Humidity Measurements at NASA Glenn Research Center Wind Tunnels

Aaron Johnson/Jacobs Technology

WTCWG Meeting at NASA GRC

7/25-27/2023

Overview

1. Motivation

2. GRC Facilities
   a. 9x15 LSWT
   b. 8x6 SWT
   c. 10x10 SWT

3. Impact of Saturation Vapor Pressure Model Choice

Motivation

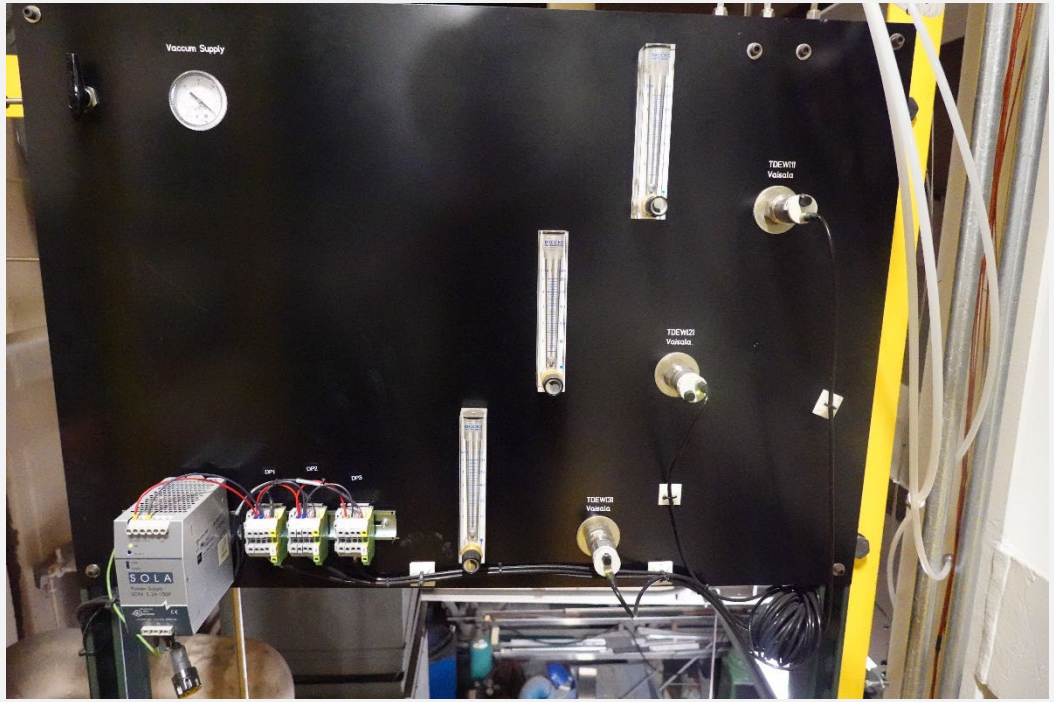
- In supersonic flow, the presence of water vapor can impact data quality (if not characterized)
  - “Condensation shocks”
  - Mach number & total pressure decrease
  - Static pressure & total temperature increase

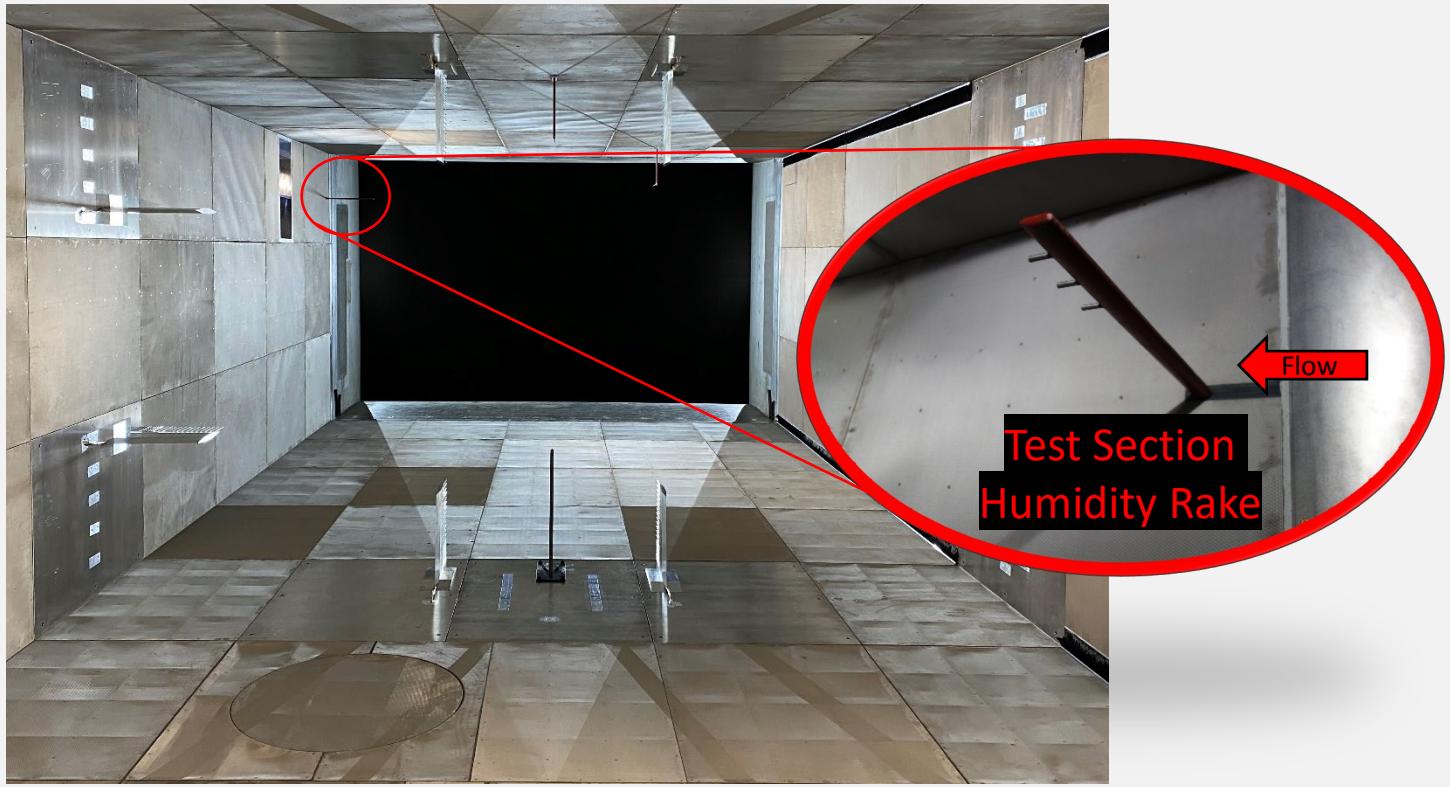
- Mike Mills (AEDC) and Max Amaya (NASA ARC) have presented on this topic multiple times

