Thermal Recovery Testing & Investigations in CE-12 Free Jet Calibration Facility

Aaron Johnson/Jacobs Technology

WTCWG Meeting at NASA GRC

7/25-27/2023

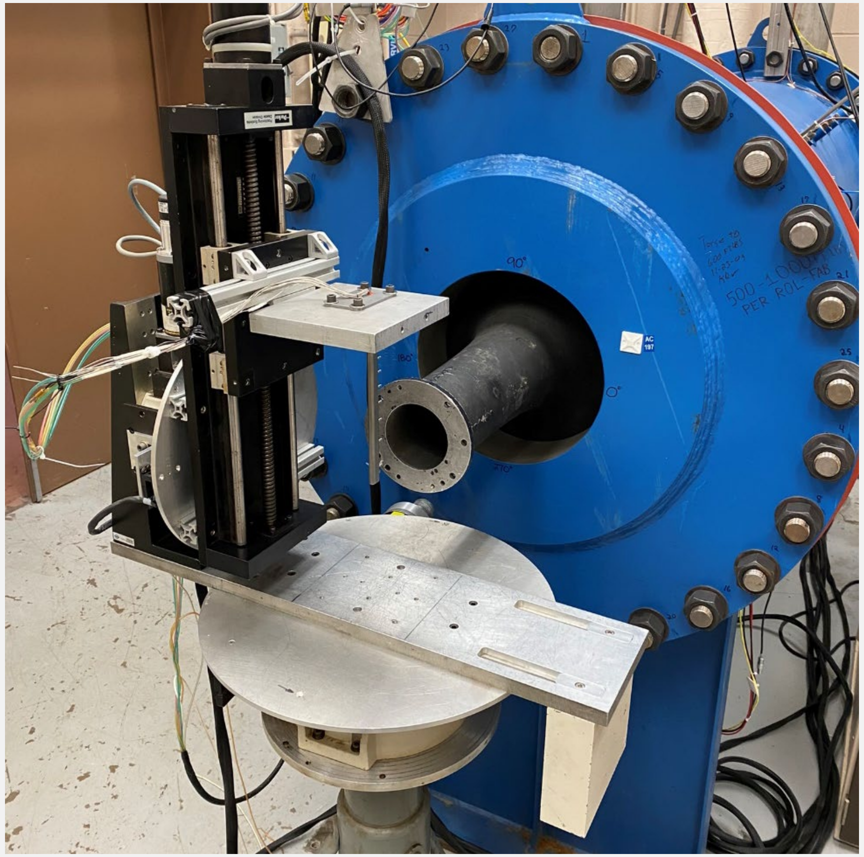
Overview

1. Background
2. Recent Thermal Recovery Test Results
3. Additional Investigations
4. Improvement Plans

Background

- CE-12 is a free-jet probe calibration facility in the NASA Glenn Research Center Engine Research Building
  - Nozzle diameter: 3.5 inches
  - Mach: 0.05 – 0.95
  - Total temperature: Ambient – 200°F

- Typical customer types:
  - 3- & 5-hole flow angle probes
  - Hot-wire & hot-film probes
  - Thermal recovery testing (RTD’s & TC’s)
  - Miscellaneous



