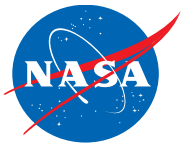


Overview of Facility Checkout Runs Planned for Spring 2014 at the NASA Glenn Research Center 10x10 Supersonic Wind Tunnel

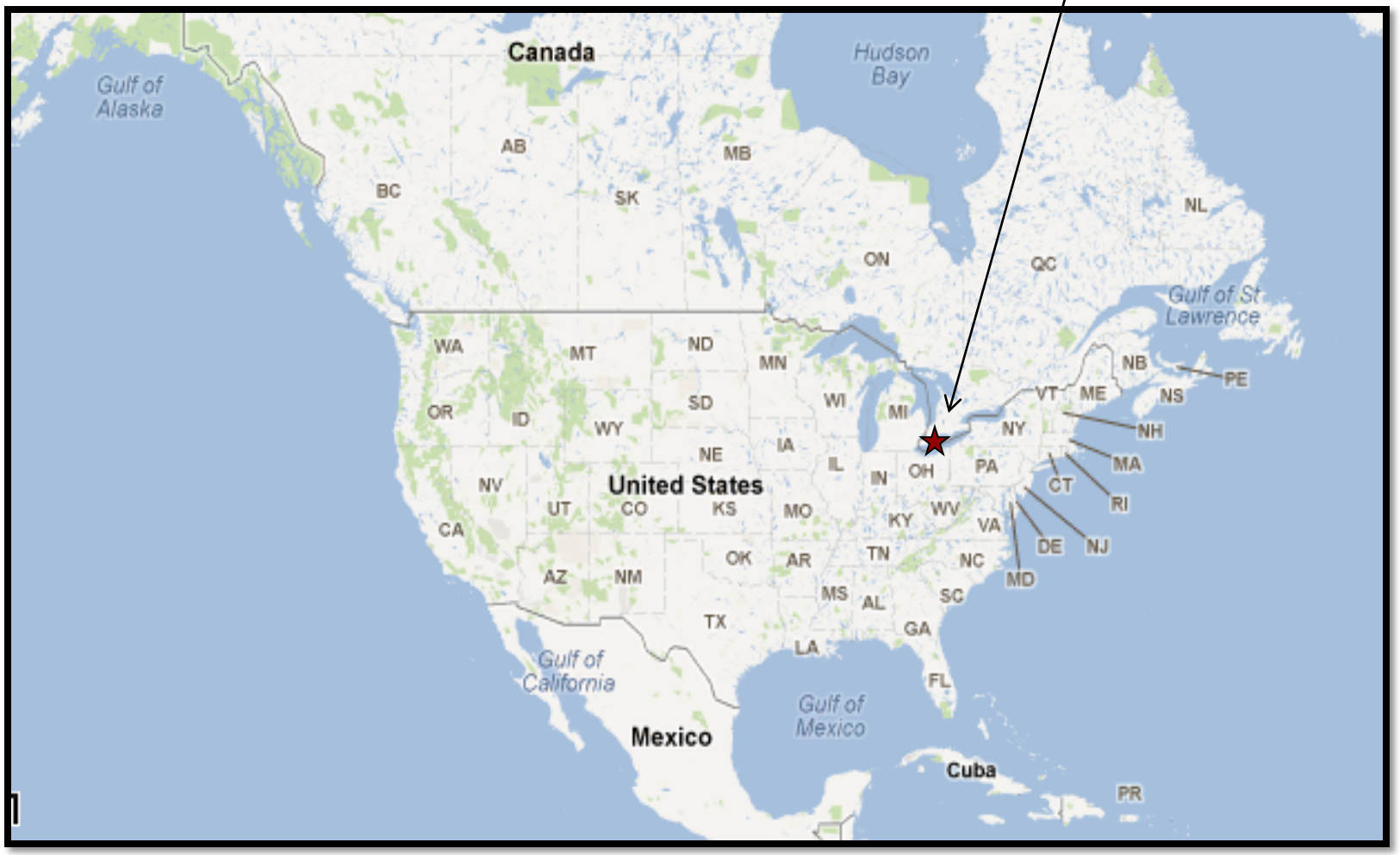
Julius A. Giriunas

Supersonic Tunnel Association International (STAI)

