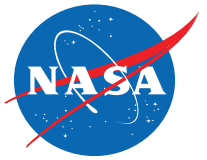



# Historical Overview and Recent Improvements at the NASA Glenn Research Center 8x6/9x15 Wind Tunnel Complex

## AIAA SciTech, January 2015

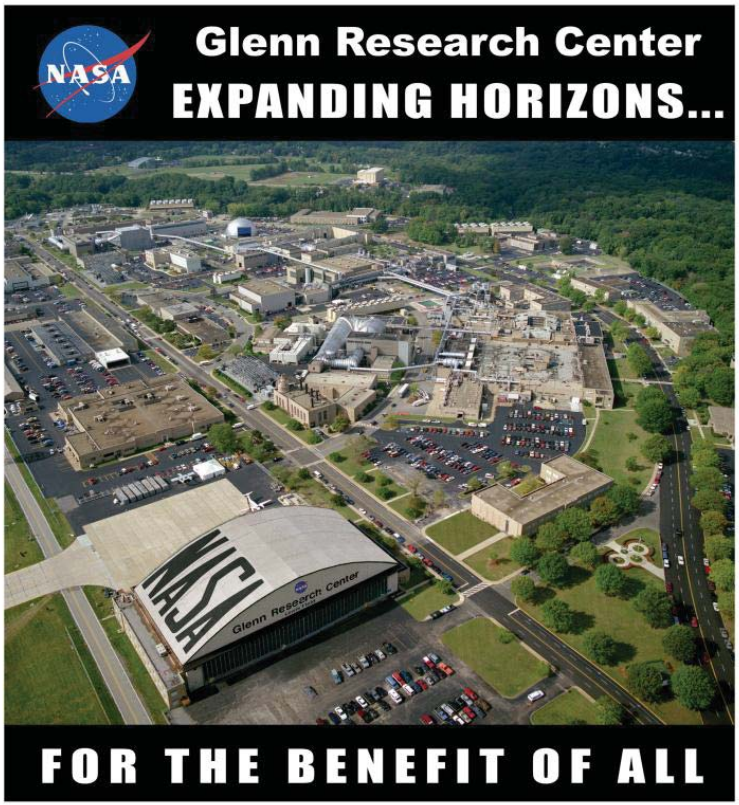
Joseph J. Dussling
Data Engineer, 8x6 SWT/9x15 LSWT
NASA Glenn Research Center
TFOME Contract, Jacobs Technology

# HISTORICAL OVERVIEW

# Brief Timeline of Glenn Research Center
## Cleveland, Ohio

- January 1941 (founded under NACA)
  - Ground breaking of Aircraft Engine Research Laboratory
- April 1947
  - Name changed to Flight Propulsion Research Laboratory to reflect expanding role in flight propulsion
- September 28, 1948
  - Name changed for Dr. George Lewis; NACA Director of Aeronautical Research, 1942-1947
- October 1958
  - NASA established, renamed to NASA Lewis Research Center
- March 1999
  - Renamed to John H. Glenn Research Center at Lewis Field

NASA
C-2004-567




National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field

C-2004-567

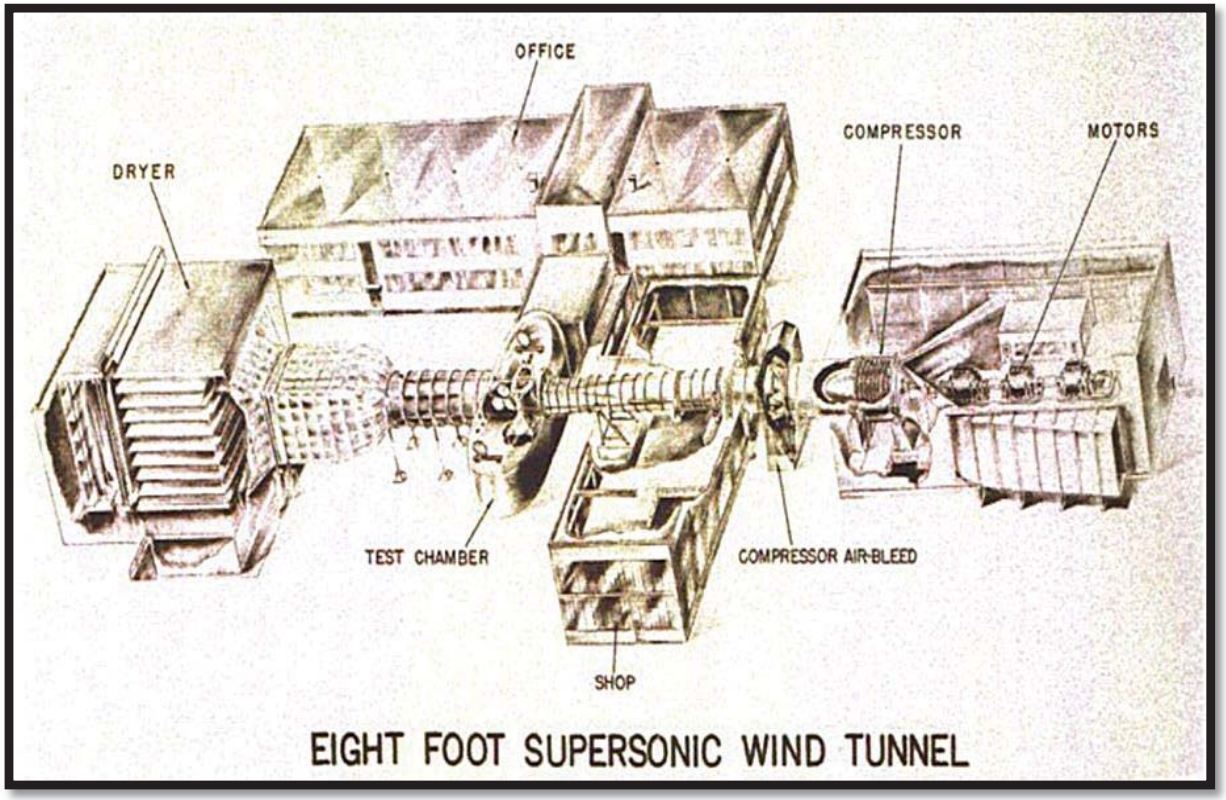
# Capabilities of 8x6/9x15 Wind Tunnels

| | 9x15<br>Low Speed Wind Tunnel (LSWT) | 8x6<br>Supersonic Wind Tunnel (SWT) |
|---|---|---|
| Test section speed (Mach) | 0 to 0.23 | 0 to 0.1 & 0.25 to 2.0 |
| Simulated Altitude (ft) | Sea Level | 1000 to 35000 |
| Test Section Reynolds number / feet | 0 to 1.4e6 | 3.6e6 to 4.8e6 |
| Dynamic Pressure ($lbf/ft^2$) | 0 to 72 | 200 to 1340 |
| Test Section Total Temperature (°R) | Ambient to 550 | 520 to 720 |
| Auxiliary Air Supply<br>At 40 psig<br>At 150 psig<br>At 450 psig<br>Model Exhaust | (Heated)<br>30 lbm/s<br>30 lbm/s<br>30 lbm/s<br>Variable | <br>30 lbm/s<br>30 lbm/s<br>30 lbm/s<br>Variable |

# 8x6 SWT History

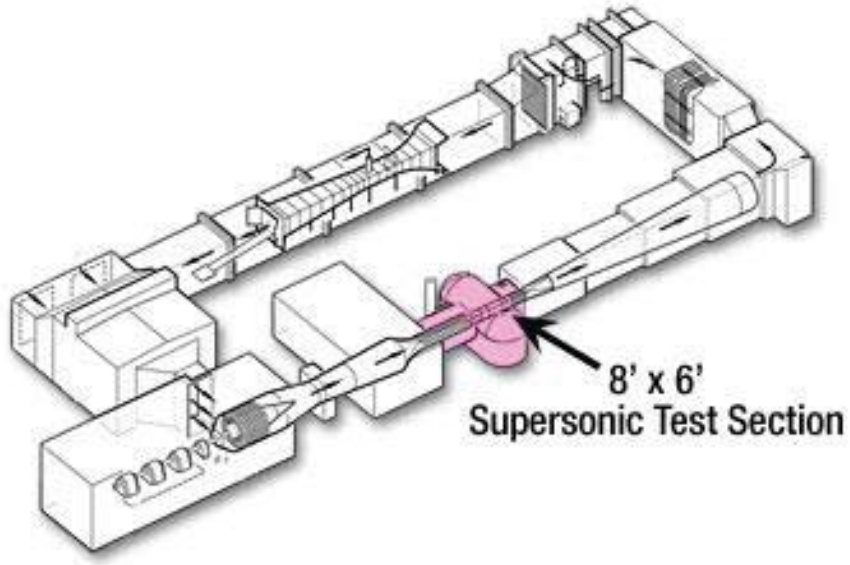
NACA decided to concentrate research on aerodynamic and propulsion issues at supersonic speeds (1945)

- Sound barrier broken October 14, 1947
- Supersonic research facility would allow study of engines, airfoils, and scale models of planes

