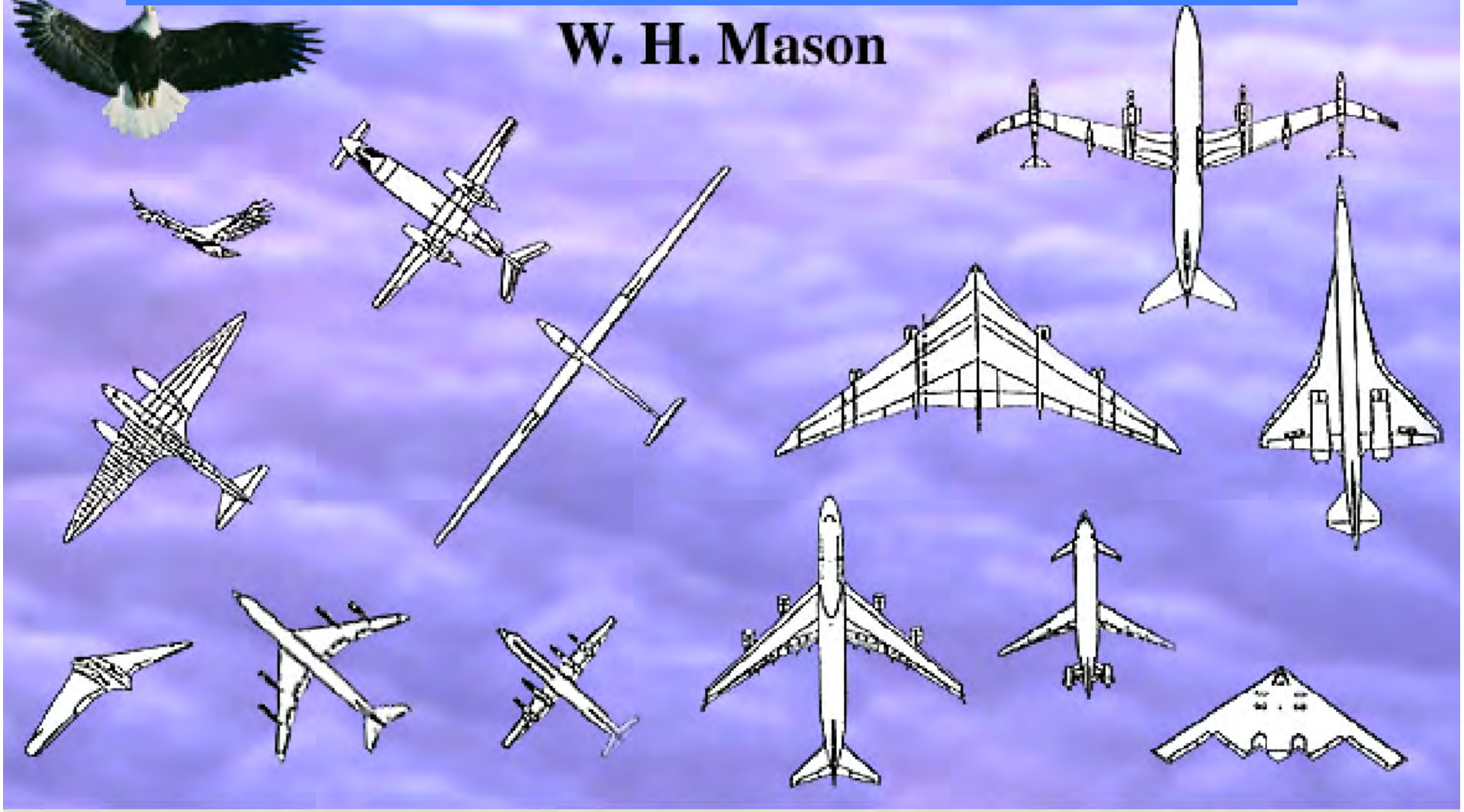
Configuration Options: Connecting Concepts to Requirements

W. H. Mason



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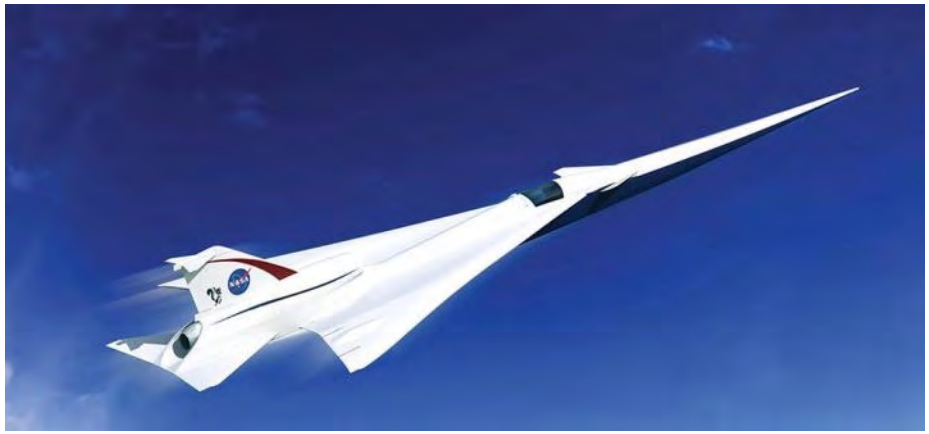
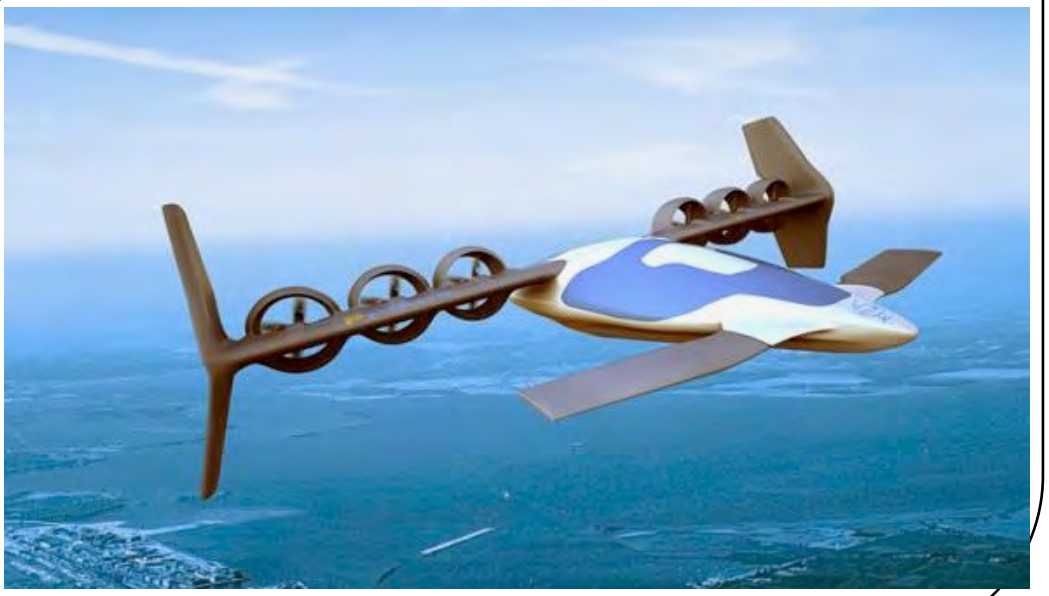
Ocean Engineering

collage from John McMasters

Huge variety of concepts at the moment



- Latest Hypersonic
- NASA Low Boom Supersonic
- Delft distributed propulsion



Designer

Technology Advances?

A new capability someone might pay to have? **Requirements**

How to exploit technology for capability?

Configuration Concept

Airplane Shapes Have Changed to Exploit Advances in Technology

Aerospace and Ocean Engineering

To Start: Define a Mission

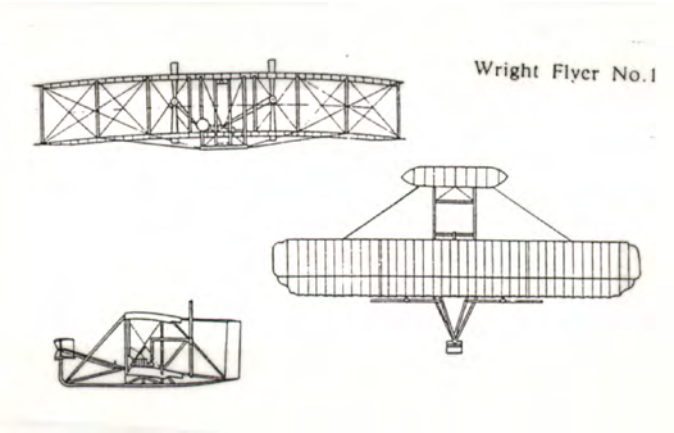
What is the airplane supposed to do?

- What and how much does it carry?
- How far does it go? How fast?
- What are the landing and takeoff requirements?
- Are there any maneuver/accel requirements?
  (these are known as point performance req'ts)
- What MIL or FAR req'ts must be satisfied?
  -includes noise and emissions

Taken together, the answers to these questions are known as the **Mission Statement**, and also imply that you think of concepts to do the job

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 (relatively)
- Continual design evolution/refinement

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 (cheaply) and have low maintenance costs
- Today: quiet, nonpolluting - ***Green***

The NASA/Grumman
Research Fighter Configuration

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

Configuration 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?

