NASA Glenn Research Center
10- by 10-Foot Supersonic Wind Tunnel
Air Heater Capability and Characterization Plans

Aaron Johnson
Amentum/TFOME II, NASA Glenn Research Center

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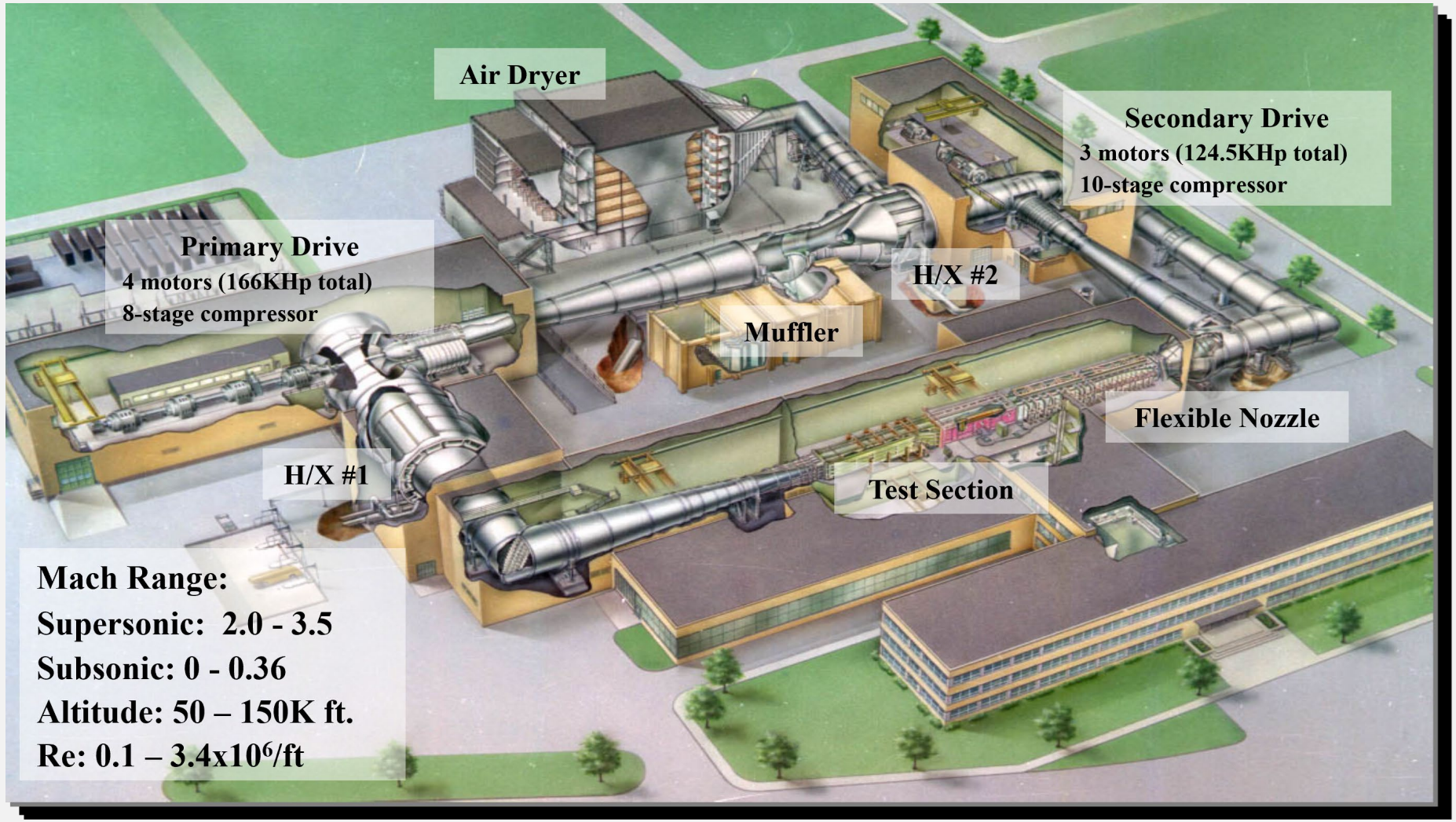
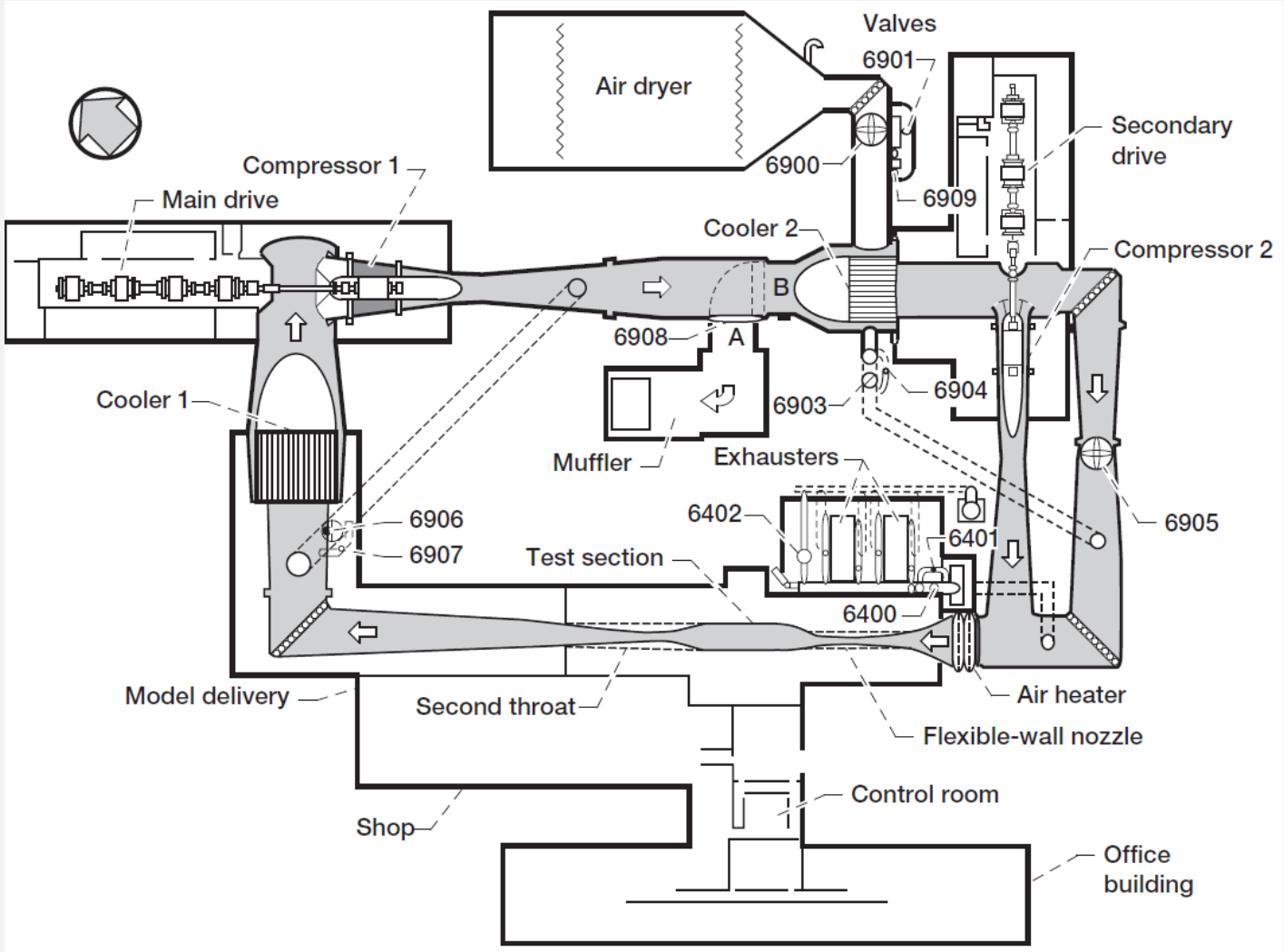
Overview

