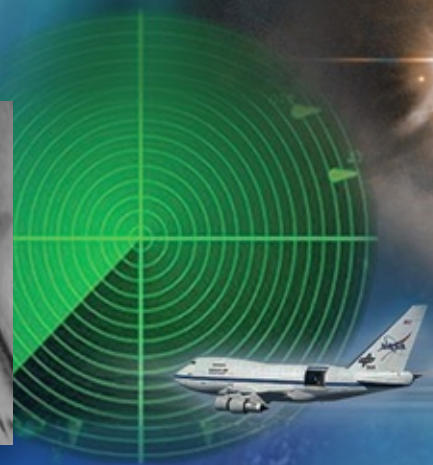
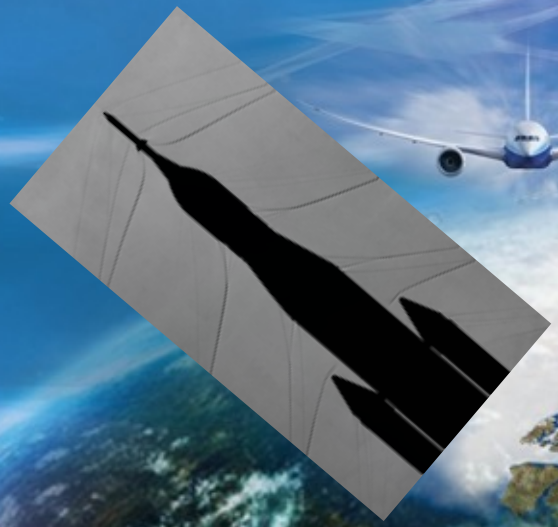
National Aeronautics and Space Administration



The Brothers Were Wright – An Abridged history of wind tunnel testing at Ames Research Center



Presented by Steve Buchholz
Test Manager, Wind Tunnel Division
Ames Research Center

The Brothers Were Wright: History

Two brothers from Dayton Ohio who ran a bicycle shop

Neither graduated from high school

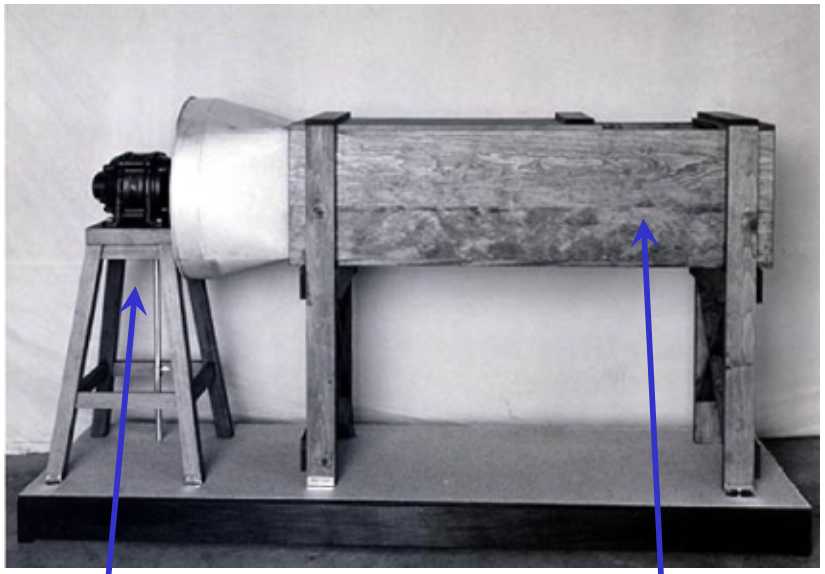
Developed a strong interest in manned flight

Very creative intelligent self-made engineers

Applied their knowledge of bicycle balance control to flight control

The Brothers Were Wright: History continued

Built a wind tunnel to test different wing/airfoil designs



View Window

Fan

Fan Drive Motor

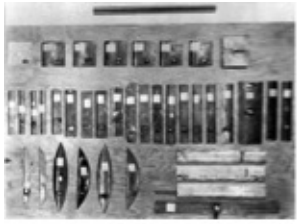
Test Section

Flow Straightener

The Brothers Were Wright: History continued

Built balances to measure model loads: lift and drag

Sample of model wings



Sheet Steel fabricated using tin shears, hammer and file

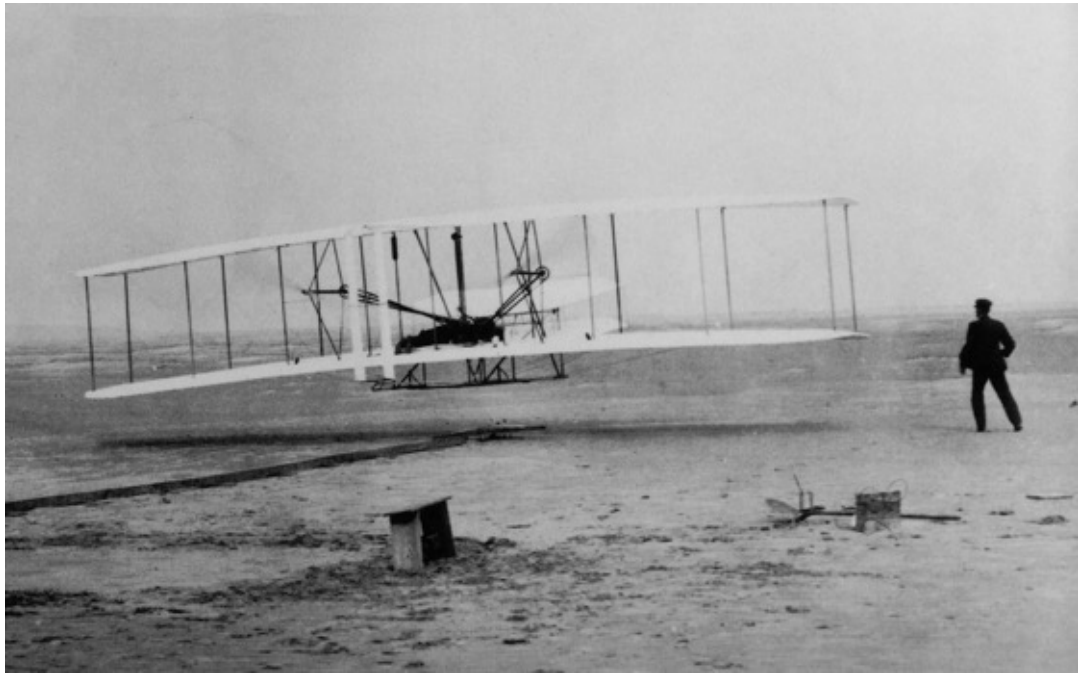
The Brothers Were Wright: History continued

Based on their methodical wind tunnel test data:

Developed better airfoil design

- **Greater Lift / Reduced Drag - Better Lift to Drag Ratio**
- **Located Center of Pressure - Stability**

Developed a very efficient propeller



December 17, 1903

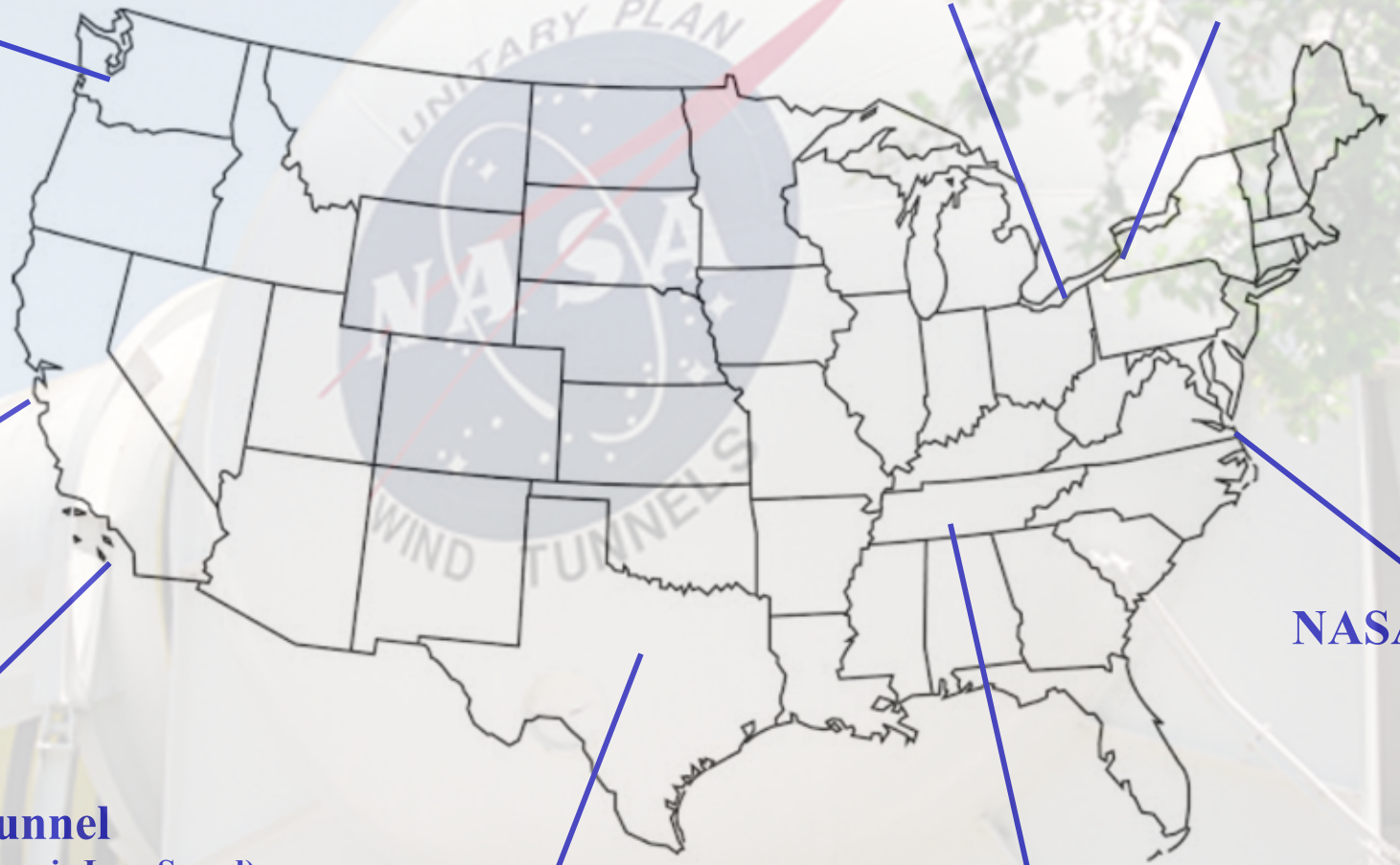
National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