Brewster P-33A

courtesy Dr. George Inger

Example of an airplane management decided was too risky to build

We' ll look at these possibilities

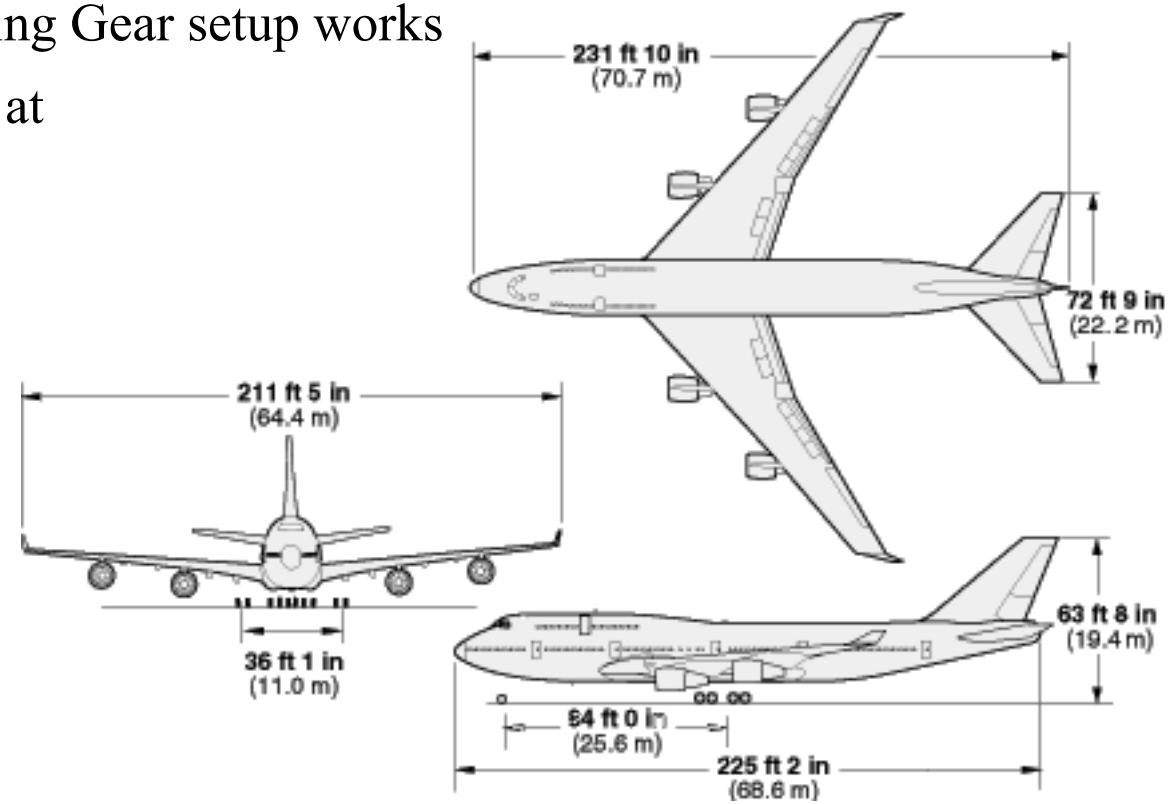
- Conventional baseline
- Wing Sweep?
  - - why would you sweep it forward?
- Canards?
- Flying Wings?
- Three-surfaces?
- Winglets?
- Variable Sweep?
- Slender Wings
  - -Sonic Boom
- Propulsion Integration
  - Electric?
  - Powered Lift
- Hypersonics
- Recent Novel Concepts

Ryan X-13

Air Force Museum

Conventional Subsonic - A Baseline

- Payload/Fuel distributed around *cg (minimize cg travel)*
- Longitudinal control power from tail (with moment arm)
- Vertical Tail for directional stability, rudder for control
- *cg*/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 aero center relative to *cg (DC-3)*
- On flying wing, get moment arm length for control

Transonic (significant, 30°-35°)

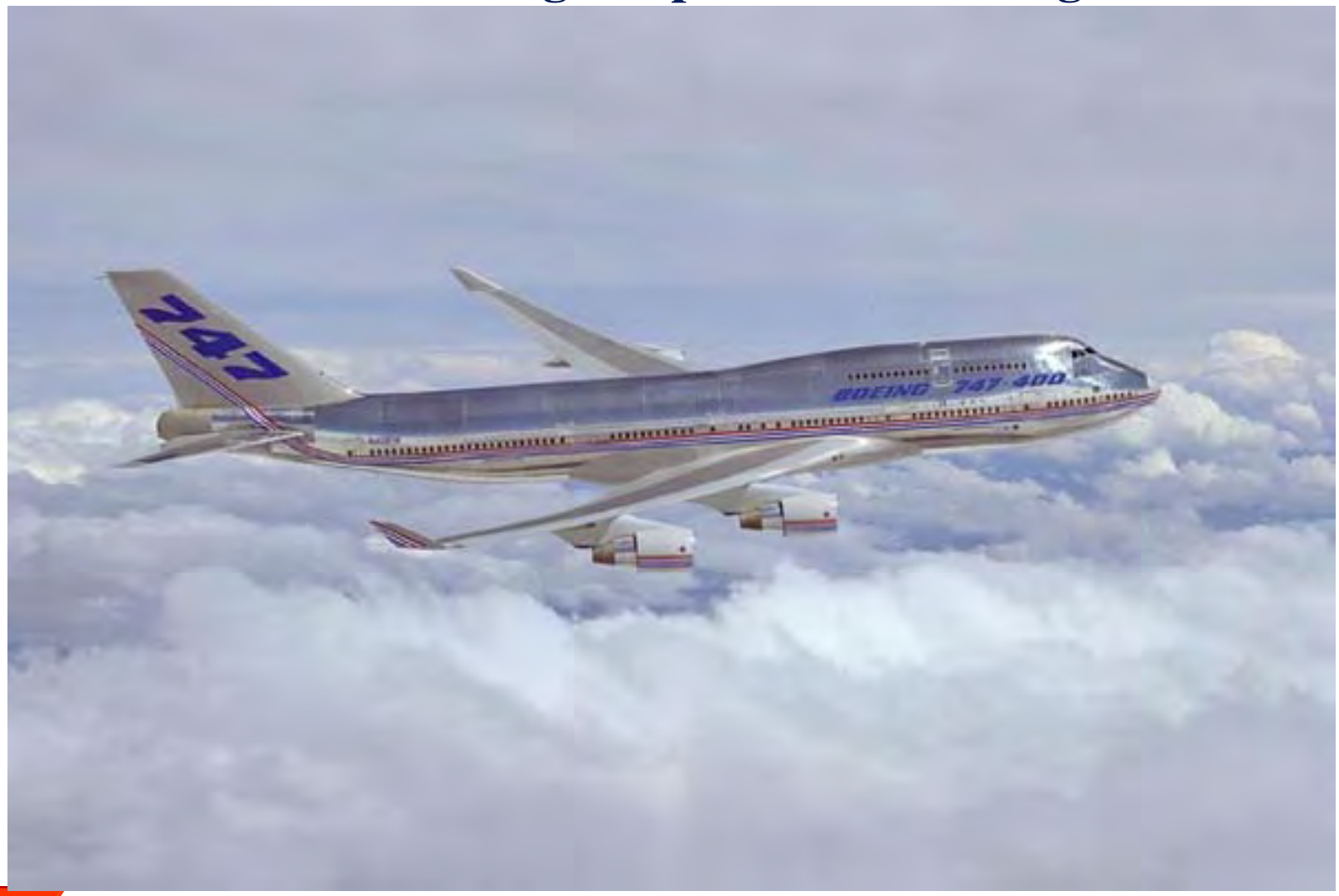
- Delay drag rise Mach (compressibility effect)
  - definition of the drag divergence Mach no.?

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

The classic large airplane: The Boeing 747



source: www.boeing.com

Why Sweep the Wing Forward?

- For transonic maneuver, strong shock is close to trailing edge,
  - highly swept TE (shock) reduces drag.
  - forward swept wing allows highly swept TE
  - equivalent structural *AR* less than aft swept wing
- Synergistic with canard
- Good high angle of attack (root stall, ailerons keep working)
- But: - must be balanced at least 30% unstable
  - not stealthy
  - poor supersonic volumetric wave drag

Example: X-29

Note: some would also say for laminar flow and for less twist in wing.

the X-29

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC87–0182–14 Date: July 24, 1987 Photo By: NASA