- Facility Overview
- Tunnel Air Heater
- Characterization Hardware Details
  - 17-Wedge Array
  - Characterization Array
- Previous Characterization Tests Entries
- Recent Efforts

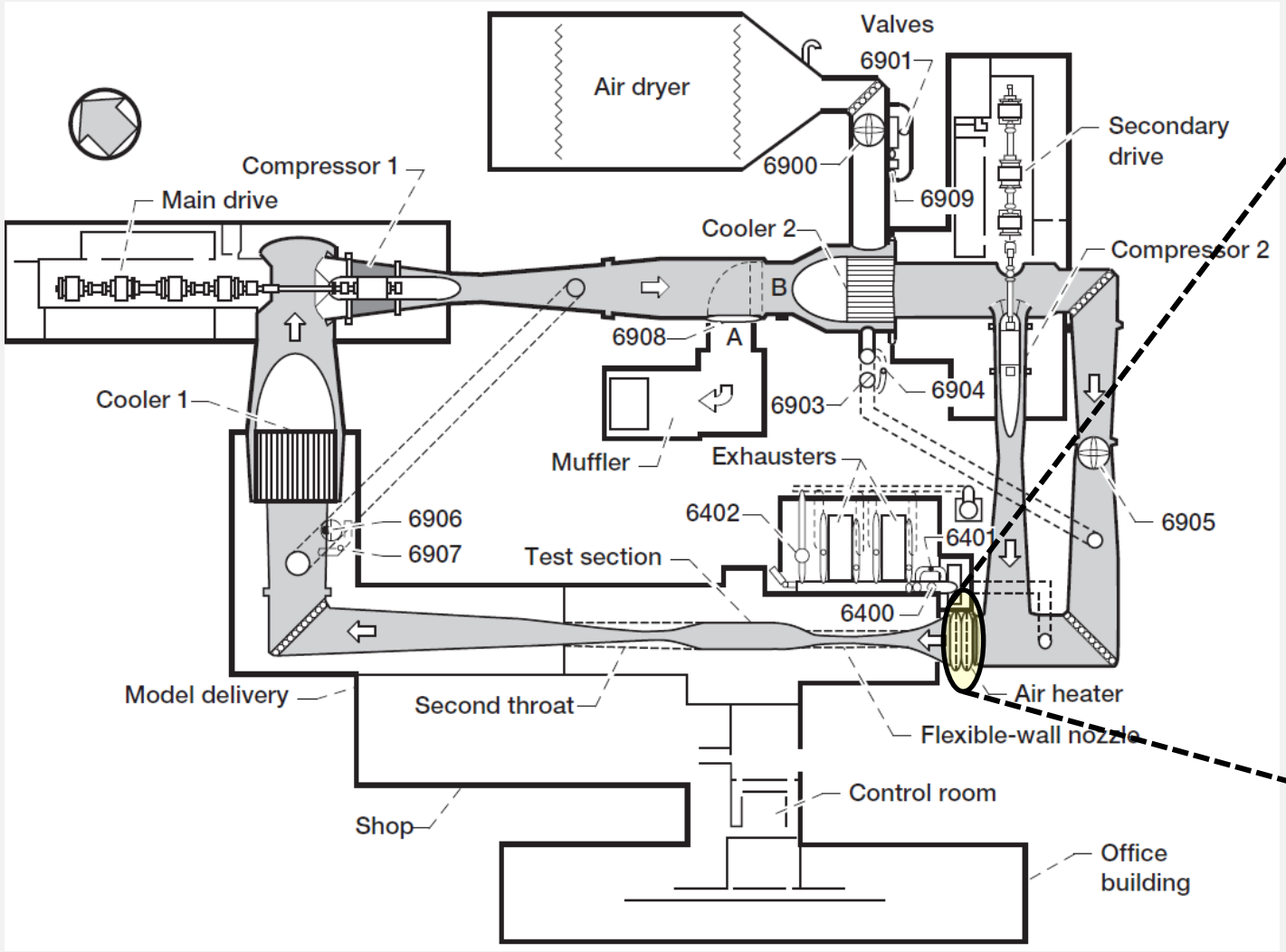