121st Semi-Annual Meeting

May 11- 13, 2014

NASA Glenn Research Center
Cleveland, Ohio USA



NASA Glenn Research Center
Cleveland, Ohio

Glenn Research Center
Cleveland, Ohio

10x10ft. Supersonic Wind Tunnel

Test Section
10ft.x10ft.x40ft. long

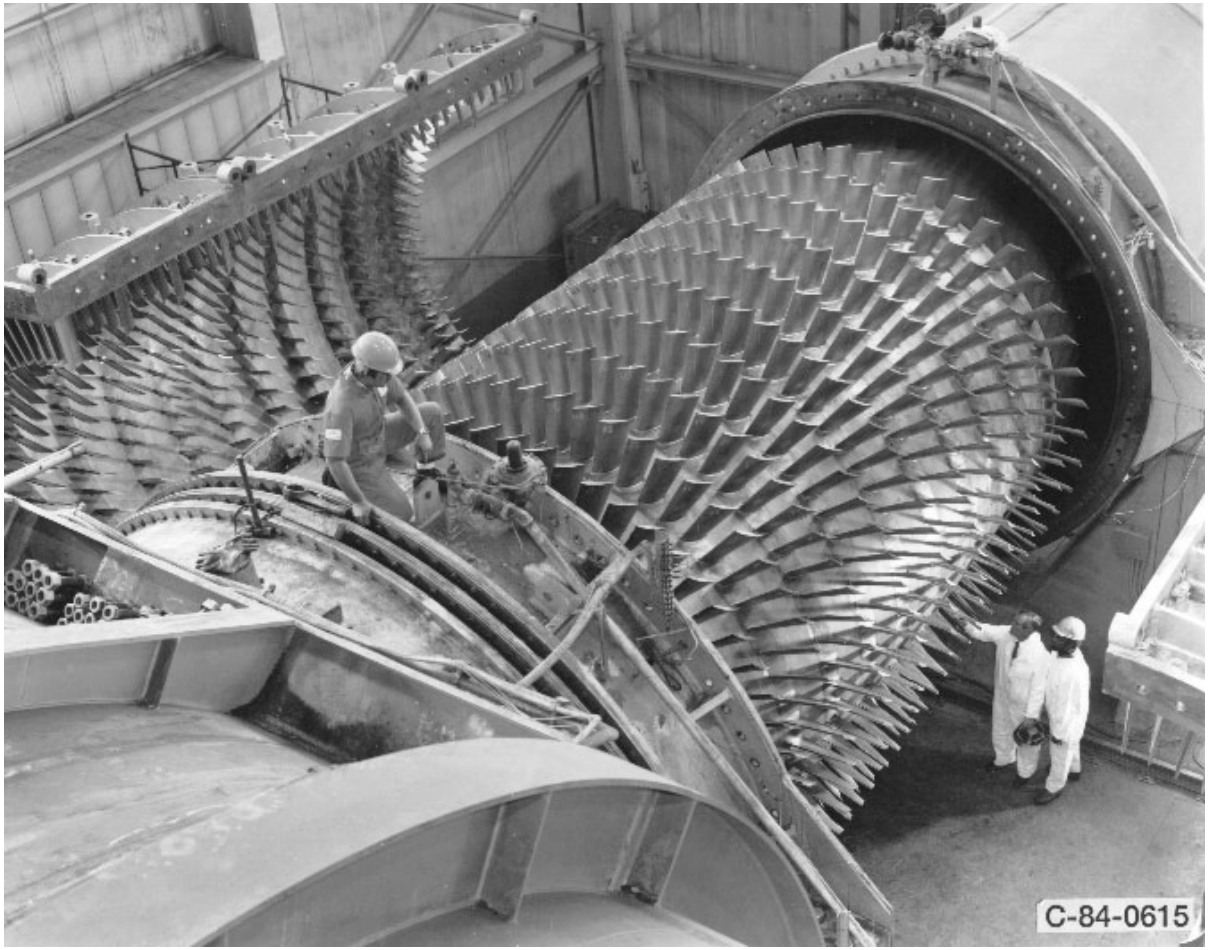
Supersonic and Subsonic test modes
Aerodynamic–Closed loop
Propulsion–Open loop

Mach No.: 2.0 to 3.5
and 0 to 0.4 (240 knots)
Altitude: 50,000 to 150,000 ft.
Temperature: 60° to 680°F
Fuels: Liquid JP, hydrogen and oxygen
Continuous Operation: 250,000 hp drive motors
Remotely accessible real-time data display

CD-98-77058

Compressor-1
8 stage
Mach 2.0-2.5
Pr=2.8

Compressor-2
10 stage
Mach 2.5-3.5
Pr=2.4



Facility Checkout Runs Planned

1. Integrated System Test (IST) of
   a. new Facility Control System (Ovation)
   b. new Data Acquisition System (COBRA)
2. Tunnel Calibration - check calibration using 5 wedge array
3. Mach 4 test run - attempt to expand operating envelope
4. Expansion Joint No. 2 - collect displacement data

1a - IST Facility Control System (Ovation)

New Facility Control System – why replace current one?