X–29 in Banked Flight

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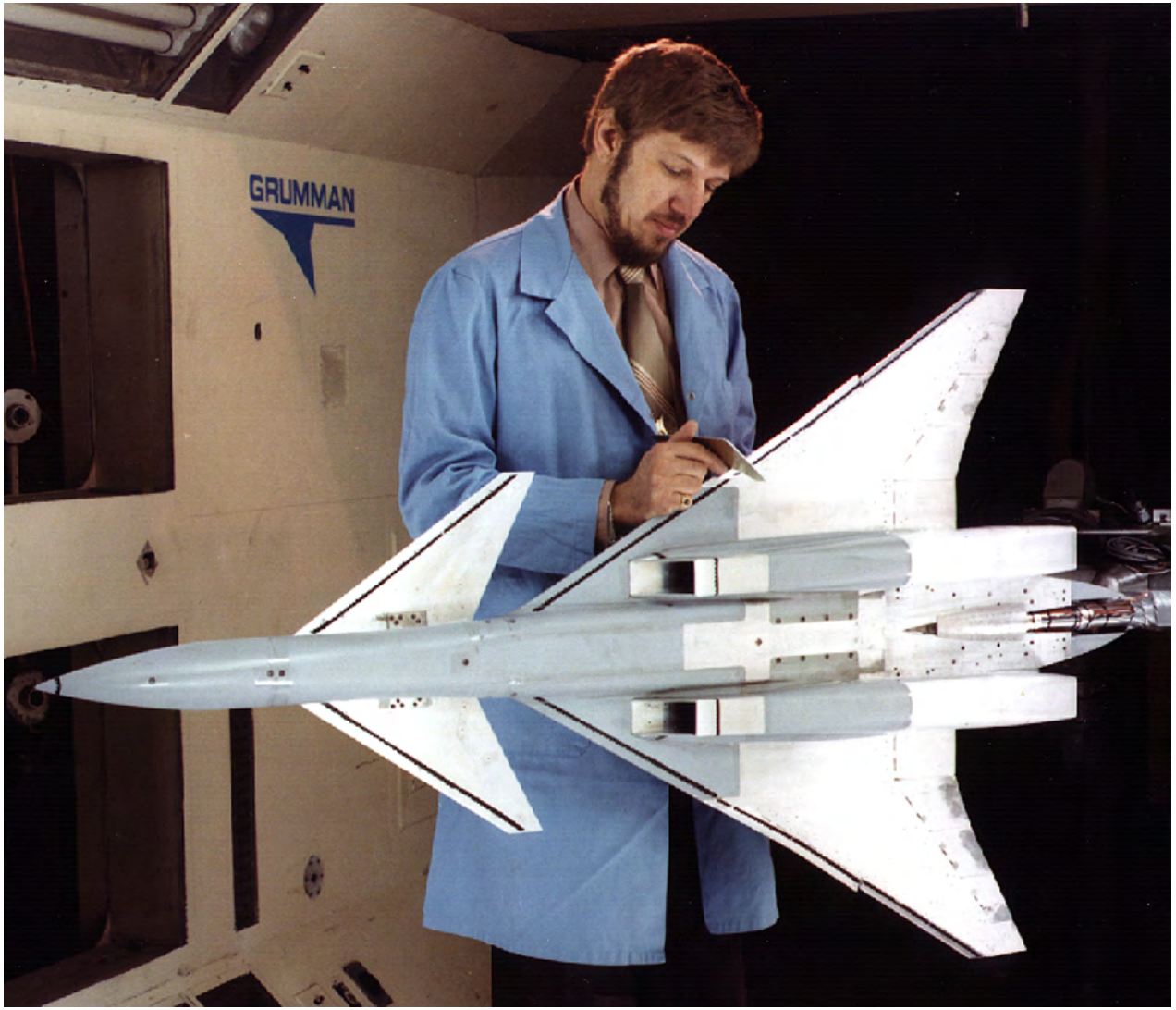
Mason worked on this before it was called the X-29, one of about 3 or 4 engineers working on it.

Why Canards?

- 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
- not stealthy

The Grumman Research Fighter



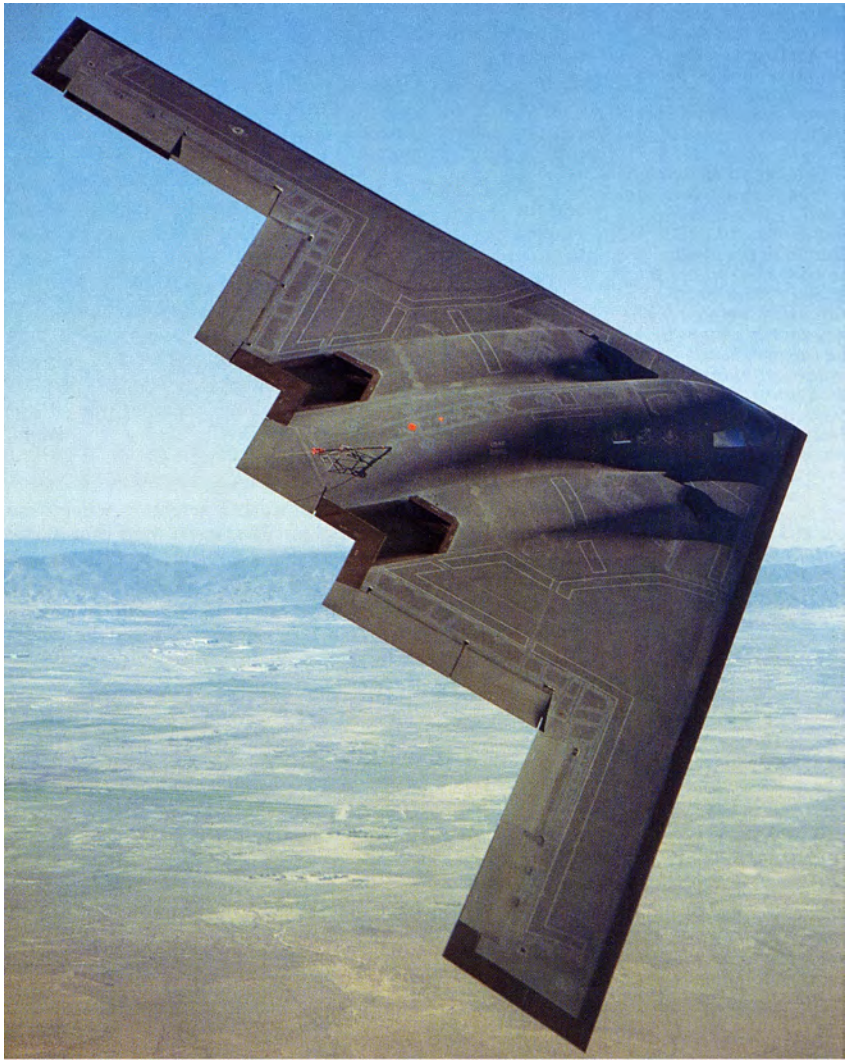
designed by Nathan Kirschbaum, Ron Hendrickson in pix

Why a Flying Wing?

- removing fuselage must improve aero efficiency
  - reduces wetted area
  - but, payload volume distribution is still an issue
- synergistic effect with relaxed static stability
- military: stealth
- commercial: distribute load spanwise, reduce weight
- but: can't trim to a high C_{Lmax}, limited cg range
  - leads to low W/S for takeoff and landing

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

The B-2 Stealth Bomber



Stealth and Fighters

Sept. 2017

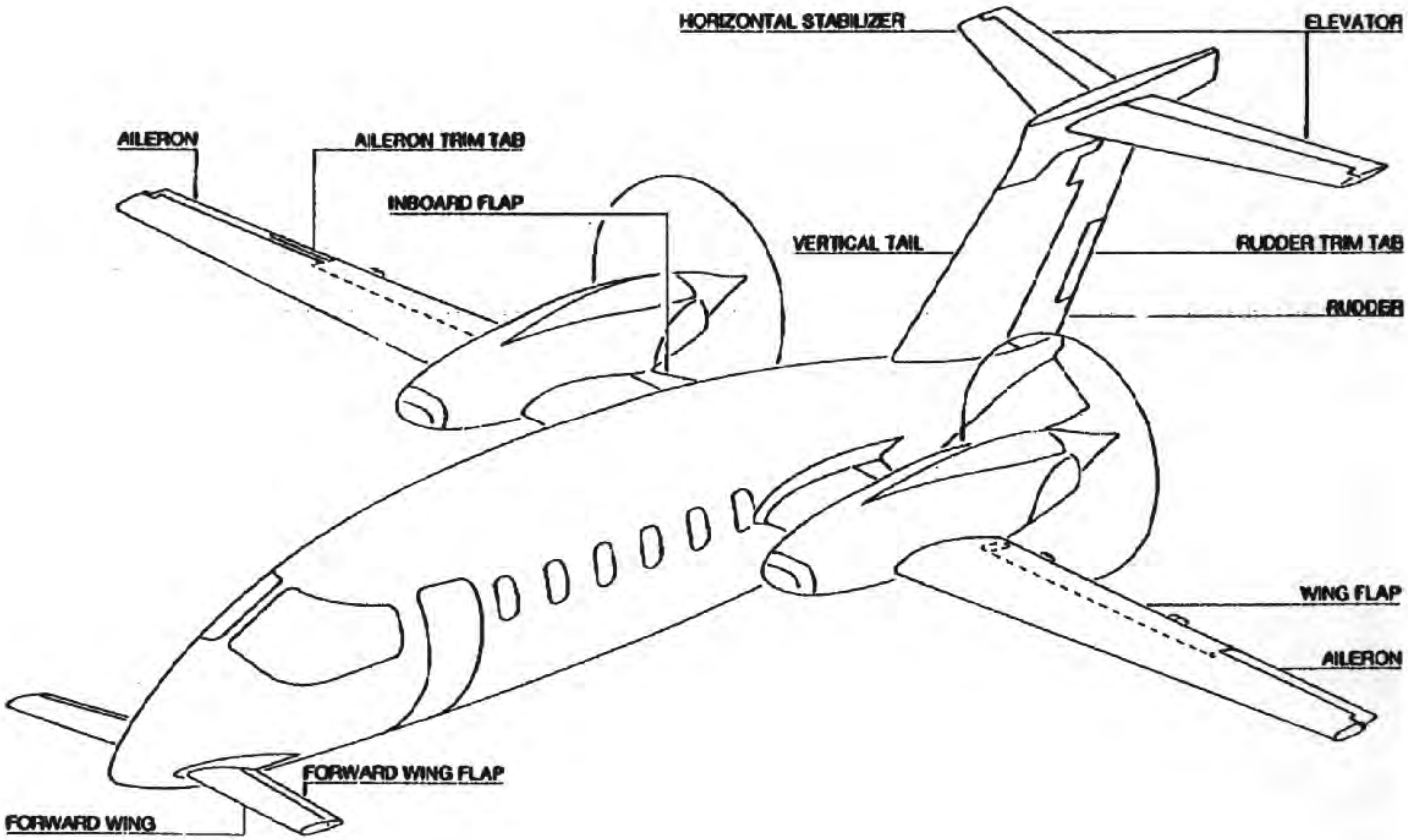
Note edge alignment

Why Three-Surfaces?

- Can trim with near minimum drag over wide *cg* range
- But: If you can make a design with two surfaces, why use three?
  - Adds cost, weight, wetted area
- Sometimes, efficient component integration leads to three-surfaces to save weight

Example: Piaggio Avanti

Piaggio Avanti



Drawing courtesy of Piaggio

Why Winglets?

