Sensitivities of using a Sonic Choke on HR2 (BurnsRITE)

Theodoros A. Spanos

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Discussion Topics

- Background
- Sonic Choke
- Parametric Study
- Examples
- Summary

Goal: Provide information on sensitivities of using the sonic choke as a passive method of airflow control into heat release apparatus.

Background

- Multiple studies have been presented in this forum documenting the various sources of variability in OSU heat release data.
- One major contributor to variability is the airflow into the apparatus.
- Studies have documented airflow control is effective in reducing variability.
  - Active flow control uses mass flow controllers
  - Passive flow control uses a mass flow meter
- Lessons learned from OSU are being incorporated in the development of the HR2 (BurnsRITE).
- Passive flow control using a sonic choke has been proposed for HR2. Sonic chokes are currently in use in oil burner test apparatus.
- Sonic choke may provide a more cost-effective, lower maintenance solution to controlling a key parameter to variability. **Goal: Set it and forget it!**

Sonic Choke in Gas

- *Certainly rocket science – math included – but I'll avoid the derivations.*
- *Dr. Peter Kay from University of the West of England, provides a very clear derivation of the governing equations; lecture(s) available online.*
  https://www.youtube.com/watch?app=desktop&v=h308rjI-vIc
- *Compressible gas flow governed by:*

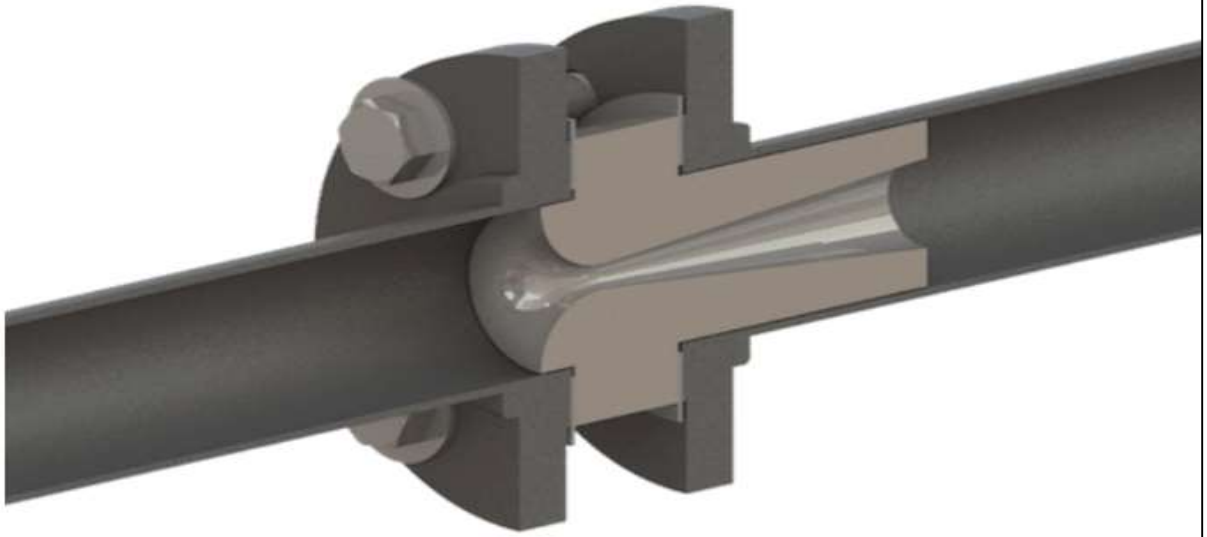
$$\dot{m} = \frac{AP_0}{\sqrt{T_0}}\sqrt{\frac{\gamma}{R}}M\left[1+\frac{\gamma-1}{2}M^2\right]^{-\frac{\gamma+1}{2(\gamma-1)}}$$

$$\frac{P_0}{P_c} = \left[1+\frac{\gamma-1}{2}\right]^{\gamma/(\gamma-1)} = \left[\frac{\gamma+1}{2}\right]^{\gamma/(\gamma-1)}$$

Where:
Mdot = Mass flow rate
A - Cross section area
P_0 – Stagnation pressure
P_c – Critical (throat) pressure
T_0 – Stagnation temperature
G ~ Constant 1.4 for air
R – Gas constant
M – Gas velocity (Mach)

Sonic Choke in Gas

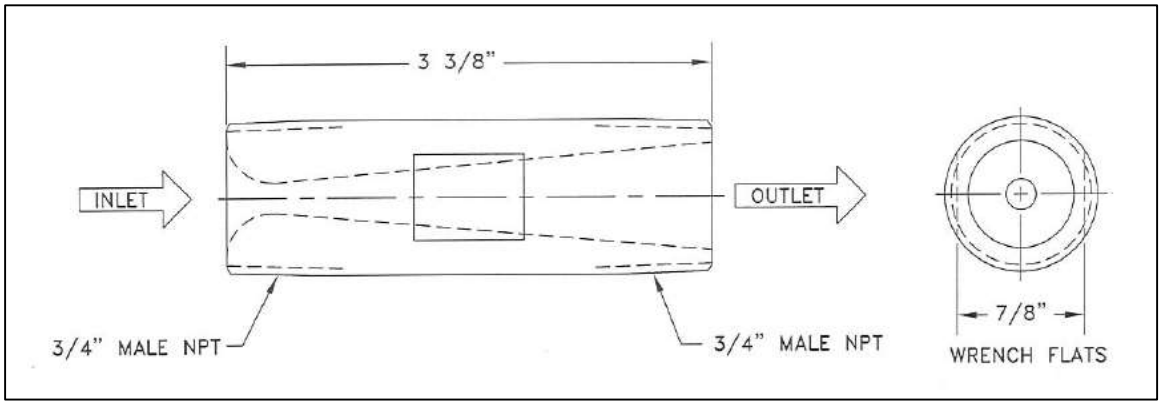
- *Maximum flow rate (mdot) occurs when local gas velocity reaches sonic velocity (Mach 1).*
- *Sonic choking occurs when* $\frac{Pc}{P_0} \leq 0.528$.
- *Shock wave develops at/near the critical throat area, limiting downstream mass flow.*



https://www.foxvalve.com/venturi-flow-controls/sonic-choke

Parametric Study

- FAA Research presented in April 2021 focused on Fox Venturi Product (p/n 625442)
  https://www.fire.tc.faa.gov/pdf/materials/April21Meeting/Burns-021-SonicChokeResearch.pdf