Facility Overview

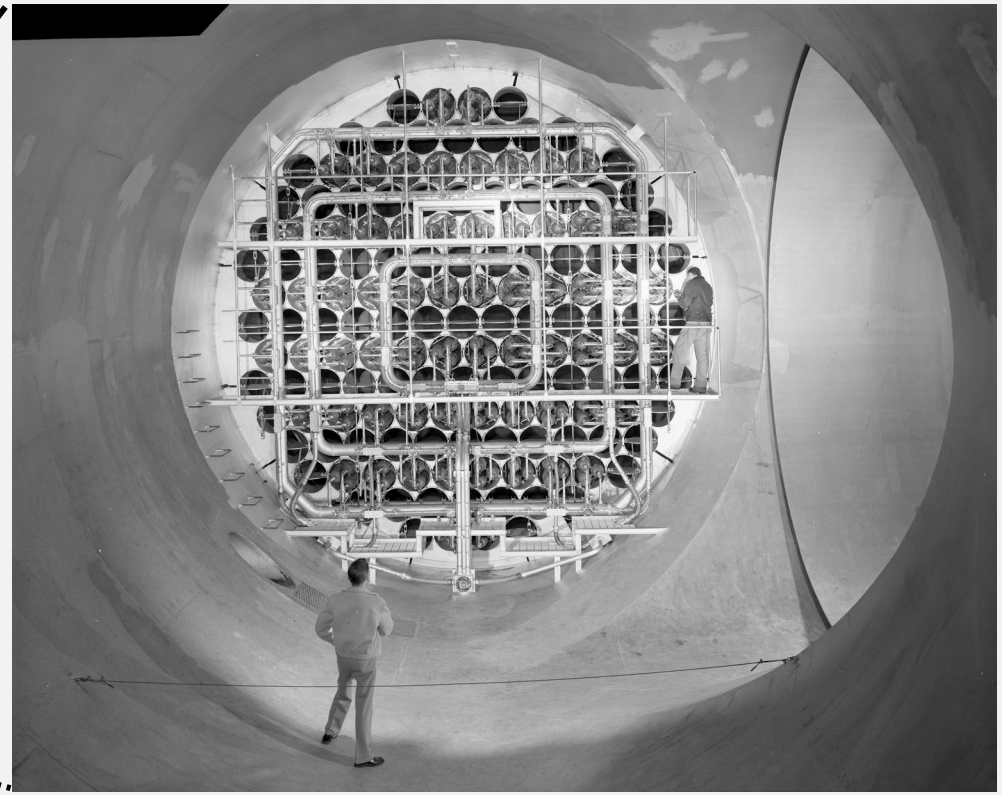


Facility Overview



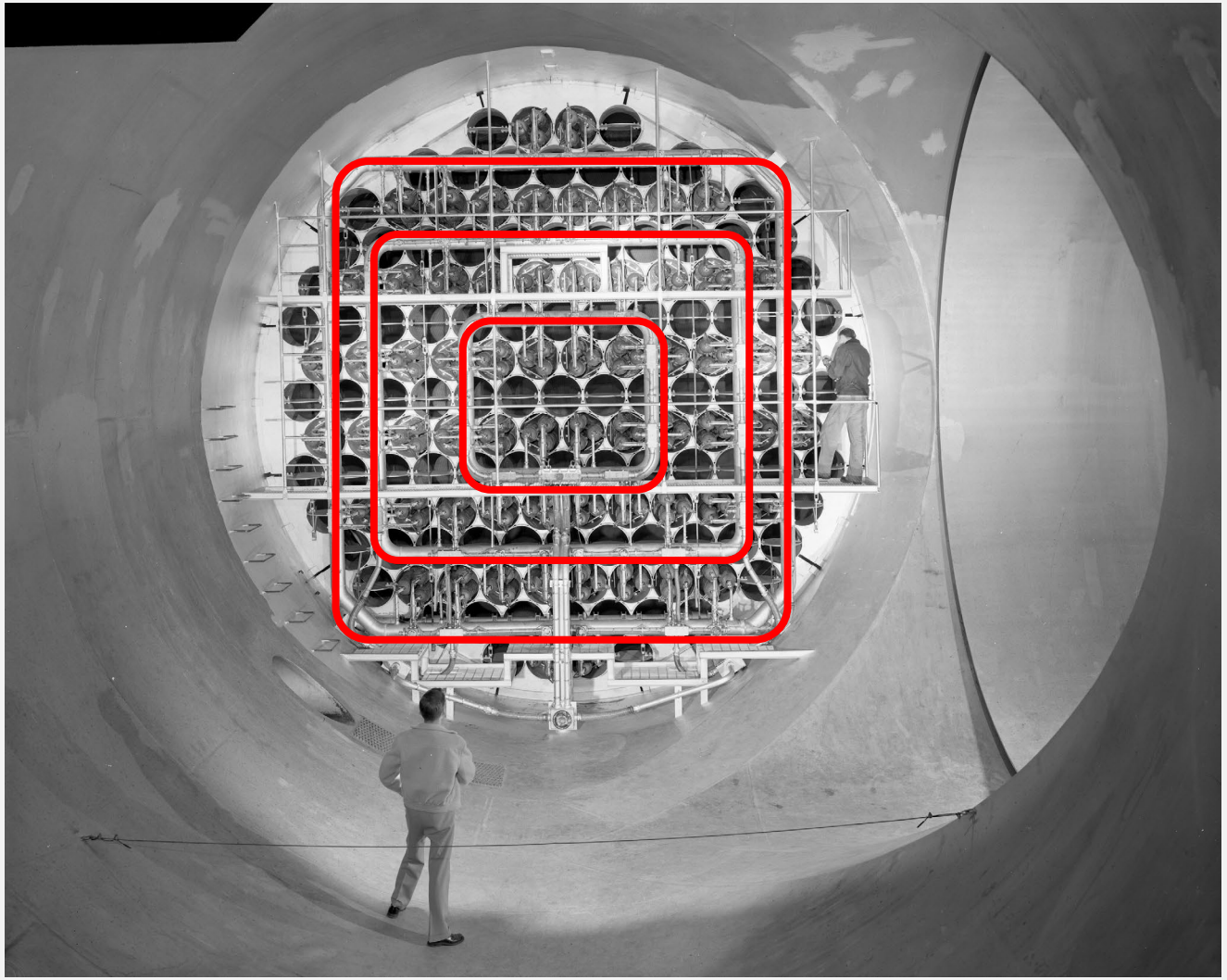
Tunnel Air Heater





(view looking downstream from turning vanes, GRC-1958-C-47713)