- The original WDPF (Westinghouse Distributed Process Family) control system was installed in 1990 and was upgraded to Ovation in 2002.
- Control system PC's that were installed in 2002 are obsolete and spare parts for them are difficult to find.
- Emerson will discontinue support for the Q-Line I/O card hardware in 2018 - was in place since 1990.

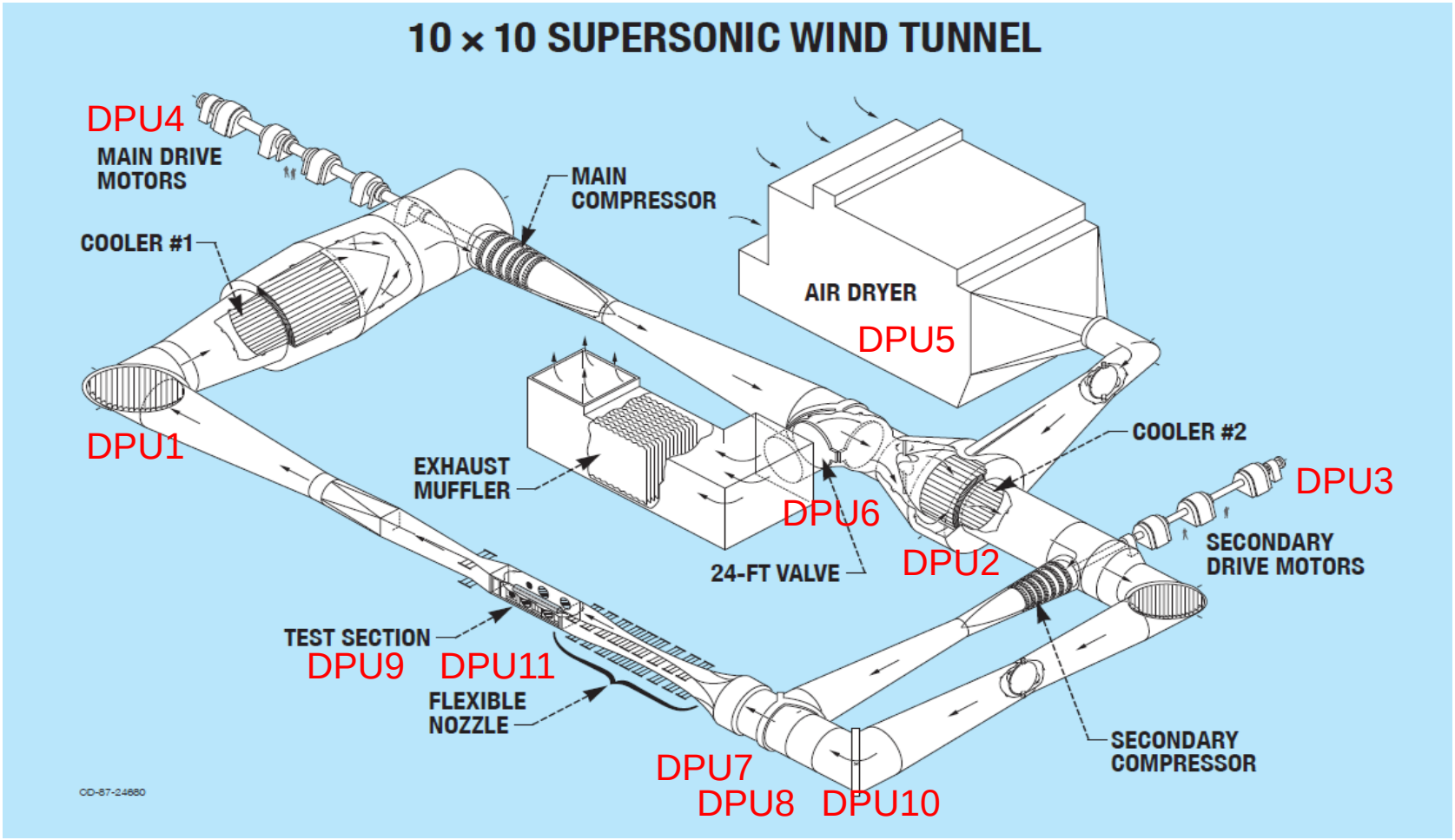
1a - IST Facility Control System (Ovation)

- Activities from Fall 2012 to Spring 2014
  - Original control system functions were fully documented
  - Emerson performed the system conversion
  - System procured from Emerson
    - Factory acceptance tests performed for Software and Hardware
  - Removed the old system / installed new system
  - Perform sub-system checkouts