NASA Ames Research Center
Wind Tunnel Division

Major Wind Tunnel Facilities In the United States



Boeing

NASA Glenn

CALSPAN

NASA Ames

NASA Langley

San Diego Tunnel
(Formerly the Convair Low Speed)

Lockheed Martin
(Outside Dallas and Atlanta)

Arnold Engineering Development Center (AEDC)

The Science and Art of Wind Tunnel Testing

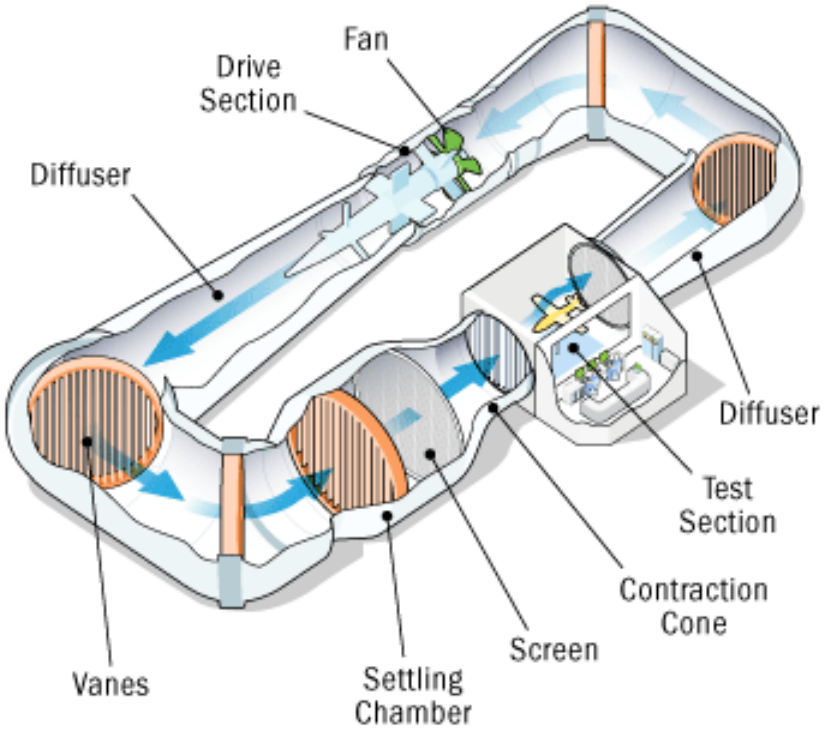
Wind Tunnel Testing is only a Simulation of Real Flight

Pros:

- Less Expensive than building a flying a new vehicle
- Easier and faster to make changes to a configuration or design
- Creates a accurate data base that can be used in design trade offs
- Conditions can be measured and controlled with high accuracy
- Safer than putting a human in a untested design

Cons:

- Corrections to the data need to be applied
  - (You are essentially flying tethered in a box?)
- Operation and maintenance of wind tunnels are expensive
- Possible physical limitations
  - (i.e. model size, test conditions, etc.)
- Usually requires scaled down version of the real thing



NASA Ames: Present Day

NASA Ames Unitary Plan Wind Tunnel: Background

Built in the early 1950's

Has been used in nearly all commercial and military aircraft development projects since

Mach 0.3 to 1.4 in 11- by 11-Foot test section

Mach 1.5 to 2.5 in 9- by 7-Foot test section

Major upgrades in late 1990s

Most productive wind tunnel within NASA

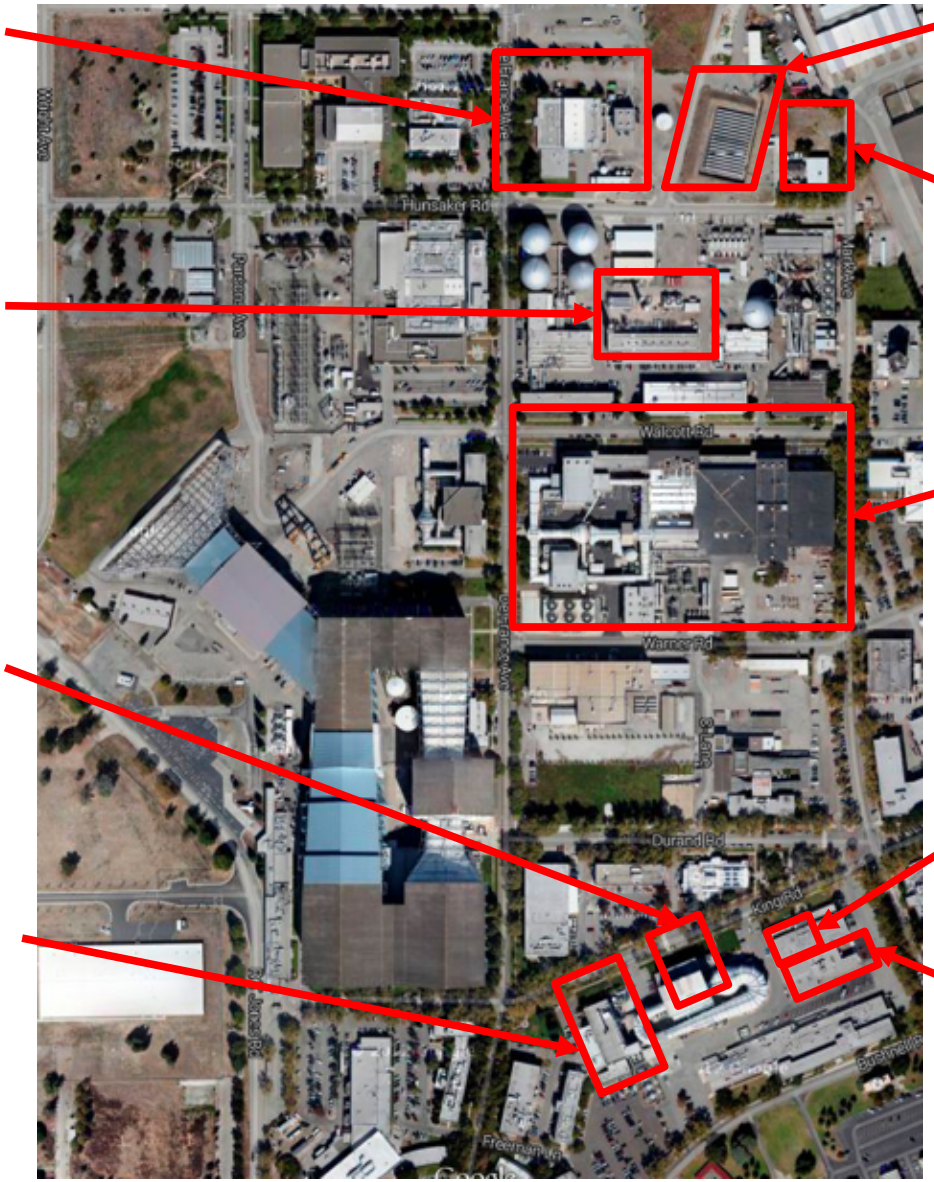
Wind Tunnel Division Facilities

Fluid Mechanics Laboratory (FML)

High Pressure Air (HPA) Compressor C1A & HPA Control Room

12-Ft PWT Model Preparation Rooms (MPR)