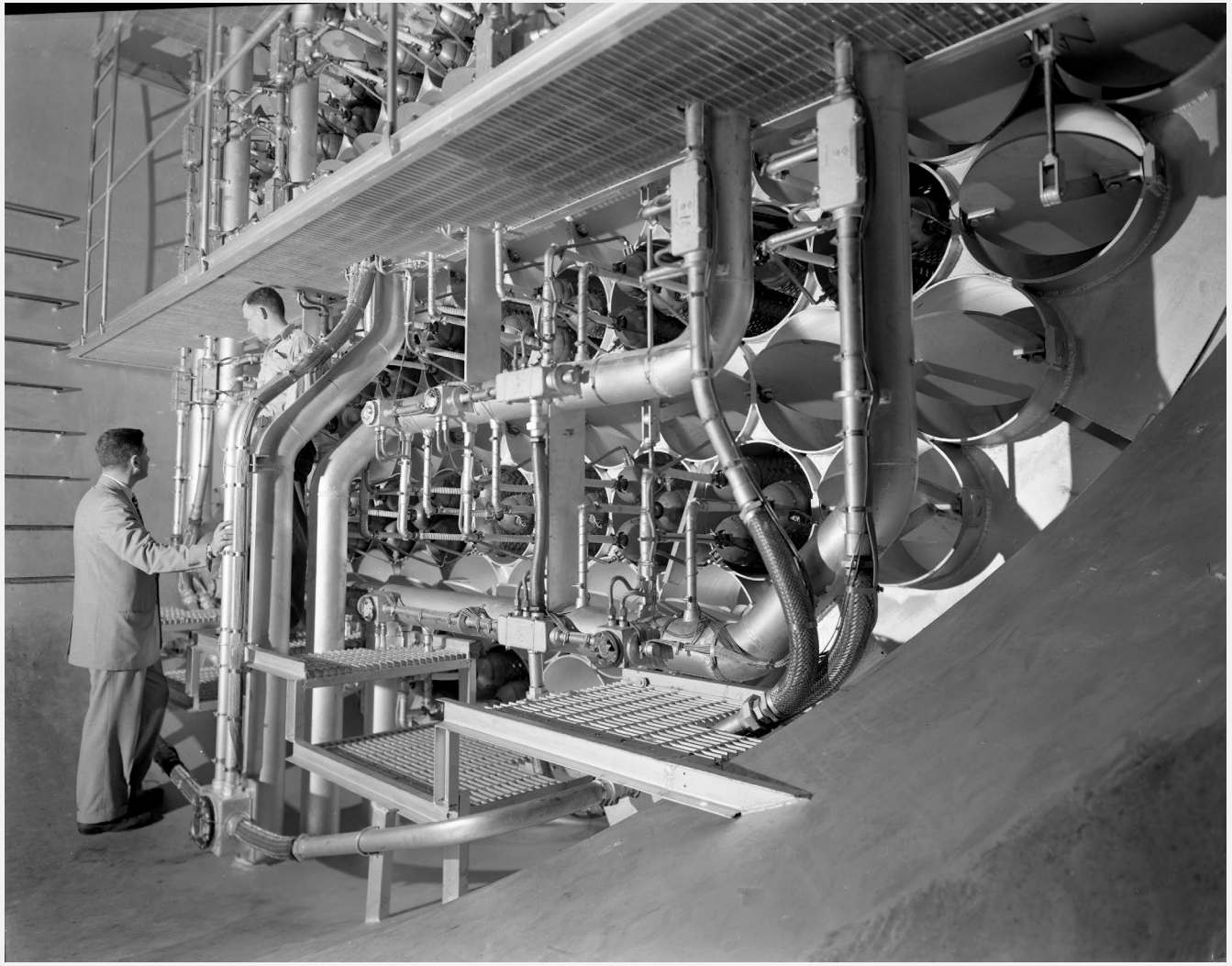
Tunnel Air Heater



(view looking downstream from turning vanes, GRC-1958-C-47713)

- Three natural gas supply lines feed three zones
- Orifice plate on each supply line for natural gas mass flow measurement

Tunnel Air Heater



(view looking downstream, GRC-1958-C-47804)

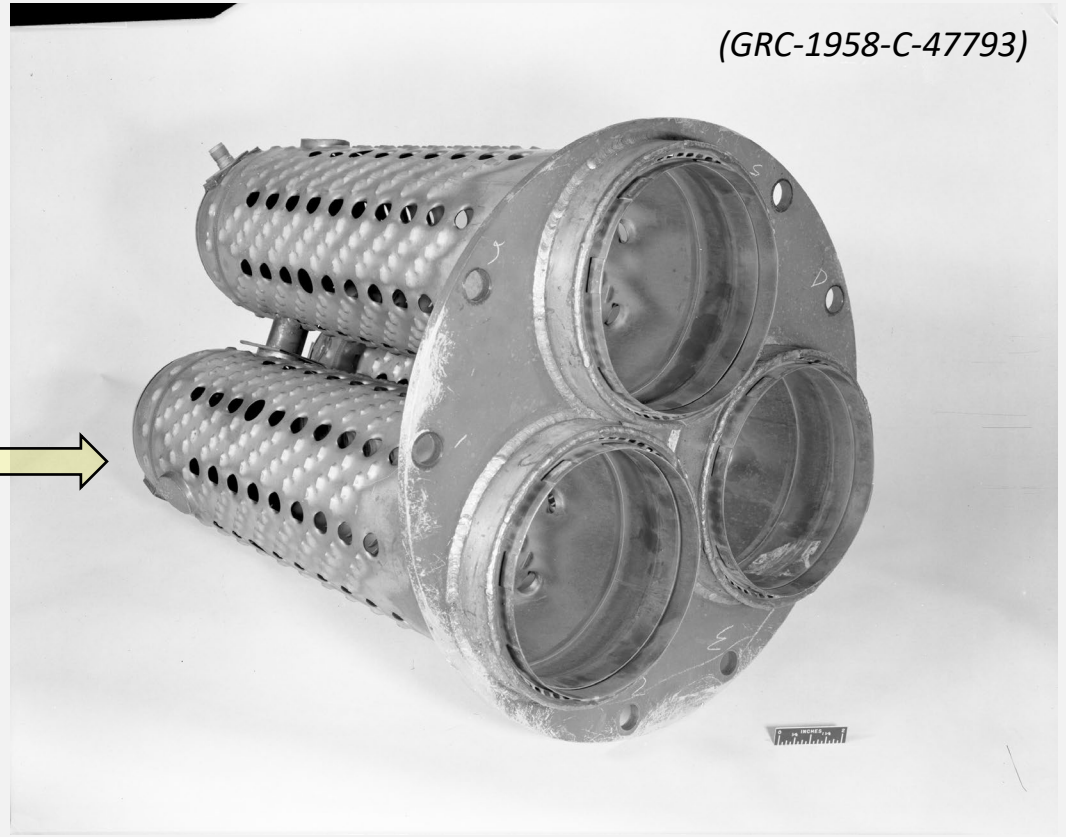
- Three natural gas supply lines feed three zones
- Orifice plate on each supply line for natural gas mass flow measurement