- Begin Integrated System Test

1a - IST Facility Control System (Ovation)

Tunnel layout with 11 DPU locations supporting 19 sub-systems



1a IST - Facility Control System (Ovation)

17 of 19 Subsystems being verified

1. Ovation
2. Main compressor
3. Secondary compressor
4. Air Dryer
5. Coolers #1 and #2
6. Hydraulic stations
7. Pressure Ratio #1
8. Pressure Ratio #2
9. Pressure Level
10. 24-Foot Valve
11. Valves 6900 and 6905
12. Miscellaneous Valves
13. Flexwall
14. Second Throat
15. Exhausters
16. Tunnel Manholes-doors-gates-vent fans
17. Test Section Struts
18. Model Air Systems
19. Tunnel Air Heater

1b - IST Data Acquisition System (COBRA)

New Data Acquisition System – why replace current system?

- Current steady state data systems have components that are over 30 years old.
- Replacement parts and/or system components are no longer being made or supported by manufacturers.
- New items can no longer be incorporated due to software incompatibilities with existing systems.
- Current data system no longer provides customers with the recording rates that are often requested in test.
- Software support for the computer systems ended in 2013.

1b - IST Data Acquisition System (COBRA)

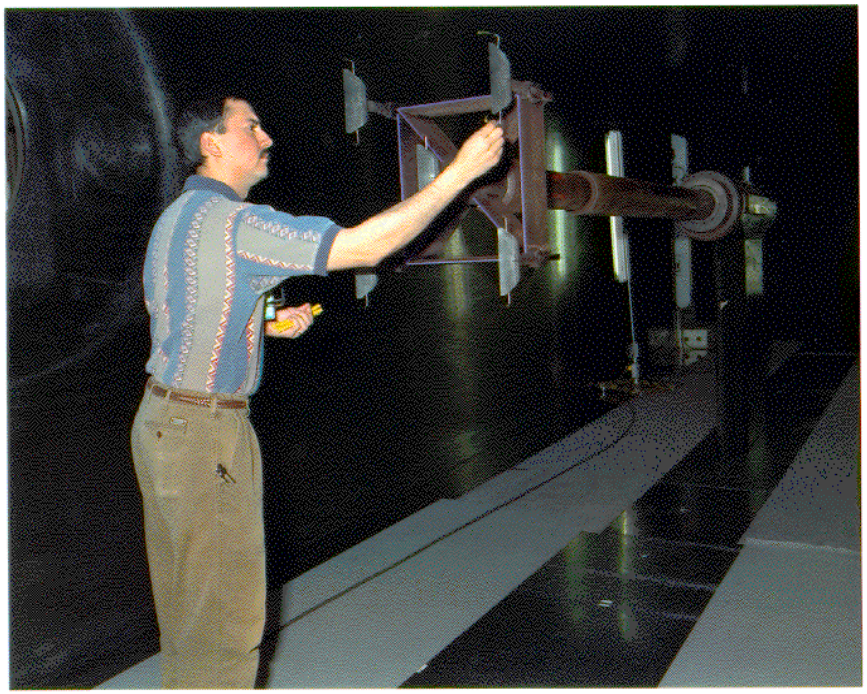
System Comparison

	ESCORT	COBRA
Architecture	Central/Bus Level	Distributed/Network
Input Channels	2000 Max	Over 5000 (upper limit not determined)
Calculations	8000 Max	Over 20,000 (upper limit not determined)
Sampling Rate	1 per sec. (typical) up to 10 per sec. (custom w/limitations)	12 ½, 25, 50, 100, 200, 400 & 800 samples per second
Display Windows/ Views	16 Max	32 stations with multiple pages/monitors per station
Display Update	1-2 updates per second	12 ½ updates per second
Display Type	Alphanumeric or Graphical page	Alphanumerics and Graphics on same page
Storage	36 Gigabytes (application/data)	TeraBytes (scalable to PetaBytes)
Signal Conditioning Support	Limited	Precision Filters, Endevco, Pacific, etc.
Time Stamping	IRIG B	IRIB B, GPS
System Configuration/Setup	Multiple ACSII files	Spreadsheet
User Interfaces	Command Line	Graphical

2 - Tunnel Calibration Using 5 Wedge Array

- Primary objective of the check calibration is to verify that the 1999 full calibration has not changed.
- Secondary objective is to apply the principles of statistical process control (SPC) to determine if the 10x10 SWT is a stable system (that is repeatable and predictable)
- Verify that the new data system COBRA collects data as effectively as the current data system Escort.