12-Ft PWT Mitsubishi Makeup Air (MUA) Compressor



High Pressure Air (HPA) Storage Tanks

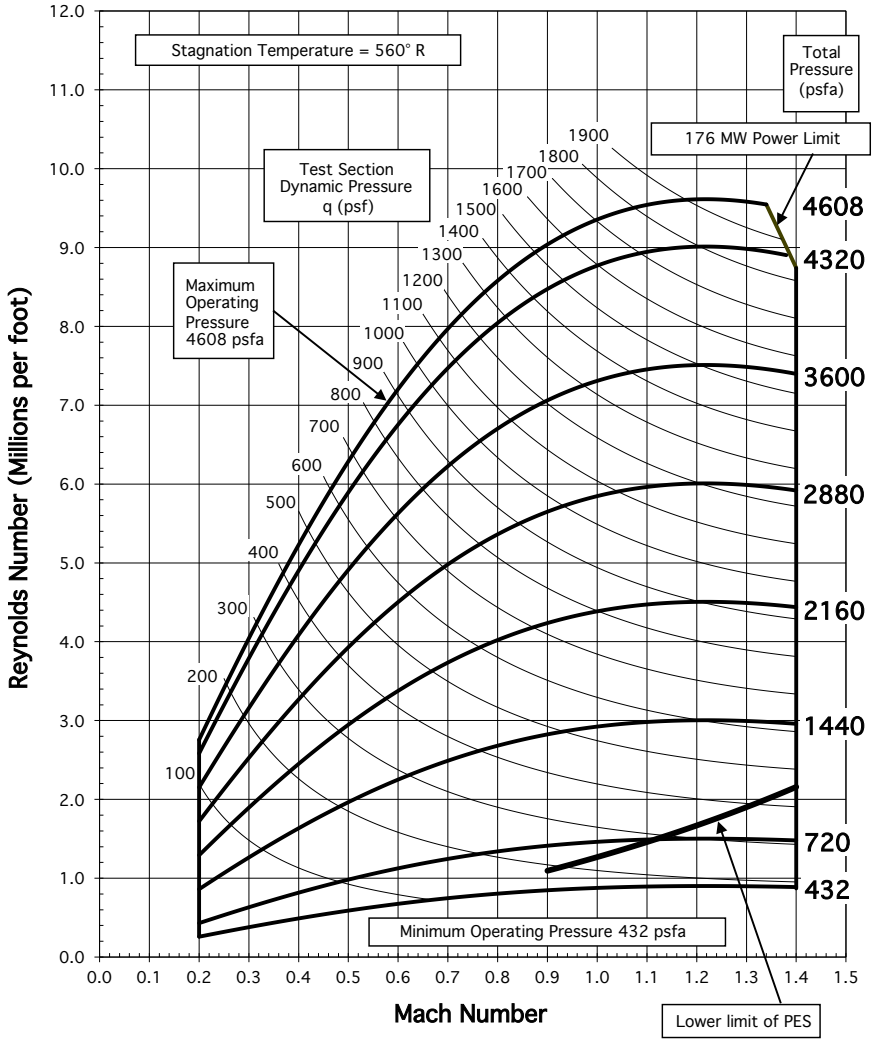
High Pressure Air (HPA) Compressor C1D

Unitary Plan Wind Tunnel (UPWT)

Balance Calibration Laboratory

Compressor Blade Shop

OPERATING CHARACTERISTICS OF THE NASA AMES RESEARCH CENTER 11-BY 11-FOOT TRANSONIC WIND TUNNEL



Source: Test 11-0051 IST

Revised 2/2015

Gemini Capsule with Titan II Rocket

Saturn V Rocket

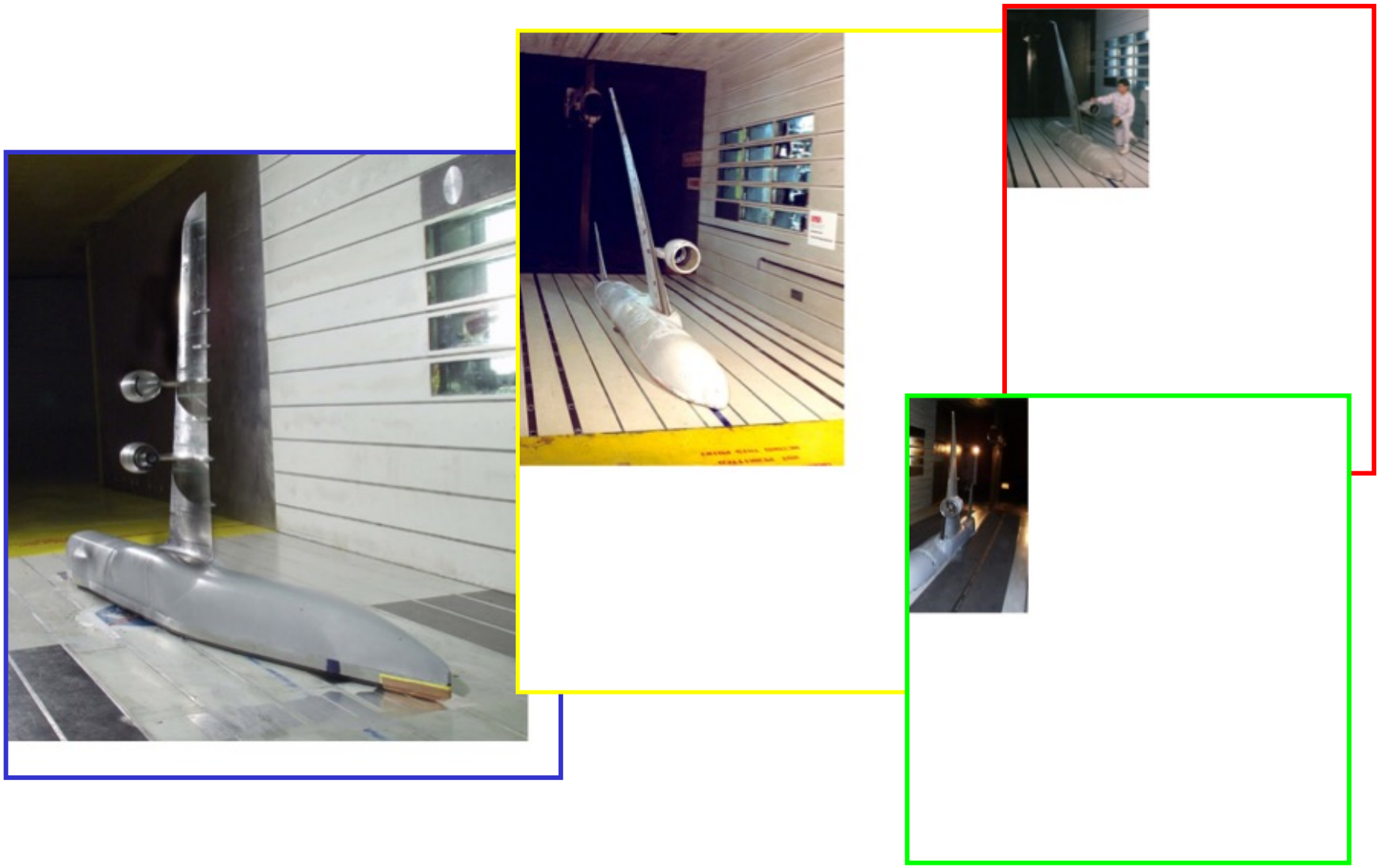
11x11-Foot Transonic Test Section Sting Mounted Models from the 1960's

National Aeronautics and Space Administration

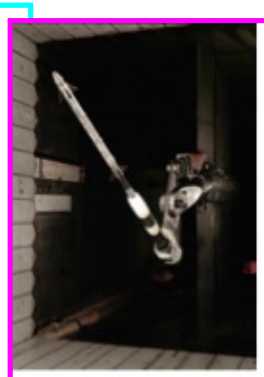
Ames

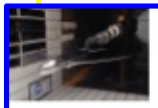
Discovery Innovations Solutions

NASA Ames Research Center
Wind Tunnel Division



11x11-Foot Transonic Test Section - Semi-Span Models

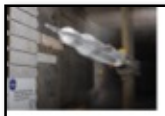




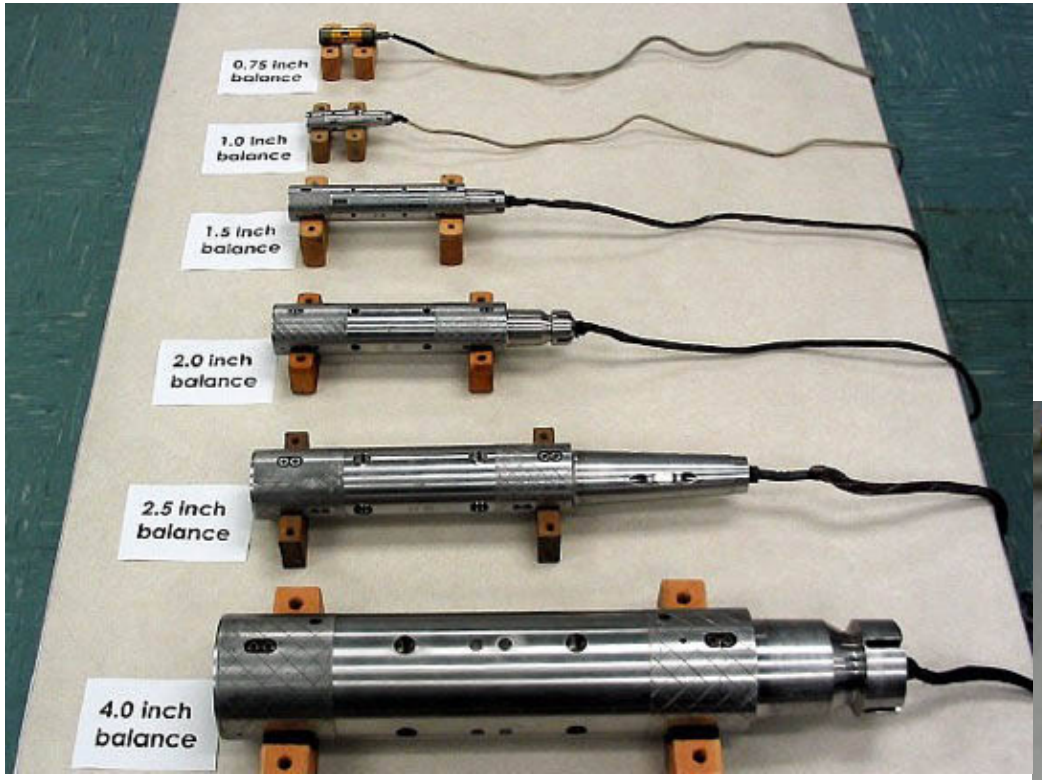
11x11-Foot Transonic Test Section – Sting Mounted Models

Space Launch System Testing

- **Initially just aeroacoustics tests**
  - **~350 unsteady pressure transducers on model(s)**
- **Subsequent "scare" about buffet loads led to second test**
  - **Came up with good buffet-reduction concepts that worked**
  - **Further analysis of unsteady pressure data showed buffet wasn't a problem…**
- **Recently ran a transonic aerodynamics test to verify the vehicle database**