Tunnel Air Heater

(view looking upstream, GRC-1958-C-47803)

Tunnel Air Heater

(view looking upstream, GRC-1958-C-47803)

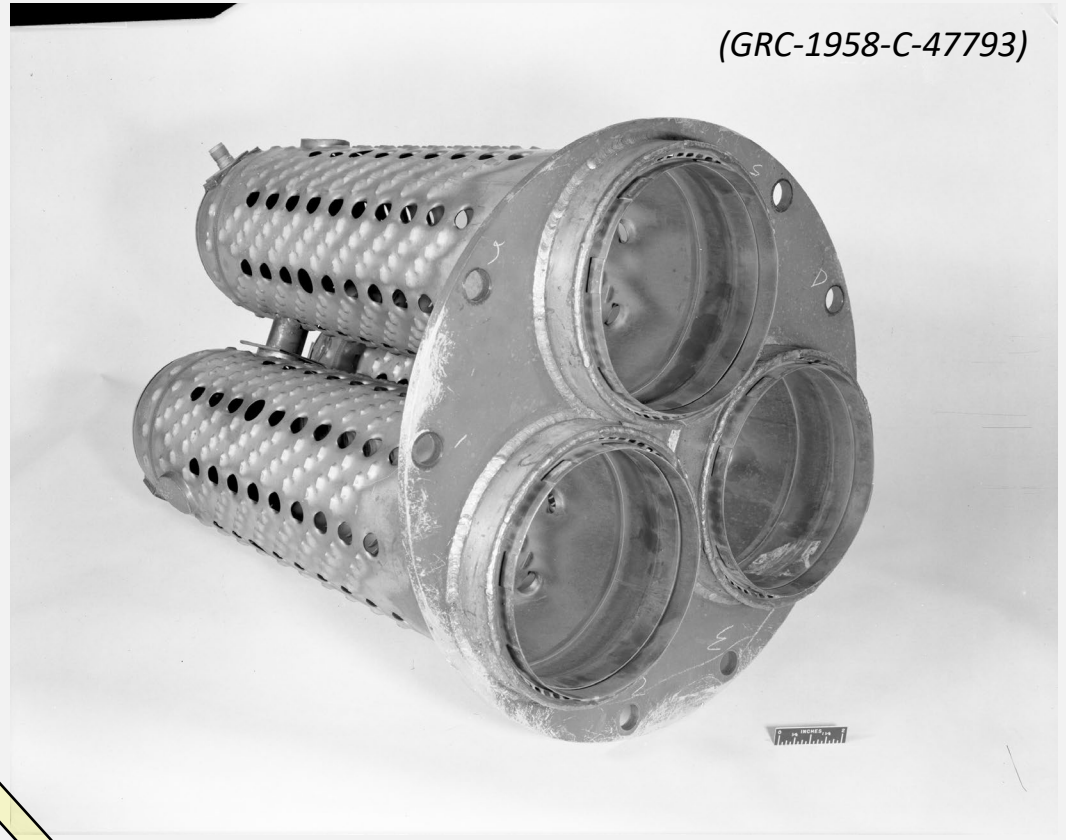


(GRC-1958-C-47793)

- Array of 64 sets of combustors
- Three J47 combustor cans per set

Tunnel Air Heater

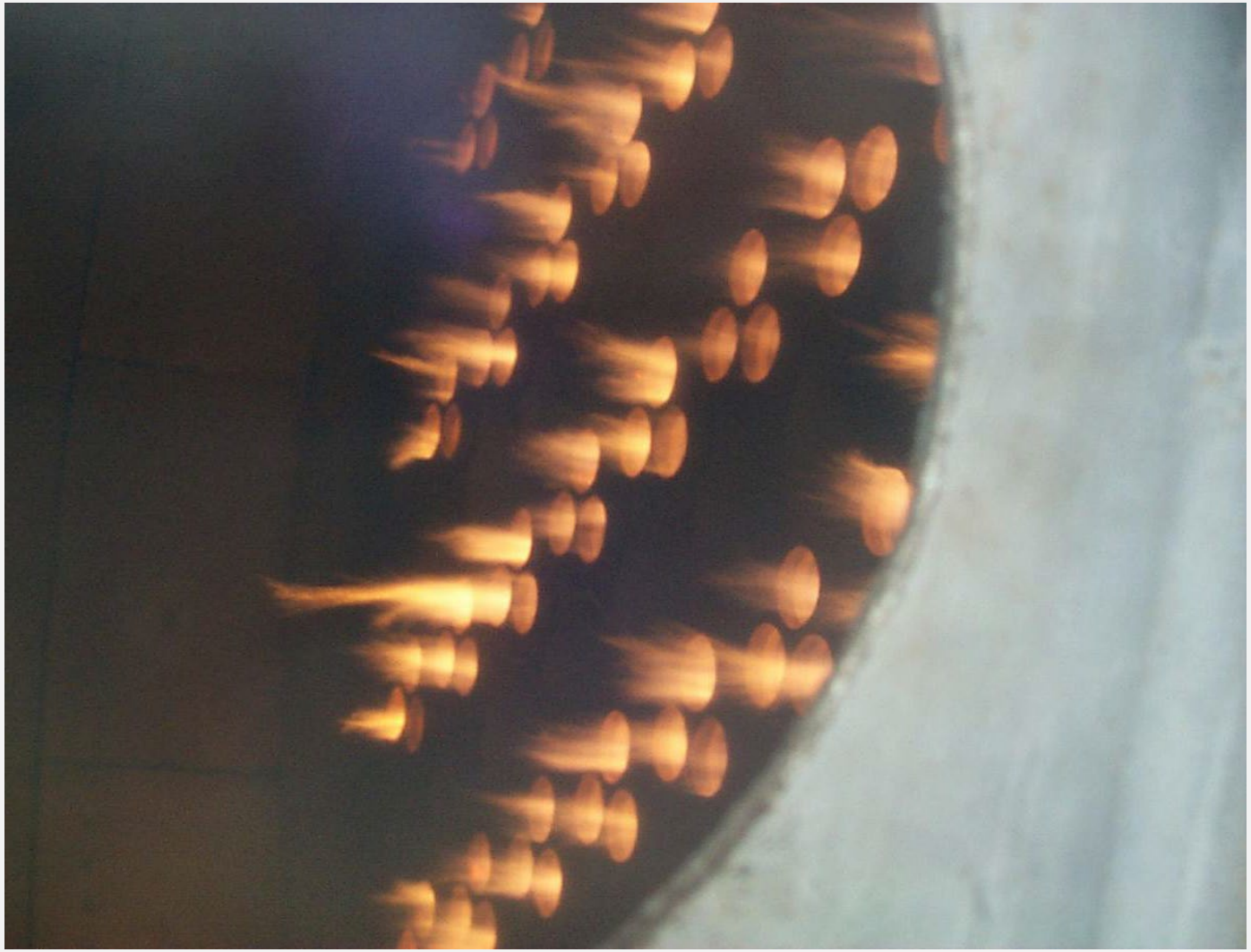
(view looking upstream, GRC-1958-C-47803)