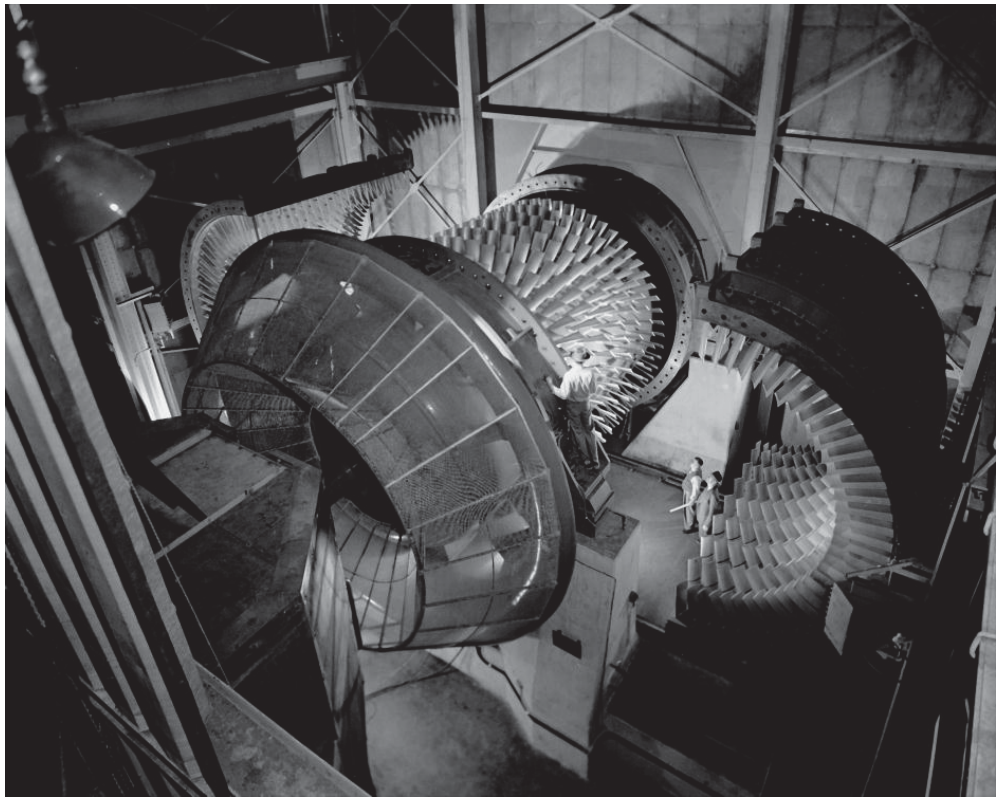


# 8x6 SWT History

- Designed: mid 1940s
- Built: 1946-1949
- First Run: April 3, 1949
- Original Configuration:
  - High speed leg only (air dryer, drive system, 8x6 test section and diffuser)
  - Solid Wall Tunnel; M=1.4 to 2.0
- Largest supersonic wind tunnel at that time

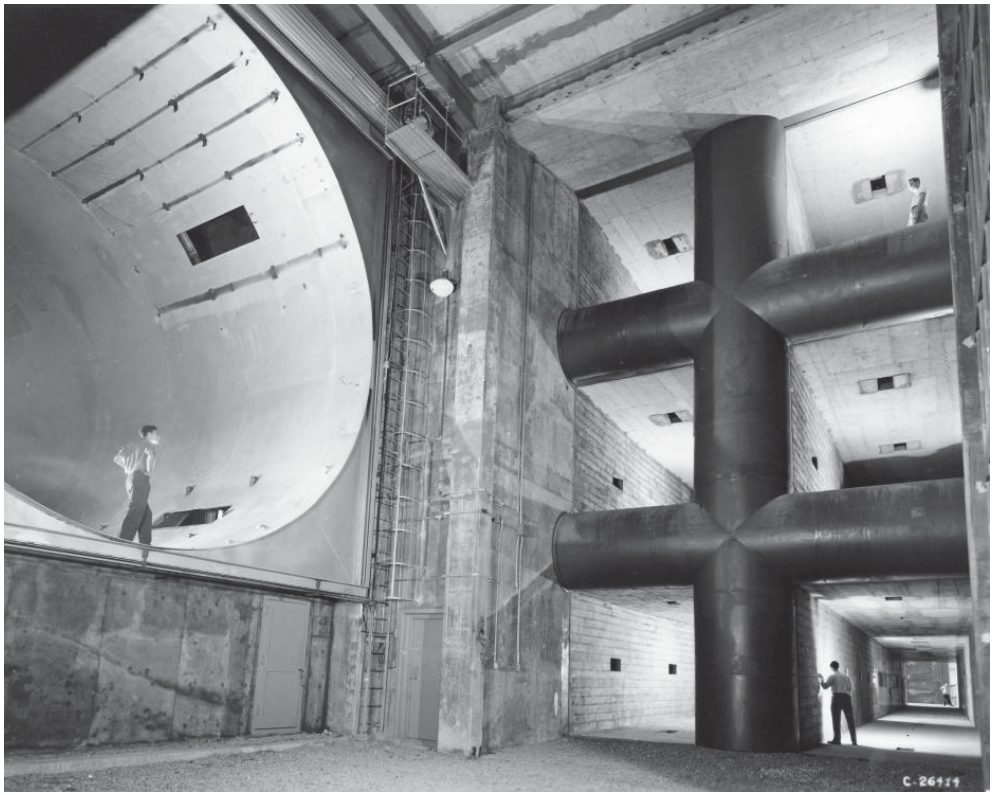


# 8x6 SWT History



C-1945-23277

Seven Stage Axial Compressor driven by three motors producing 87,000* hp



C-1950-26414

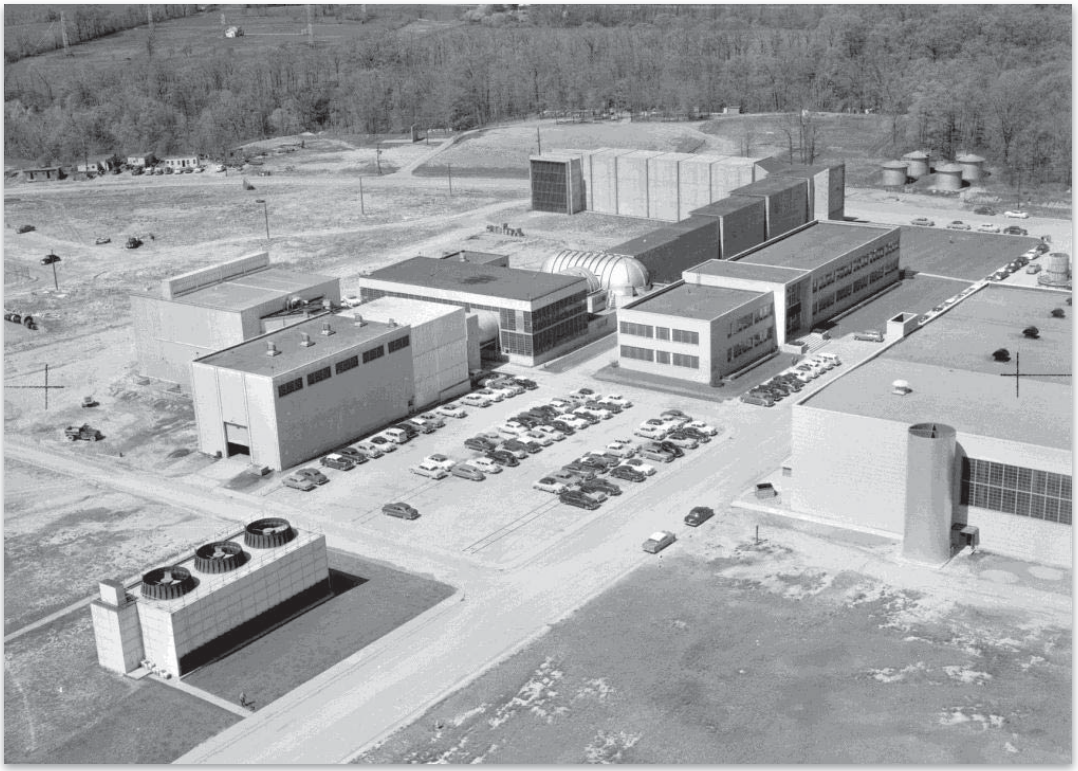
Construction of Acoustic Housing to dampen noise produced during supersonic testing

"87,000 hp bugle aimed at the heart of Cleveland"

# 8x6 SWT History

Acoustic Problems

- January 1950: Noise generated by 16-in. ram jet test was objectionable within a 5 mile radius
- August 1950: Acoustic Modifications completed
  - Acoustic Muffler
  - Turn 2 and acoustic baffles installed

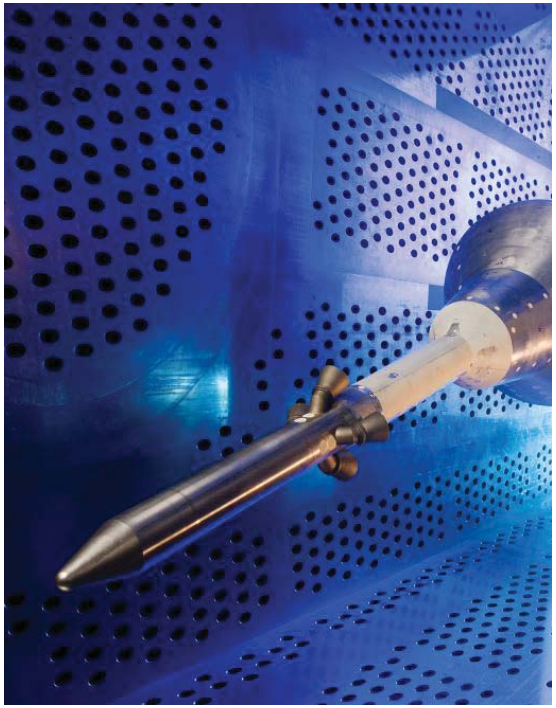


# 8x6 SWT History

## Transonic Operation

- Converted to a transonic tunnel in 1956
  - 4700 porosity holes added to test section to “bleed” air through walls
  - Flexwall modified for operation for Mach 1.0 to 1.3
  - Altitude exhaust installed for test section bleed