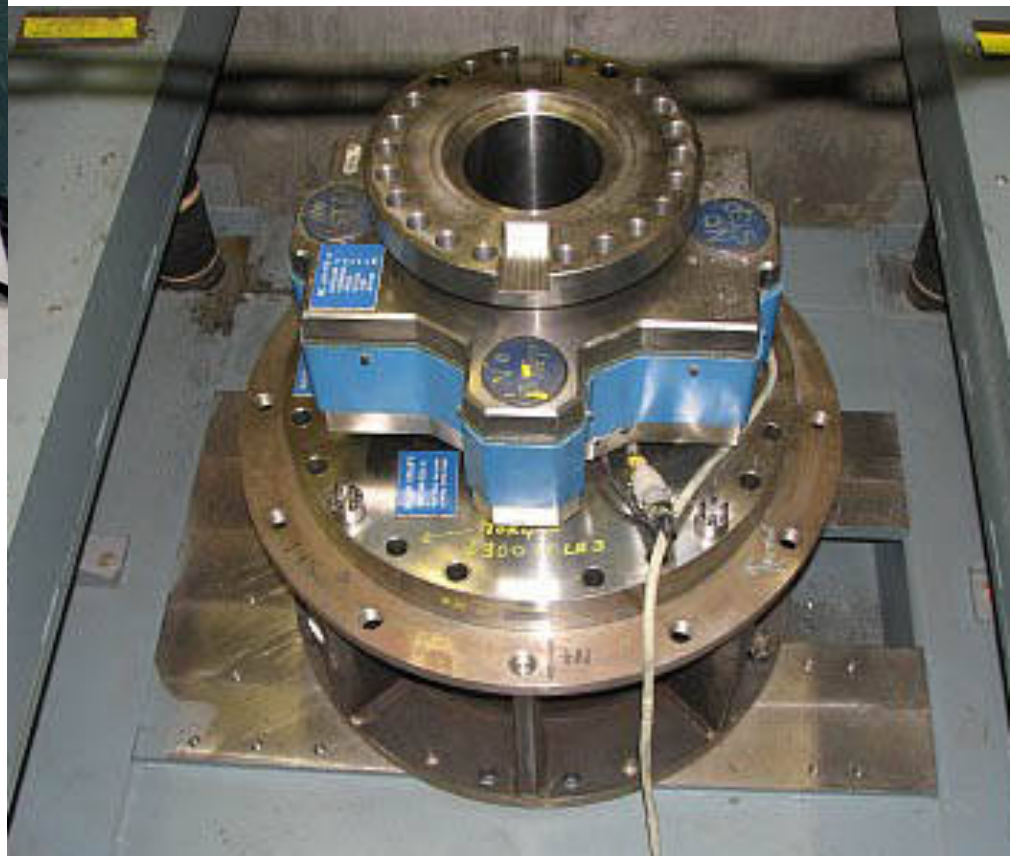


Instrumentation – Strain Gaged Balances



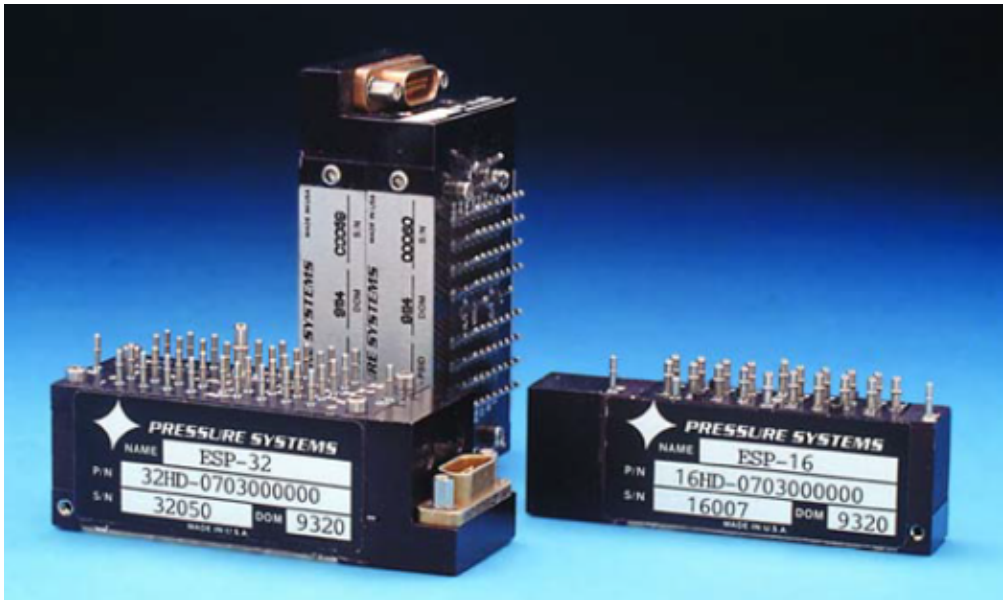
Sting Balances of Various Sizes and Capacities