- As humidity-assessment instruments and methods for accounting for humidity in our tunnels were compared amongst several WTCWG members, it’s become apparent that there are subtle differences to discuss.

9x15 LSWT

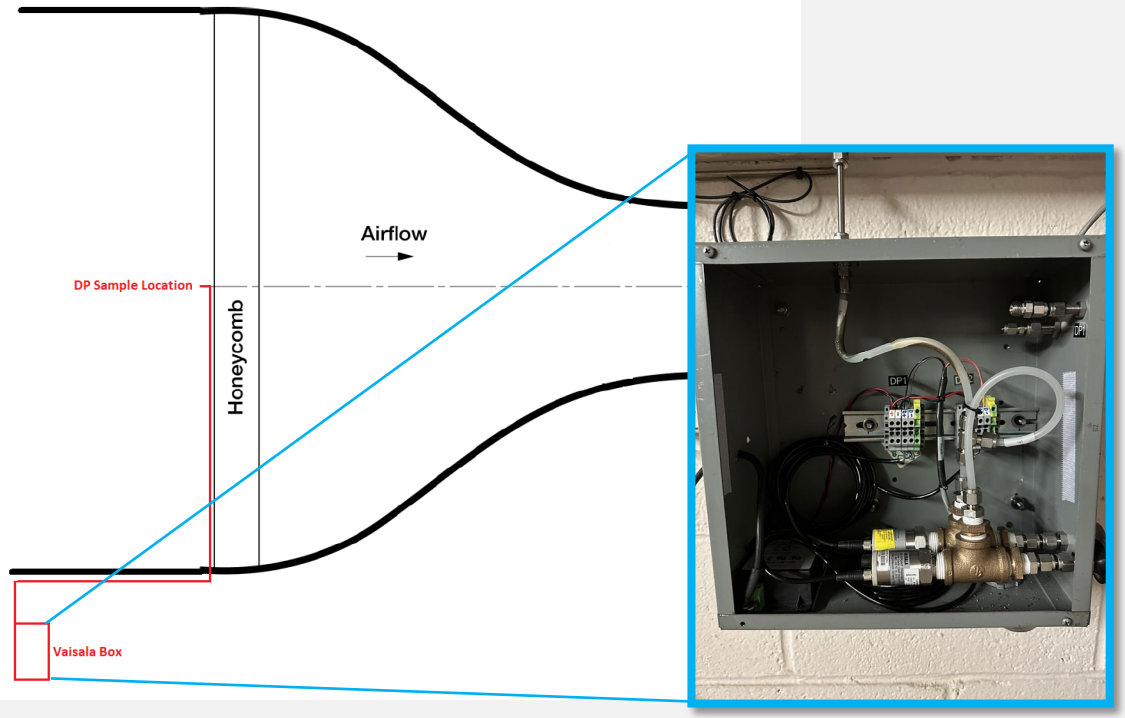
- Three (3) Vaisala (DMT143) Miniature Dewpoint Transmitters
- 10%-90% RH recommended for acoustic research objectives
- Dewpoint requirements are different for each engine test entry