C-1956-42930
Hole Drilling Operation in 8x6 SWT

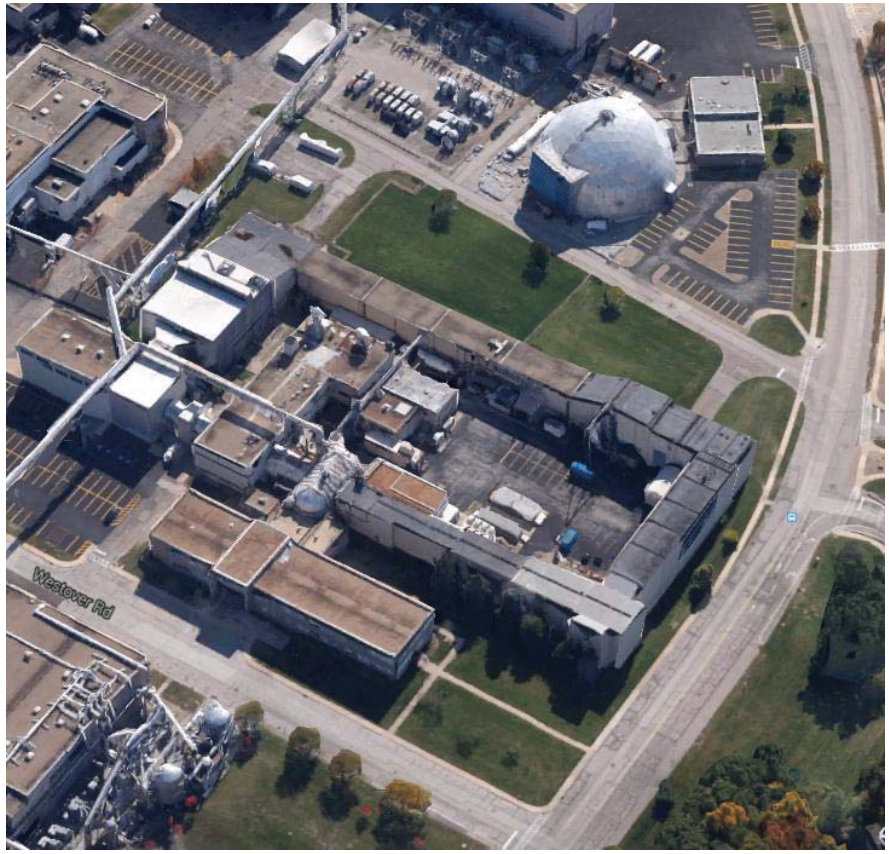


2007-2469
Porosity holes clearly visible behind Orion Launch Abort System model

# 8x6 SWT History

## Return Leg

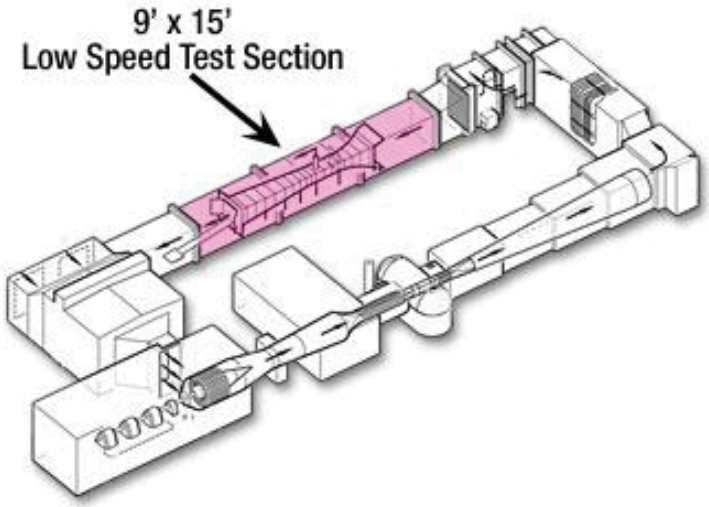
- Tunnel loop (back-leg) was completed in 1956
  - Dried air within tunnel could be reused
  - Doors allow easy conversion between running open/closed loop
- Aerodynamic testing in closed loop
- Propulsion testing in open loop




Aerial view of 8x6/9x15 complex showing return leg

# 9x15 LSWT History

- Need for a large low-speed facility for Vertical/Short Takeoff and Landing (V/STOL) aerodynamics research
  - Designed: 1967
  - Built: 1968-1969
  - First Run: 1969
- Built in return leg of 8x6 SWT
- Originally a “hard-wall” test section; acoustic boxes added later for noise suppression



# 9x15 LSWT History

- Originally built for Vertical/Short Takeoff and Landing (V/STOL) testing
  - Aerodynamic performance and acoustic testing
- Capable of testing large-scale hardware in a continuous subsonic airstream (0-175 mph)
  - Nozzles, inlets, and propellers
  - Crossflow conditions, varying angles of attack

1970-01199

Model showing STOL and v/STOL wings

# 9x15 LSWT History

- Now, used extensively for low air-speed aero-performance and acoustic testing for fan rigs
  - ➢ Provides a 5,000-hp drive rig for testing subscale high bypass ratio fans
  - ➢ Provides a 750-hp (per shaft) counter-rotating fan drive rig for open rotor (unducted fan) testing

2009-04566

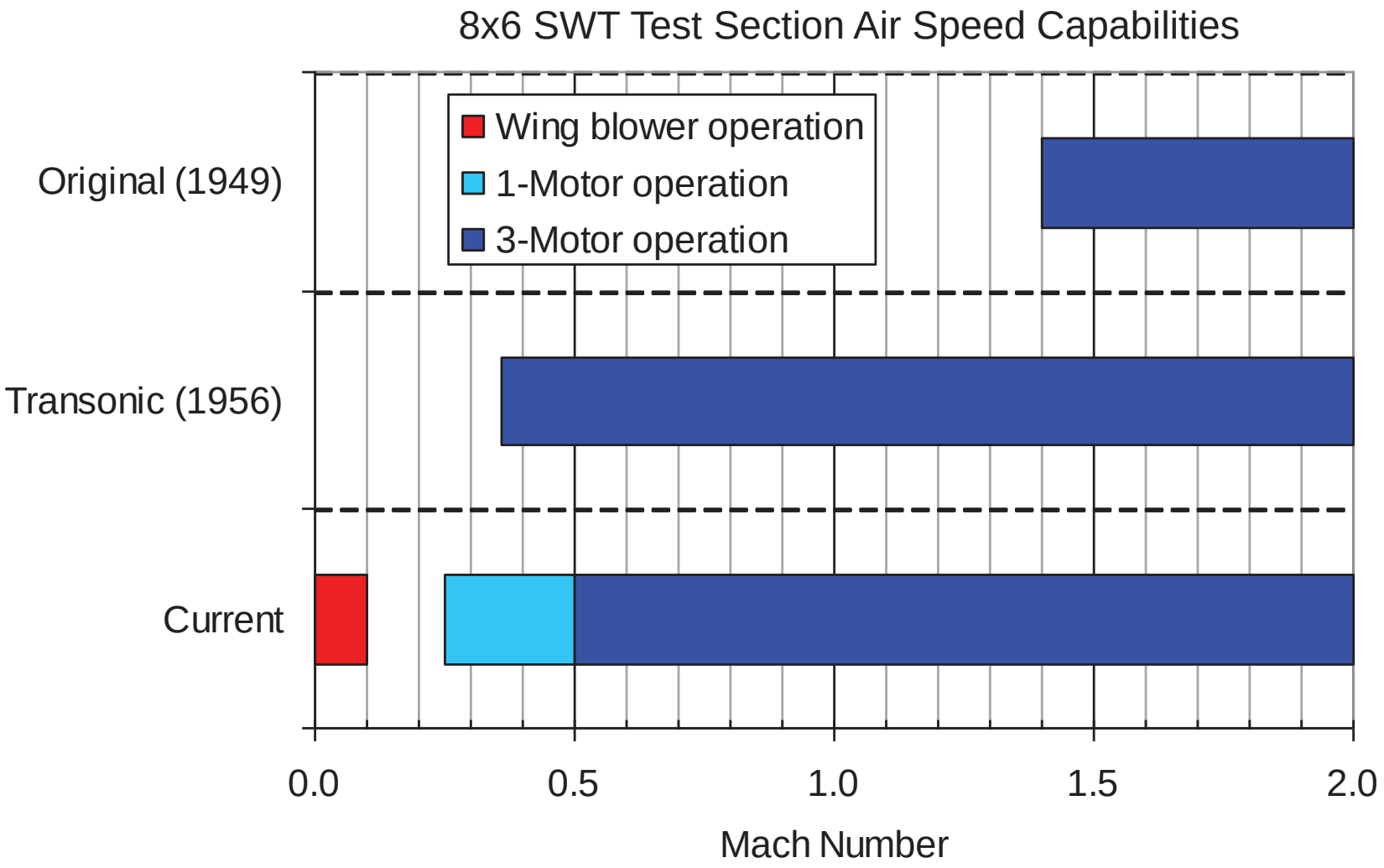
Open Rotor testing in the 9x15 LSWT using the counter-rotating drive rig

# 9x15 LSWT History

One-Motor Drive Operation

- Conceived and successfully demonstrated in 1995
- Desire to reduce power consumption at low speed operation for the 9x15
  - Can run the 9x15 up to Mach 0.14 on 1 motor
- Added benefit of expanding the operability envelope at the low end for the 8x6 SWT
  - Can run the 8x6 up to Mach 0.5 on 1 motor
  - Minimum speed of 8x6 reduced from Mach 0.36 to Mach 0.25

