AOE 2104

A Lecture
on
Aerodynamic Testing

W.H. Mason
March 18, 2003

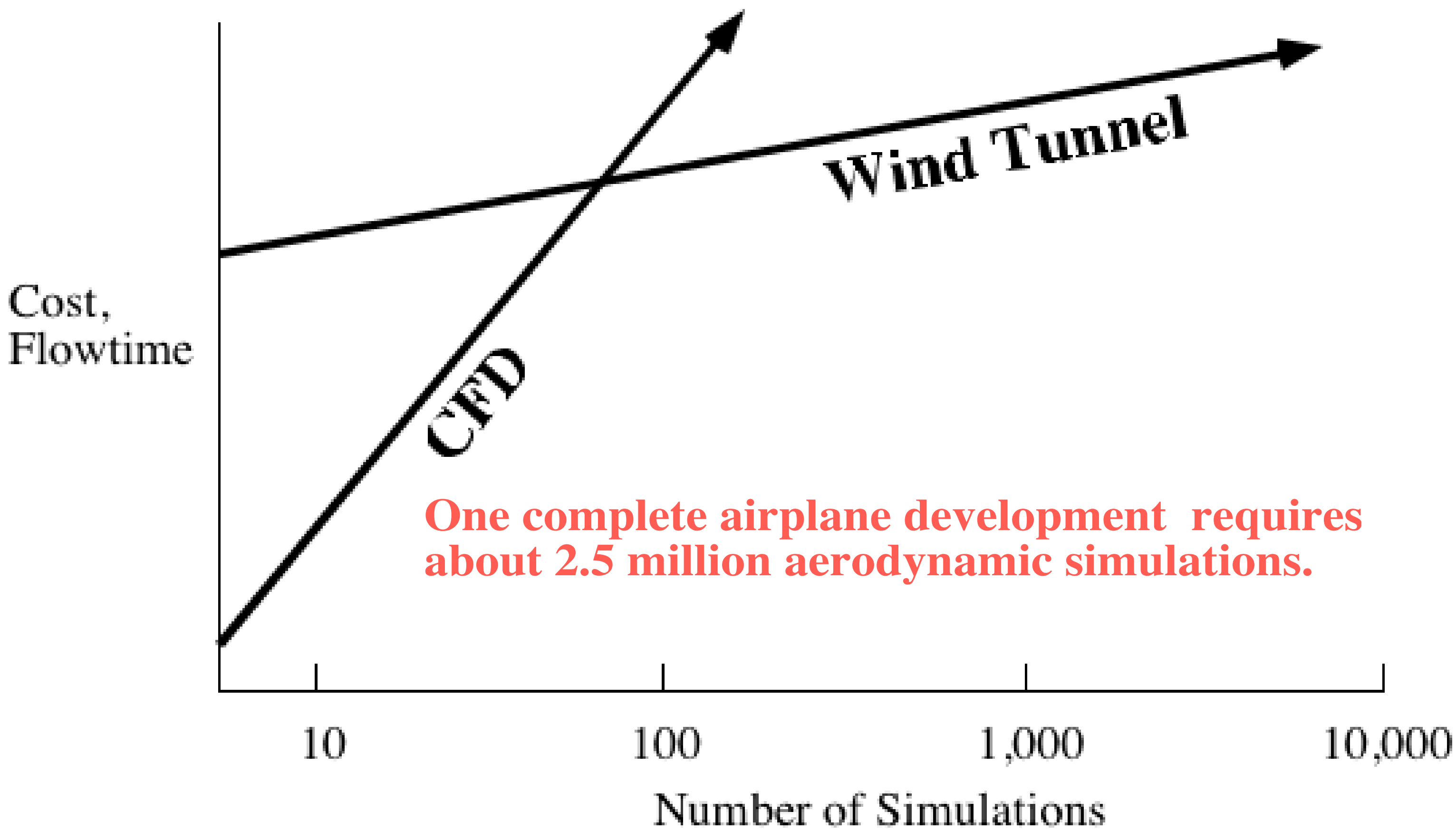
Aerospace and
Ocean Engineering

What the Heck is Testing All About?

- We need many, many checks before we have a good, safe design (*that makes money*)
- Progressively
  - Computational simulations
  - Wind tunnel testing for aerodynamics
  - Subscaleflight tests
  - Full scale flight testing
- Note: Lots of other tests:
  - Systems
  - Structures
  - Flying qualities: The Iron Bird

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



Comptational Simulations and WT Testing are Complimentary

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

Key Idea of a WT 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

WT vs Flight

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

Aerospace and
Ocean Engineering

What's the Problem?