- Nearly equivalent to span extension *w/o* increased root bending moment
- Used where span limitations are important
- Good wingtip flow crucial to low drag
- The local flowfield is extremely nonuniform, to work:

  Requires advanced computational aerodynamics methods to design

Note: Latest Boeing 777 uses folding wings, not winglets

Winglets now becoming routine

An RJ at the Roanoke Airport,
Winter 2003

Abrupt corner poor -
corners make drag,
Should round it off –
called a Blended Winglet

Now evolved to the
Split Scimitar

Denver Airport, Summer 2016

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And now the Tamarack Active Winglet System

Why Variable Sweep?

- Swept back: low supersonic drag,
  - good "on-the-deck" ride quality (lift curve slope decreases)
- Unswept position – larger span
  - low landing speed (carrier suit.), efficient loiter
- Optimum sweep back available over transonic speed range
- But: adds weight/complexity, currently unfashionable

Example: F-14 Tomcat

The F-14 Tomcat

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ECN-33403-2 Date: 1986

F-14 VSTFE

Our Current Favorite: the Strut Braced Wing

AIAA Paper 2005-4667
Journal of Aircraft, Nov.-Dec. 2010

- Werner Pfenninger's strut-braced wing concept from 1954

  He really wanted laminar flow, but *L/Dmax* means $C_{Di} = C_{D0}$

- We need MDO to make it work

Compared to a conventional cantilever design:

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

- The strut allows a thinner wing without a weight penalty
  - It also allows a higher wingspan, 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

Developed in 1990s at VT, working on it again in 2009

And it continues to be studied

Aviation Week Cover
January 27, 2014

Featured on the cover again:
March 28, 2016

And Boeing at SciTech Jan. 2019

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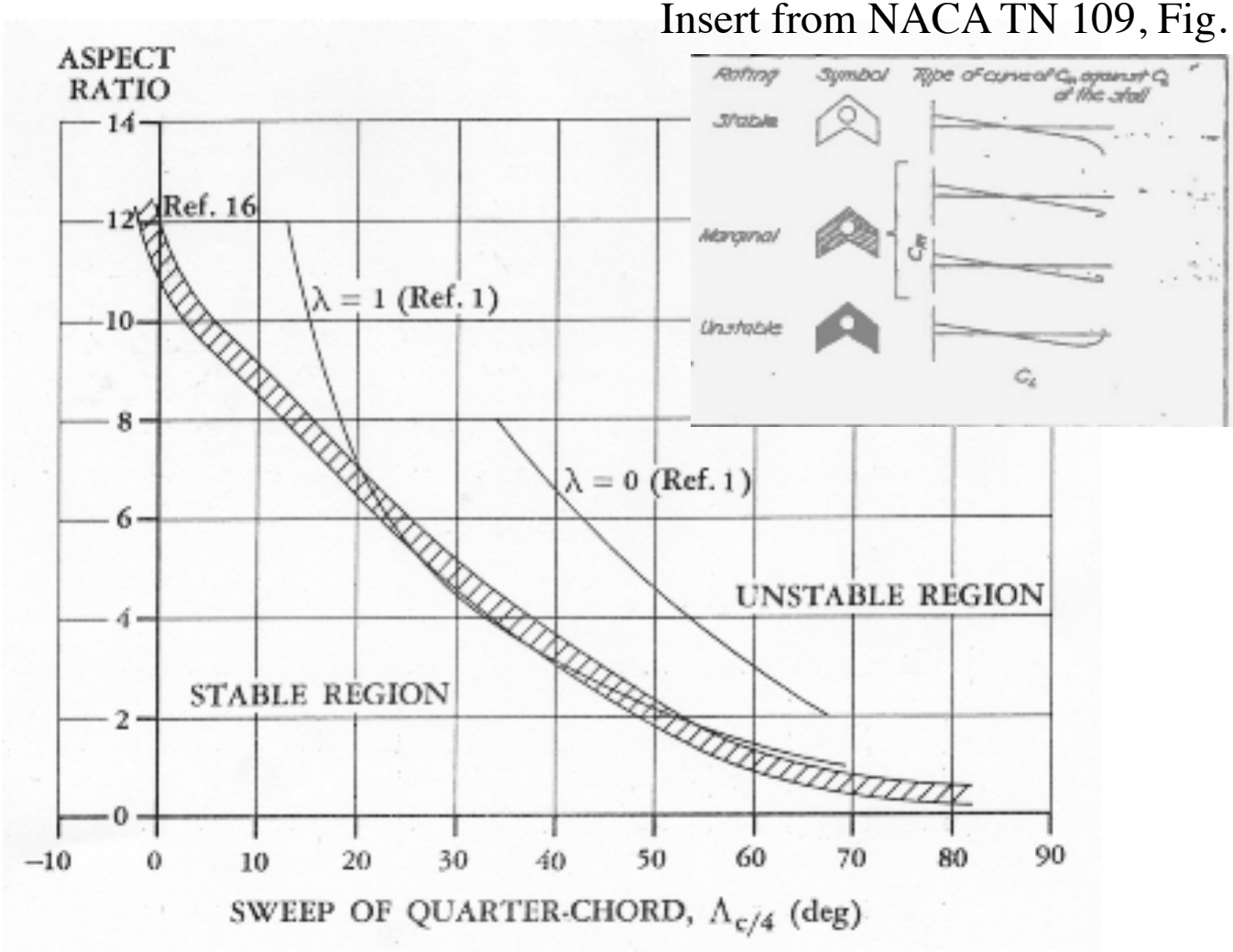
Planform Choices: swept wings can be pitchup prone

Insert from NACA TN 109, Fig. 41



from DATCOM

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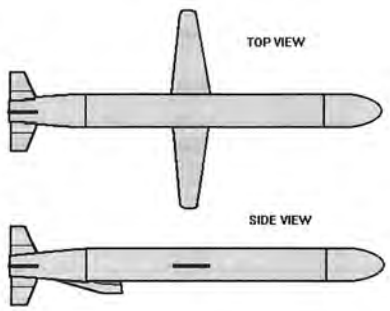
The Wing Size Dilemma

- Efficient cruise implies C_L close to C_L for L/D_{max}

  (if drag rise were not an issue, C_L for max range would be much less than C_L for L/D_{max})

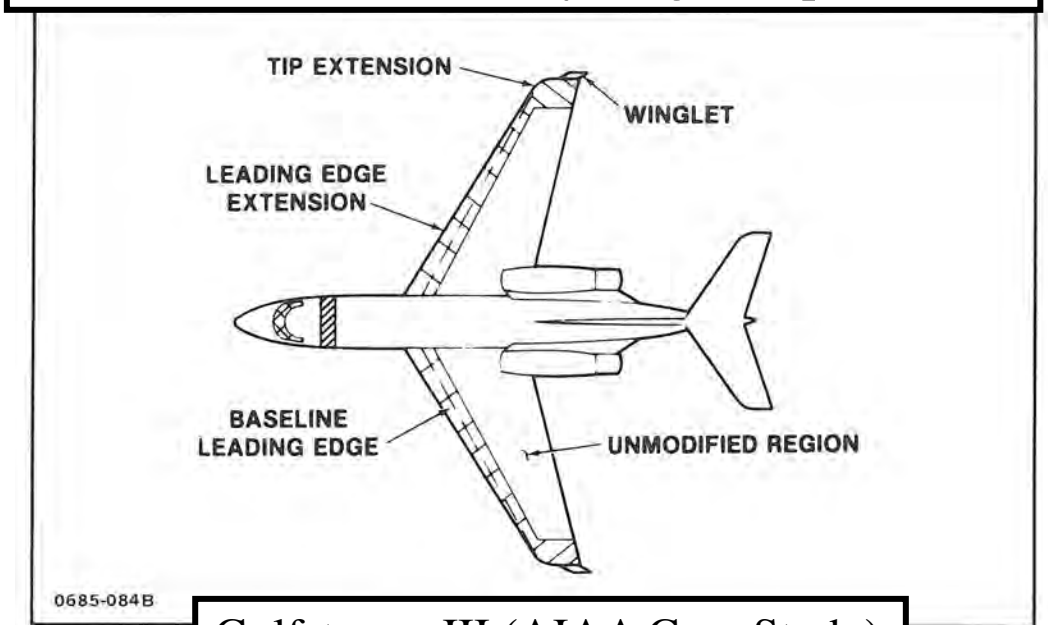
- Wings sized for efficient cruise require high max lift coefficient, or long runway to land.

Small wing:
No need to TO or Land!



Tomahawk Cruise Missile

Big Wing: Modest runway length requirement



Gulfstream III (AIAA Case Study)

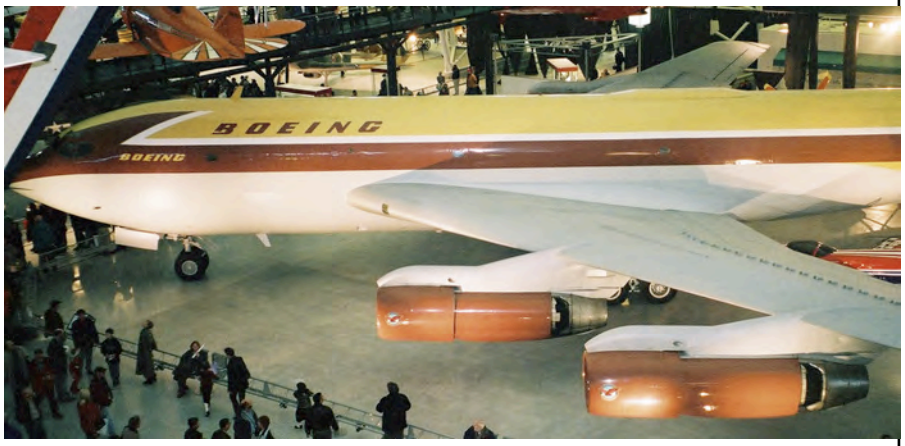
Why Put Engines in Pods on Wing?

