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

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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
## Capabilities of 8x6/9x15 Wind Tunnels

<table>
<thead>
<tr>
<th>Test section speed (Mach)</th>
<th>9x15 Low Speed Wind Tunnel (LSWT)</th>
<th>8x6 Supersonic Wind Tunnel (SWT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 0.23</td>
<td>0 to 0.1 &amp; 0.25 to 2.0</td>
</tr>
<tr>
<td>Simulated Altitude (ft)</td>
<td>Sea Level</td>
<td>1000 to 35000</td>
</tr>
<tr>
<td>Test Section Reynolds number / feet</td>
<td>0 to 1.4e6</td>
<td>3.6e6 to 4.8e6</td>
</tr>
<tr>
<td>Dynamic Pressure (lbf/ft²)</td>
<td>0 to 72</td>
<td>200 to 1340</td>
</tr>
<tr>
<td>Test Section Total Temperature (°R)</td>
<td>Ambient to 550</td>
<td>520 to 720</td>
</tr>
<tr>
<td>Auxiliary Air Supply (Heated)</td>
<td>30 lbm/s</td>
<td>30 lbm/s</td>
</tr>
<tr>
<td>At 40 psig</td>
<td>30 lbm/s</td>
<td>30 lbm/s</td>
</tr>
<tr>
<td>At 150 psig</td>
<td>30 lbm/s</td>
<td>30 lbm/s</td>
</tr>
<tr>
<td>At 450 psig</td>
<td>30 lbm/s</td>
<td>30 lbm/s</td>
</tr>
<tr>
<td>Model Exhaust</td>
<td>Variable</td>
<td>Variable</td>
</tr>
</tbody>
</table>
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

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

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
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 L SWT 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
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

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 Test Section Air Speed Capabilities

- Original (1949)
- Transonic (1956)
- Current

Mach Number

- Wing blower operation
- 1-Motor operation
- 3-Motor operation
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
  ➢ Collect, Observe, Broadcast, Record, & Analyze
  ➢ 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

• 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
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

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.
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

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