- Suppose we have a 20th scale model: $L_m / L_{fs} = 0.05$
  - Can we make $V_m = 20 V_{fs}$? - Mach number would be different
  - Can we change □?□?
- **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

Aerospace and Ocean Engineering

Big Models: Full Scale WT at NASA Ames

40x80 Foot
Test Section

80x120 Foot
Test Section

Aviation Week & Space Technology, Dec. 7, 1987

Aerospace and
Ocean Engineering

Wind Tunnel Testing is Expensive

Preparation and planning are required to get into any tunnel:

- Make pre-test estimates
- Prepare a pre-test report including a Run Schedule

Key Items

- Safety, accidents can happen
- Pretest Planning - the key to success
- Model Design
- The Run schedule
- Typical Tests:

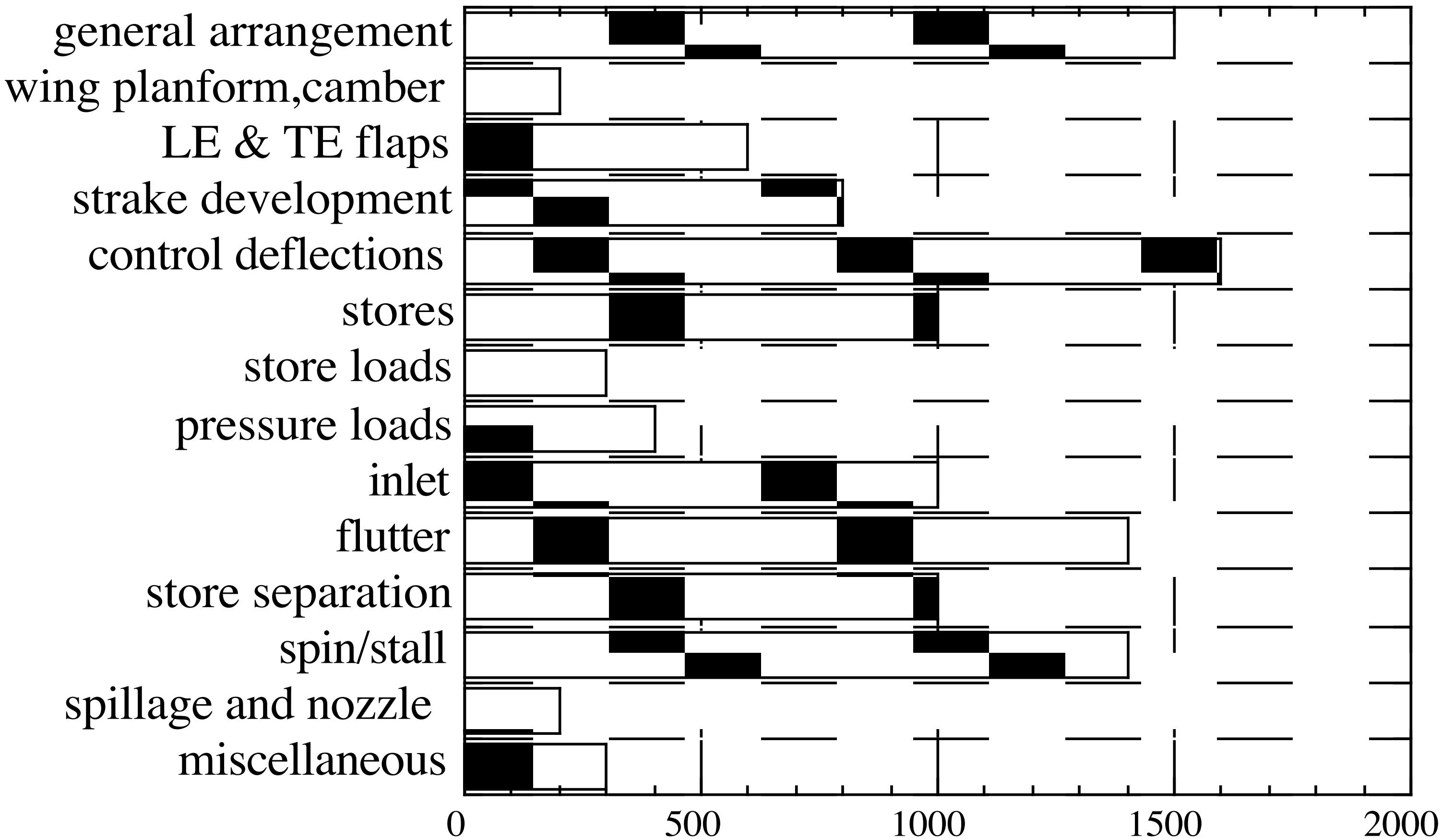
  - force and moment

    both performance, stability, and control

  - pressure distributions
  - flow diagnostics

    on and off surface flow visualization

Test Hours, F-16 WT Test



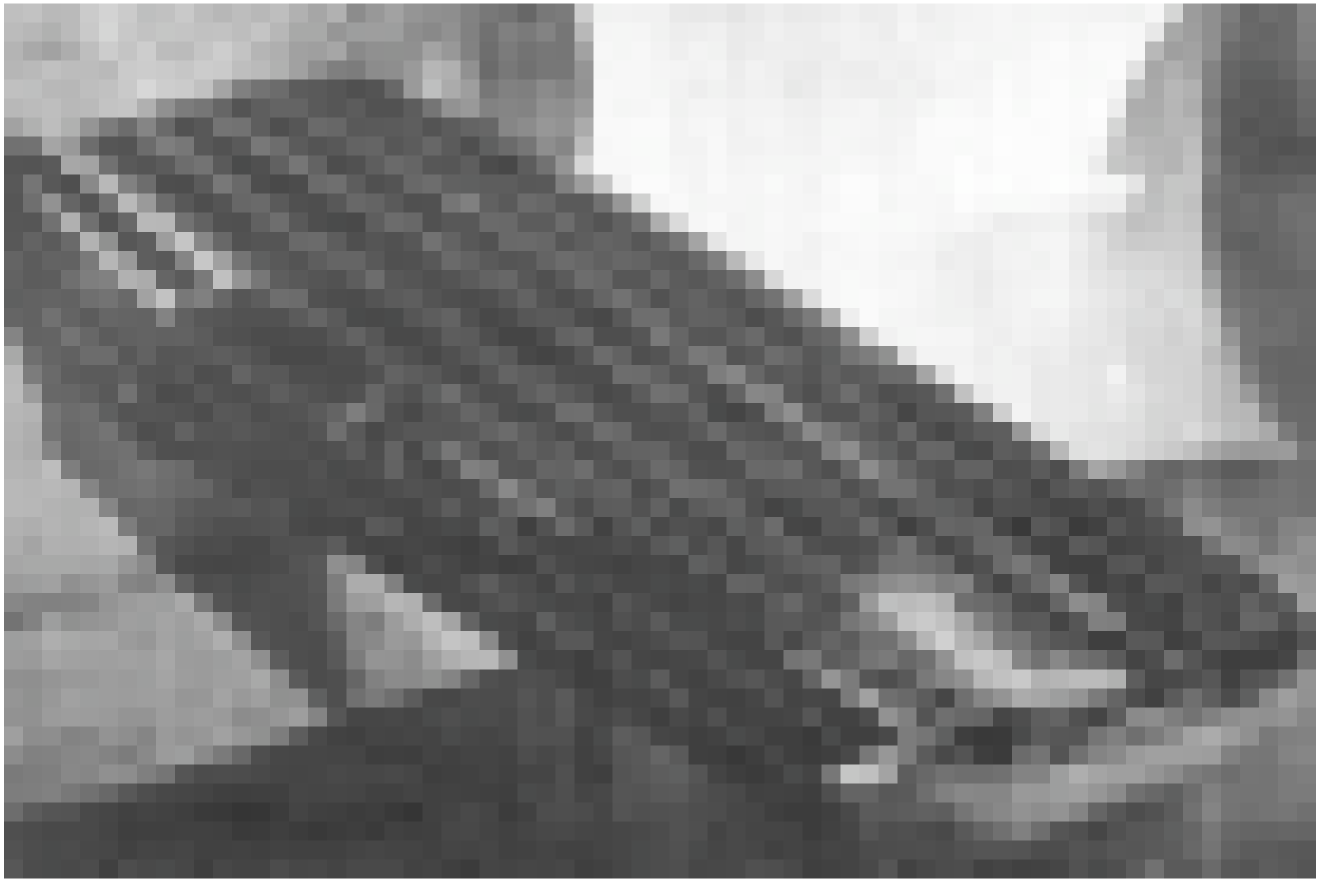
Research Fighter Configuration (RFC) Visualization with a Tuft Grid