2 Tunnel Calibration using 5 Wedge Array



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

- The array is a 16-inch square frame
- Supports 5 supersonic wedge probes
  - One wedge at each corner
  - The fifth at the center of the array
- A larger 17-wedge array was used for the 1999 full tunnel calibration tests)

2 - Tunnel Calibration Using 5 Wedge Array

The instrumented wedges will measure

- Total pressure
- Mach number
- One component of flow angle
  - vertical orientation for measurement of yaw angle
  - horizontal orientation provides pitch flow angle

Test Conditions

- Aerodynamic (closed-loop) cycle
- Mach number sweep from 2.5 to 3.5 in 0.1 increments
- 3 different Reynolds numbers (2.5, 1.5, and 0.5 x 10^6 per ft)
- Multiple repeat runs on different days

3 - Mach 4 Test Run

- Current tunnel speed range is Mach 2.0 to 3.5.
- Tunnel was originally built to reach a speed of Mach 4.0.
- Possible limiting factors are the flow characteristics and terminal shock in the second throat which caused higher losses than expected.
- The objective for the Mach 4 test is to evaluate the behavior of the second throat.

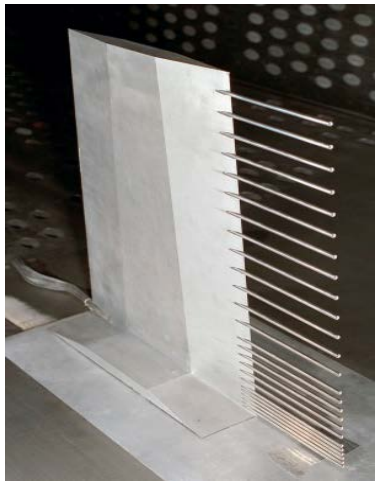
3 - **Mach 4 Test Run**

- The flexwall contours can achieve the area ratio for Mach 4 operation.
- As currently operated, the pressure ratio required to achieve Mach 4 operation exceeds the available pressure ratio from the two compressor drives.
- At the time of the tunnel's design (early 1950's) the proper design and operation of a variable second throat was more of an art than a science.
- CFD tools have been used to prepare a better understanding of second throat fluid dynamics - tunnel procedures could be changed to enable Mach 4 operation.

3 - Mach 4 Test Run

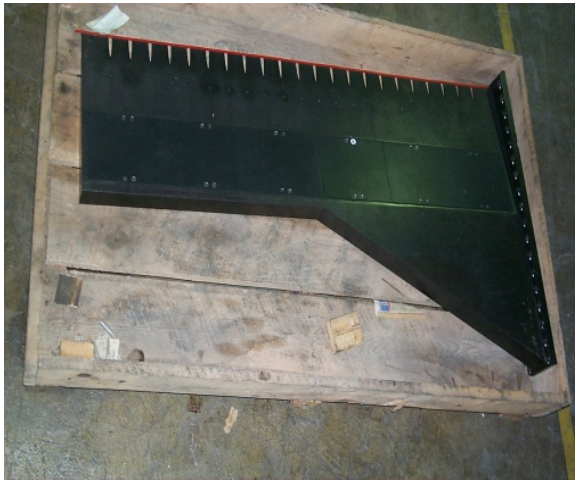
Instrumentation will be collecting data during the entire test entry (IST, check-calibration up to M3.5) in addition to the data collected during the actual Mach 4 portion of the test.