(GRC-1958-C-47793)

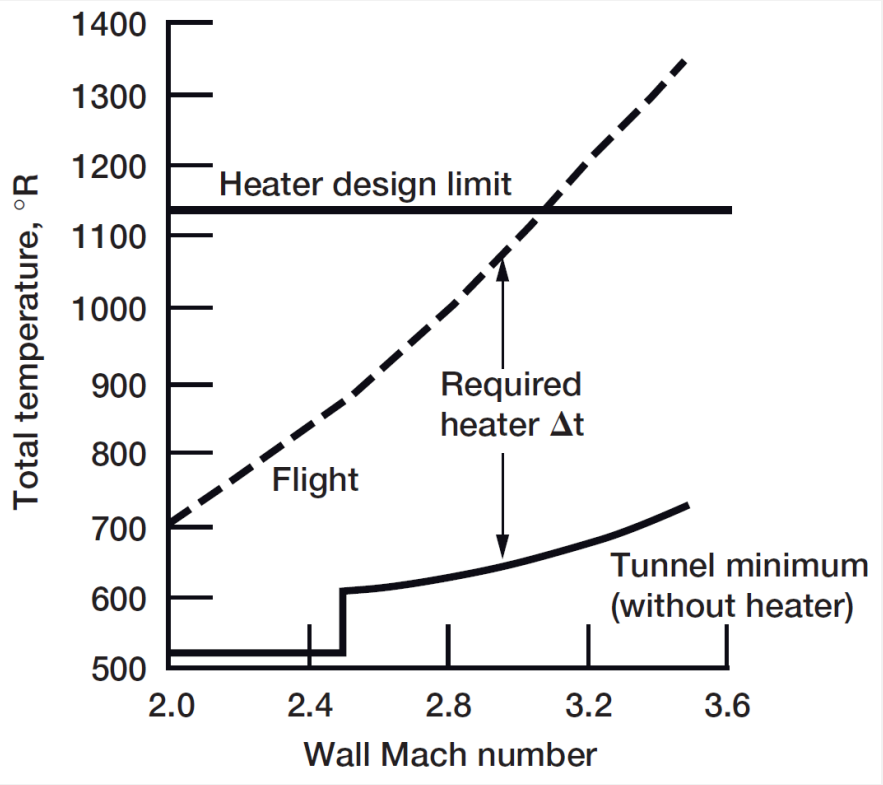
- Butterfly valves for throttling air flow through tunnel air heater

Tunnel Air Heater



(view looking upstream)

- Tunnel air heater operation monitored via thermocouple measurements and visually.



Characterization Hardware

17-Wedge Array

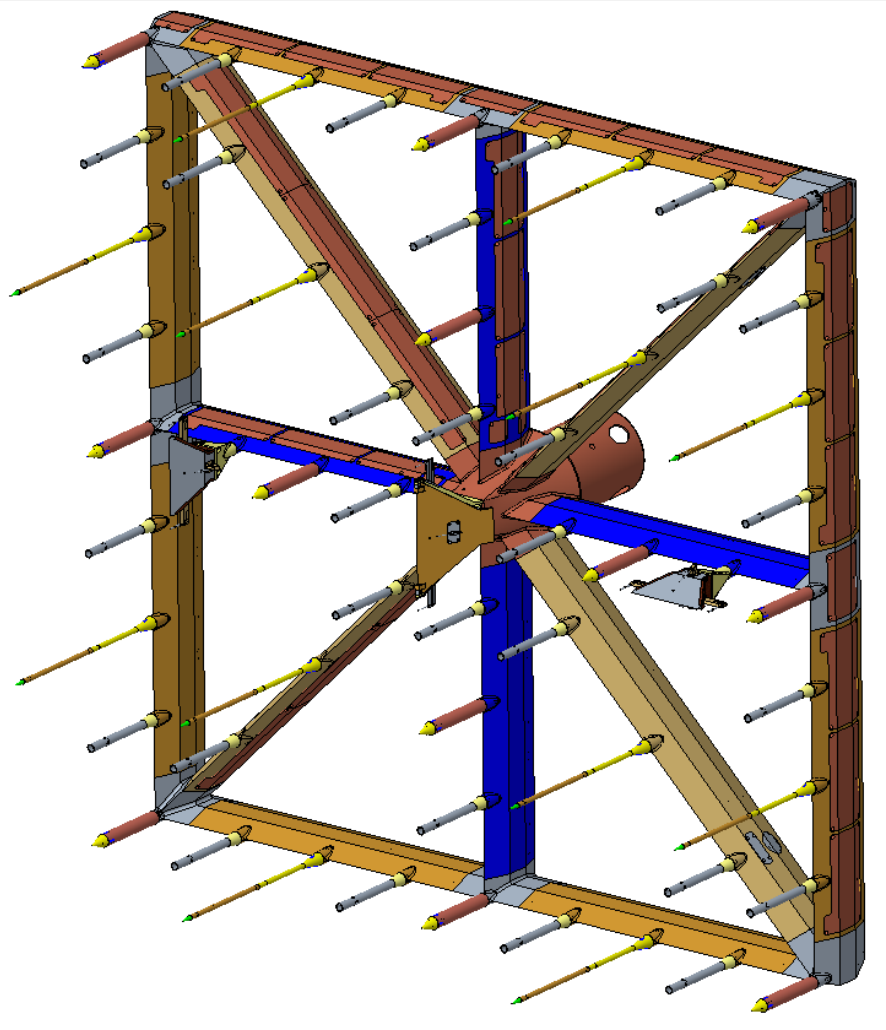
- 4- by 4-ft array
- In operation since 1964
- Last used in 1999
- 20-degree-half-angle supersonic wedge probes
- Thermocouple at each wedge location (2 at center)
- 8-ft of axial translation at two streamwise locations