# 8x6 SWT / 9x15 LSWT History



# 8x6 SWT / 9x15 LSWT Areas of Testing

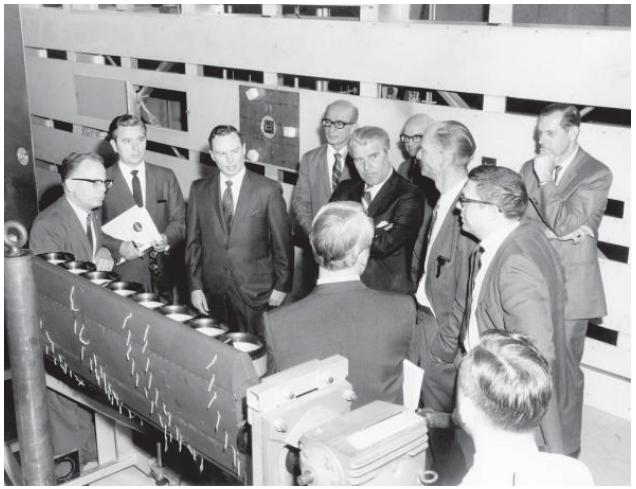
- Wide range of applications and customers (NASA and external)
  - Military, civil aviation, space testing
- Basic aerodynamic research
- Force and moment
- Propulsion systems
- Airframe integration
- V/STOL
- Space Transportation
- Transport Cruise Performance
- Environmental
  - Acoustics
  - Sonic Boom

# 8x6 SWT / 9x15 LSWT Areas of Testing

## Space Applications

1960-54465

Saturn Model in 8x6 SWT

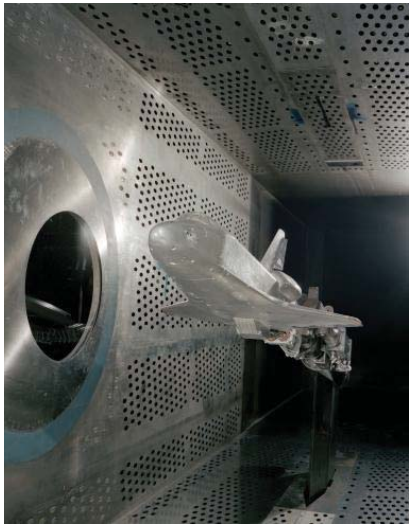


1970-1385

Wernher von Braun visits the 9x15 LSWT

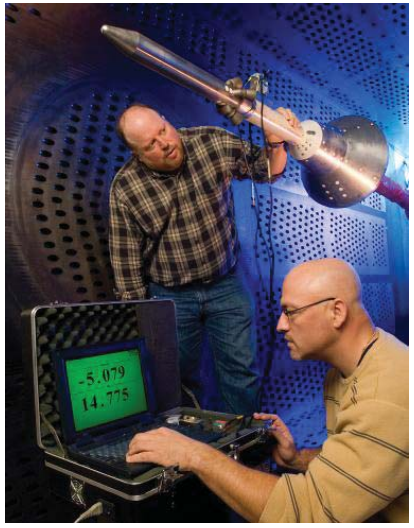
1964-72479

0.059 Scale Model of Apollo Launch Escape System



1983-6425

Space Shuttle in 8x6 SWT

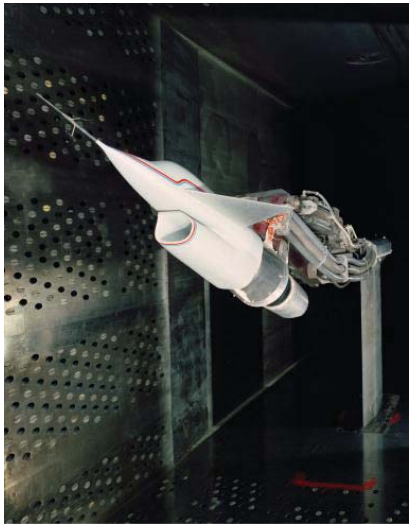



2007-2471

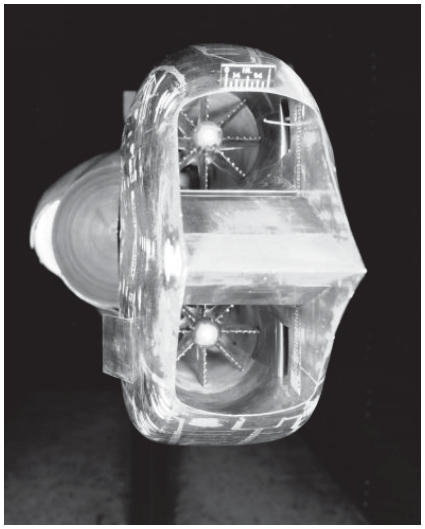
Orion Capsule and Launch Abort System (LAS)

# 8x6 SWT / 9x15 LSWT Areas of Testing

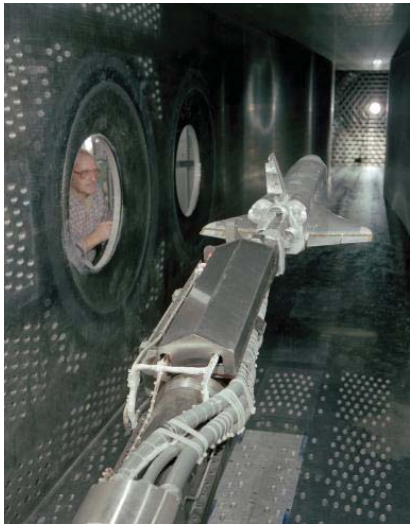
## Supersonic Inlets and Nozzles



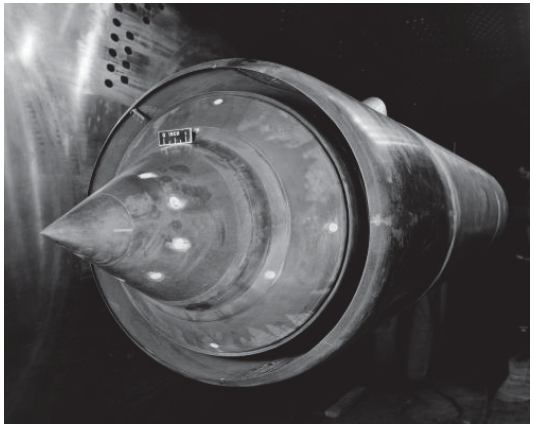
1979-0673
Highly Maneuverable Aircraft Technology Inlet