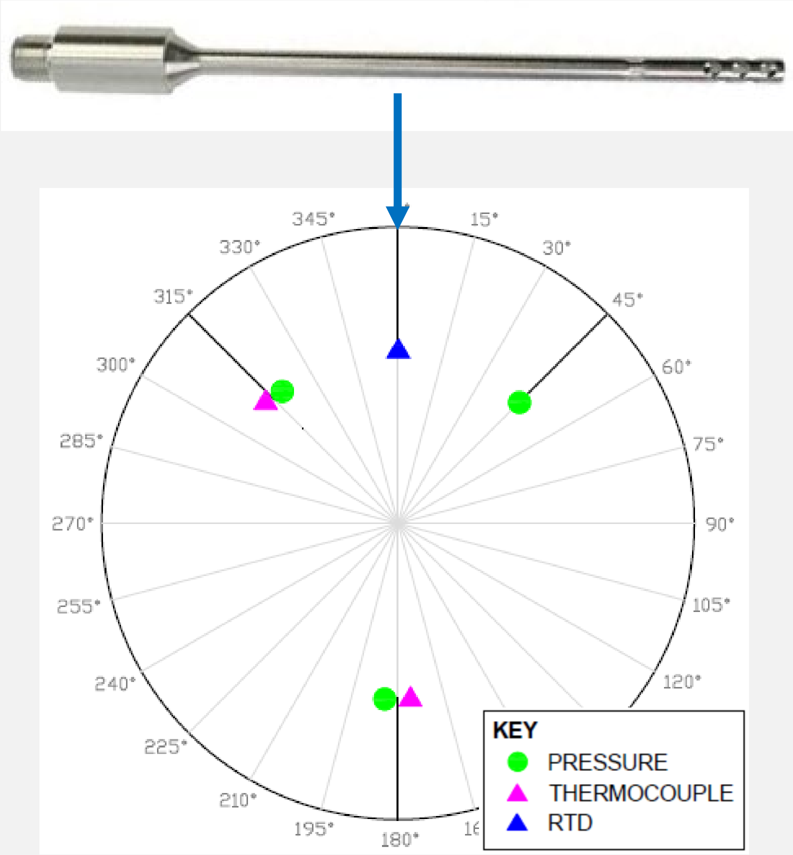
Recent Thermal Recovery Tests

- Internal customer requested thermal recovery testing of aspirated-tip thermocouple probe thermal recoveries
  - Mach 0.1 – 0.8
  - Rake/probe orientation settings between +/- 30^{o} in pitch/radial and yaw/swirl flow angles.

*Timelapse video; actual movement speed much slower

Recent Thermal Recovery Tests

- Customer:
  - Type E thermocouple special-limit-of-error wire
  - Direct termination to facility HyCal Reference Block
  - Accutech transmitter (AI-1500) & RTD monitor junction temperature
- Facility:
  - Total temperature measured in plenum upstream of nozzle
  - 70:1 contraction ratio ensures near-stagnant flow in plenum
  - Omega 1/10-DIN aspirated RTD probe
    - 1/10-DIN ~= $0.1*(0.3 + 0.005*t)$ °C, where t is in °C
    - Secondary Type K TC installed as sanity check
  - Probe tip inserted approx. 7 inches into plenum
    - Plenum I.D. is 29.2 inches



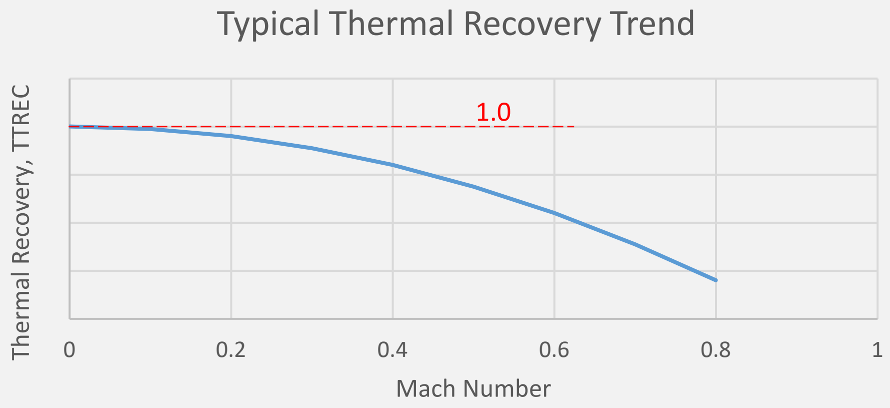
Looking upstream into plenum

Recent Thermal Recovery Tests

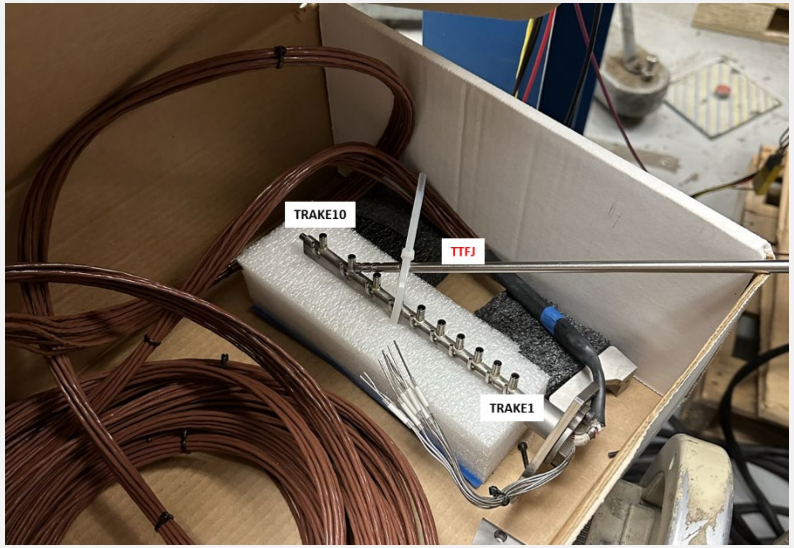
- Long-story-short, results indicated that the predicted thermal recovery of the thermocouple probes was above 1.0 at low speeds