Small Model in Grumman Tunnel

Another Way To Do Flow Diagnostics

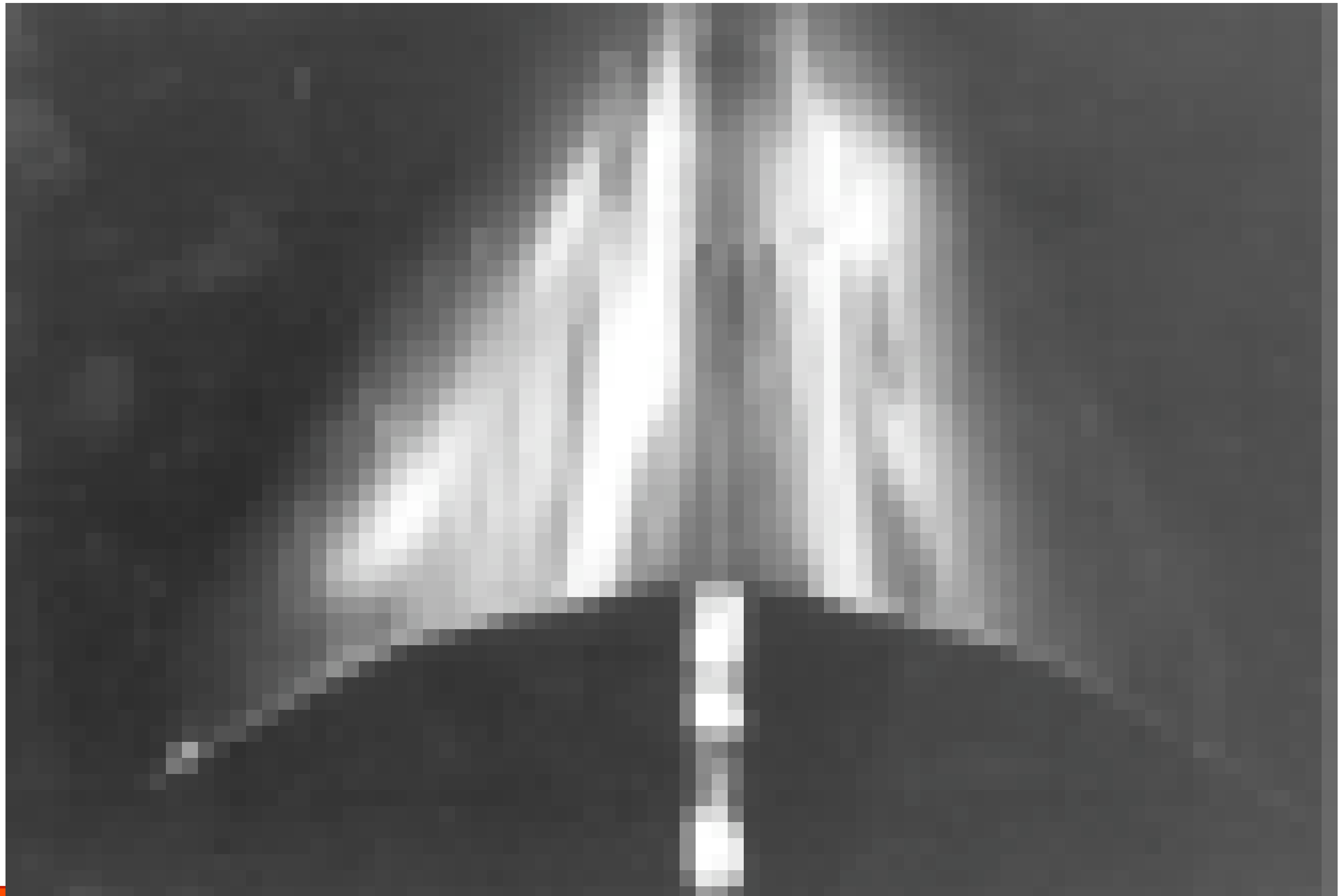
Kurt Chankaya, Grumman (now Lockheed)