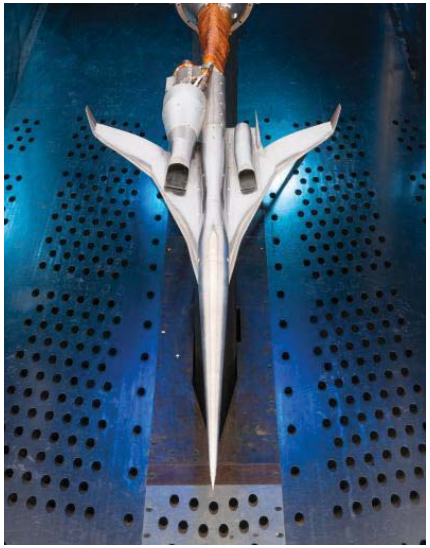
1959-49977
Double Inlet Bell Model



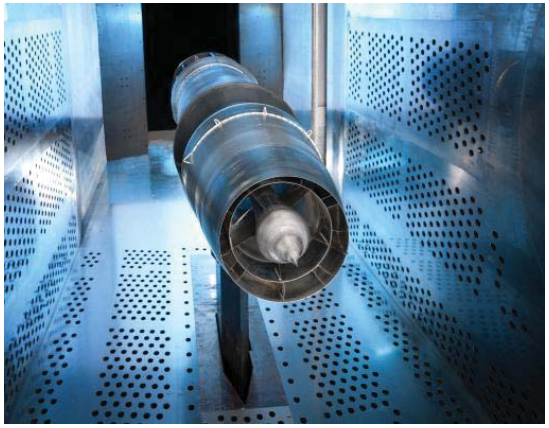
1983-6428
Space Shuttle Nozzle Test



1957-45564
Spike & Return Bleed Scoop & Bump with 17-in Inlet



2013-1171
SST Propulsion Inlet

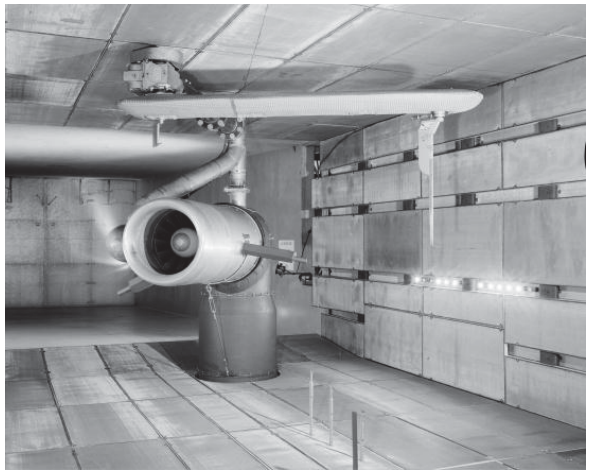


2010-4864
Large Scale Low Boom Propulsion Inlet Test

# 8x6 SWT / 9x15 LSWT Areas of Testing

## Vertical/Short Takeoff and Landing

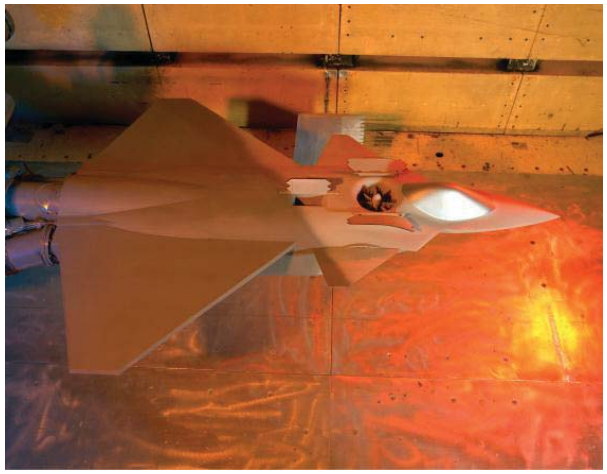
1990-4389
STOVL 279-3C Model



1976-2620
Quiet Clean STOL Experimental Engine Low Mach Hardwall Inlet

1986-4703
F-16 STOVL

1996-0851
STOVL Model

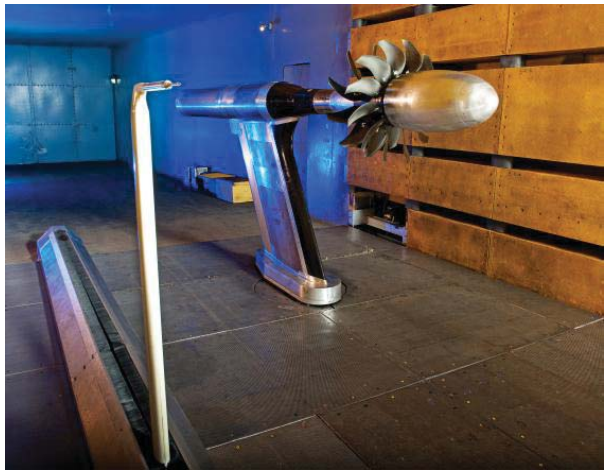


1994-4441
Lockheed X-32 Model

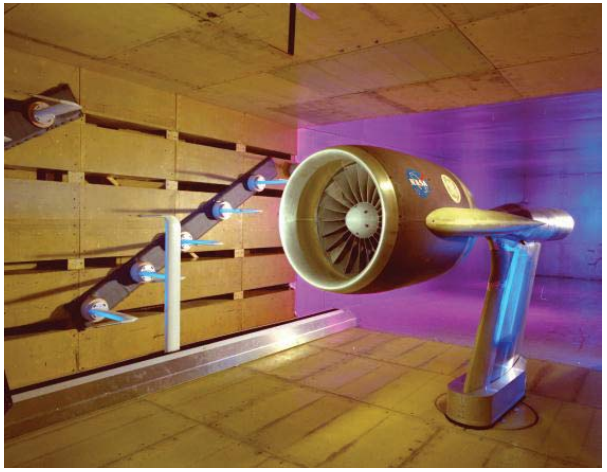
1986-3413
F-15 Hot Gas Model

# 8x6 SWT / 9x15 LSWT Areas of Testing

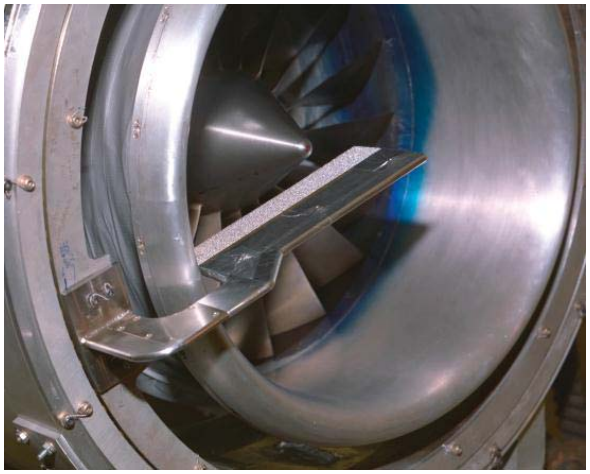
## Acoustics



2010-3454
Open Rotor Propulsion Rig installed for Farfield Acoustics



1994-1827
Universal Propulsion Simulator Fan Model



1996-3949
Rotating Microphone installed on the High Bypass Ducted Propeller

1996-4524
Acoustic Barrier Wall installed during Noise Reduction Test

Data Systems

# RECENT IMPROVEMENTS

# COBRA

- Upgrade of facility “steady-state” data system in 2016; COBRA
  - ***C***ollect, ***O***bserve, ***B***roadcast, ***R***ecord, & ***A***nalyze
  - Replaces existing ESCORT DAS (1980s)

## COBRA

- Faster, multiple sampling (12 ½, 25, 50, 100,…,800 samples per second)
- Over 25,000 channels, sampled and calculated (upper limit not determined)
- 32 stations with multiple pages per station
- Alphanumeric ***AND*** graphical on same page
- Terabytes of storage
- Graphical User Interfaces

## ESCORT

- 1 sample/sec (up to 10 samples/sec with limitations)
- 10,000 channels max., sampled and calculated
- 16 data viewing windows max.
- Alphanumeric ***OR*** graphical pages
- 36 Gigabytes storage
- Command line interface

# 6 Component Rotating Balance

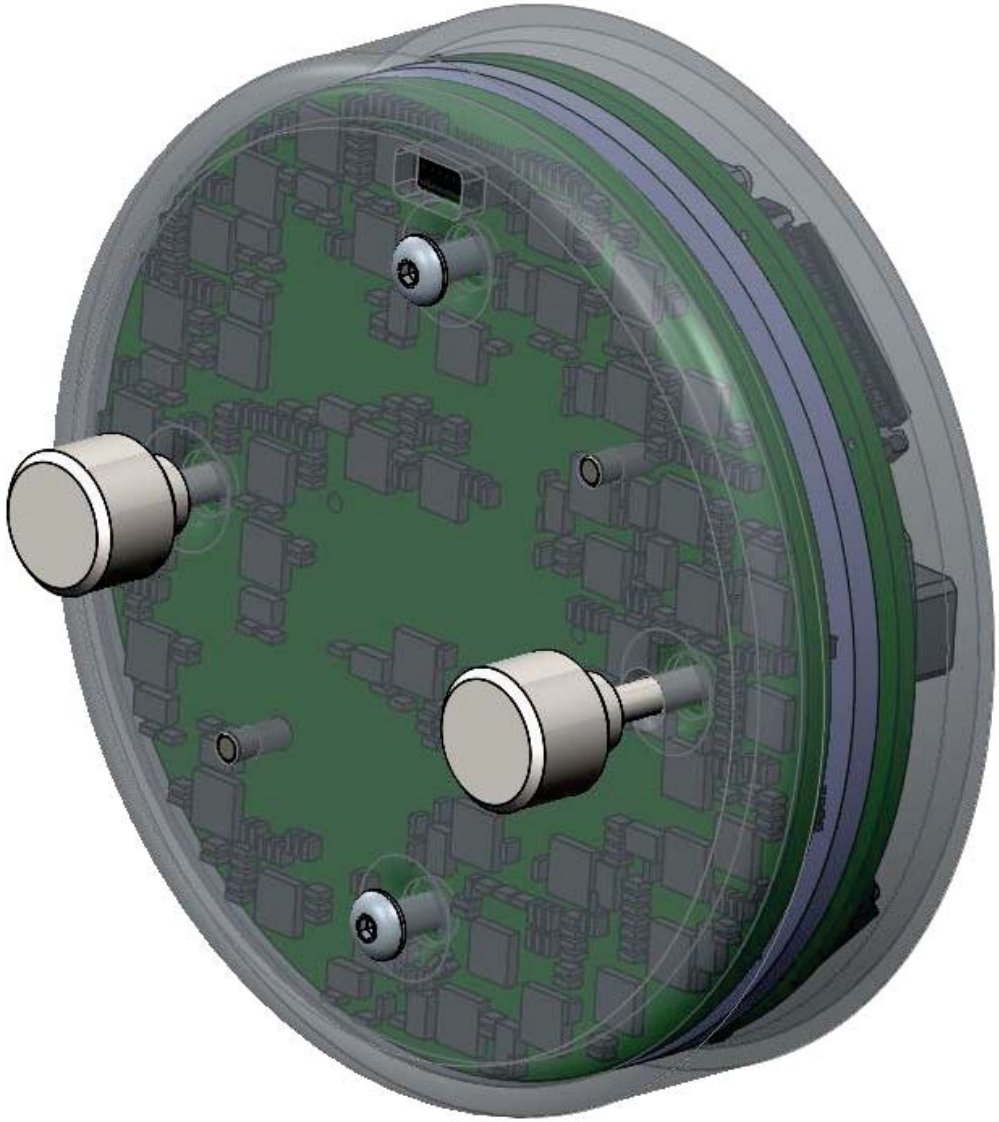
- Developed in conjunction with several Environmentally Responsible Aviation (ERA) tests in the 9x15 LSWT
- Metric shell for “B” Balance was modified and balance delivered April 2014
  - ➢ Check loading successfully accomplished in May
- Balance installed in drive rig and testing completed in 9x15 LSWT in May-July 2014
  - ➢ Initial data analysis shows balance behavior much improved when compared with initial results
- Balance to be used for most future fan testing in 9x15 LSWT

**6 Component Rotating Balance**

- Capacity
  - 1000lb NF, SF
  - 2000lb AF
  - 2000in-lb PM,YM
  - 18000in-lb RM
- Two full sets of gauges
- Custom Telemetry
- 8 RTDs
- 4 pressure transducers
- Accommodates up to 12 two-wire blade strain gauges

# Telemetry for Rotating Balance

- Custom Designed
- FPGA based for reconfiguration
- Default Configuration:
  - 12 Balance Bridges
  - 12 Dynamic Strain Gauges
  - 4 Kulites
  - 8 RTDs
  - 8 Board Monitors
- Alternate Configuration:
  - Up to 28 Dynamic Strain Gauges
  - 8 Board Monitors