- Assumedly, there's no heat transfer occurring in the short time the flow has before it exits the nozzle

- Verified lack of significant bias between plenum RTD & rake TC's via overnight comparison
  - TC & RTD agreement within ~0.02°F



T_T Recovery = TTREC = $T_{measured,TC}$ / $T_{true,plenumRTD}$



Additional Investigations

1. Conduction of heat through plenum RTD body from fitting?

- Potential Fix: Purchased PTFE reducer fitting to replace existing stainless steel fitting.

- Result: Exact same data trends were acquired; thermal recovery at low speeds still exceed 1.0, which violates theoretical results.

Additional Investigations

1. Conduction of [illegible] through plenum RTD body from fi[illegible].

- Potential Fix: Purchased [illegible] reducer fitting [illegible] place existing stainless steel fitting.

- Result: Exact same data trends [illegible]; thermal recovery at low speeds still exceed 1.0, whi[illegible]lates theo[illegible] results.

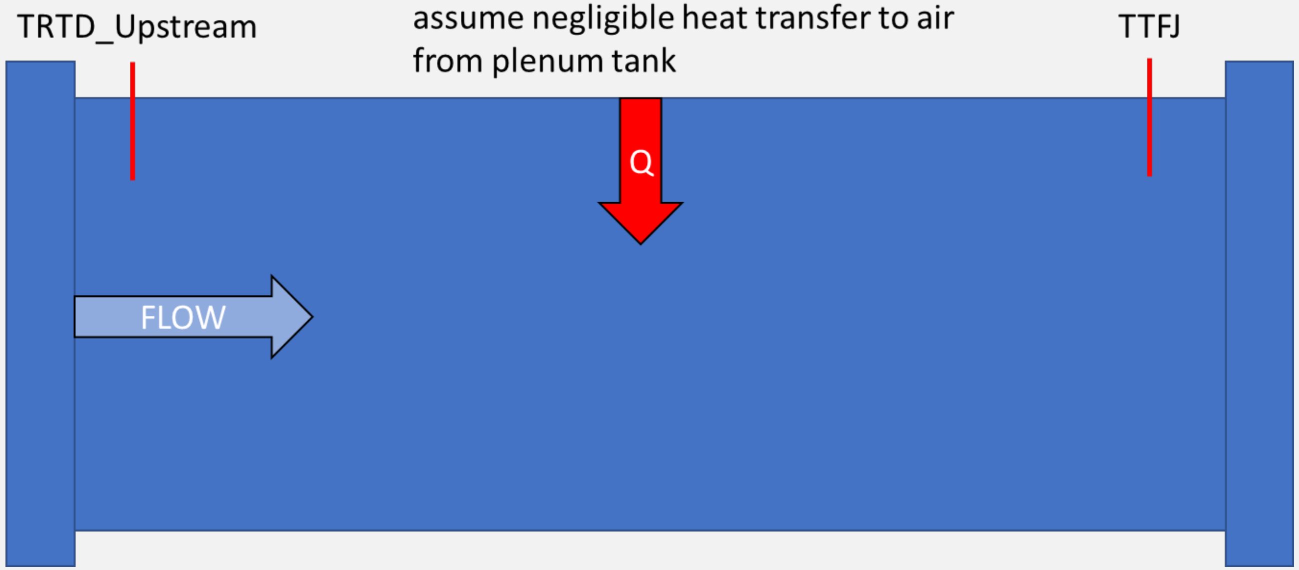
Additional Investigations

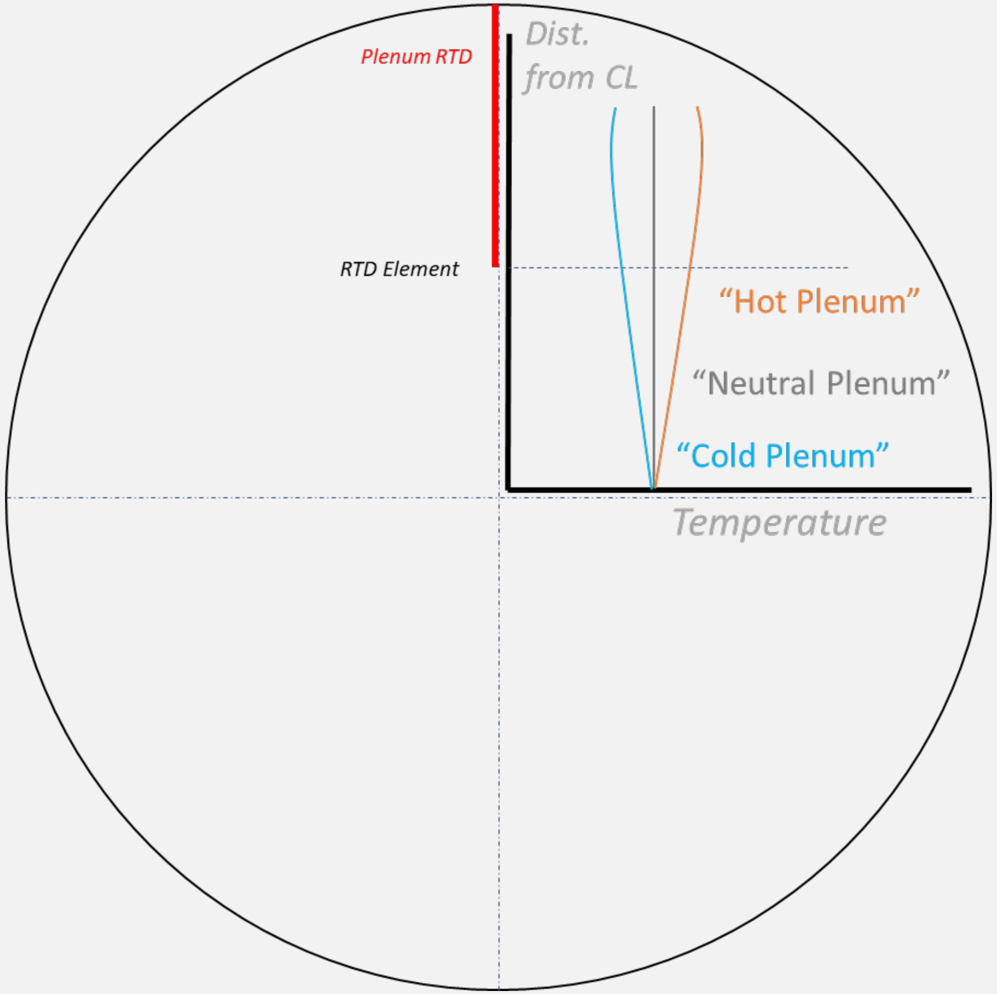
2. Are we transferring heat with the plenum walls, thus creating a thermal gradient with the plenum, which biases the plenum RTD low?

- Ideas/Potential Fix:
  - Install surface-mounted TC's to the outside of the plenum walls
    - Monitor wall temperatures relative to supplied air temperatures
  - Install 2nd Omega RTD at upstream end of plenum at same insertion depth
    - Monitor delta temperature across length of plenum to observe heat losses at the radial location of the RTD probe tips.
  - Use tunnel air heater to force plenum walls to be approximately equal to incoming air temperatures

Additional Investigations

$Q \sim \Delta T$
Therefore, if TTFJ – TRTD_Upstream = 0, assume negligible heat transfer to air from plenum tank