Typical way to put tufts on the wing



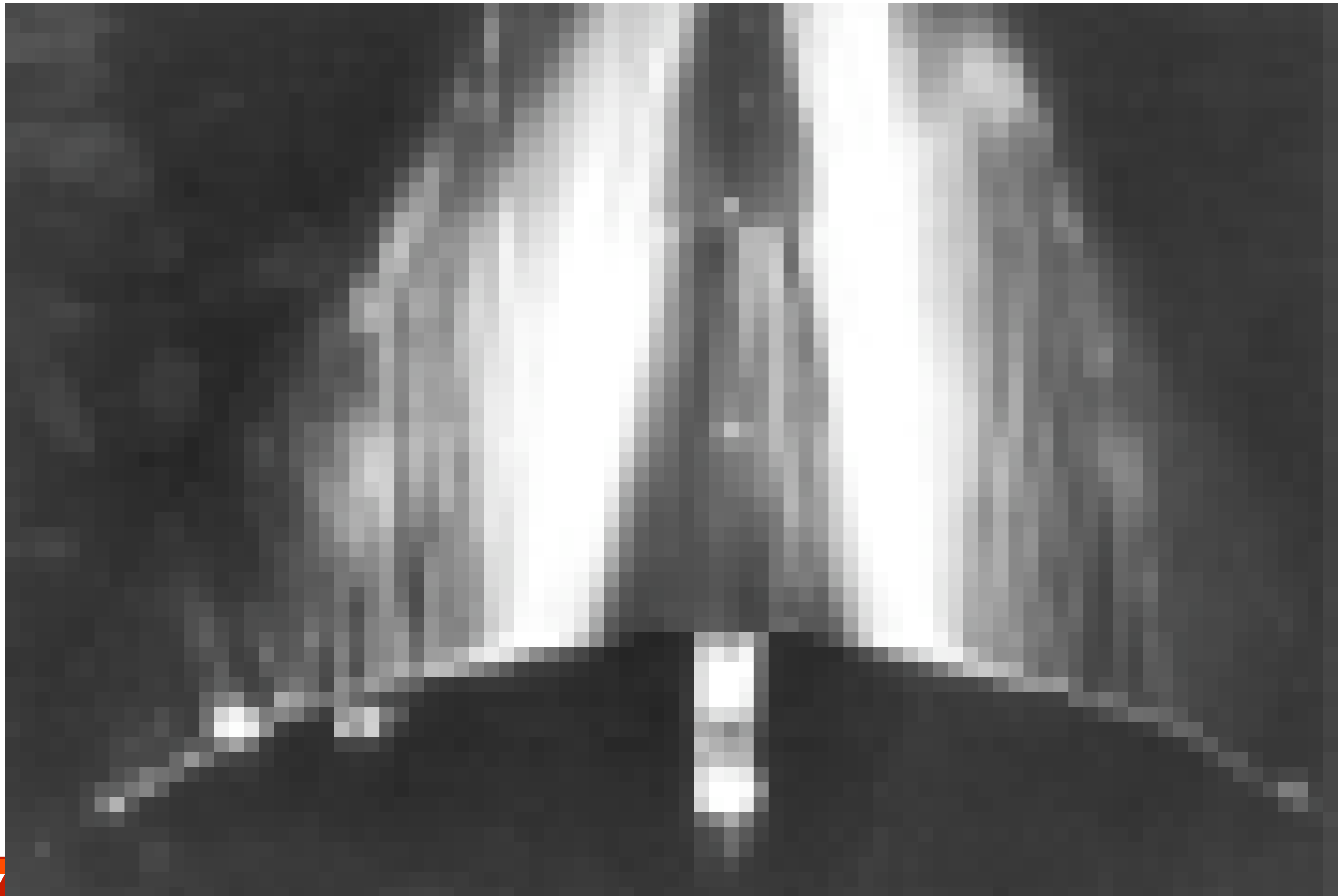
From Pope and Harper's text, taken in the Wichita State tunnel

Oil Flows for Surface Visualization 1



SC3 Wing, M = 1.62, α=8 ° (nominally attached)

Oil Flows for Surface Visualization 2



SC3 Wing, M = 1.62, α=12 ° (TE flow separation)

Laser Light Sheet example

Light Sheet from an argon laser, the flow is seeded with an standard smoke generator.

Northrop IR & D example of vortex flow over a delta wing configuration.

Exhibited at the 36th Paris air show.