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

Original idea by the British – in wing!

De Havilland Comet, Airliner Tech Series, Vol 7.

Boeing Made Wing Mounted Engines Work



The Dash-80, at the Udvar-Hazy, Dulles Airport

If the plane's small, can't put engines below wing

At the Tech airport

Aero-Propulsion: Especially critical for Supersonics

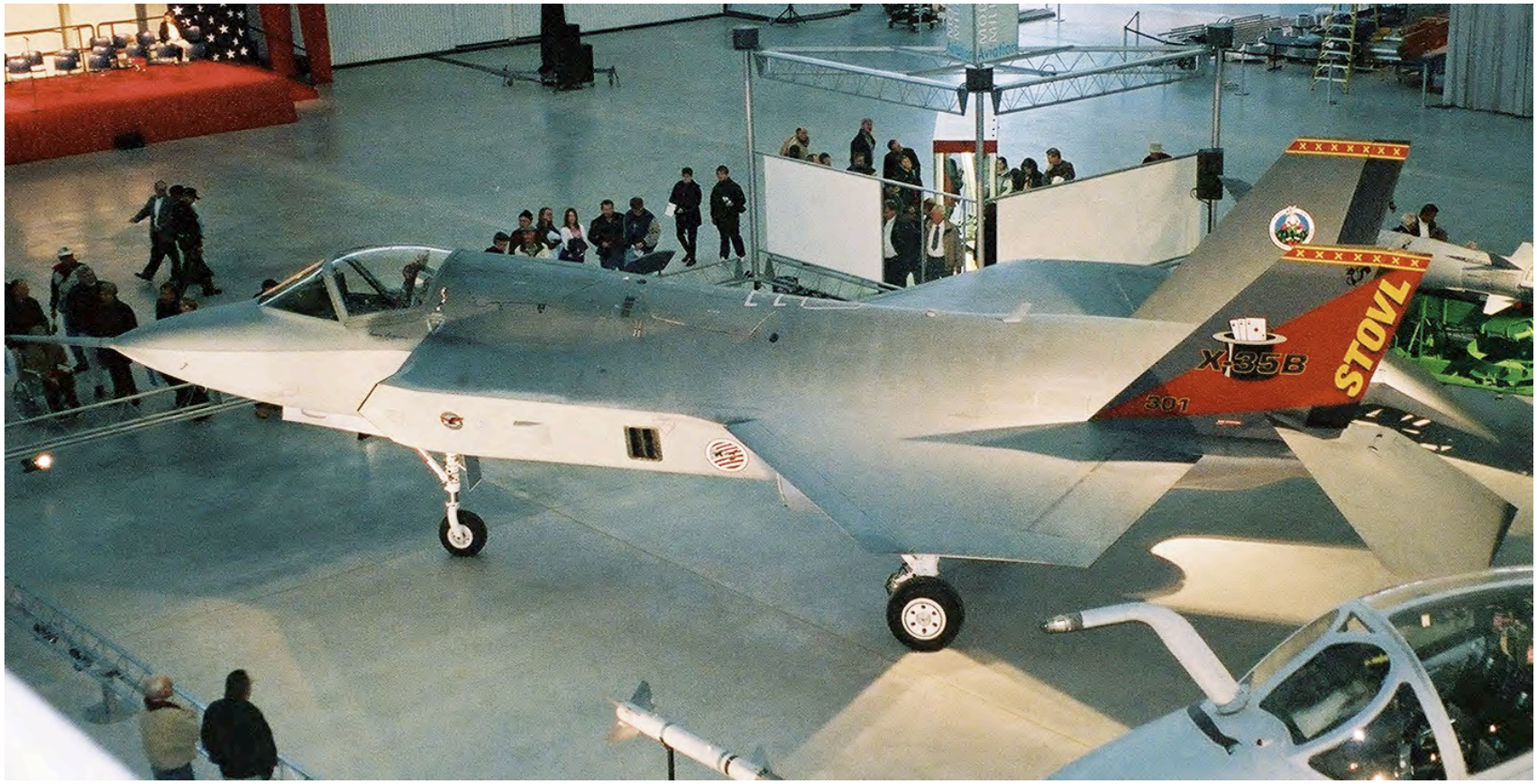
RF-84 – basis for F-105?

Kartveli decided to use the inlet from the XF-103 on the F-105

Another consideration: Propulsion for lift/control

- Aero-Propulsion integration also needs to be considered
- Thrust vectoring for control.
- Powered lift for VTOL/STOL

And the X(F)-35 is now at the Smithsonian



At the Air & Space Museum, Dulles Airport, Dec. 2003

How about the Honda Jet?

Courtesy of Honda Jet

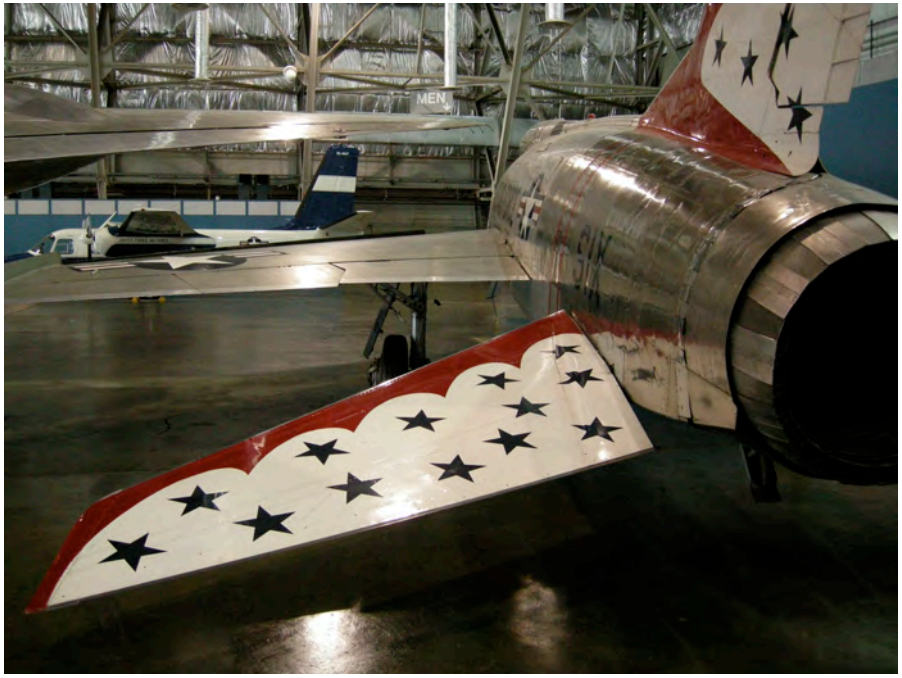
Control Surfaces
Classic Stabilizer-Elevator vs All Flying Tail

Chuck Yeager: "The key discovery of the X-1 Program"

The "normal" horizontal stabilizer-elevator

Douglas A-3 at the Navy Museum
Pensacola, FL

The All-Flying Tail or Stabilator
Differential for roll!

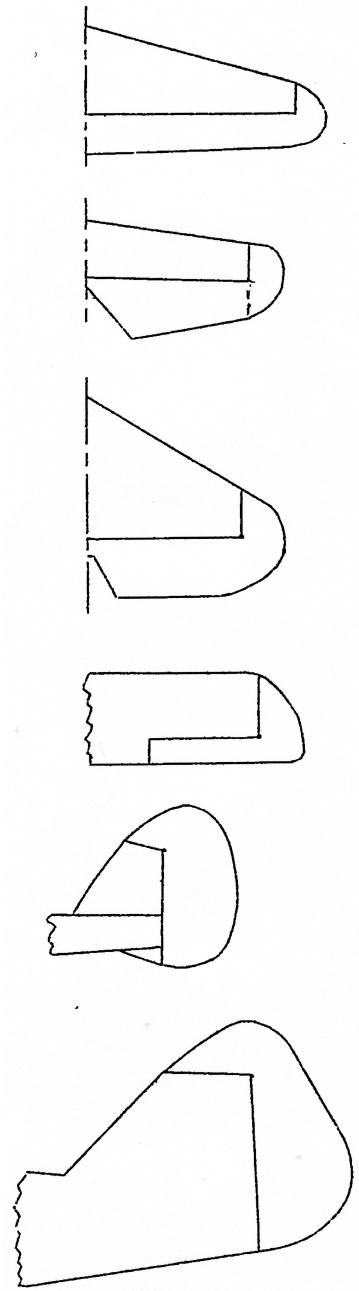


North America F-100 at the
Air Force Museum, Dayton, OH

What about control surfaces for recent UAVs?