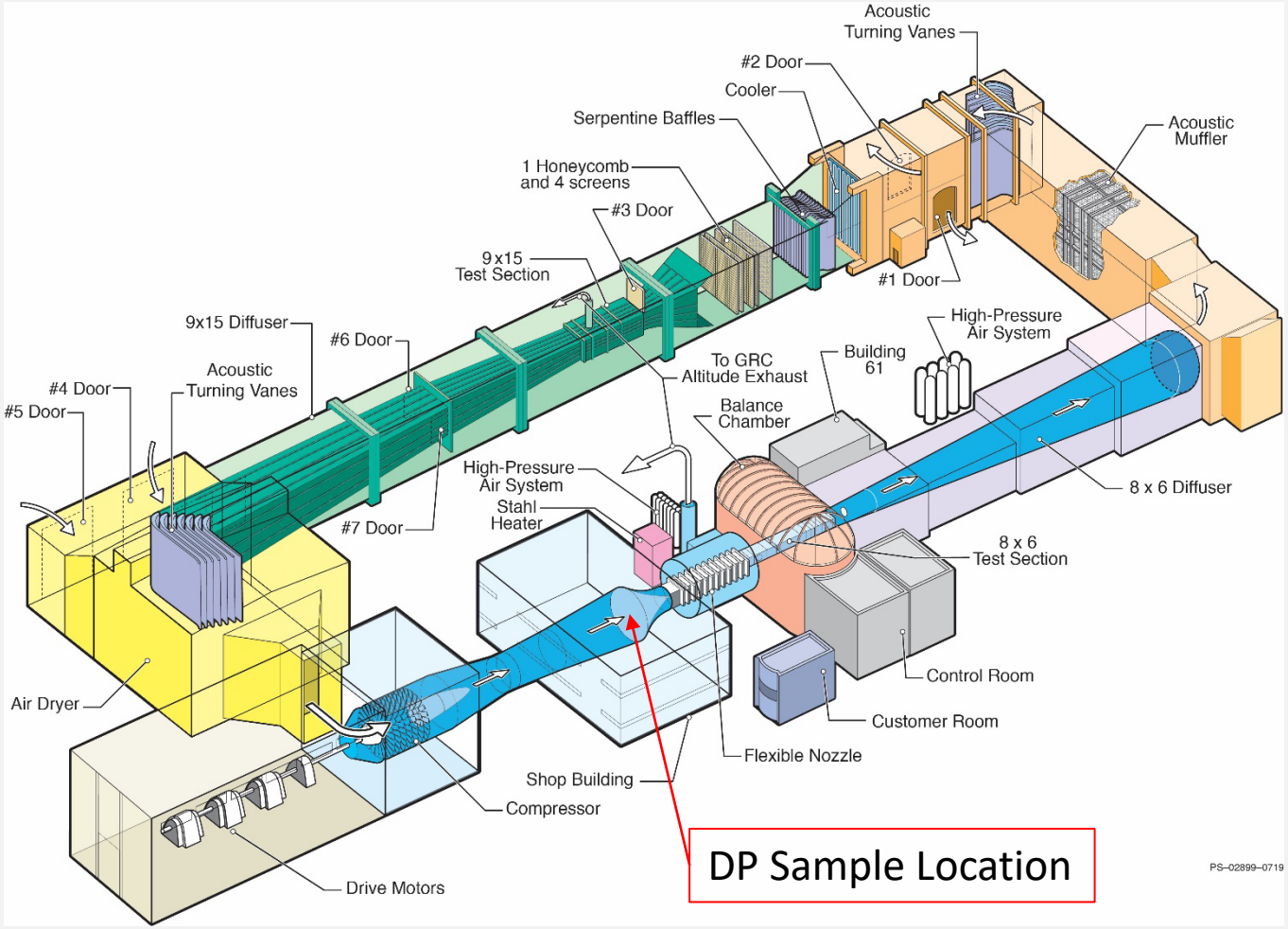




8x6 SWT

- Dewpoint sample acquired in settling chamber
- Total pressure in tunnel drives sample flow





8x6 SWT

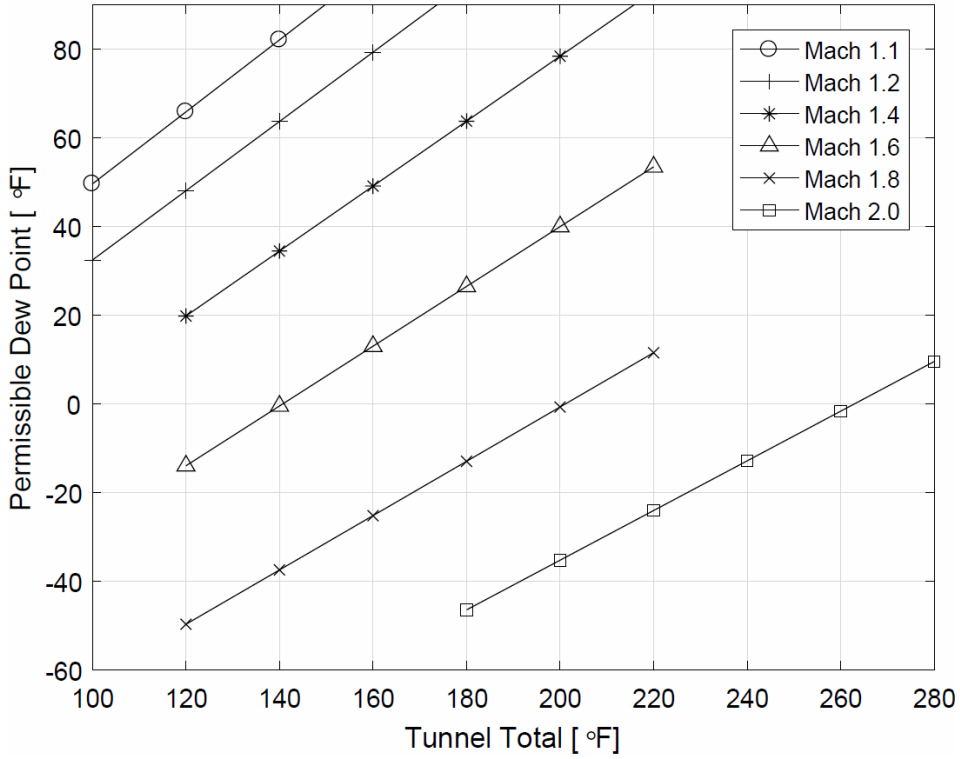
- Approximately < 50 feet of ¼” tubing between sample and sensor