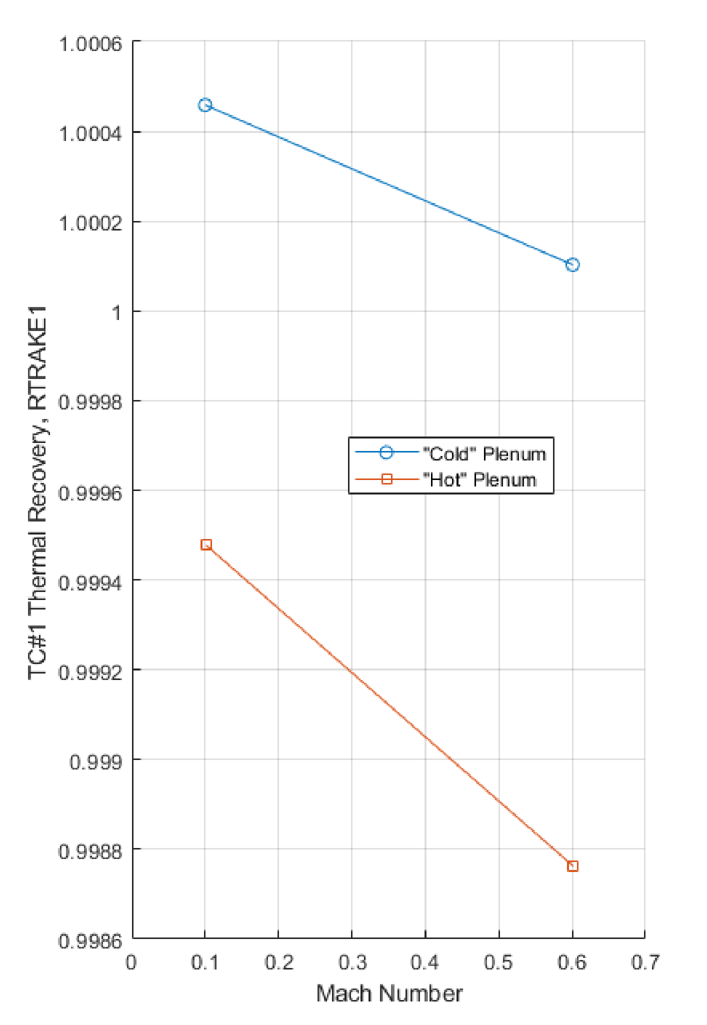
Additional Investigations

BINGO!

- Incoming Air Temps to plenum: 85-88°F
- "Cold" Plenum wall temps: 80-82°F
- "Hot" Plenum walls temps: 94-100°F

- Very different thermal recovery results if plenum walls are forced to a higher temperature.

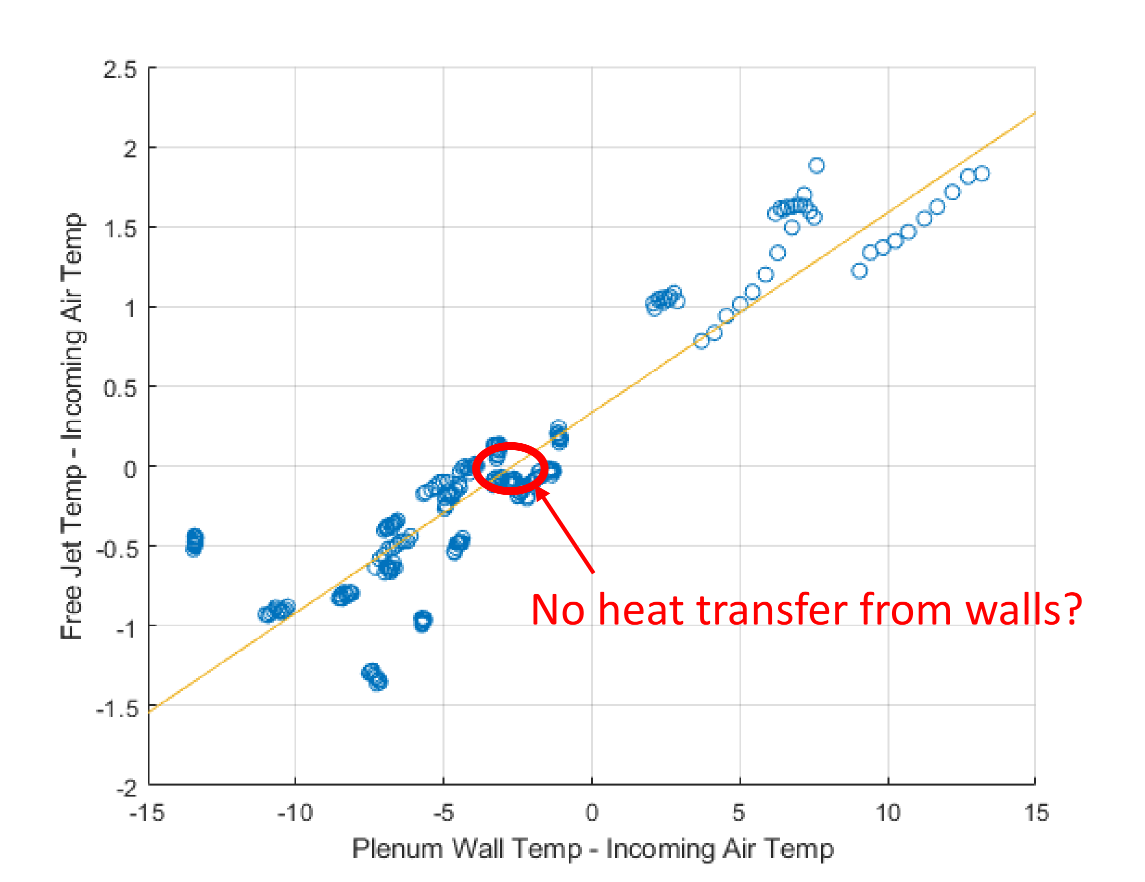
- Note: We typically thermally soak the facility for 60-90 minutes before we take this type of data by blowing air at a moderately high Mach number, which is how we acquired the "cold" wall condition