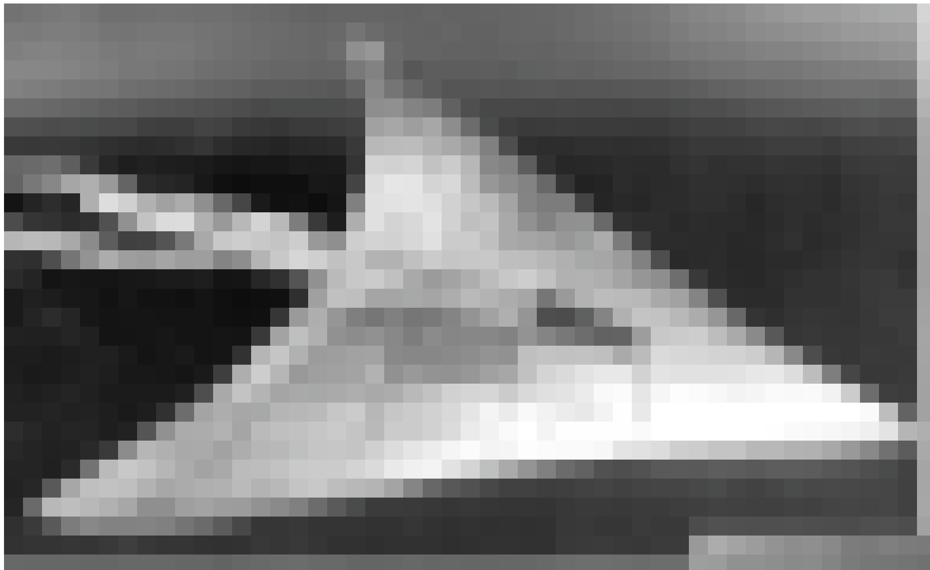
Aviation Week & Space Technology, July 29, 1985

Aerospace and Ocean Engineering

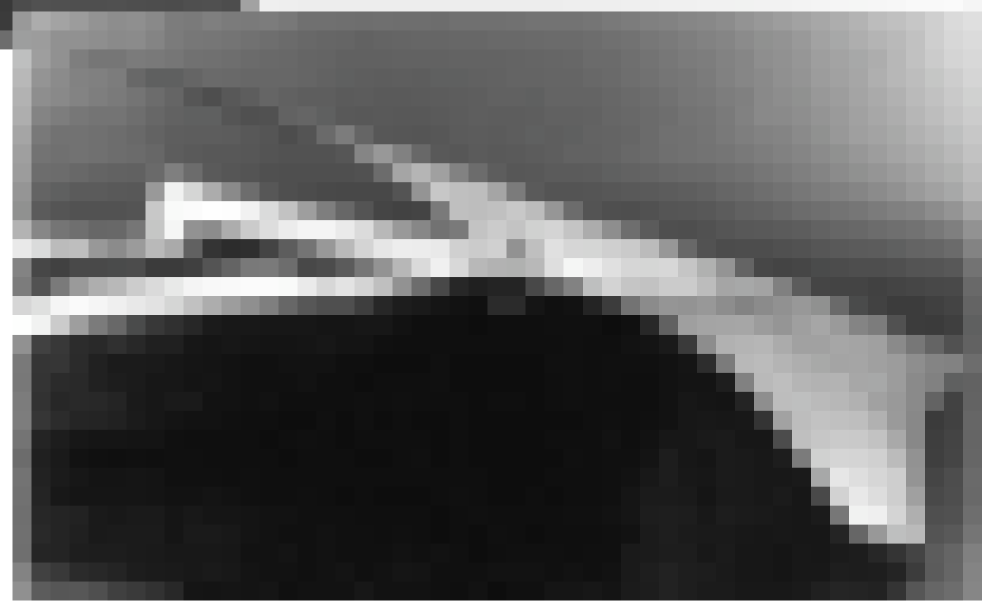
Model Fabrication:

- Accuracy important!
  - drag, under all conditions
  - low speed near max lift
  - transonic cruise condition

WT model with high LE accuracy Req'ts.



Supercritical Conical Camber (SC3) Wing, developed using CFD.
The leading edge contour accuracy is critical.



Note the arc of the wing along the trailing edge, a sort of "gull shape"