Two 18” rakes



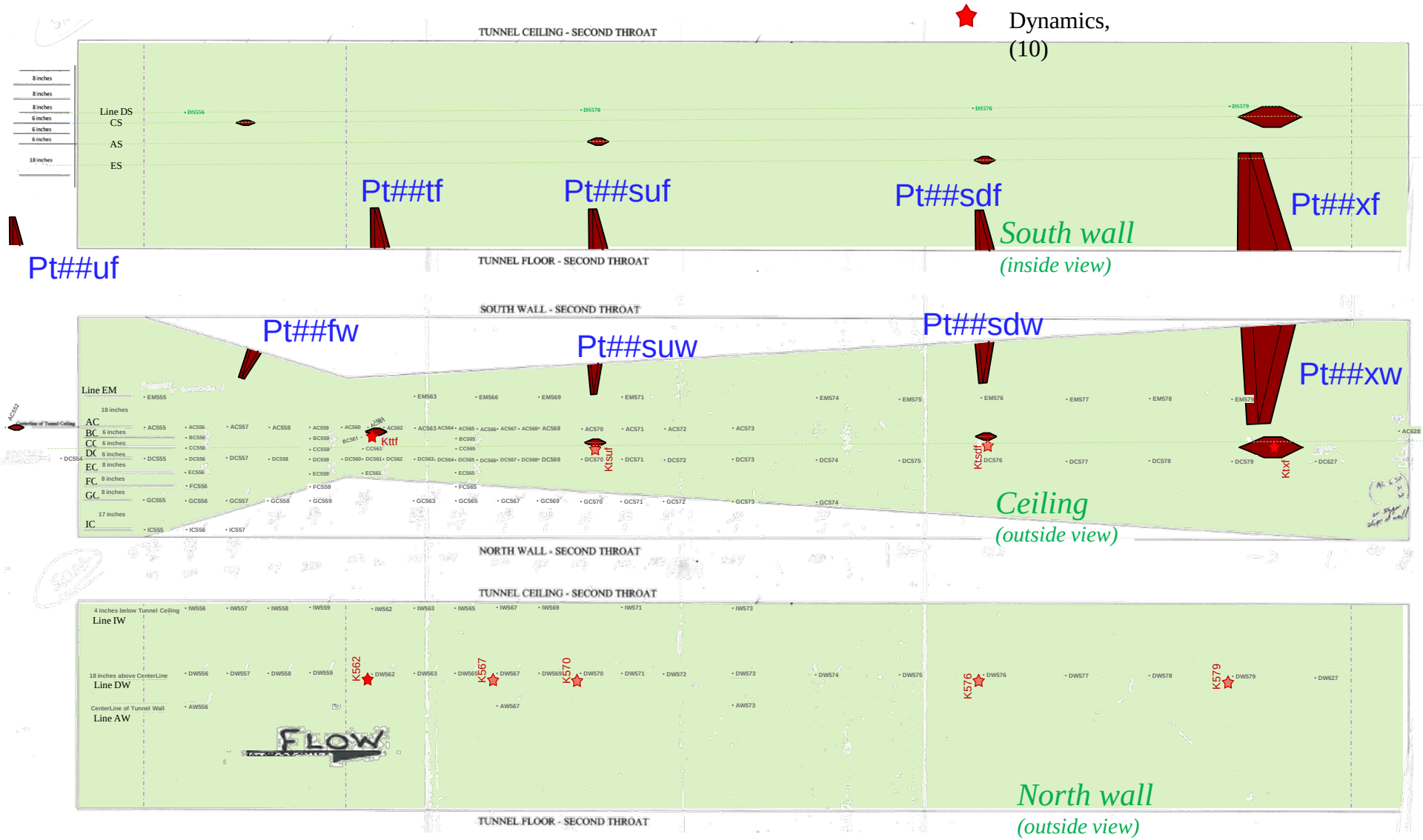
Five 24 “ rakes

Two 60” rakes



In-stream pressure from large rakes and wall statics (next chart) will be recorded as the tunnel pressure ratio and second throat geometry is varied.

3 - Mach 4 Test Run



4 - Expansion Joint No. 2 Collect displacement data

Expansion Joint Description

- Provides for the relative tunnel motion between the test section exit and compressor #1 inlet leg of the tunnel loop.

- Diameter 26 ft
  Material: 304ss
  No. of convolutions: 5

- Current expansion joint needs to be replaced due to cracks in the bellows.