# Thermocouple Upgrades

- Upgrades to 9x15 LSWT temperature measurement system completed 2012
- Thermocouples (TCs) now connected to Kaye Uniform Temperature Reference (UTR)
  - Kaye offers higher accuracy over conventional references
- Health monitoring of the entire system is achieved using an Oil Temperature Bath
  - Thermistors and TCs are read into Escort and compared against each other for overall health checks of system
- Similar upgrades planned for 8x6 SWT in next couple of years

Fluke Black Stack RTD Reader

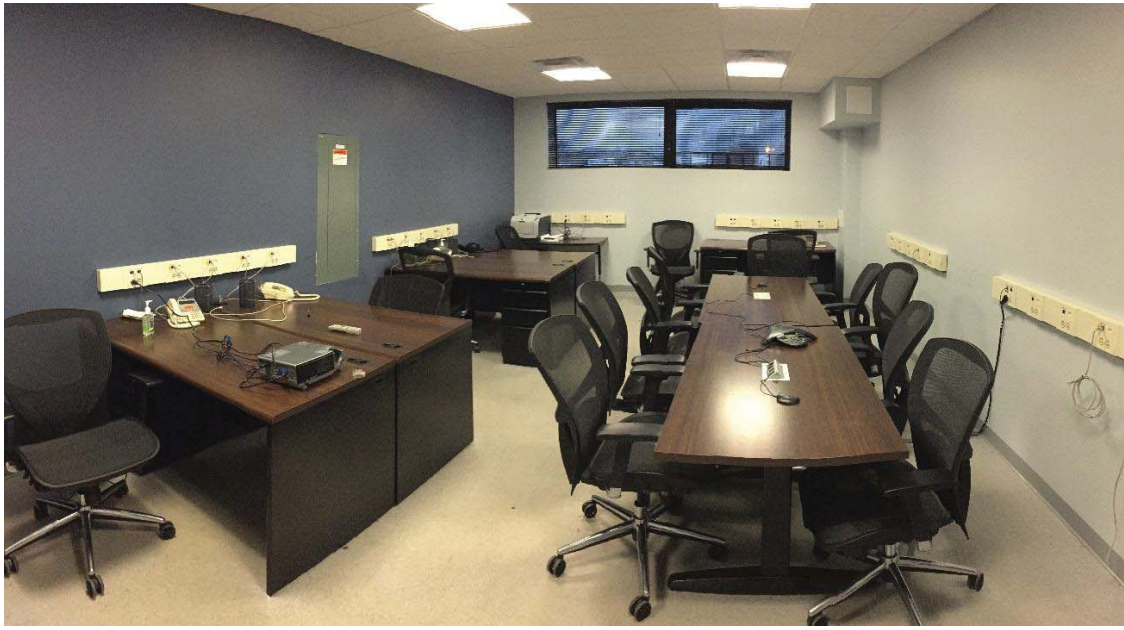
Oil Temperature Bath

Facility Upgrades

# RECENT IMPROVEMENTS

# Customer Accommodations & Improvements

- Customer Room
  - Former
    - Outdated
    - Minimal seating of 5-6 comfortably
    - Single phone
  - Current
    - Can now seat 10-12 comfortably
    - Internet access
    - Data access from facility servers
    - Projector
    - Multiple phones and conference line
    - Color printer



- Restrooms
  - Former
    - Outdated
    - Men only
  - Current
    - Well maintained
    - Now men’s and women’s

# Conventional Schlieren System Upgrades

## Conventional Schlieren Enhancements

1. Receiving Optics Upgrade:
   - Replaced the receiving optics with new off-the-shelf SOA optical components
2. High Speed Digital Imaging Capability:
   - Phantom V310
     - 1200x800 at 3250 fps
     - 500,000 fps at reduced resolution
3. New schlieren windows:
   - Involved a new seal design and modifying existing window frames
4. Light source:
   - Replaced existing antiquated 150W Xenon light source utilizing newer LED technology
5. Knife Edge Technologies:
   - Investigated & implemented newer knife edge technologies – Optical phase knife edges

Standard “razor” knife edge

Optical Phase Knife

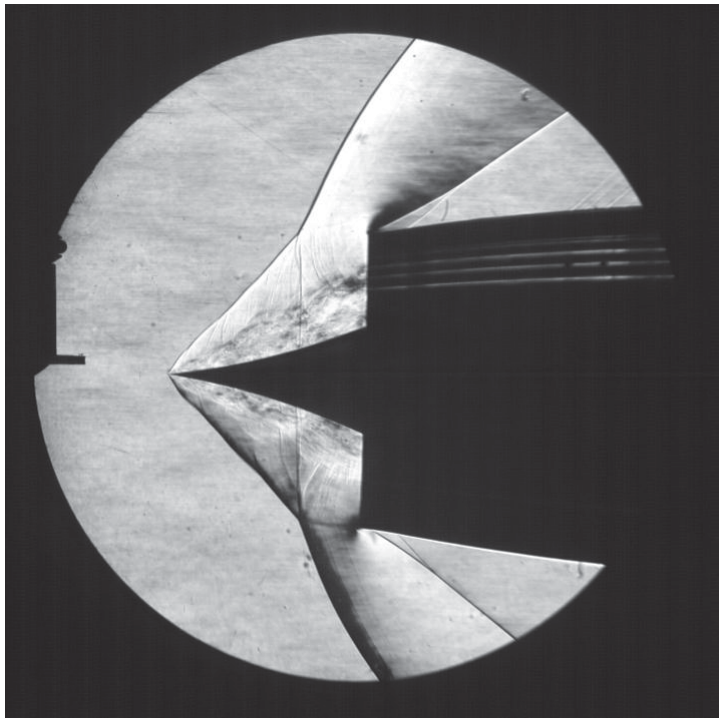
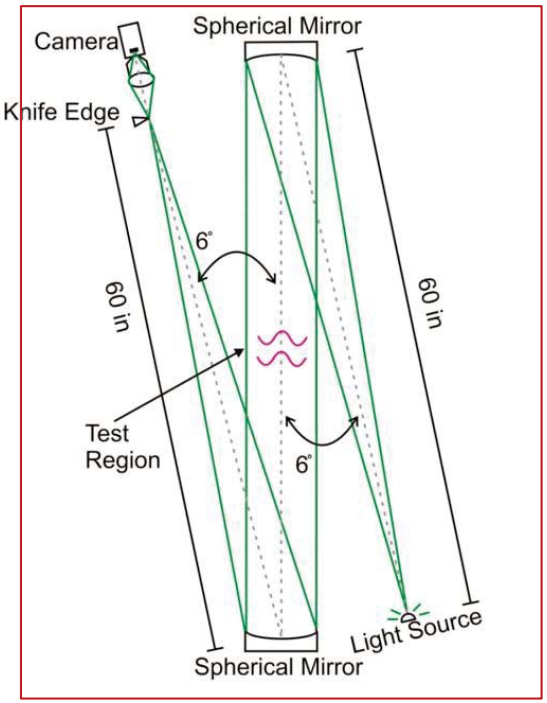


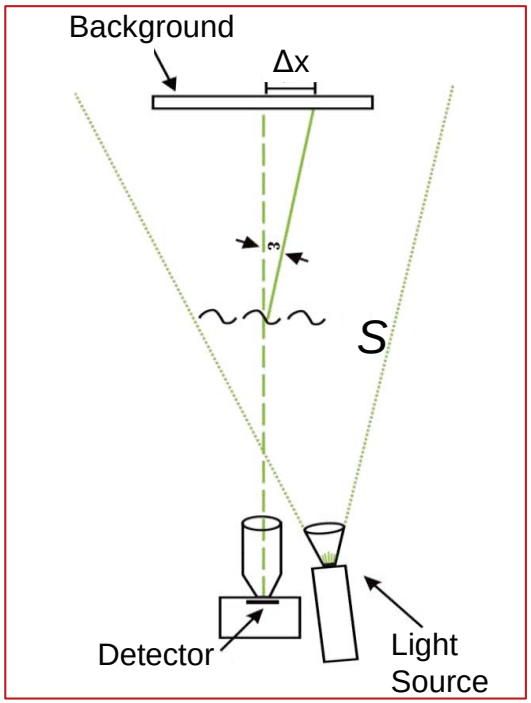
Image acquired from 8x6 Schlieren System on Large Scale Low Boom Inlet test - Showing Inlet at “Buzz” condition.