(GRC-1991-C-09146)

Characterization Hardware

Characterization Array

- Fabricated in 2023, to be used in 2025/26
- 5- by 5-foot array
- Variety of flow sensing probes for measuring test section conditions for calibration and flow quality assessment
- Uses 96-inch Translation System for normal operation or fixed-sting for tunnel air heater operation.
- Capable of holding up to five gas-sensing probes (to be discussed further)



AIAA 2024-4201

Previous Characterization Test Entries

- 1964 – Original ‘Hot’ Calibration
  - 17-wedge array
  - ‘Cold’ condition prior to each heater ignition at a given Mach number
  - *“Water Condensation Effects of Heated Vitiated Air on Flow in a Larger Supersonic Wind Tunnel”* - Cubbison (1968)

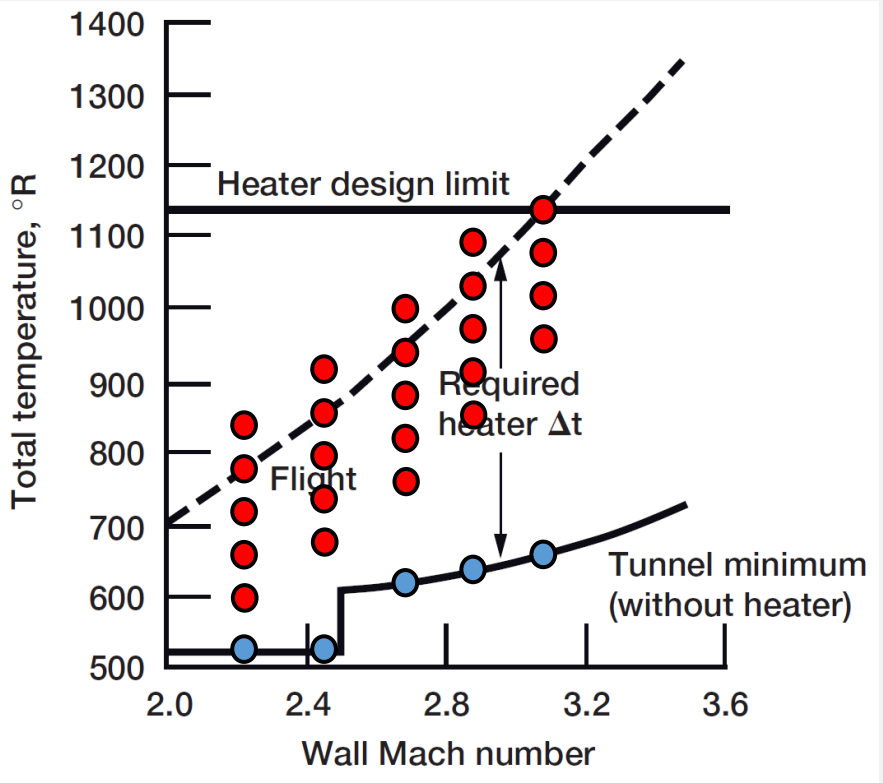
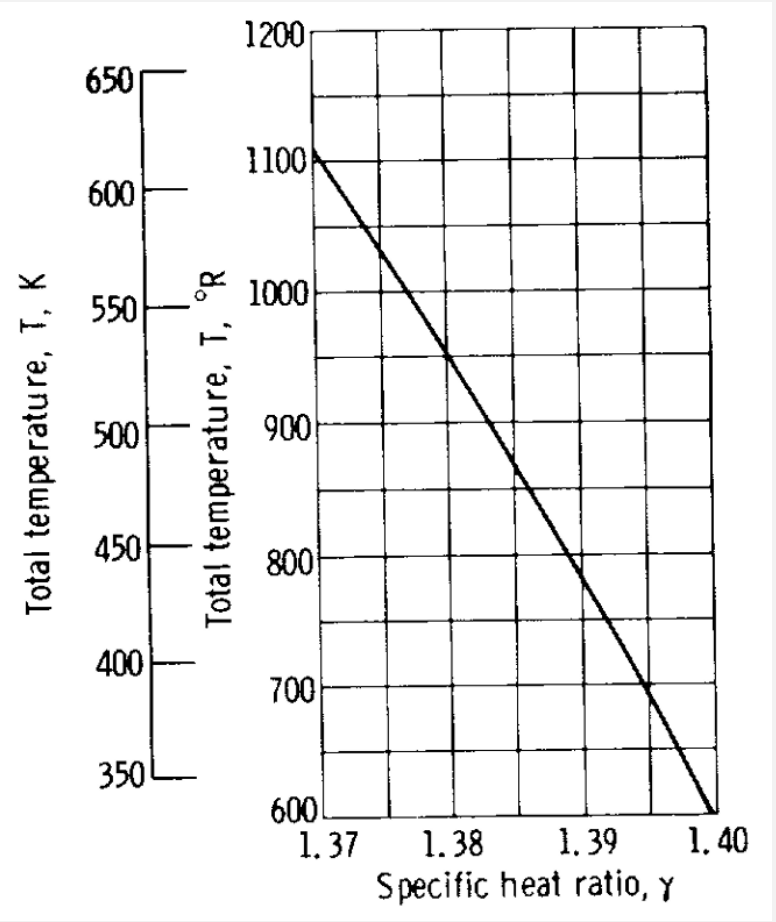


Illustration of test matrix for heater characterization (not the actual 1964 test matrix)

Previous Characterization Test Entries

- 1964 – Original ‘Hot’ Calibration
  - No gas samples acquired/measured
  - Assumed complete combustion of natural gas to achieve required ΔT
  - Analysis showed combustion products were 7.5% of total airflow



Variation of specific heat ratio with temperature for 10x10 SWT with heaters operating (Figure 5 from NASA TM X-1636)

Previous Characterization Test Entries

- 1990's Heater Characterization Tests
  - 1991 – Air samples collected via probe on 17-Wedge Array into external gas cannisters below test section. Error in sampling technique/analysis prevented conclusions.
  - 1999 – 17-Wedge Array, but no gas sampling effort. Recommended to perform gas sampling efforts pending customer interest.

Previous Characterization Test Entries

- Following 1999 test entry:
  - 2007 – Heater used for particle-induced velocimetry (PIV) seeding; freestream turbulence levels estimated at 0.5%.
  - Following seeding effort, heater unused but thoroughly cleaned.
  - In 2017, customer interest arose in heater operation and determination of gas composition in test section.
    - Plan for heater reactivation developed.
    - Customer abandoned test campaign.