4 - Expansion Joint No. 2 Collect displacement data

Crack along and across convolutions

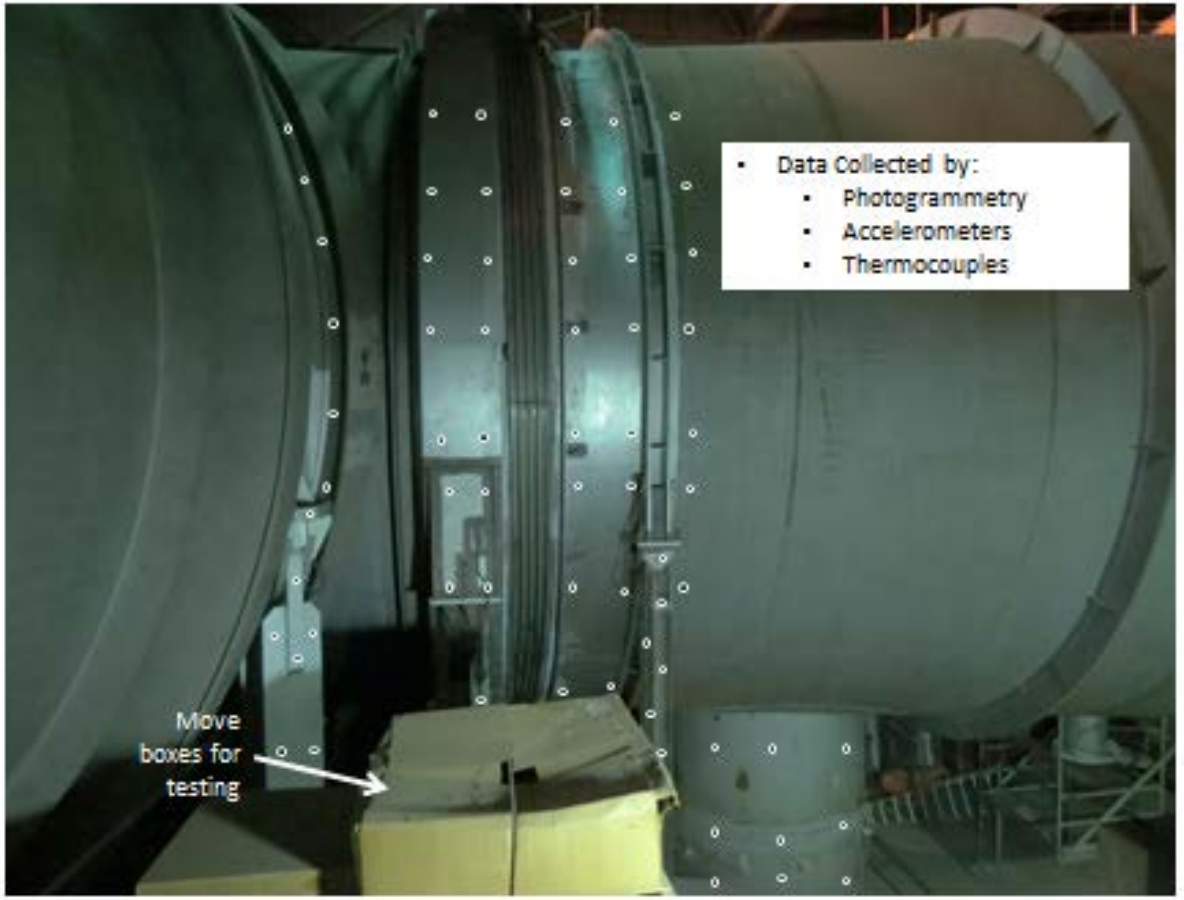
Crack repaired via weld

Crack covered with RTV coat for additional sealing

4 - Expansion Joint No. 2 Collect displacement data

Global Analysis from Mezzanine

- Attach targets with self adhesive tape or magnetic backing



4 - Expansion Joint No. 2 Collect displacement data

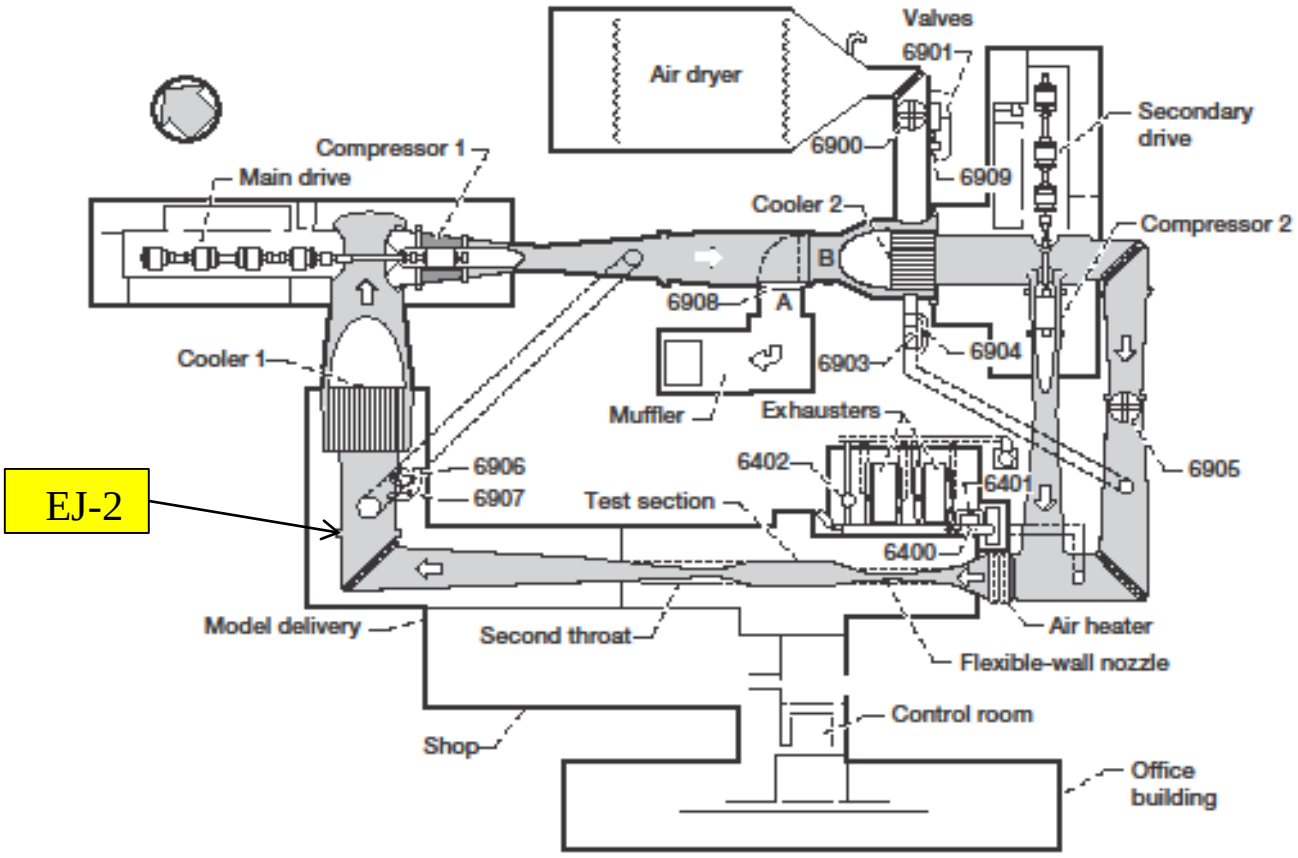


Figure 1.—10- by 10-Foot Supersonic Wind Tunnel (10×10 SWT).

4 - Expansion Joint No. 2 Collect displacement data

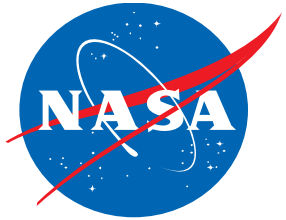
Global Analysis from Lower Level

- Attach targets with self adhesive tape or magnetic backing

Facility Checkout Runs Planned - Schedule

1. IST - Integrated System Test of
   a. new Facility Control System (Ovation) (10 days)
   b. new Data Acquisition System (COBRA)
2. Tunnel Calibration - check calibration using a 5 wedge array (5 days)
3. Mach 4 test run - attempt to expand operating envelope (2 days)
4. Expansion Joint No. 2 - Collect displacement data during calibration run

Schedule – Checkout runs planned for May-June 2014


NASA

Backup Slides

Data Acquisition System Replacement

Collect
Observe
Broadcast
Record &
Analyze

1a - IST Facility Control System (Ovation)

History and rationale for upgrade

The WDPF control system was installed in 1990 and was upgraded to Ovation in 2002.
Emerson will discontinue support for the Q-Line I/O cards in 2018.
Control system PC's are obsolete and spare parts for them are difficult to find.

There are 2 phases of upgrades required.

1. "Evergreen" upgrade.
    - Upgrade from OCR161 to OCR400 controllers