# Background Oriented Schlieren (BOS)

- BOS is a more recent development of the schlieren and shadowgraph techniques used to non-intrusively visualize density gradients
- Based on an apparent movement of the background when imaged through a density field onto a detector plane
- BOS captures the density field but only requires a CCD camera, light source, and a high-contrast background



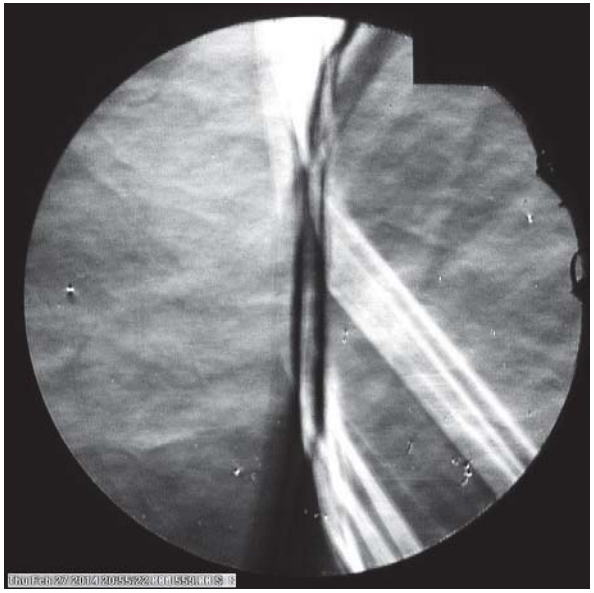

Classical Z-type Schlieren

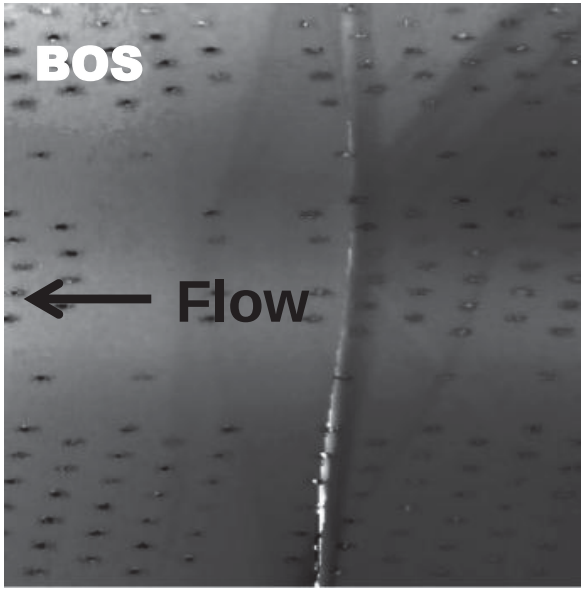


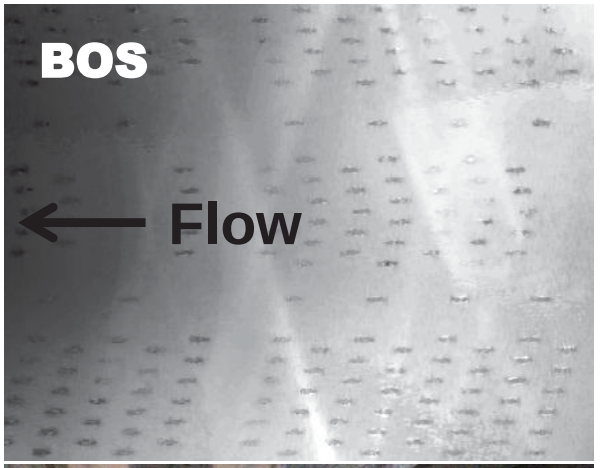

BOS

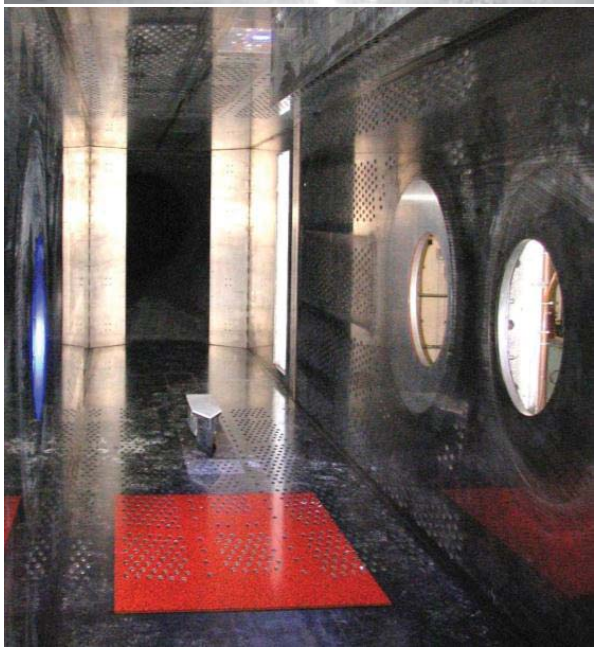
# Background Oriented Schlieren (BOS)

- Technique successfully demonstrated in 8x6 SWT
  - First time BOS has been implemented in a GRC wind tunnel
- Fluorescent BOS background designed and installed onto tunnel floor
  - Fluorescent background allows lighting to be applied at any angle as opposed to being nearly perpendicular as required by traditional retro-reflective backgrounds





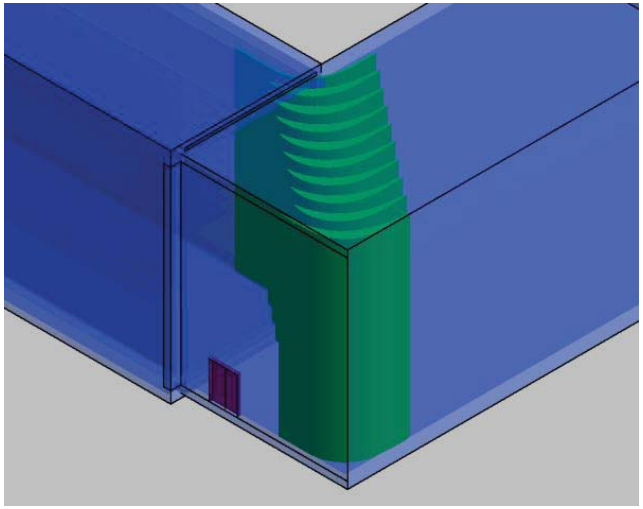



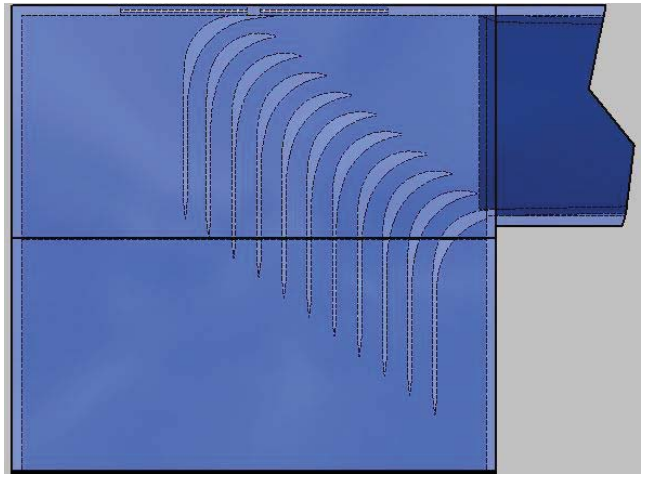



BOS and Conventional Schlieren at same condition. Different views: BOS from top and conventional from side

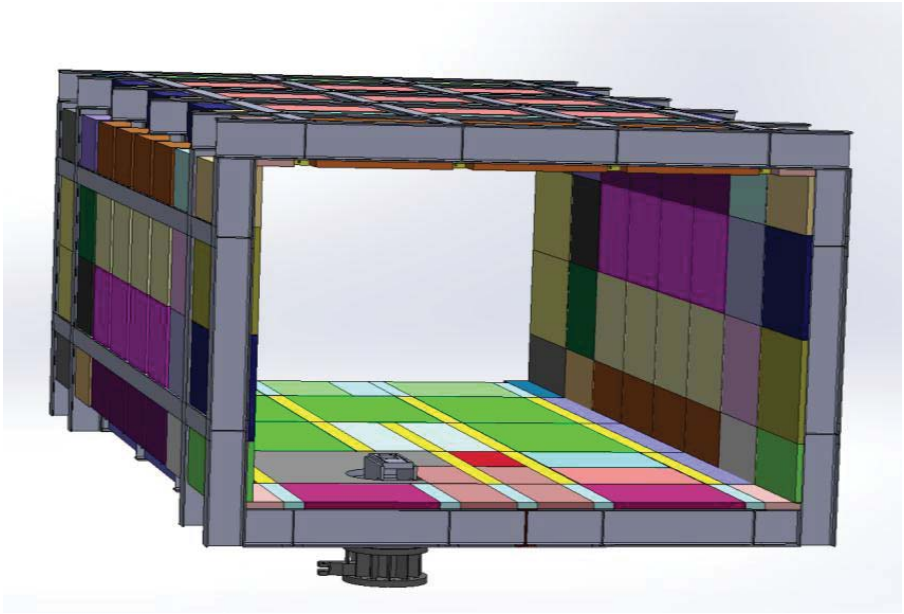
# 9x15 Acoustic Test Section Upgrade

- Acoustic Study performed with overall goal of developing solutions to reduce background noise of 9x15 LSWT at Mach 0.2
  - Maintain (or improve) current aerodynamic test capabilities in terms of Mach number, temperature, flow quality
    - Additionally, no negative impact on flow quality or test capability for 8x6 SWT test section
- Computational Fluid Dynamics (CFD) model created for baseline geometry and validated with experimental data
  - Five recommended modifications identified:
    1. Test section acoustic treatment
    2. Turning vanes in Corner 2
    3. Turning vanes in Corner 3
    4. Acoustic baffles
    5. Diffuser modification
- Available funding will dictate magnitude, duration and schedule of facility improvements