Typical Floor Balance

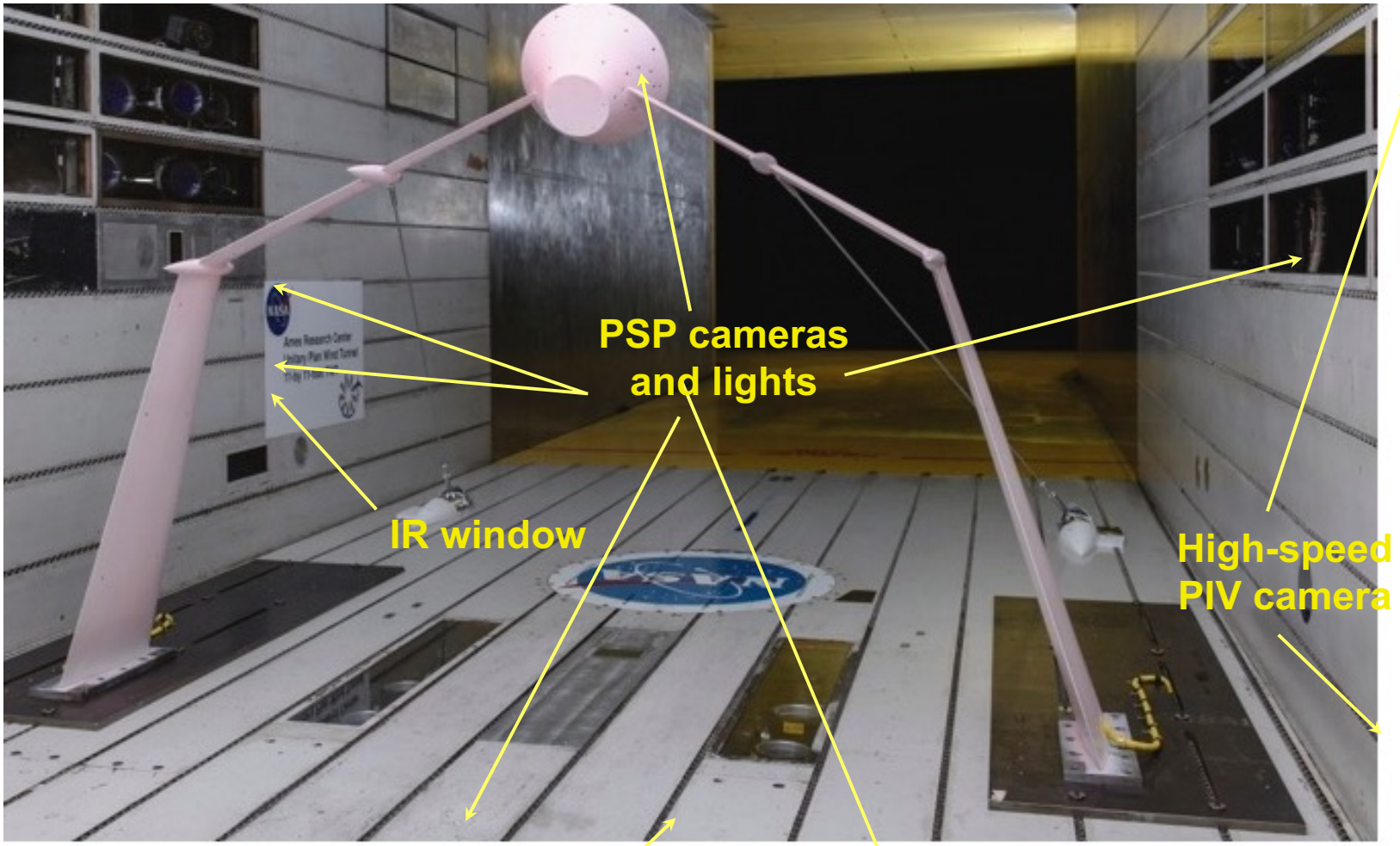


Instrumentation – Pressure Measurement

Pressure Scanners



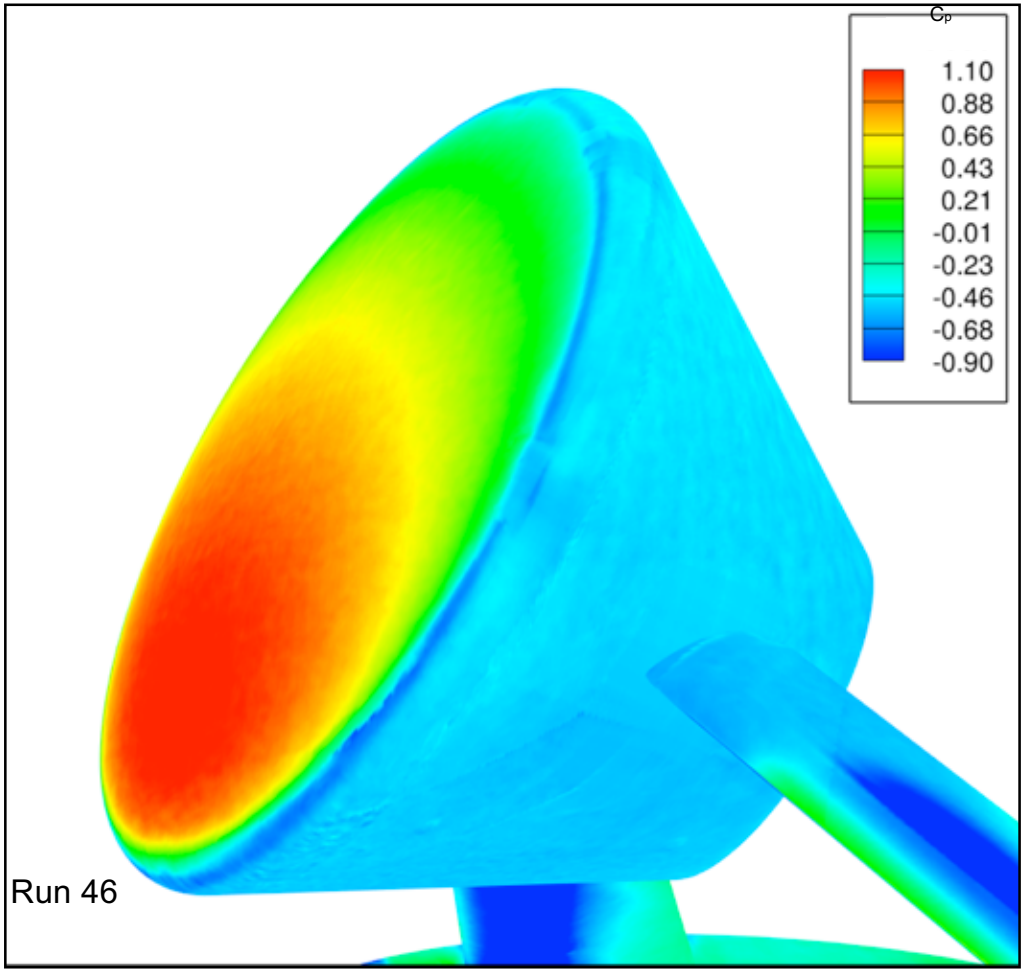
Pressure Scanners installed in 3% scale Shuttle Model

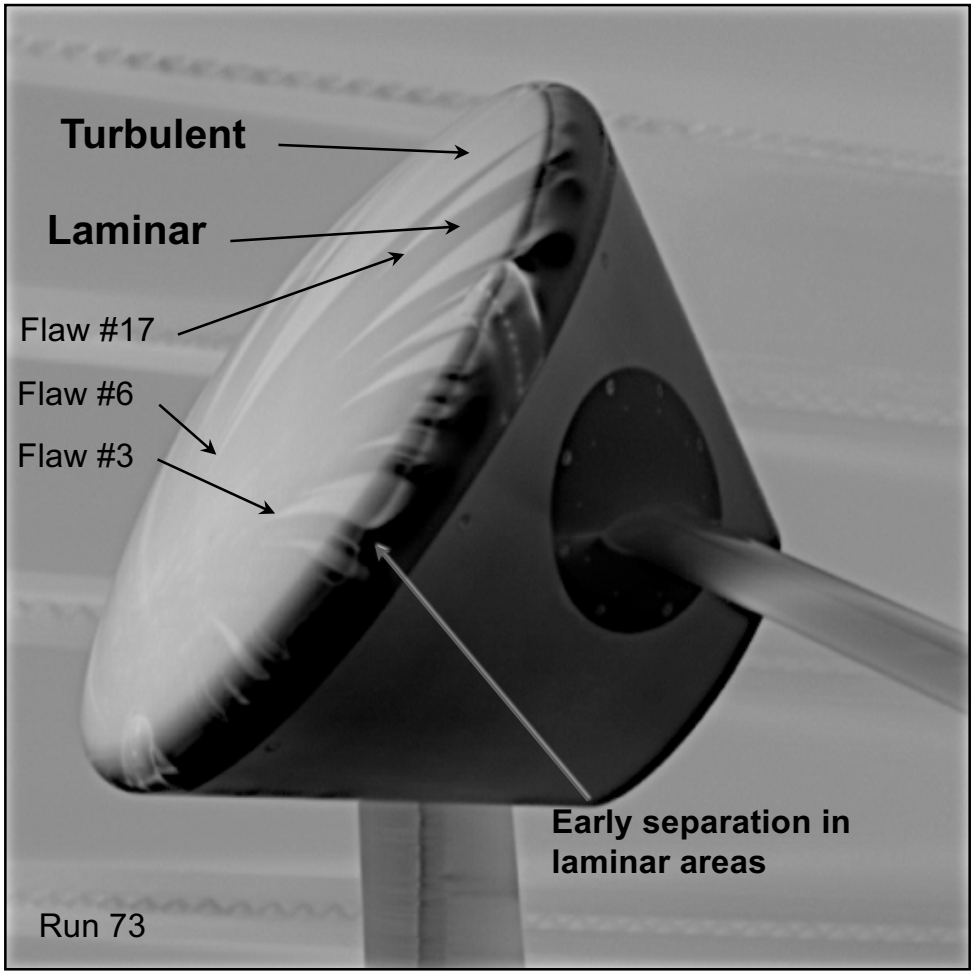


11x11-Foot TWT Optical Access

(8.08% Scale Model of the Orion)

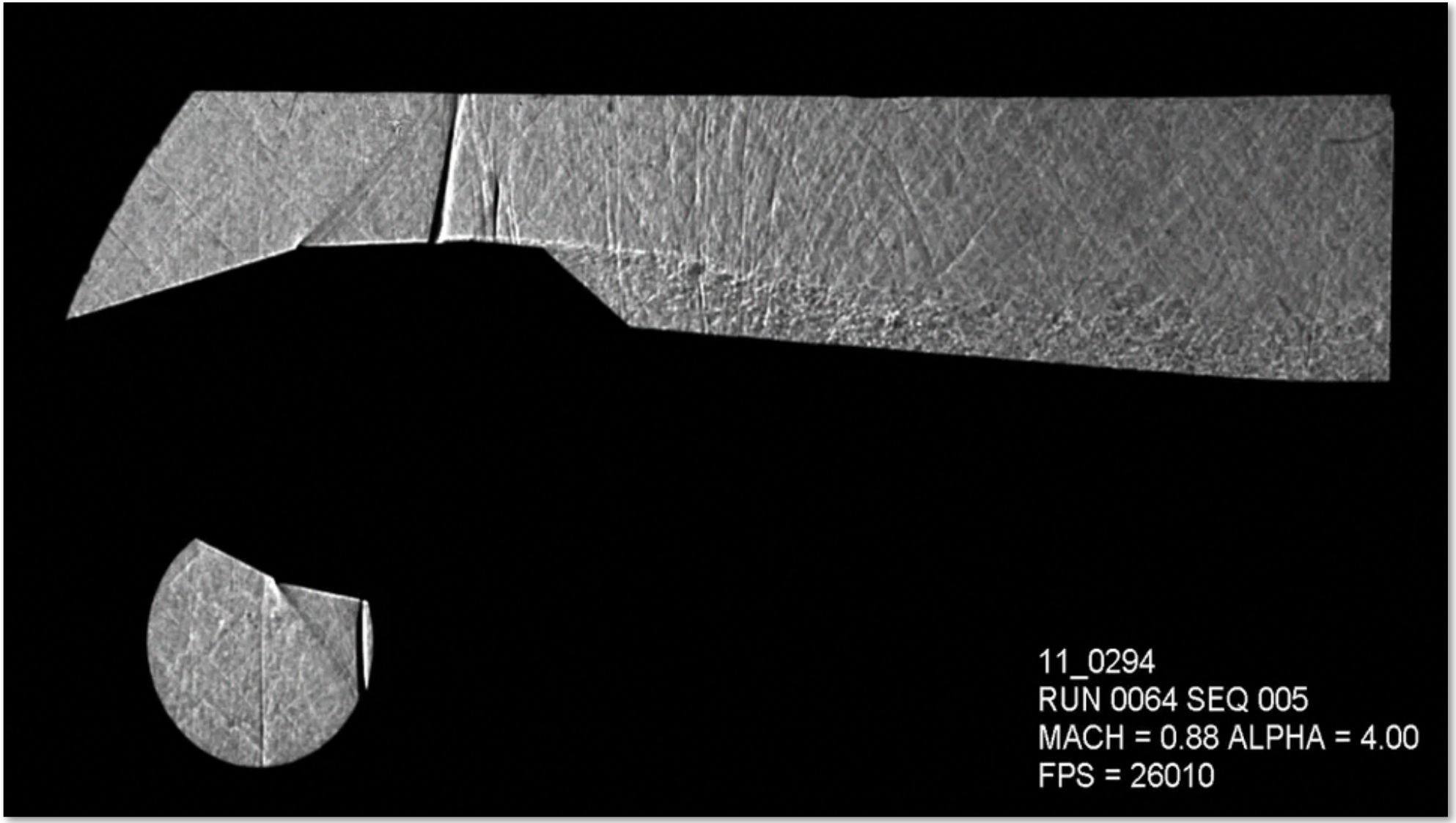
Conditions Mach 0.7, $Re_D = 10 \times 10^6$