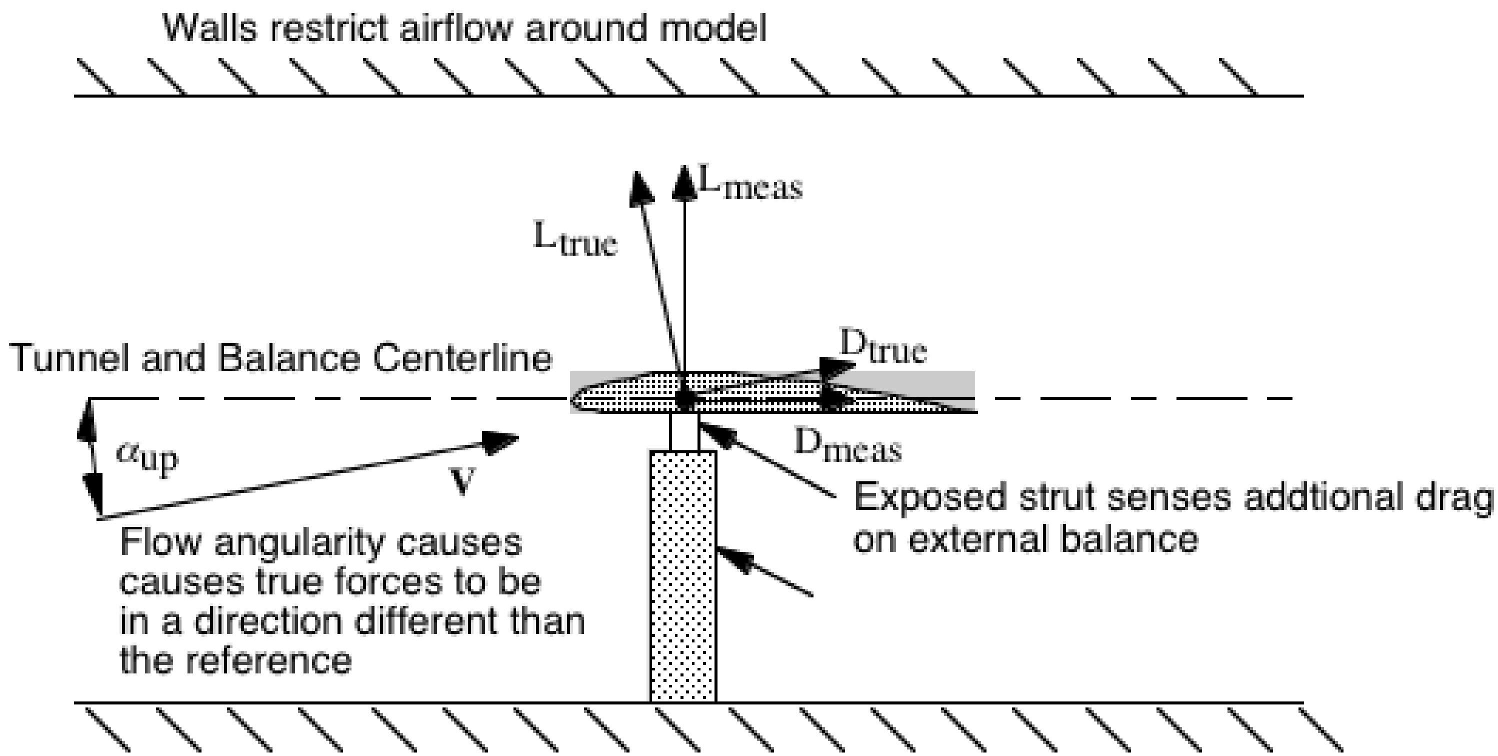
Aerospace and Ocean Engineering

Fab agrees with designed contour!

Other Key WT Simulation Issues

- Wall interference
- Support interference
- Flow angularity, nonuniformity
- Adjustment from model scale to full scale