- Current large airplanes use mechanically actuated controls, hinge moments are not as important (usually)
- UAVs (and DBF) may have limited forces available to move the surfaces (hinge moments)
- They are slow, so:
  - Aerodynamic balance can be used to reduce the hinge moments

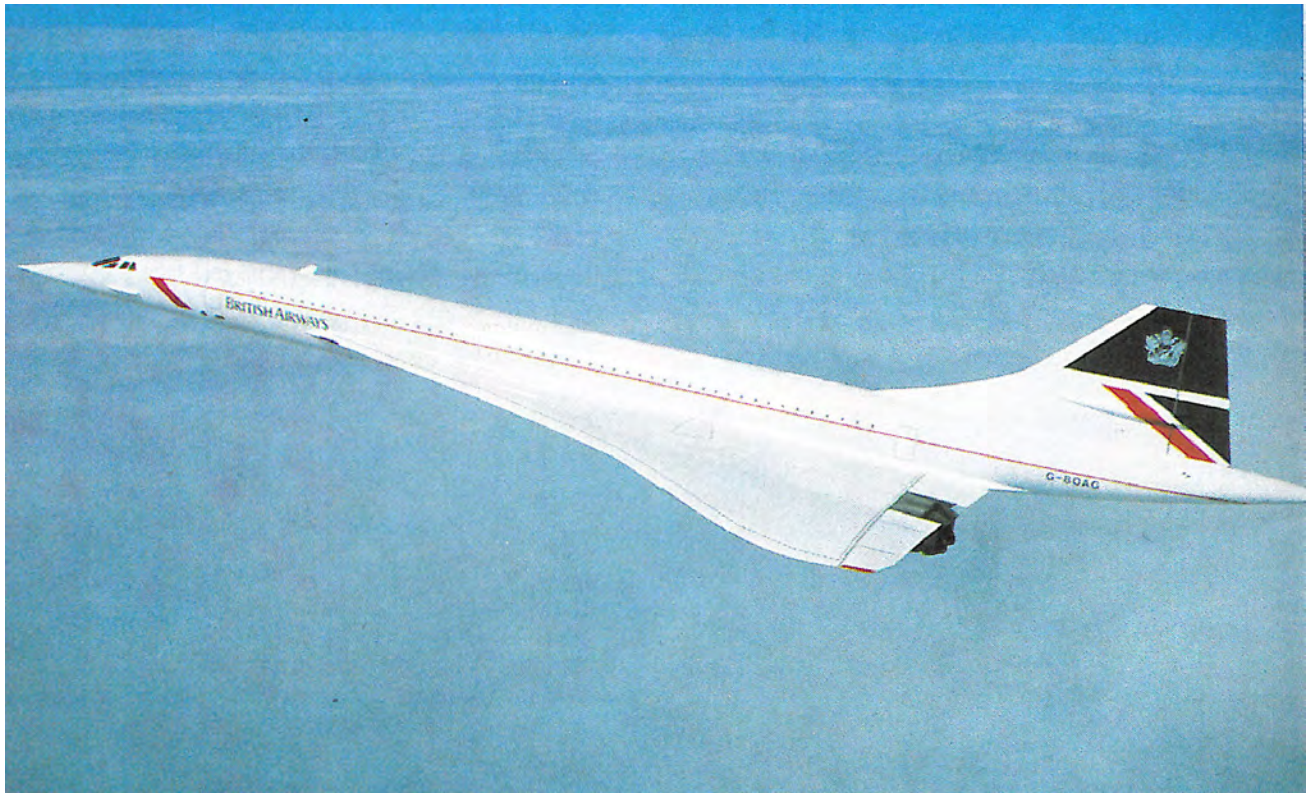
Figure from NACA RB 3F19, 1943, "Resume of Hinge Moment data for unshielded horn-balanced control surfaces"
See also NACA TR-927



Aero balance for control surfaces (reduced hinge moments)

Supersonic Flight leads to Slender Wing Concepts

The Concorde epitomized the ideal shape for supersonic cruise

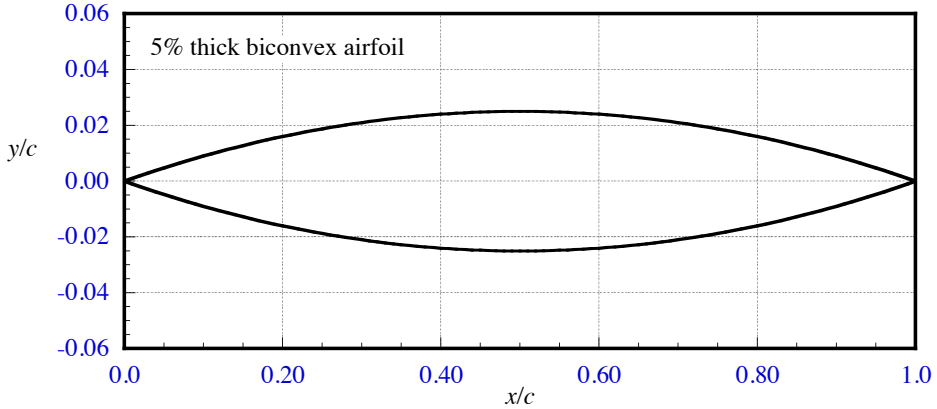


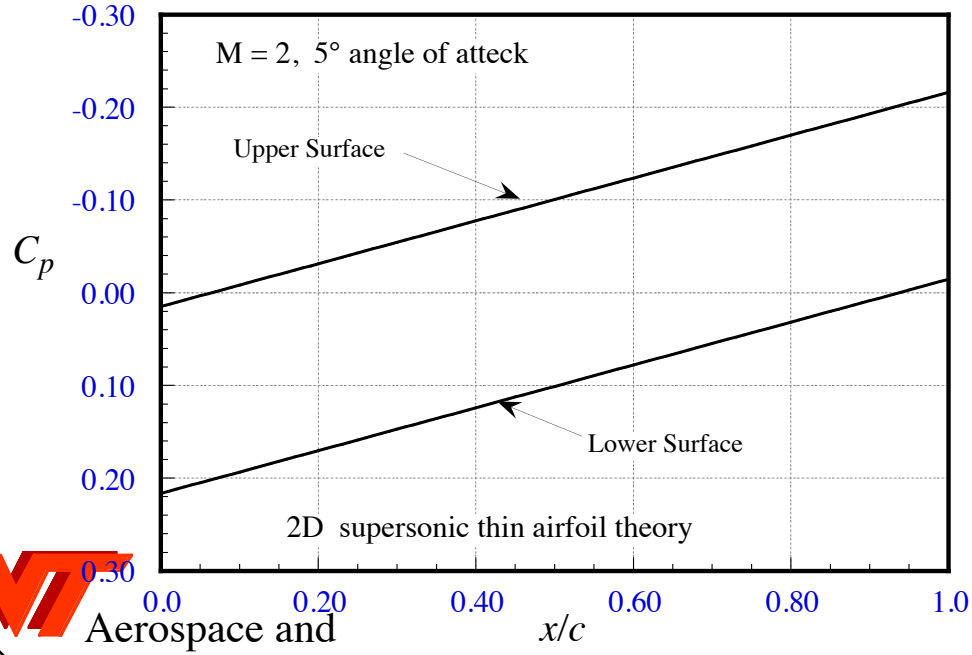
BUT: Aerion keeps going (with ~~Lockheed~~ Boeing)

8-12 pax, $M = 1.4$, boomless at $M = 1.1$, range – 4750nm,
field length - 7500 ft, expected entry into service - 2023

What's the *Aerion* Idea?

This *is* a case where 2D supersonic airfoil theory is interesting





2D supersonic airfoil pressures look nothing like the subsonic pressures

A favorable pressure gradient all the way to the trailing edge means that you might be able to get laminar flow!

- -Small chord
- -High altitudes

Implies a relatively low Re

Also observe that the upper and lower surface pressures don't have to be equal at the TE when it's a supersonic TE edge

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.

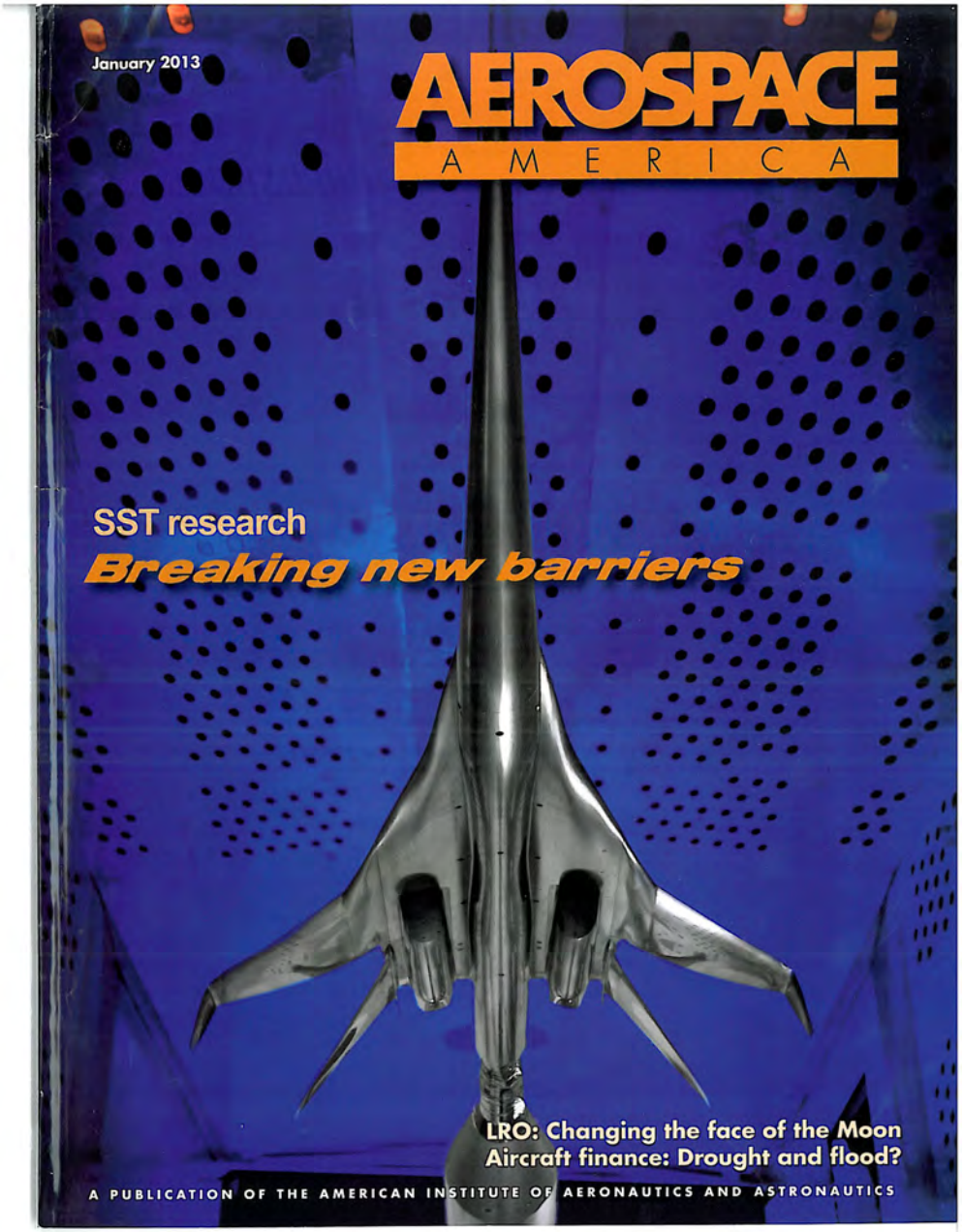
And from Gulfstream: The Quiet Spike

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED06–0184–13 Date: September 27, 2006 Photo By: Carla Thomas

NASA F–15B #836 in flight with Quiet Spike attached.