PSP Image

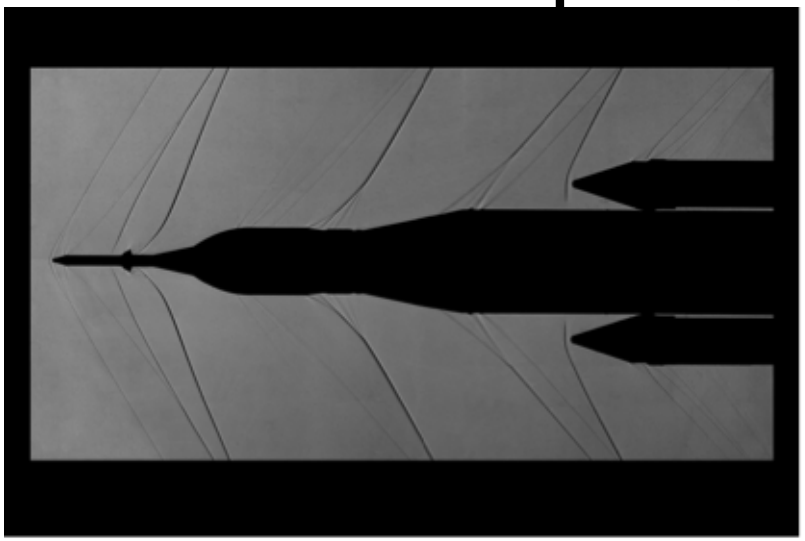
IR Thermography Image



High-Speed Shadowgraph

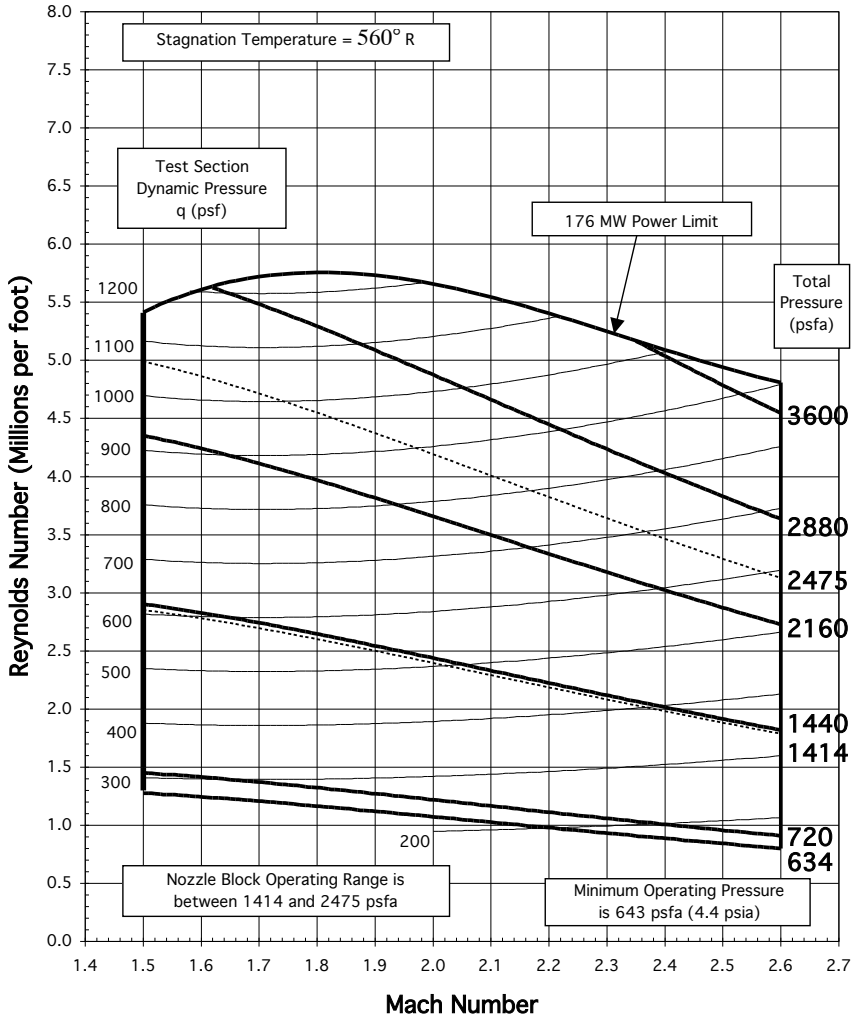
(Generic Launch Vehicle Configuration at 26,000 frames/second)

Composite Shadowgraph at Mach 1.2



Space Launch System (SLS) in the 11x11-Foot TWT

OPERATING CHARACTERISTICS OF THE NASA AMES RESEARCH CENTER 9-BY 7-FOOT SUPERSONIC WIND TUNNEL



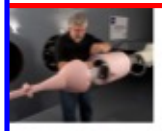
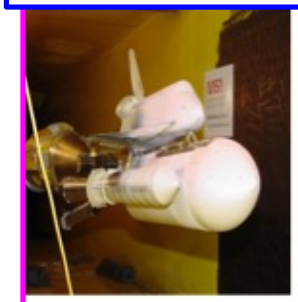
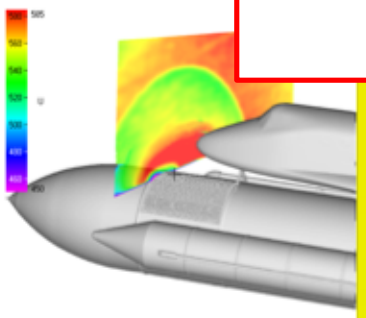
Source: Test 97-0065 IST

12/2001

XB-70 " Valkyrie"
3% Scale Model
Tested at UPWT 1960 to 1971

XB-70 Model in Lobby

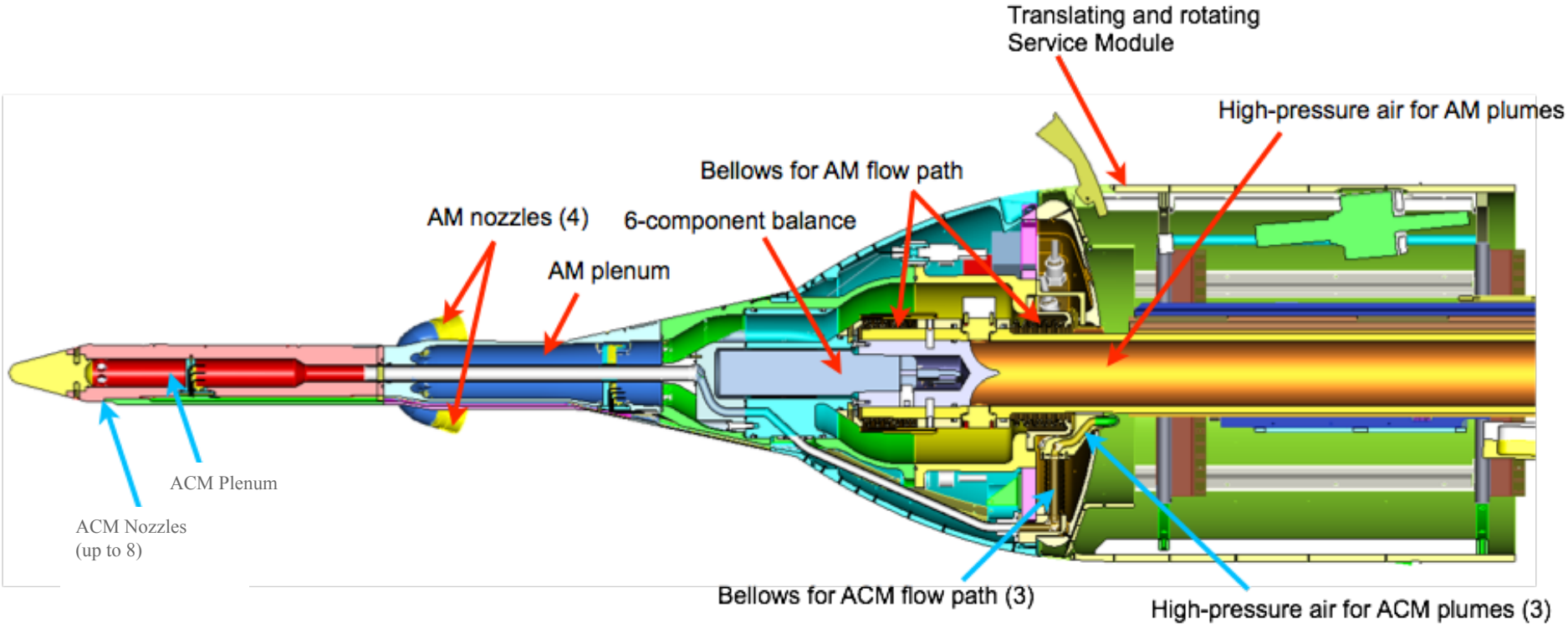
XB-70 Model in the 9x7 SWT


Models in 9x7-Foot Supersonic Test Section

AM/ACM Combined Plume Jet Interactions

- **Mutual interaction of the ACM and AM plumes was very non-linear**
- **Performed a test documenting both for as many conditions as possible**
- **Documented the aerodynamics of the LAV as it separates from the launch vehicle during initial stages of an abort**
- **Used data to populate an early version of the aero database and to validate/calibrate CFD (Computational Fluid Dynamics) tools**