- Two (2) Vaisala DMT143
  - Supposed to be insensitive to flow rate
  - Anecdotally, dew point values decrease rapidly when the compressor starts up, even at relatively low Mach numbers

- No pressure or flow rate measurements made on sample line @ hygrometer
  - Plan to recommend both measurements to be added as potential improvements, but not necessary.

8x6 SWT

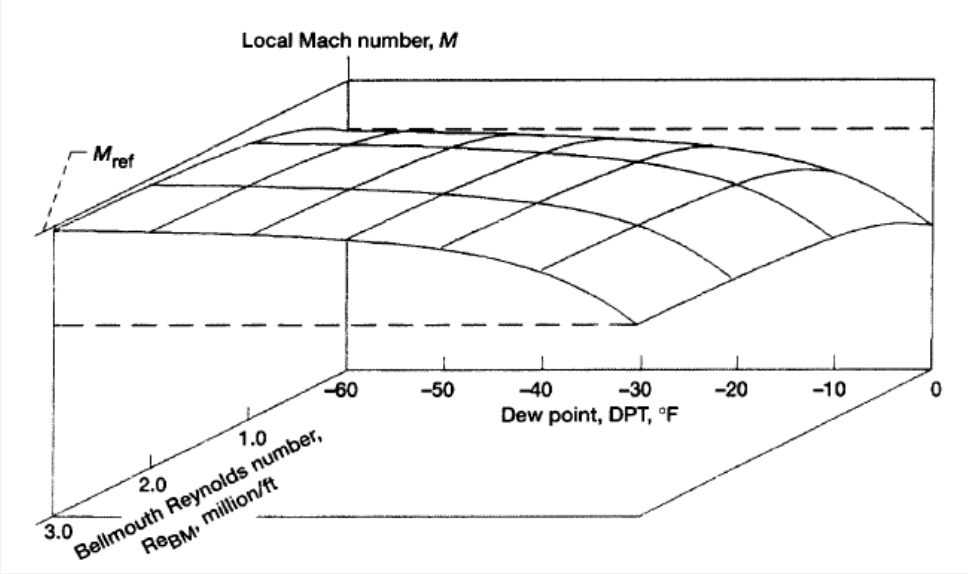
- Historical rule of thumb: dew point < -15°F
  - Acceptable at all Mach numbers
- 55°F of supercooling
  - Depending on the situation, low dew points may not be achievable for long at highest speeds, default to -15°F rule.
- Dry air typically turned “on” at Mach 1.4, but this can be delayed until data needs to be acquired or model visibility diminishes



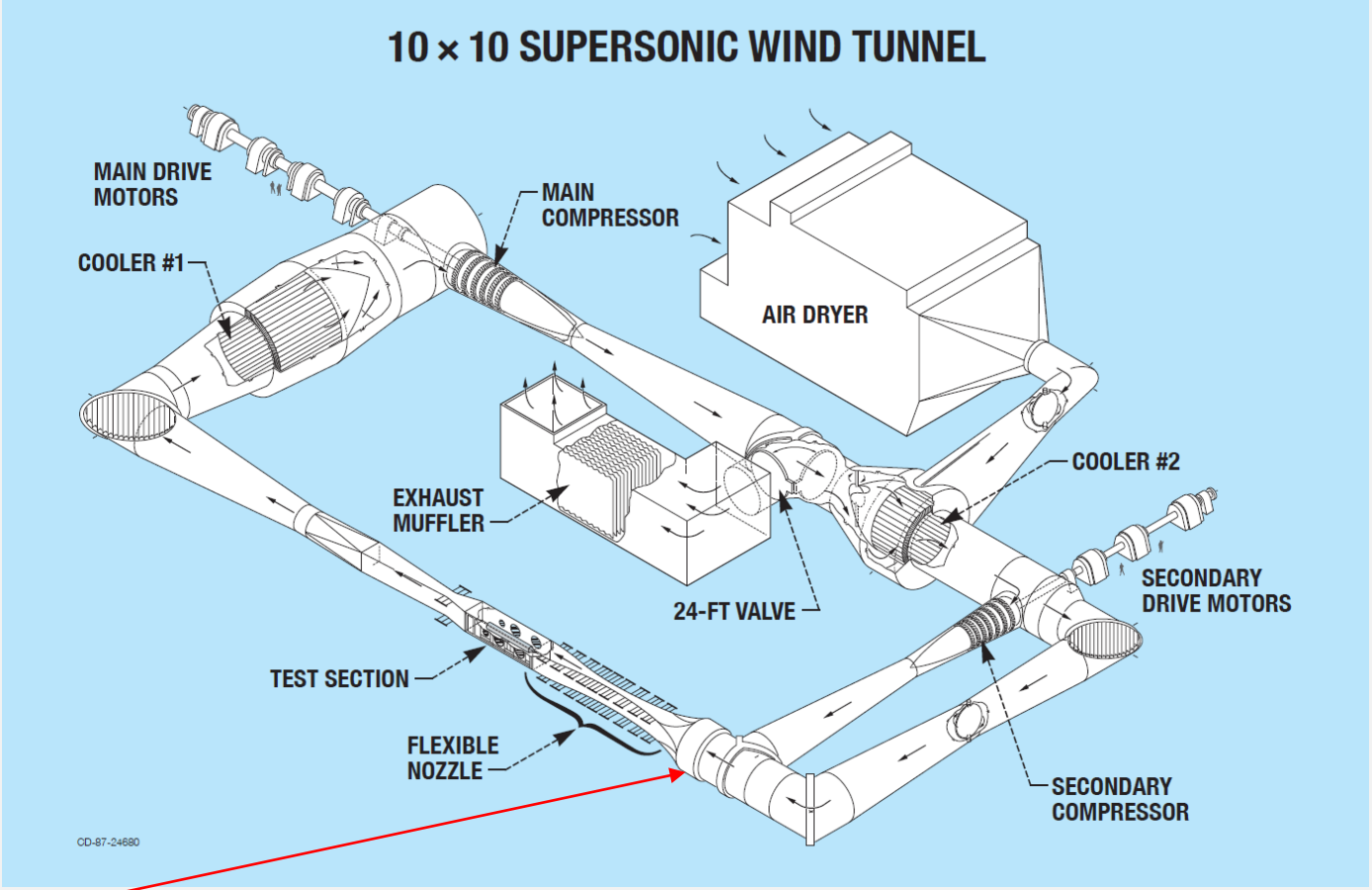
Permissible dew point based on $55°F$ of supercooling.