Did you see the cover of the Jan 2013 Issue?

Issue: Low noise AND low drag



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Even Faster: Hypersonics

The X-51A scramjet Demonstrator- 1st flight May 26, 2010

Photo courtesy of Karen Berger, a former student in this class and now working on this concept (at NASA Langley)

A Novel Concept?

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

The concept built
and flown as the X-48
- 1st flight July 20, 2007
- Last: April 9, 2013

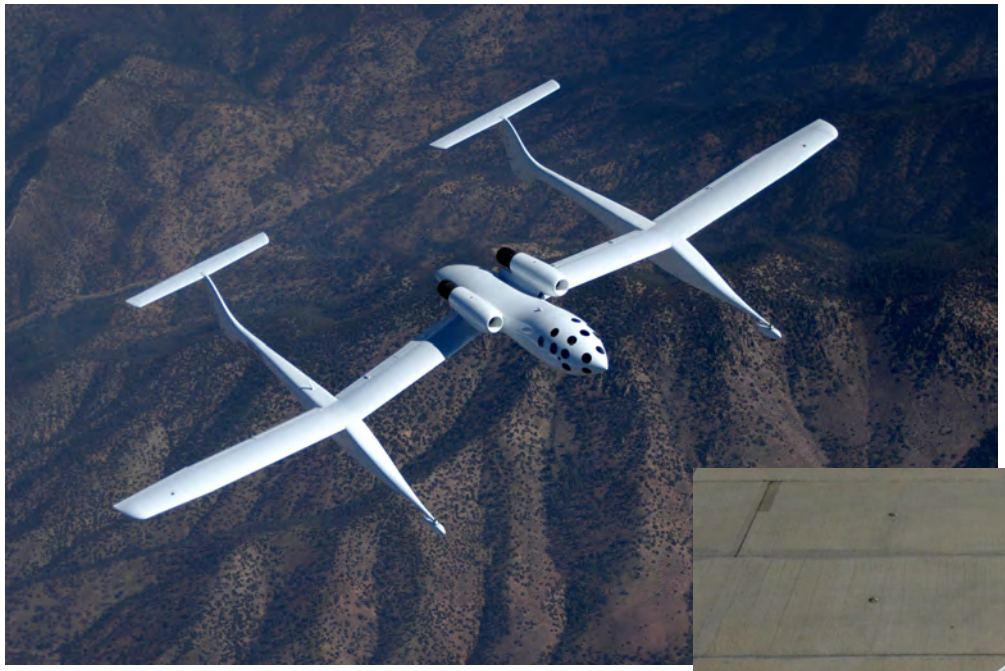
And one I like

- **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

A small plane!

NASA AD-1, 1st Flight Aug. 1982

Another Novel Concept: SpaceShipOne



The White Knight

Burt Rutan: Still imagineering!

SpaceShipOne

Pictures from the
Scaled Composites web site

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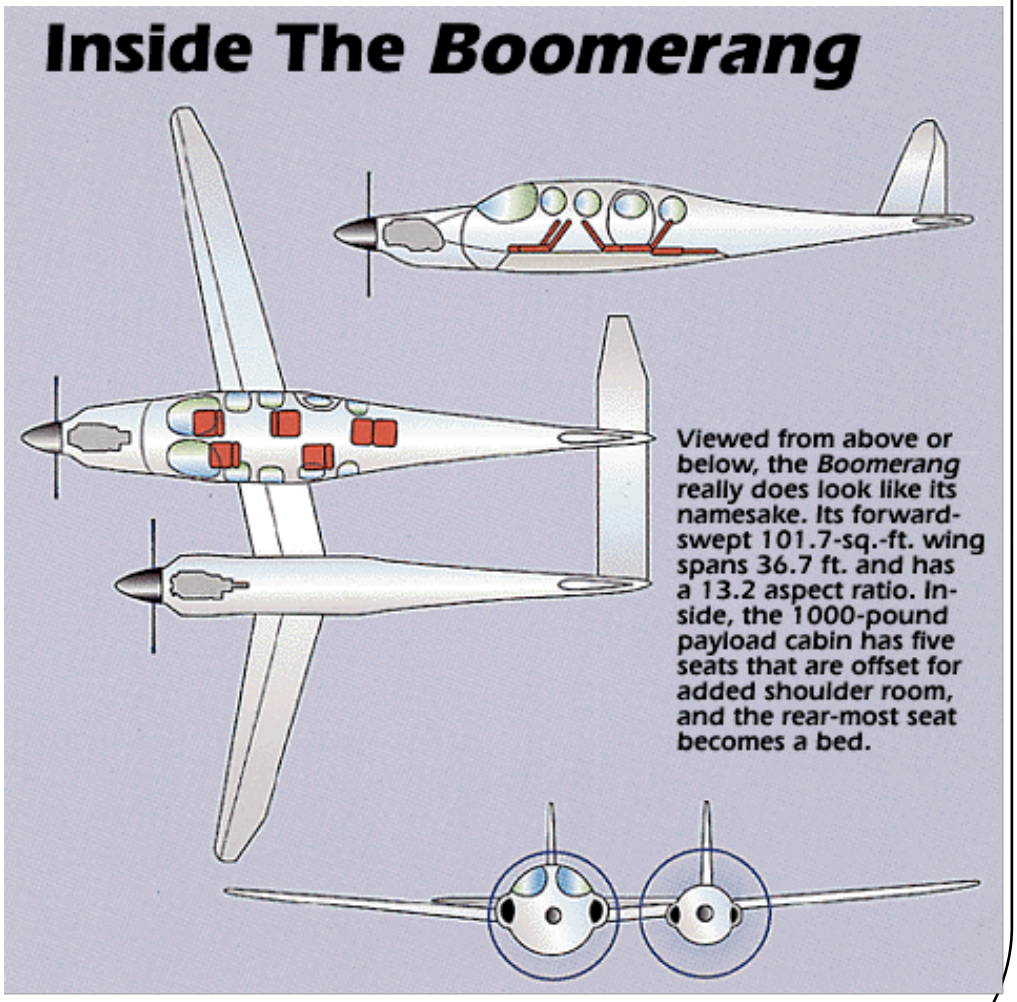
A Burt Rutan Creation: the Boomerang

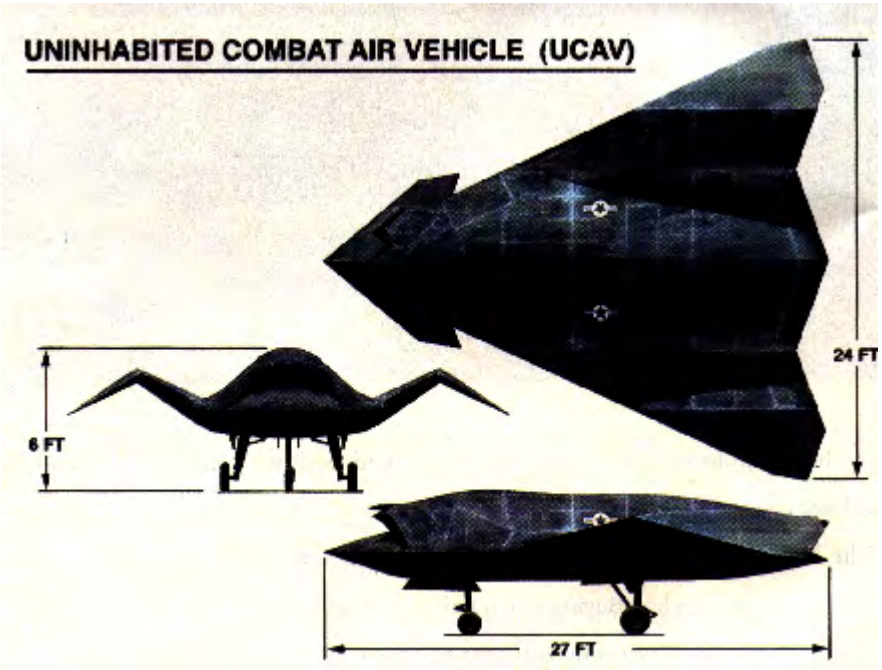
To make twins safe for one engine out flight, engines closer to the centerline.