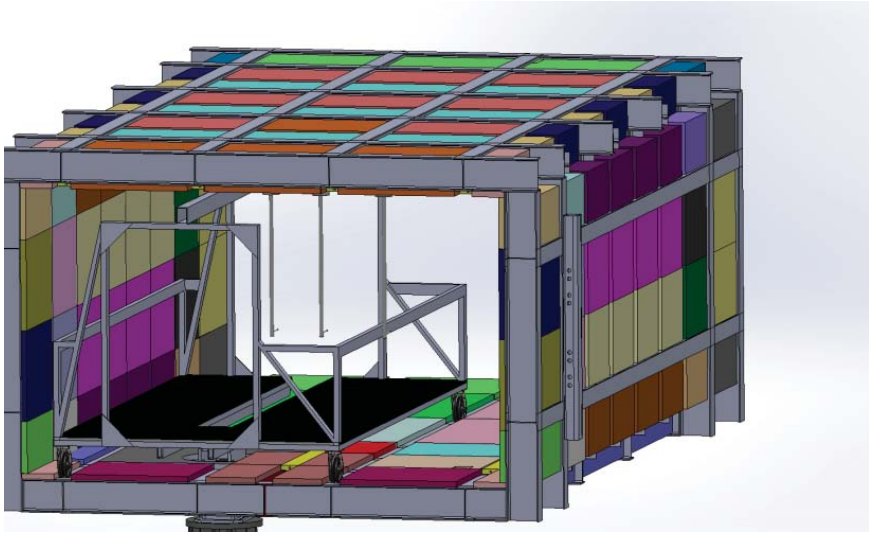


# 9x15 Acoustic Test Section Upgrade



- Currently focusing on the selection of 9x15 test section flow surface acoustic treatment
  - Goal to reduce boundary layer noise by 5-7 dB
  - Acoustic treatment study in progress to test treatment samples to verify noise reduction magnitude

- Design requirement is to have acoustic boxes be more of a “modular” design
- Specialized work cart will be available for model work while floor is installed to prevent damage to treatment

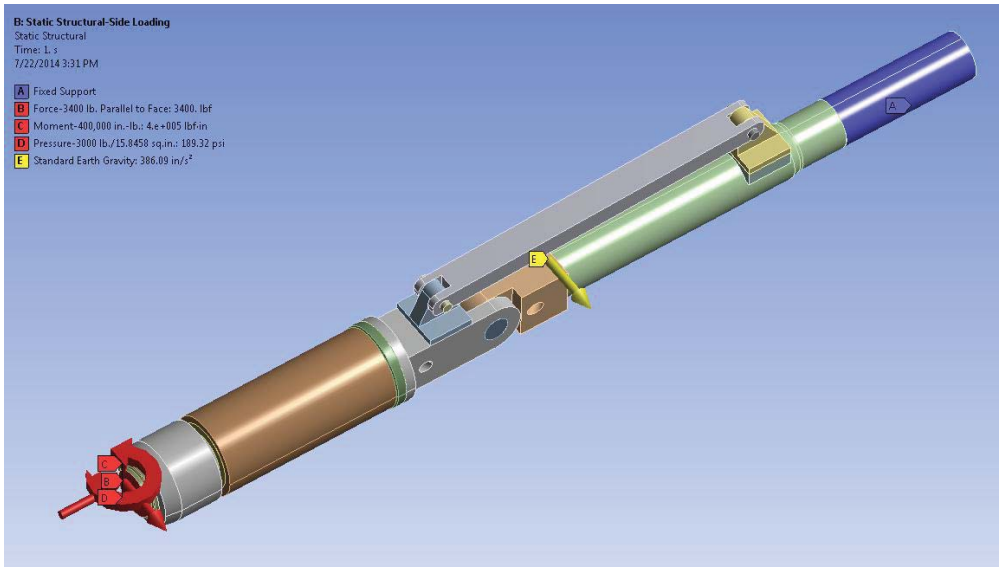


# Roll Mechanism

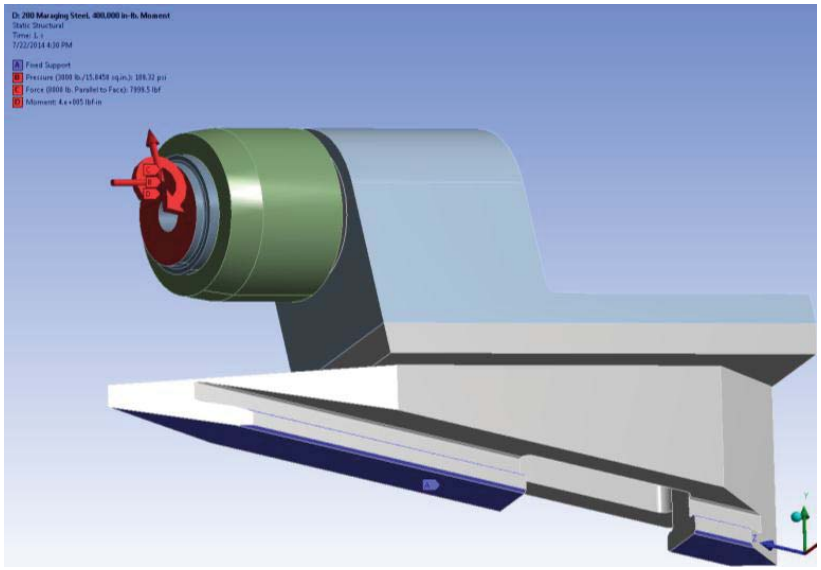
- Desire for roll mechanism for models in 8x6 SWT
- Model Support Strut can pitch for angle of attack
  - Single and double knuckles also available for angles of attack and yaw
- Hydraulically actuated roll mechanism currently being designed with following capabilities:
  - 360° of motion
  - 5000 in-lbs drive torque
  - 3000 lbs axial load
  - 8000 lbs radial load
  - 300,000-400,000 in-lbs pitching moment
  - Operating temperatures up to 250° Fahrenheit

# Roll Mechanism

- Strut (supersonic and transonic) and sting mounted roll mechanisms have been designed
- Material selection currently ongoing




Sting mounted design (includes knuckle to be used for attaining appropriate AoA)



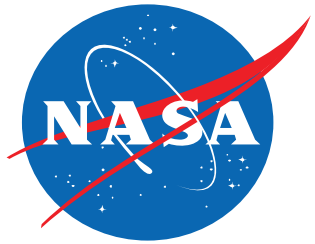
Strut (supersonic) mounted design – includes -10° kick to allow overall AoA range of about -15 to +15°

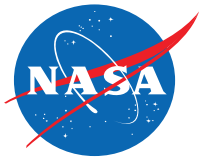
# Model Backstop

- Desire for further capabilities of model buildup in wind tunnel shop
  - Assists with balance checkouts, model fit-ups, etc.
- NASA LaRC had additional model backstop housed at National Transonic Facility (NTF)
  - Glenn accepts offer of model backstop (summer 2013)
- Hardware arrived November 2013, temporary location
- Backstop in final location, April 2014
- Currently, updating actuation and control systems

# 8x6 SWT / 9x15 LSWT Improvement Summary

| Project | Status | Implementation |
|---|---|---|
| COBRA DAS | Development | 2016 |
| 6-Component Rotating Balance | In Use / Continual Development | 2012 |
| Telemetry | Fabrication | 2015 |
| Thermocouple upgrade | In Use | 2012 |
| Customer Accommodations | In Use | 2012 |
| Schlieren System Upgrades | In Use | 2010-2013 |
| 9x15 Acoustic upgrade | Development | TBD |
| Roll Mechanism | Material Selection | 2015 |
| Check Load Stand | In Use | 2010 |
| Autoloader | In Use | 2014 |
| Model Backstop | Refurbishing | 2015 |

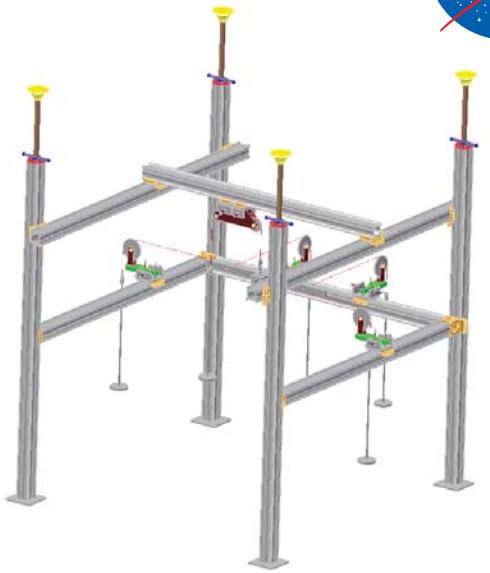

NASA



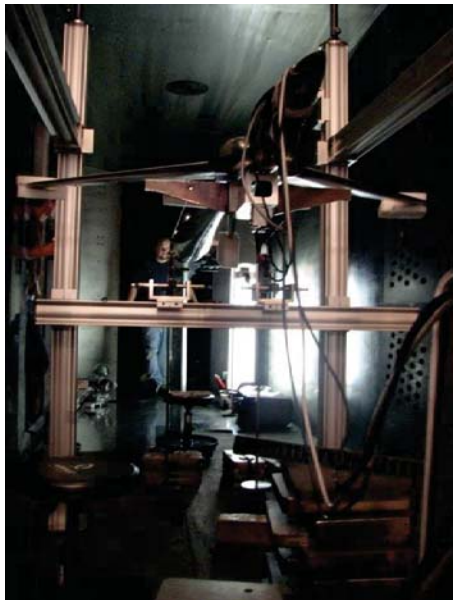

# BACKUP SLIDES

# Check Load Stands

- Portable stands for application of check loads on test articles in test section or build-up facilities
  - ➢ Used for in-situ verification of force measurement systems
- Can be built around test article if required
- 1000 lbs load capacity each axis



**8x6 SWT Check Load Stand**



**8x6 Favor Test, 2010**


**9x15 UHB, 2012**

**Portable Check Load Stand**

# Autoloader

- 1000 lb. capacity autoloader
  - Can be used to apply loads up to 1000 lbs in 50 lbs increments
  - Designed and fabricated by NASA LaRC and Modern Machine & Tool Co., Inc.
- Loading 1000 lbs manually is very labor intensive
  - Desire for device to automate the process
  - Device should have small footprint for use in test section or build up area


**1000 lbs Autoloader in use in the 8x6/9x15 WT Build up room**