10x10 SWT

- In 10x10 SWT, dewpoint measurement critical to calibration model.

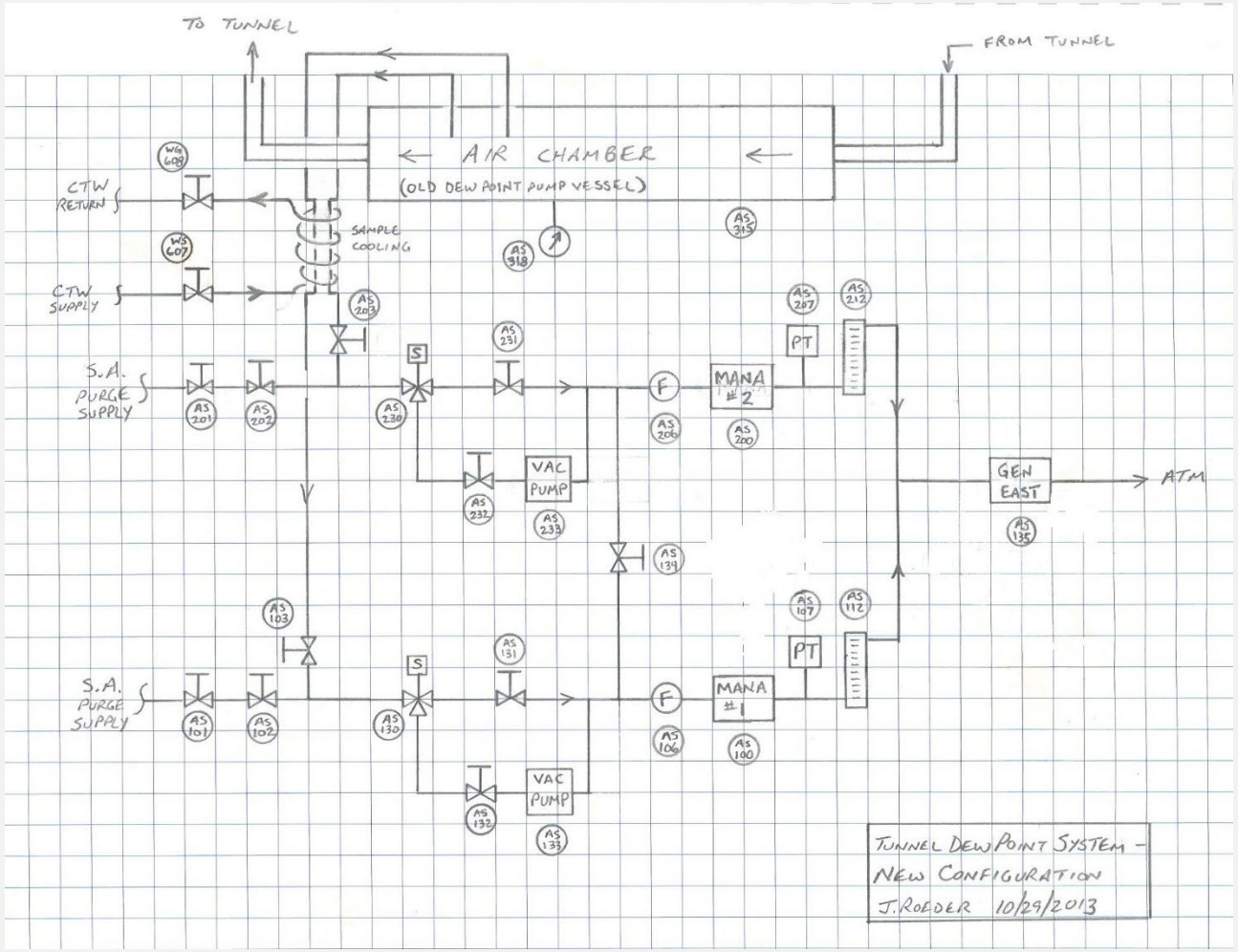


- Sample acquired near tunnel air heater in settling chamber.