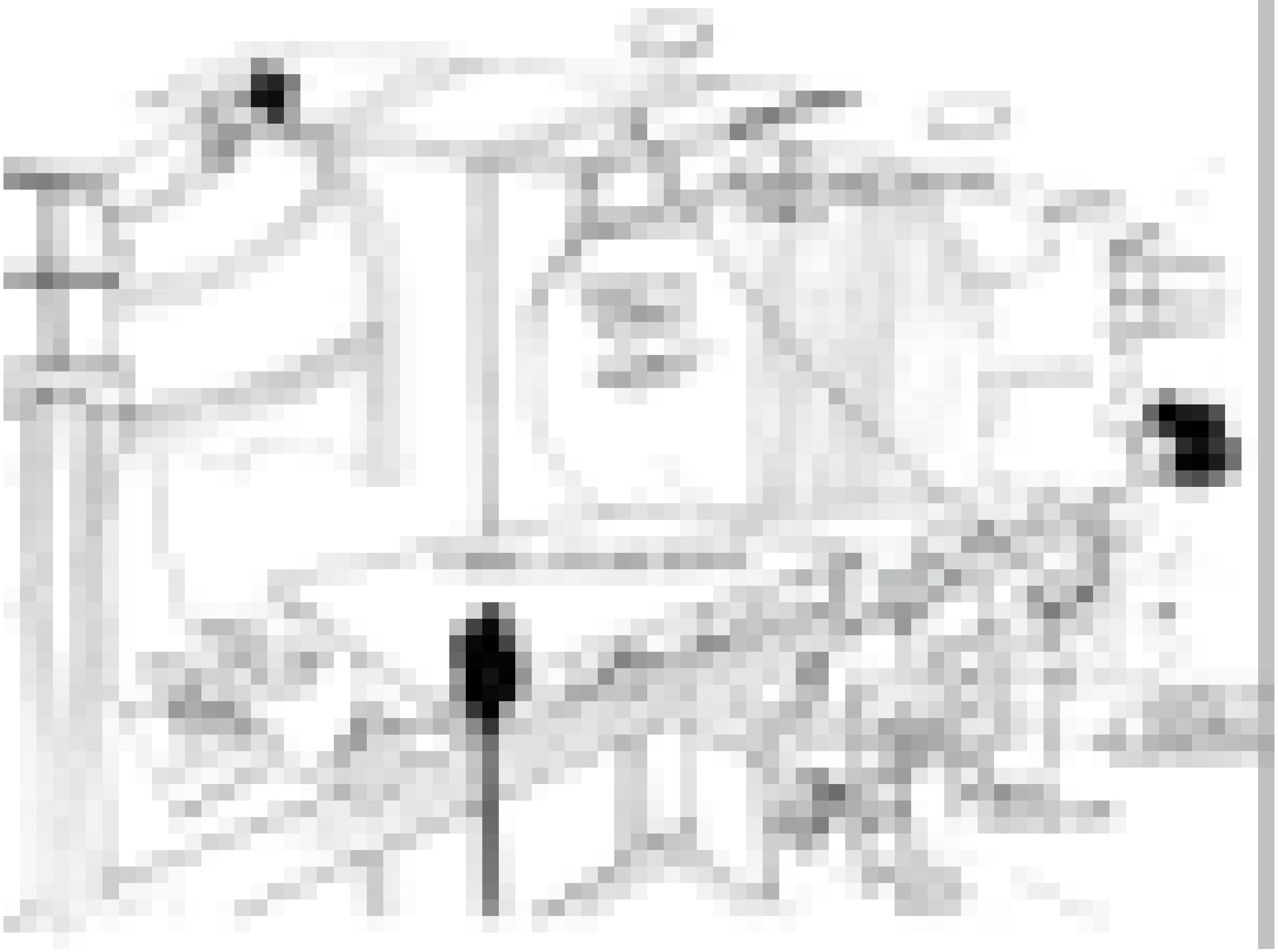
Tunnel/Mounting Interference



Sue Grafton with RFC at NASA Langley

RFC in the 30x60 at Langley: static tests

Free Flight Setup: A complicated activity



RFC Model in Free Flight at Langley

The Virginia Tech Stability Tunnel

- A high quality flowfield
  - uniform mean flow
  - low turbulence level
  - low flow angularity
- came from NASA in 1958
- 6'x6' test section, 24 ' long
- 600 hp motor/14' fan
- 275 fps max speed

Virginia Tech Stability Tunnel Layout

Aerospace and
Ocean Engineering

Flight Test

Subscale demonstration of an oblique wing airplane

Aerospace and
Ocean Engineering

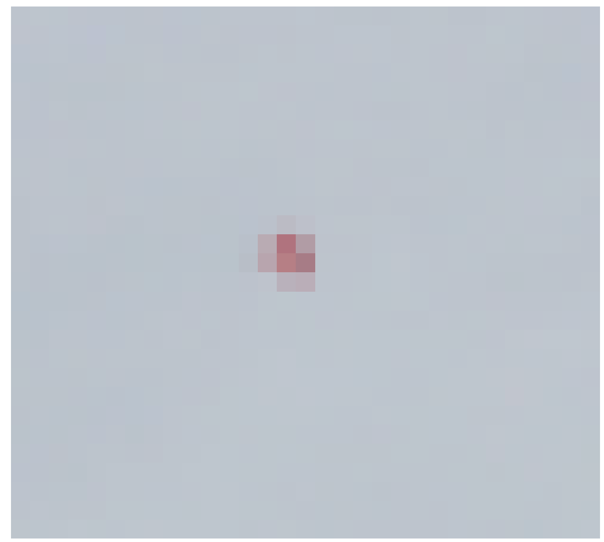
Flight Test

- *The X-45A from last November*

Find X-29 videos clips here:

http://www. dfrc.nasa. gov /gallery/Movie/X-45A/index.html

Flight Test at VT: March 14, 2003



Full scale flight test the X-29

Find X-29 videos clips here:

http://www.dfrc.nasa.gov/gallery/Movie/X-29/index.html

Flight Test Leading to the F-35!

So to Conclude

- Aerodynamic Testing is a major activity in Aerospace Engineering
- Tends to be interesting, assessing the latest products
- Types of work
  - Test Engineer (Flight *or* WT)
  - Instrumentation Engineer
  - WT Model Designer
  - Data Reductions/Analysis