Additional Investigations

- Trend observed in temperature difference between:
  - Plenum wall and incoming air
  - Upstream and downstream plenum RTDs (temperature loss within plenum)

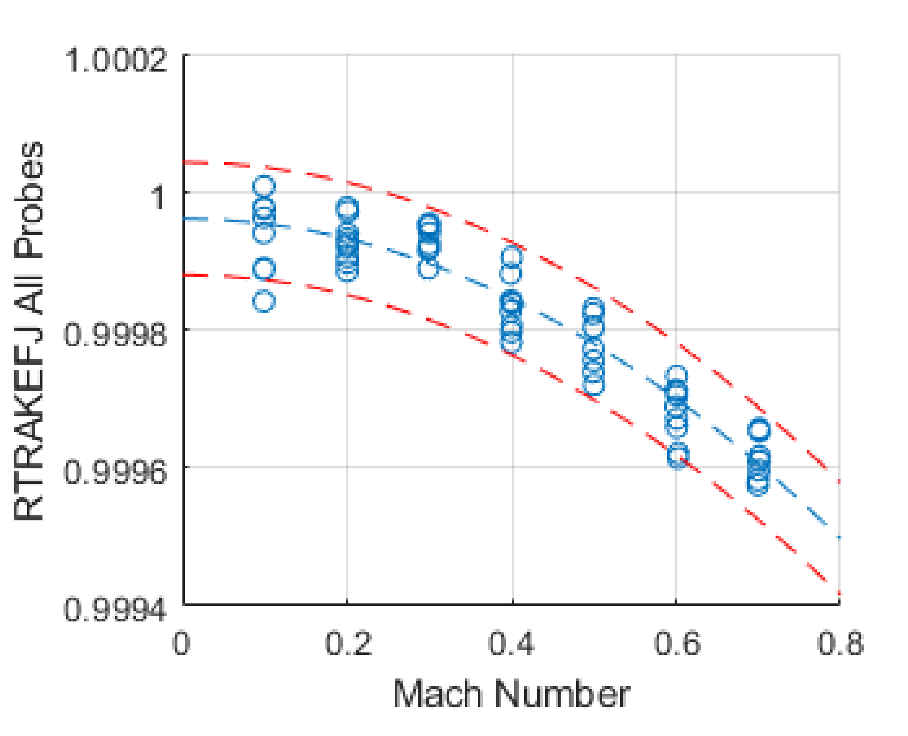
- Need to monitor plenum wall temperatures in additional locations along the plenum surface
  - OR monitor internal surface temperatures for more accurate assessment of expected heat transfer



Recent Thermal Recovery Tests

- Successfully acquired a set of data for customer that follows theoretical, as-expected trends using plenum-wall-heating method.

- Required:
  - Initial heating of plenum walls to match incoming air temperatures from central services (30-45 mins)
  - Monitor time-histories and trends in temperatures and delta temperatures
  - Reheat plenum walls, if necessary, as the day goes on and/or central services switches compressors, dryer beds, etc.



Improvement Plans

- Improvement #1: Circumferentially insulate plenum walls with ~1.5" of insulation, not including end-caps of plenum.
  - The walls of the plenum are always trying to reject the heat to the room (test cell room stays around 80F, typically).

- Improvement #2: Use a Kaye 170 Ice-Point reference to improve quality of customer thermocouple measurements
  - HyCal Reference Block temperature gradient/stability concerns

- Improvement #3: Perform heater tuning runs during upcoming IST runs to improve the speed and accuracy of heater use.
  - Current PID coefficients are [1,1,0]; it works but not efficiently
  - Primary control valve just replaced to improve Mach number automated control and stability, thus requiring IST for valve tuning, as well.

Questions

Back-up Slide: TC vs. RTD in Plenum

- TC's respond much quicker than RTD elements.

- Stability of temperature measurement crucial to avoid bias in RTD measurements within the plenum

- Real-time monitoring time-history of delta temperature between plenum RTD and TC temperatures
  - Delta T does not have to be zero, just stable w/ stable RTD and/or TC.