10x10 SWT

- Larger diameter pipe (~2”) brings air sample from tunnel air heater station in settling chamber to reservoir tank (“air chamber”)
  - Air re-enters tunnel near end of contraction, upstream of flexwall.
  - Approx. 50-75 feet of pipe/tubing between sample and hygrometers
- Small sample lines (~1/8”) transport sample from reservoir
  - Sample either pushed via tunnel pressure or pulled w/ vacuum pumps
  - 0.5 L/min flow rate set



10x10 SWT

- Two (2) Stephens Analytical MicroView On-Line Hygrometers
  - Calibrated -60 to 0°C
- GE Optica Hygrometer used as a check on the other two units.
- Dewpoint pressure-corrected to barometric pressure measurement
  - Local total pressure measured at each hygrometer
- Rule of thumb for testing: pressure-corrected dewpt < -15°F



10x10 SWT

- Question: How accurate do we need our hygrometer measurement to be?
  - 8x6 and 9x15 are using Vaisala's and are happy with their simplicity, reliability, and ease of use.
  - Would it make sense for 10x10 to adopt these units, as well?

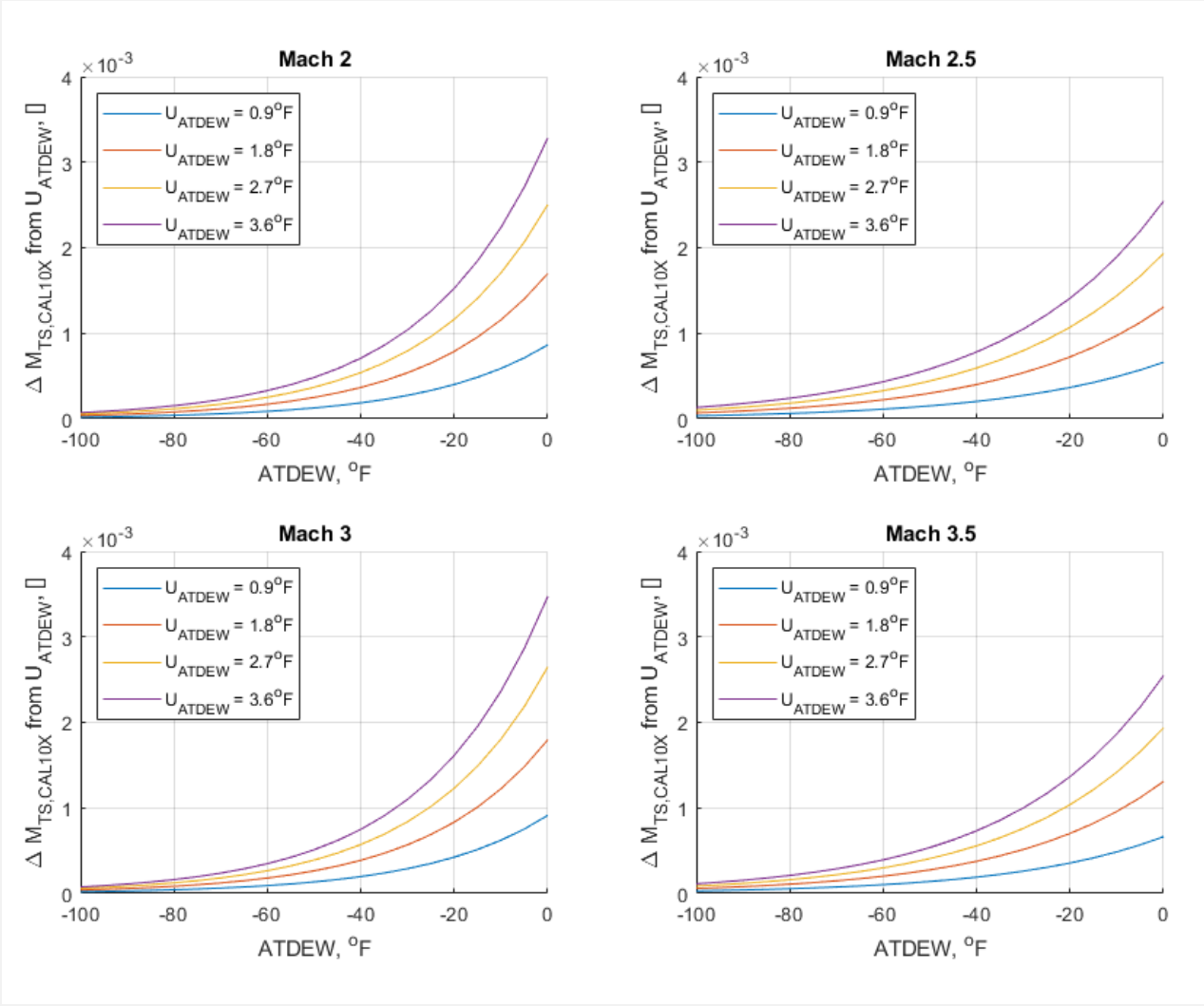
- We can assess what an error in dewpoint measurement would do to the calibrated Mach number in 10x10 using existing calibration relationships.