Abort Motor Momentum Calibration

High pressure air passing through the model could bias loads data

Performed a test that quantified momentum tares with zero thrust

Highlight of AM/ACM Jet Interaction Testing

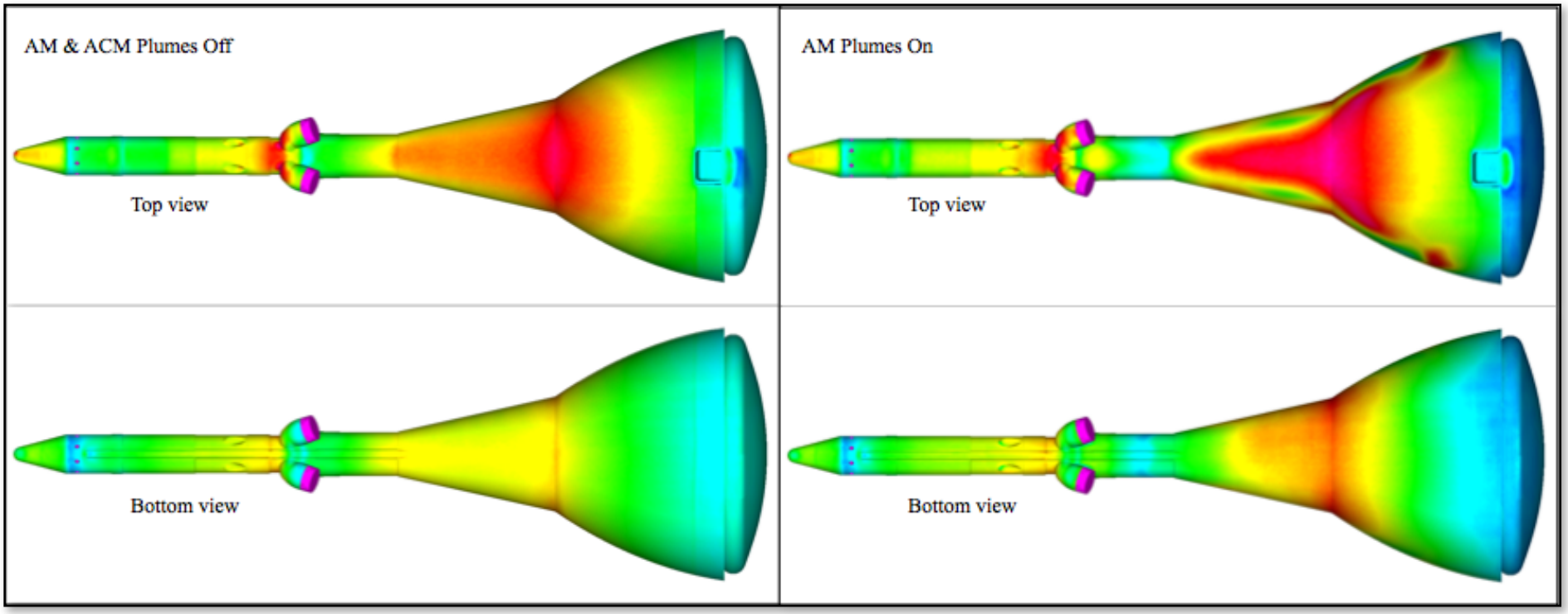
Integration of balance and bellows was difficult…

Developing bellows for the pressures required was difficult...

Calibrating out all the pressure tares was difficult...

PSP was critical to this test

- Integrated forces and moments agreed with the balance when the pressure tares were good
- Used integrated force and moments when the tares were not good



Production Shadowgraph/Schlieren

Dual shadowgraph systems provide simultaneous low-speed and high-speed image acquisition

- State-of-the-art high-speed cameras.
- High-powered pulsed LED light sources.
- Automatic acquisition with in-line image processing and real-time video feeds.

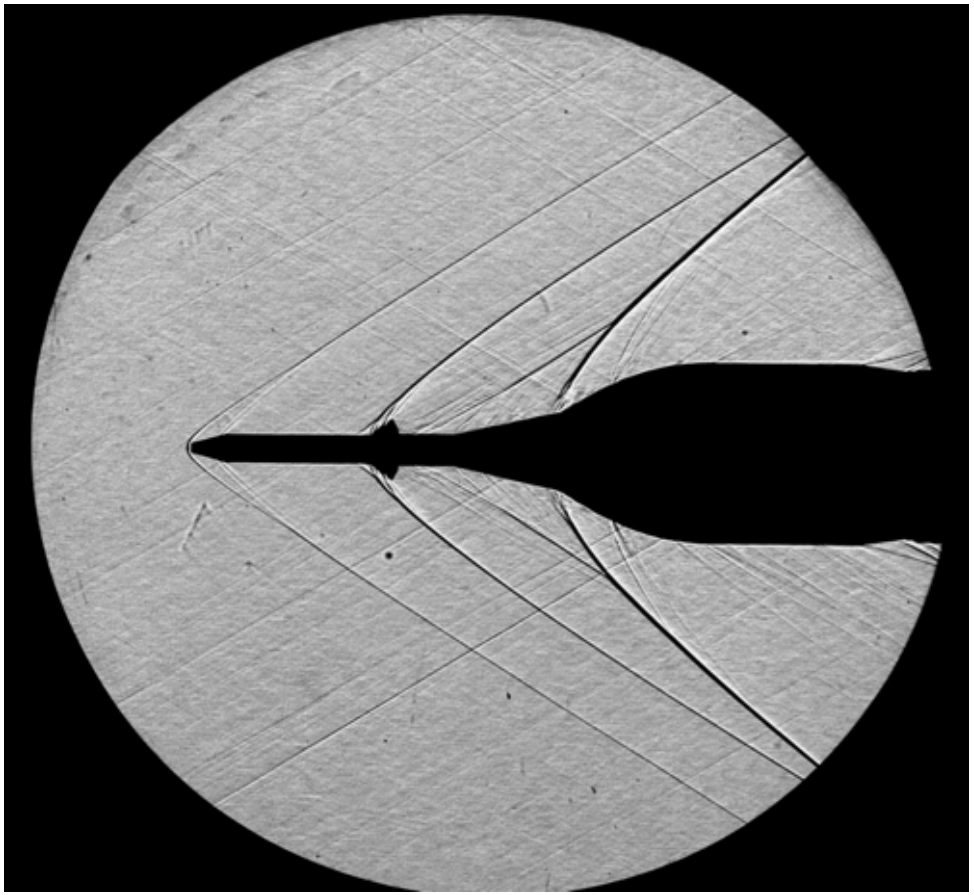
Standard Configuration Data Products

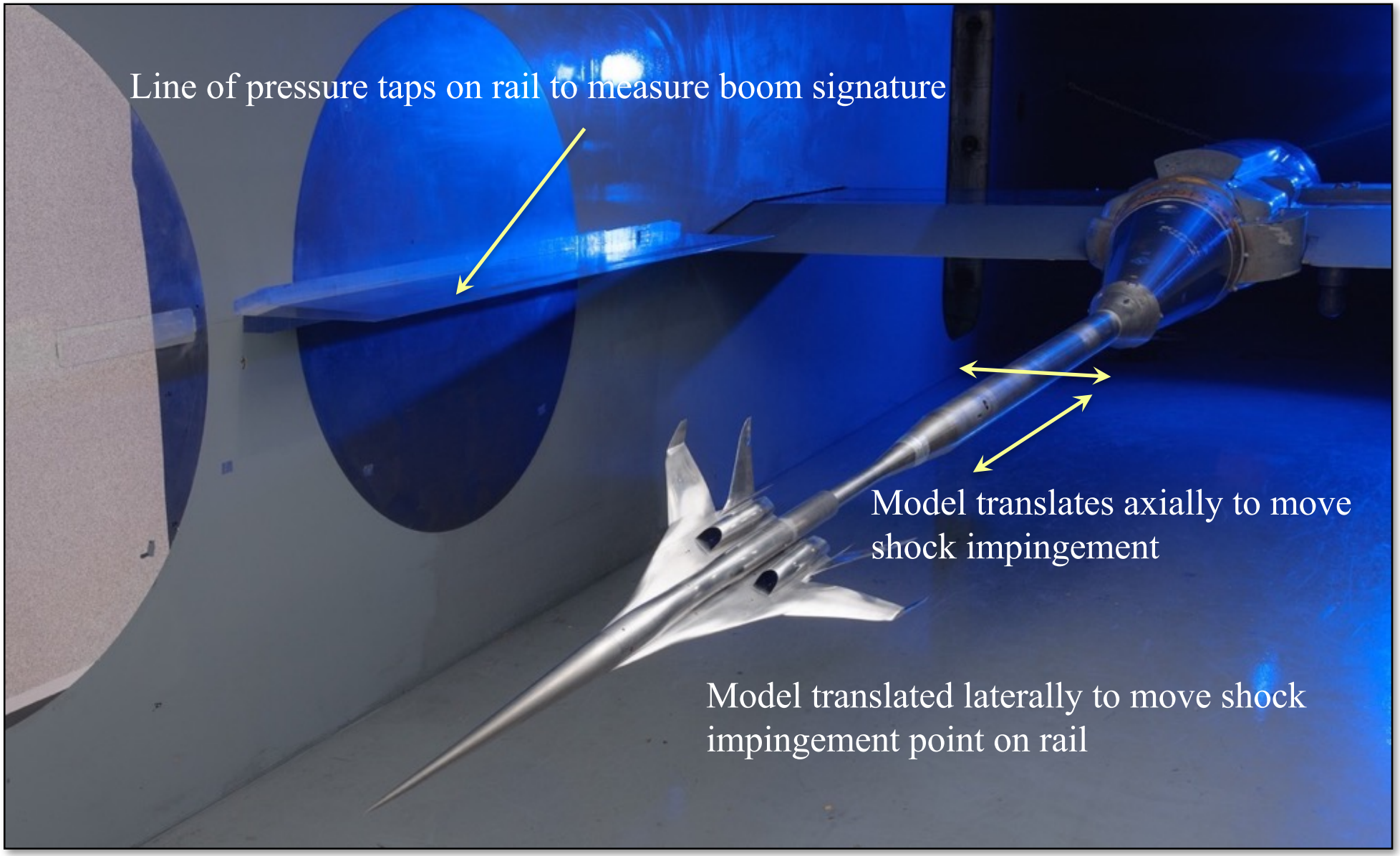
Low-Speed:

- ~4 megapixel 20 FPS movie (.avi)
- Series of high-resolution still images (.tiff) rendered at each pause point

High-Speed:

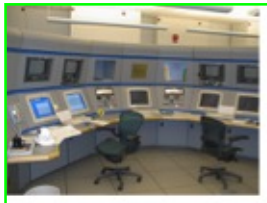
- ~1 megapixel movie (.avi) ~50,000 FPS typical recorded at each point in pitch-pause vector

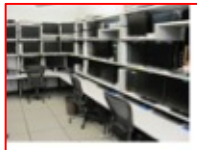




Sonic Boom Signature Testing in the 9x7-Foot SWT

Operations Area

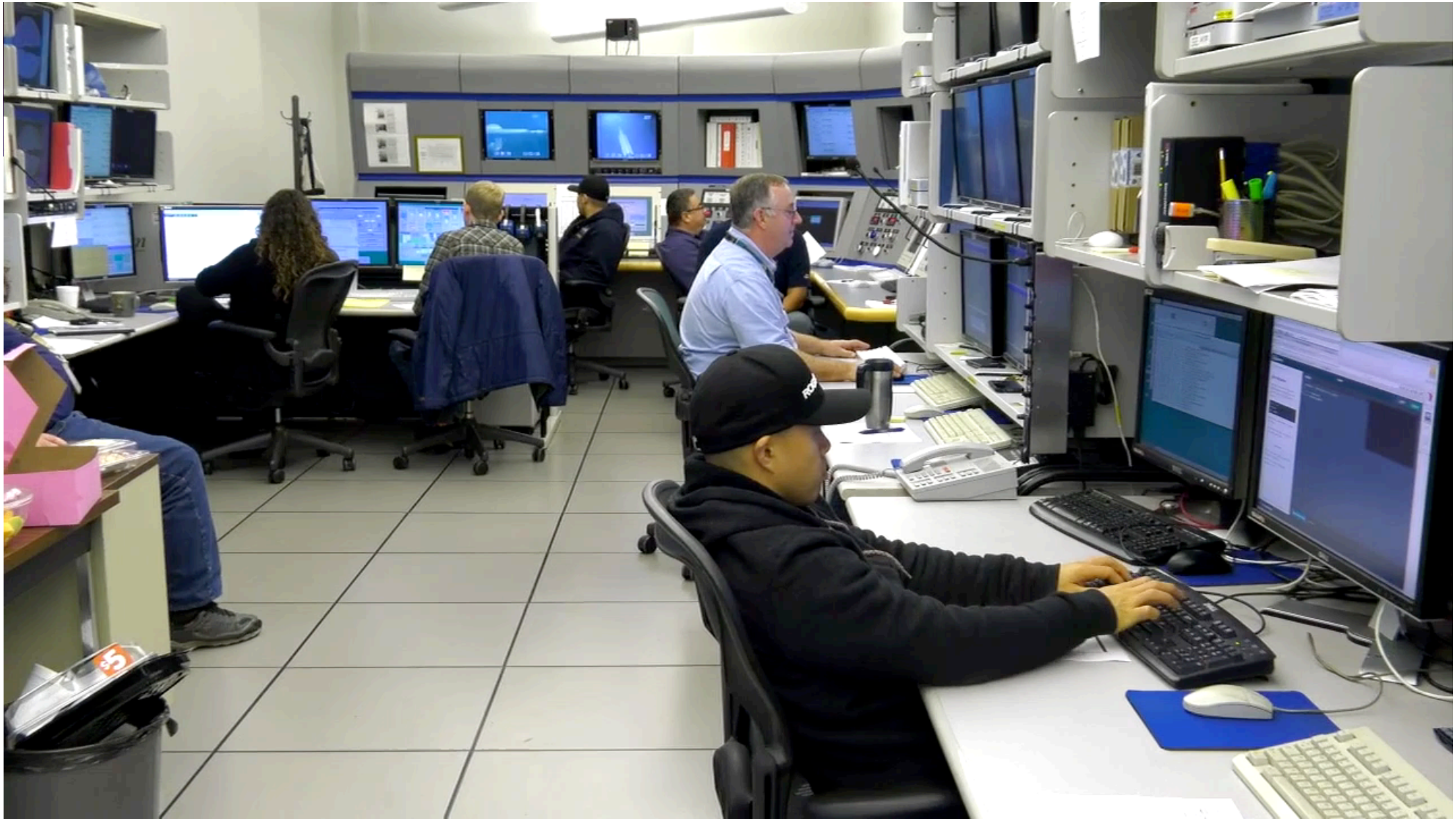




Customer Area

Facility Control Area

9x7-Foot SWT Control Room Operations Area



Video of a Typical 9x7-Foot SWT Control Room During Operations

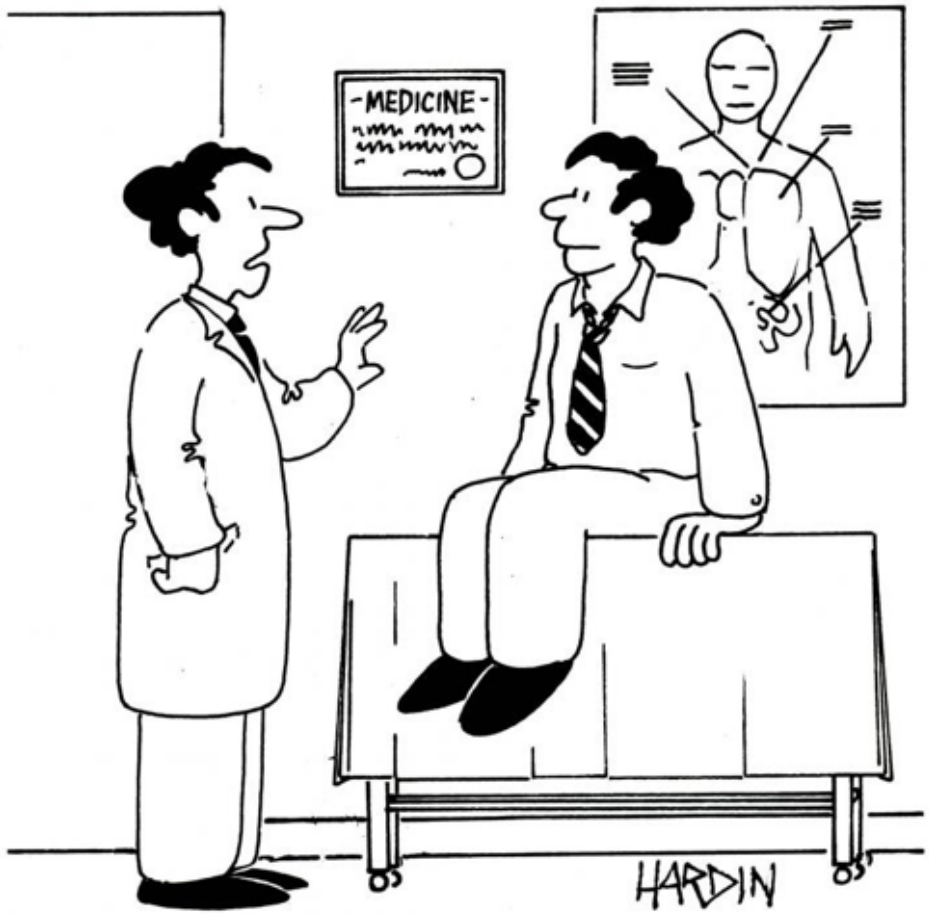
Wind Tunnel Testing Future?

- **Ames Unitary has an outstanding history of serving the aerospace community**
  - **Averages 1800 hours of testing per year**
  - **FY 17 will have over 2700 hours – back to 3-shift operation for a number of tests**
  - **Our modernized tunnels are extremely capable, reliable and productive**
  - **Validation and calibration tests have demonstrated outstanding data quality**
  - **Our team very capable and eager to respond to the needs of our customers**

- **New measurement techniques provide additional insight into flow-fields around models**

- **CFD still can't compete, especially for transonic flow**
  - **Above Mach 2 CFD looks promising**
  - **Business of CFD validation is still thriving**

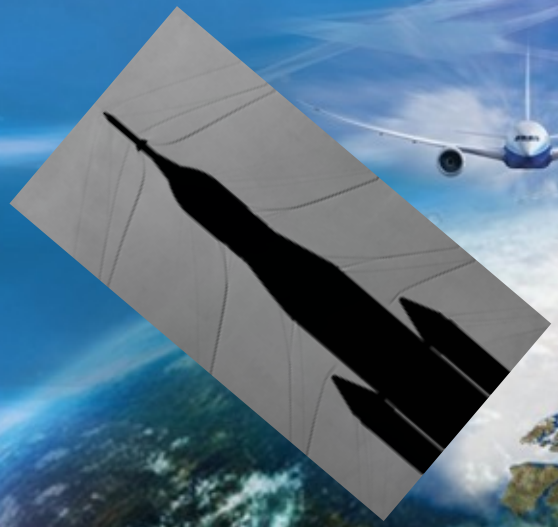
Question?



"Now don't take this wrong, but it seems the whistling in your ears is just the wind blowing through your head."

National Aeronautics and Space Administration

The Brothers Were Wright – An Abridged history of wind tunnel testing at Ames Research Center



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