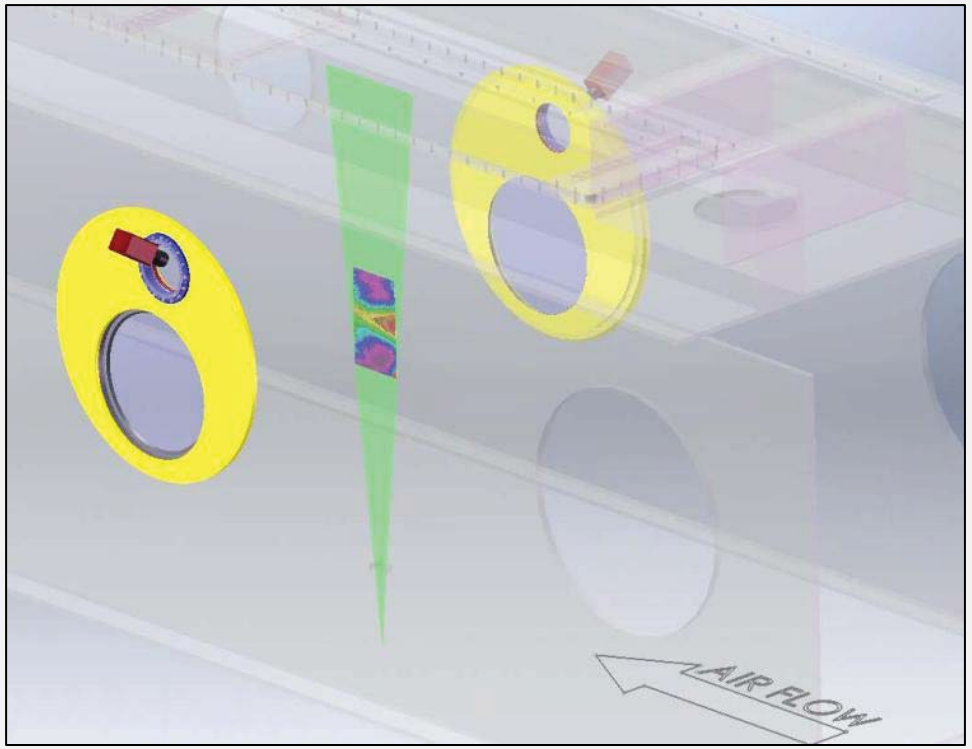


Figure 8 from AIAA-2011-1066.
PIV system installation in the 10x10 SWT test section. A processed data set is shown in the plane of the light sheet indicating the measurement region of the PIV system.

Recent Efforts

- Original gas sampling concept was costly:
  - Multiple racks of gas analyzers
  - Multiple heated gas-sampling lines out of the test section
  - Safety precautions (i.e., fume hoods, etc.)

- NASA Glenn Smart Sensors and Electronics Systems Branch contacted in 2017 regarding emissions probe development.

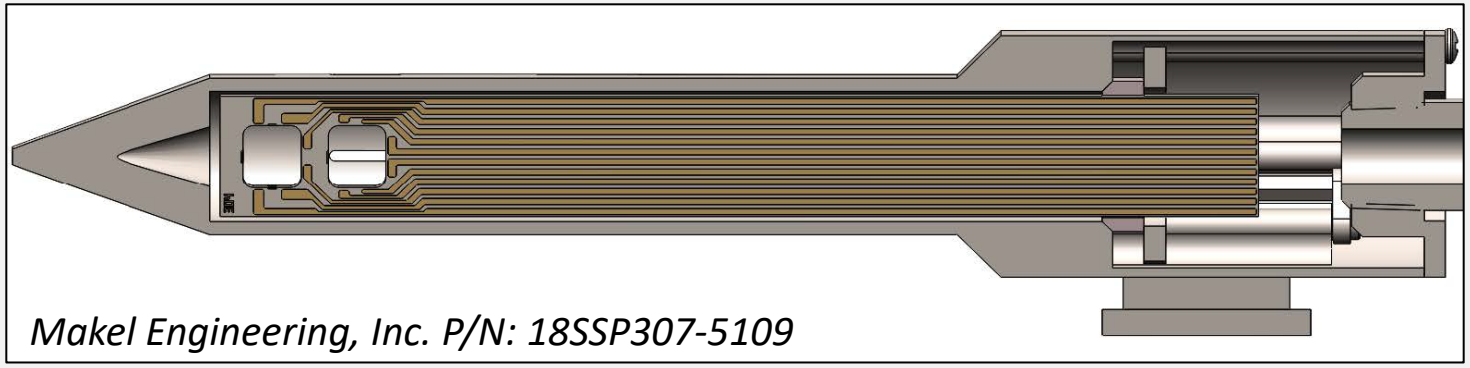
- Makel Engineering, Inc. contracted to design and build a probe for supersonic operation in the 10x10 up to 680°F [360°C].

Recent Efforts

- Gas-sensing probe from Makel Engineering, Inc.
  - Microsensors for measuring 5 different gas concentrations:

Gas Species	Concentration Calibration Range
O_2	10-21%
CO_2	0-1.5%
CO	0-400 ppm
HC	0-200 ppm (based on CH_4)
NO_x	0-400 ppm

Makel Engineering, Inc.
P/N: 18SSP307-5109



Makel Engineering, Inc. P/N: 18SSP307-5109

Recent Efforts

- Routine developed to use Newton-Raphson iterative approach to compute gas constant, R, and ratio of specific heats, γ
  - Inputs:
    - Facility bellmouth stagnation pressure and temperature
    - Flexible-wall nozzle setting
    - Dewpoint temperature
    - Gas-sensing probe concentration measurements
    - Natural gas mass flow
  - Iterative calculations:
    - Outer-loop: Initialize and adjust estimates of R and γ
    - Inner-loop: Balance mass flow of combustion products and reactants
  - Outputs:
    - Mass-weighted averages of C_p and C_v to compute R and γ

Conclusions & Future Work

- Pending customer interest and maintenance funding, a plan was developed to reactivate the 10x10 SWT tunnel air heater capability.

- Characterization Array fabricated with ability to use up to five (5) Makel Engineering, Inc. gas-sensing probes simultaneously.

- Future Work:
  - Continue evaluation of gas-sensing probe calibration/capability through testing in NASA GRC Engine Research Building.
  - Integrate gas-sensing probe into data system for real-time or near-real-time calculation of freestream gas composition.