10x10 SWT

At -15°F & Mach 3 in 10x10 SWT:

- Stephens Analytical Hygrometer
  - 2σ ~= 1.2°C = 2.16°F
  - ~0.0012 Mach error
- A Vaisala dewpoint sensor
  - +/- 2.0°C = 3.6°F
  - ~0.0020 Mach error

The difference in calculated Mach number seems small but will need to be compared to other contribution sources.



Effect of SVP Model Choice

- There are several choices of Saturation Vapor Pressure (SVP) model which we can use when computing the humidity levels.
  - Goff-Gratch (1945)
  - Hyland & Wexler (1983)
  - Buck (1996)
  - Enhanced Buck (1981), etc.

- Does it matter which one we choose?

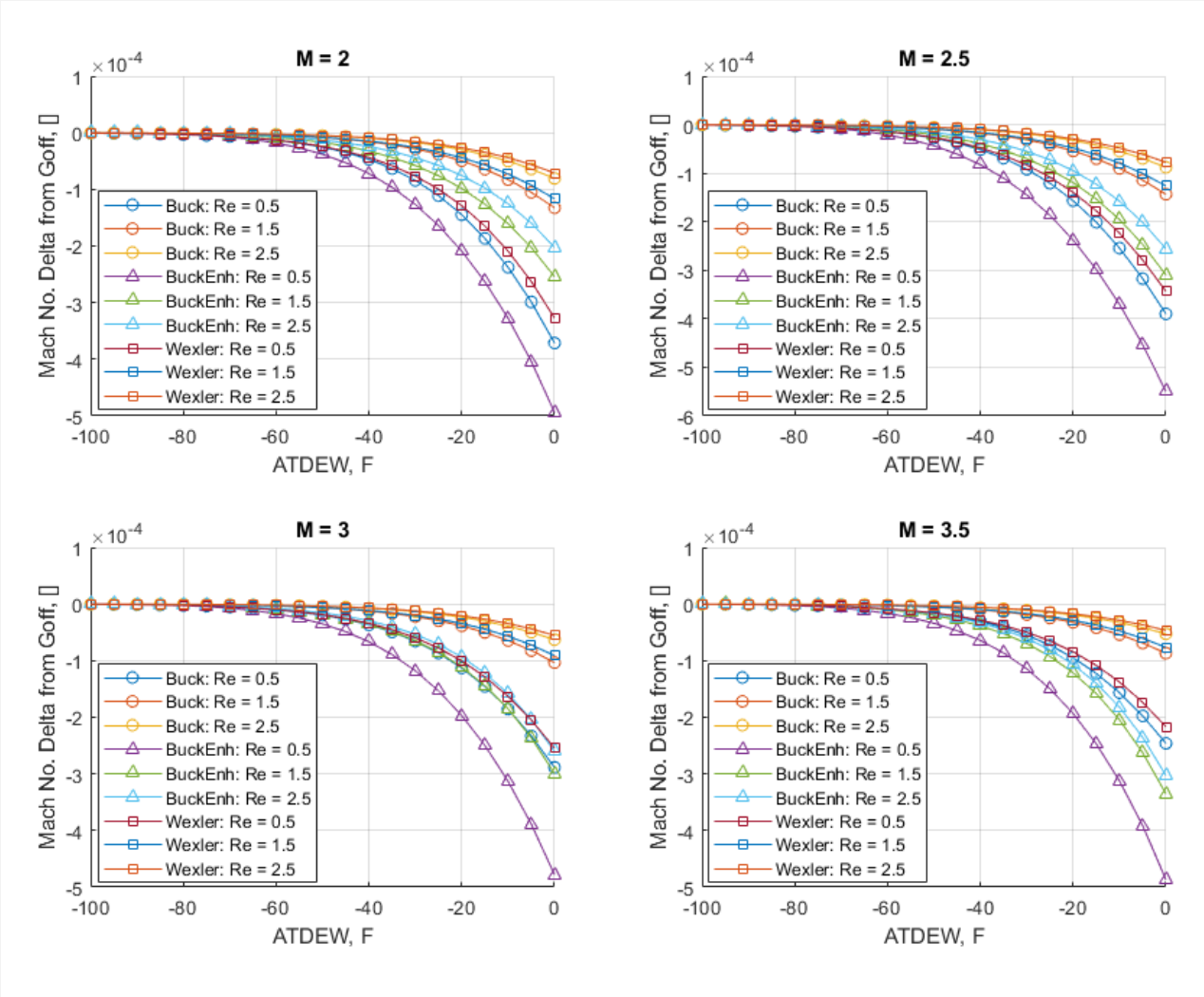
- Using simplified 1-D analysis[1] with released latent heat of condensation[2] under expected 10x10 SWT conditions:

[1] Effects of Air Humidity in Supersonic Wind Tunnels, J. Lukasiewicz & J. K. Royle - ARC 2563 (1953)
[2] Estimating Water Vapor Condensation Effects for Transonic and Supersonic Flow Fields, Robinson C. E. & Bauer R. C. (1985)

Effect of SVP Model Choice

At -15ºF

- Mach number delta if using Buck Enhanced vs. Goff-Gratch:
  - **~0.0003 Mach** (Re = 0.5e6/ft)



Effect of SVP Model Choice

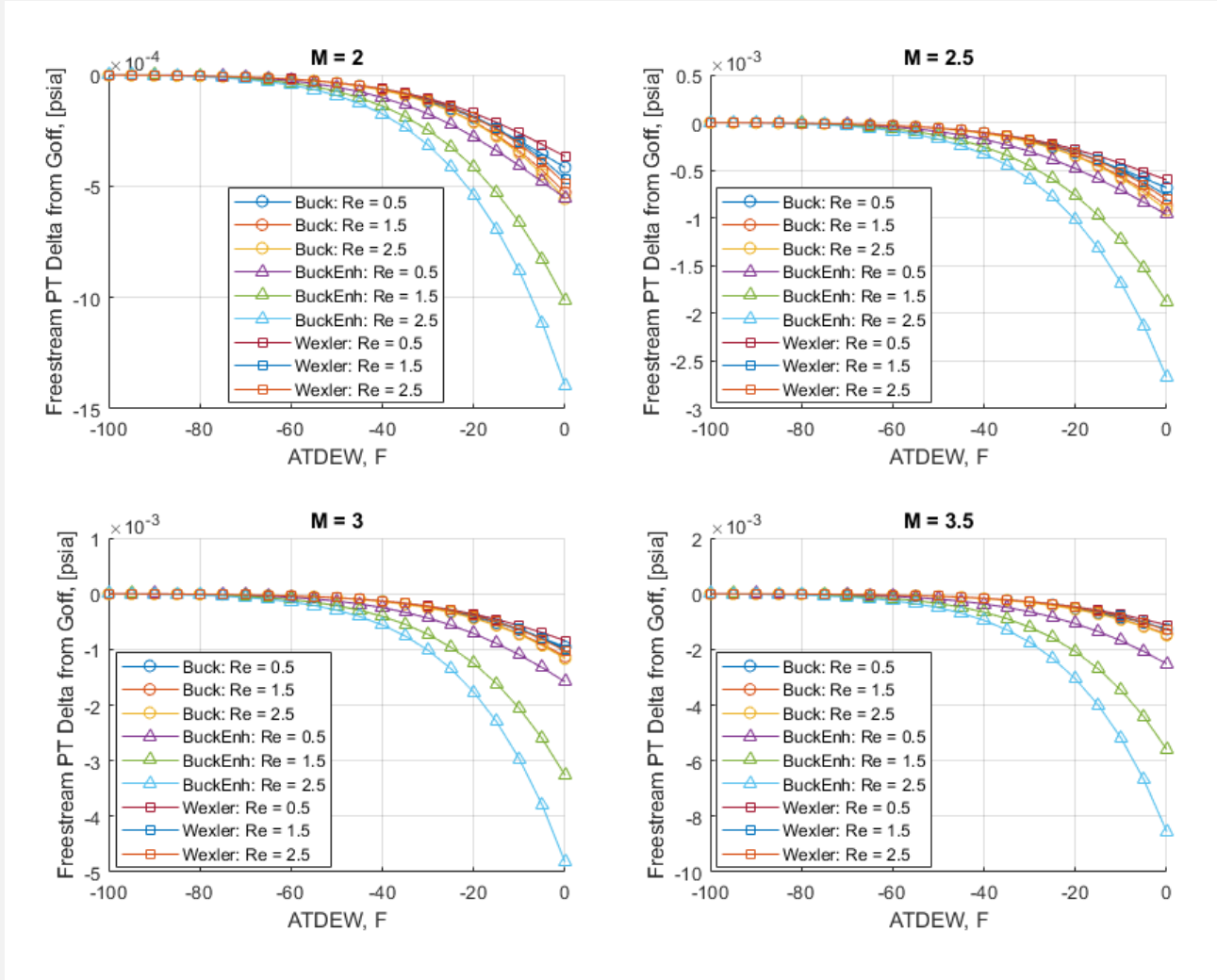
At -15°F

- Mach number delta if using Buck Enhanced vs. Goff-Gratch:
  - **~0.0003 Mach** (Re = 0.5e6/ft)

- Freestream total pressure delta:
  - **~0.004 psi** (Re = 2.5e6/ft)

Seemingly insignificant difference in Mach number and total pressure (depends on the user/facility), would suggest using Buck Enhanced (1981):

- Relatively modern
- Enhancement factors to account for pressure levels
- Definitely debatable, open to suggestions!



Conclusions & Future Work

- Choice of SVP Model doesn't make a huge difference if properly used (i.e., frost-point vs. dewpoint, enhancement factors used properly, etc.)

- Future work:
  - Add PT & flow rate sensors to 8x6 SWT Vaisala lines

  - Add calculations for pressure-corrected dewpoint in 8x6 & 10x10 SWT (corrected to tunnel total pressure & corrected to atmosphere)

  - Perform MUA following 10x10 full characterization (2025) to determine whether complex dewpoint system could be simplified.

Questions