    - Upgrade to latest Ovation software revision (3.x ?)
    - Control sheet change from AutoCAD
    - PC upgrades to Windows7 (or WindowsXP)
    - Server upgrades to Windows Server2008 (or 2003)
    - Network hardware upgrade
    - Historian upgrade to OPH
    - Upgrade of security functions utilizing AV and domain servers
2. Upgrade of existing Q-Line I/O to Ovation migration I/O and standard R-Line I/O.

1a - IST Facility Control System (Ovation)

Control system hardware

Existing DPU with OCR161 controllers and Q-Line I/O

New system with OCR400 controllers and migration I/O

1b - IST Data System (COBRA)

System Design Goals

- Incorporate existing Capabilities & Sub Systems (Current Escort Data System)
- Commercial Hardware
  - PCs
  - Switches
  - A/Ds (exploring multiple vendors)
- Operating System Independence
  - Linux (Data Viewers, Calculator)
  - Windows (Data Viewers, ADAS-Subsystem Interface)
- Standard Programming Languages
  - C^{++}, C, Fortran
- Open Source Software
  - Qt application framework for developing graphical user interfaces (GUI)
- Scalable (Displays, Calculators, Subsystems & Number of analog channels – by chassis)

1b - IST Data System (COBRA)

System Design Goals

- Multiple Data Acquisition Rates (12½, 25, 50, 100…800 – multiples of 2)
- Anti-Aliasing (analog inputs AND displays)
- Up to 32 WYSIWYG Graphical Displays (What You See Is What You Get!)
- System Configuration via “Spreadsheets” or other Graphical methods
- DSP (Digital Signal Processing)
- Life Cycle
  - High Level Network architecture, 20 yrs
  - Hardware, 10 yrs

New Capabilities!

3 - Mach 4 Test Run

Note: wall rakes are on the South wall and four (4) new south wall statics for the rakes, (Line DS)