Popular Mechanics, November 1996

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

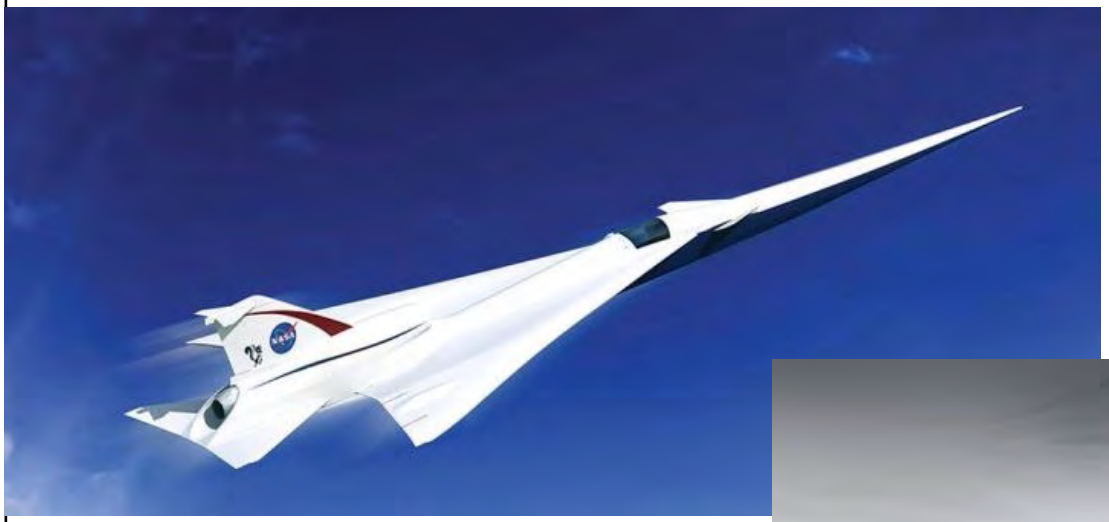
Achievements

- 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!

Watch for the huge variety of concepts being proposed

Upcoming X-59



Make the flow physics work for you, not against you!

Really? An Airbus Concept

Aerospace and
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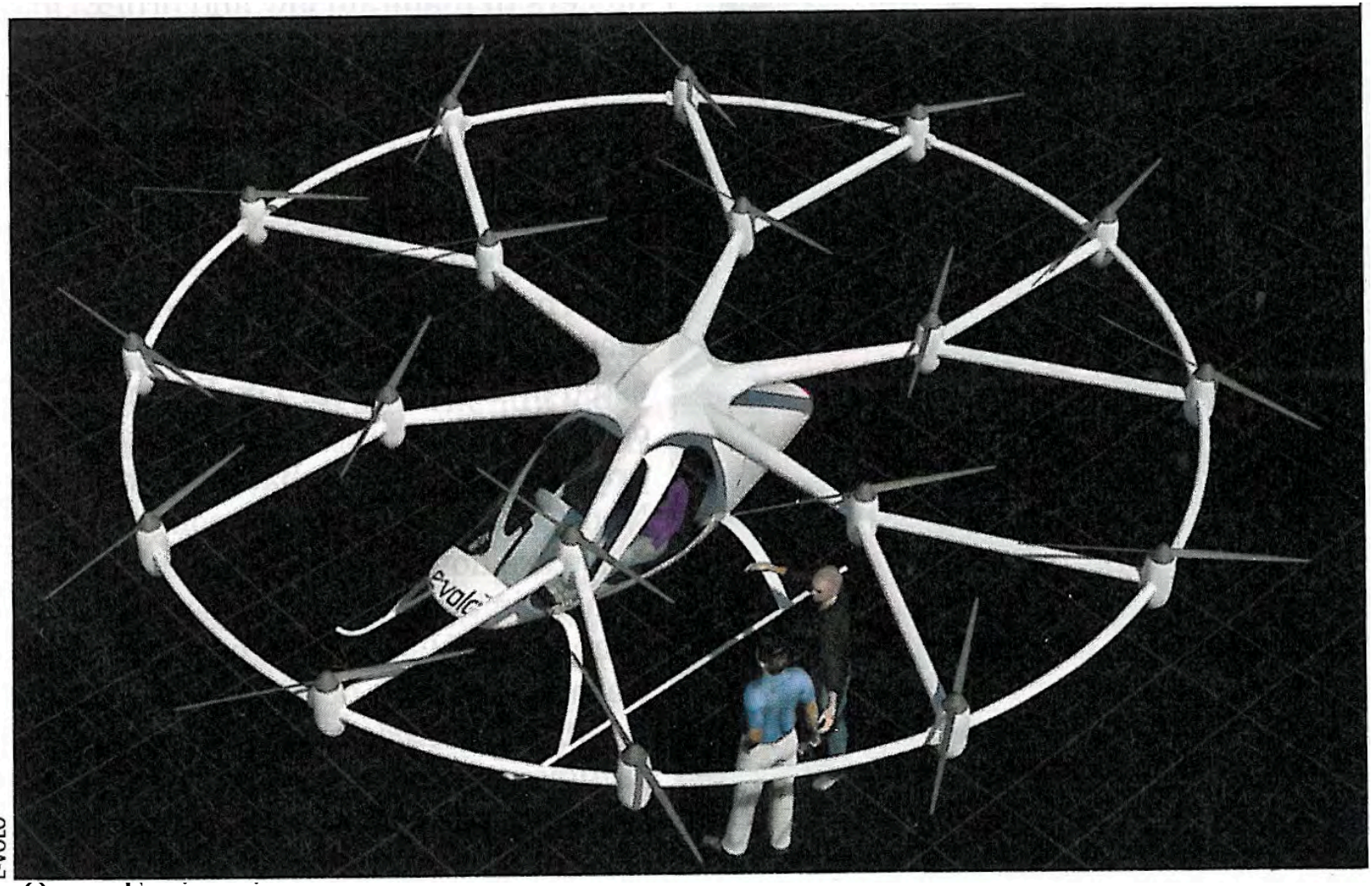
And a Quad – Mainly Prop/Controls

The electric powered Volocopter



Design for Performance

Reduce minimum drag:

- minimize wetted area to reduce skin friction
- streamline to reduce flow separation (pressure drag)
- distribute area smoothly, especially supersonic a/c (area ruling)
- consider laminar flow

Reduce drag due to lift:

- maximize span (must be traded against wing weight)
- tailor spanload to get good span e, (twist)
- distribute lifting load longitudinally to reduce wave drag due to lift
  (a supersonic requirement, note R.T. Jones' oblique wing idea)
- camber as well as twist to integrate airfoil, maintain good 2D characteristics

Key constraints:

- at cruise: buffet and overspeed constraints on the wing
- adequate high lift for field performance (simpler is cheaper)
- alpha tailscrape, $C_{L\alpha}$ goes down with sweep, AR

Design for Handling Qualities

- adequate control power is essential
- nose up for stable vehicles
- nose down for unstable vehicles
- consider full range of *cg*'s.
- implies: balance area around the *cg* properly

FAA and Military Requirements

- safety (FAR Part 25 and some Part 121 for commercial transports, MIL STD 1797 for military)
- ability to use as a stable weapons platform
- noise: community noise, FAR Part 36, no sonic booms over land (high *L/D* in TO config reduces thrust requirements, makes plane quieter)

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. I continue to contend that 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 20, "Design of Unique Aircraft Concepts" is good once you've read the first two references.

Still Room for Dreamers

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

"The scientist discovers that which exists, the engineer creates that which never was."

Theodore von Kármán
Aerospace Pioneer

W. Mason, whmason@vt.edu

Aerospace and
Ocean Engineering

A Flying Car? Terrafugia, among others

Aerospace and
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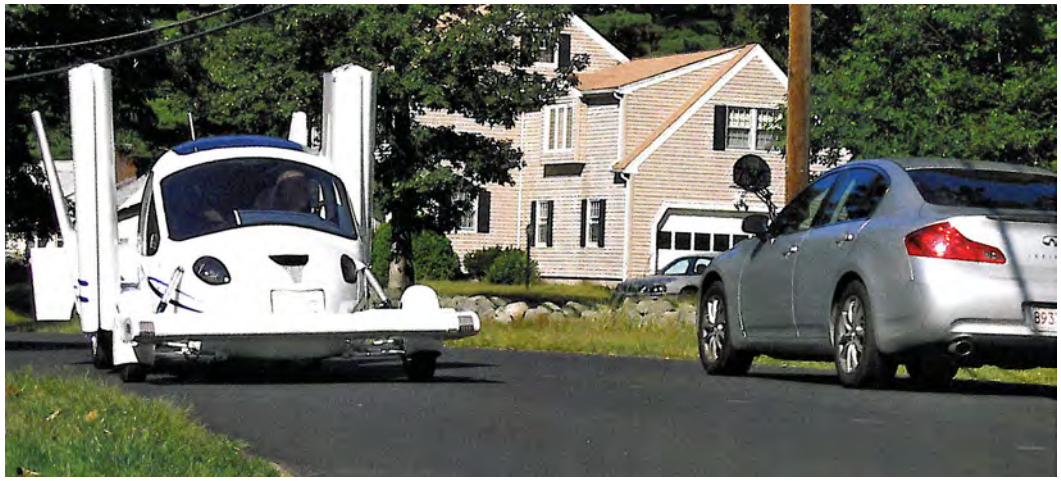
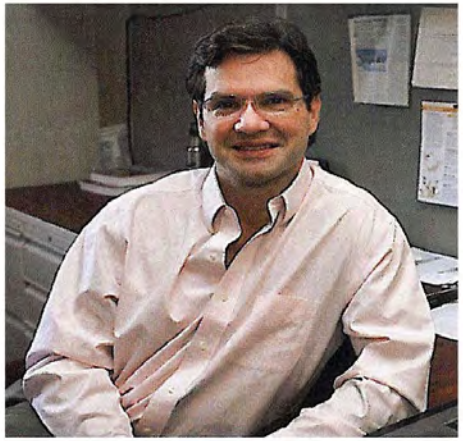
Previously, and flown:



NASA's Mark Moore, concept visionary

Leaves NASA to work for Uber



Wow