:

The Anatomy of the Airplane, by Darrol Stinton. Few equations and deceptively simple, but it's not. Lots of good information.

Design for Air Combat by Ray Whitford. Takes a deeper look at the details, again without equations and with lots of good graphics showing typical data to use deciding on design options. The title suggests a much narrower focus than the book has.

Aircraft Design: A Conceptual Approach, by Daniel Raymer. Chapter 8, "Special Considerations in Configuration Layout" and Chapter 22, "Design of Unique Aircraft Concepts" is good once you've read the first two references.

Airplane Design, Pt. II Preliminary Configuration Design etc., by Jan Roskam. Chapter 3, and 3.3 "Unusual Configurations", in particular.

There is Still Enough Room for Dreamers

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

Concerning the comments on configurations given above,

Remember:

there is a time and place for everything..

If you can justify it, you can have it !

Next Topic

LAYOUT & CONFIGURATION