Fluid Media: *Air at 34.7 psia, 72.5° F*
Line Size: *3/4" Sch 40 pipe*
Material: *304 Stainless Steel*
Throat Dia: *Approx. Dt = 0.208"*
Design Flow Rate: *Approx. 0.0269 lbs/sec of Air at 34.7 psia*
Configuration: *3/4" male NPT ends*

Absolute (total) pressure = ambient (atmospheric) + gauge

- Mathematical calculations confirm drawing expectation using input parameters
- Question arose if some external factors introduce variability

Parametric Study - Input Parameters

The specified volumetric flow rate at the exit of the sonic choke will be **21.25 +/- 0.4 SCFM(1)**. The following inputs may affect the exit flowrate and are considered variable:

- Inlet Pressure (psi)
- Ambient Pressure (psi)
- Inlet Temperature (deg F)

The following inputs are assumed constant/stable for each apparatus, but may vary between apparatuses:

- Inlet Diameter = 0.82” (20.83 mm)
- Exit Diameter = 0.88” (22.35 mm)
- Sonic Choke Throat Diameter = 0.208” (5.283 mm)

The following inputs are assumed constant for air:

- Gas Constant = 53.35 ft lbf / lb degR
- Heat Capacity Ratio of Air = 1.40

Note (1): The ‘published’ specification will be changed to 21.25 SCFM nominal to account for reference temperature range of 68-75 degrees Fahrenheit (20-24 degrees Celsius) in the lower plenum.

Parametric Study - Problem

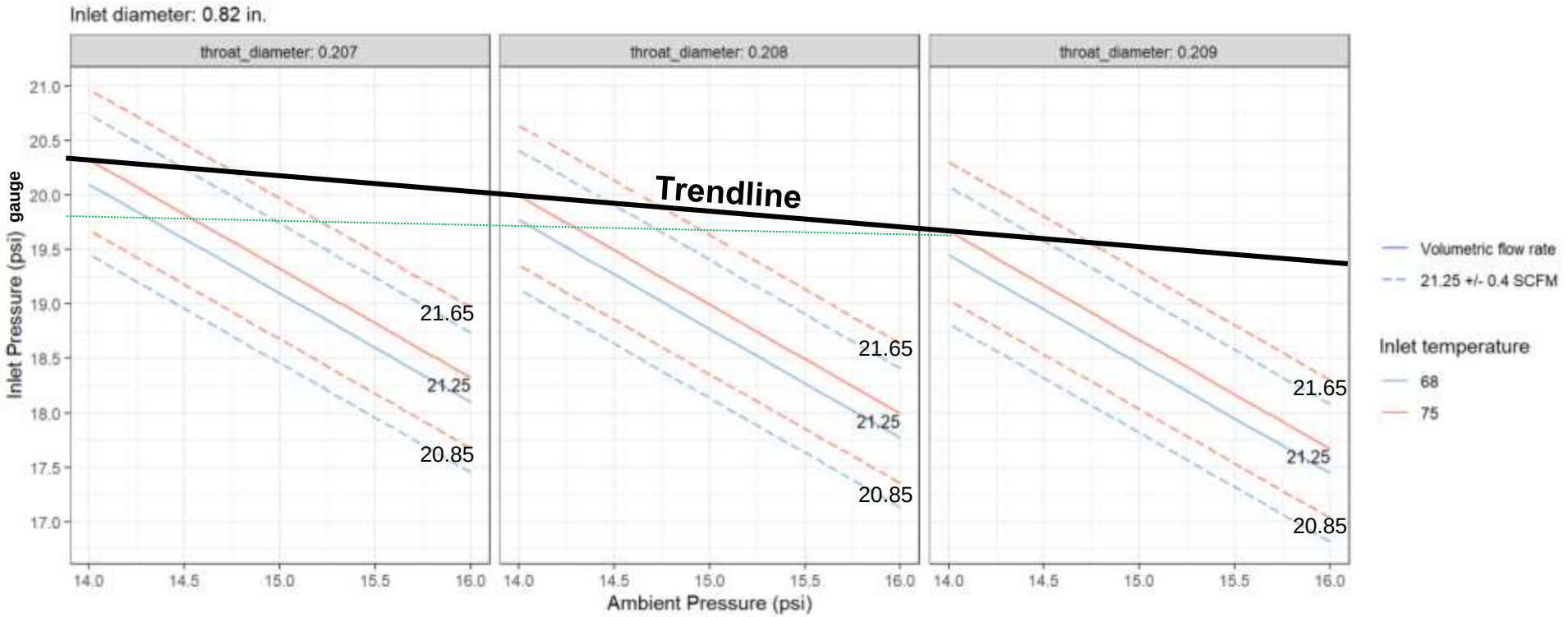
Using equations relevant to airflow dynamics of a sonic choke, develop the following:

- A single chart showing the volumetric flowrate at the exit as the inlet pressure varies from 15 to 25 psi in increments of 0.5 psi, whilst varying ambient pressure from 14.0 psi to 16.0 psi in increments of 0.1 psi, whilst varying inlet temperature from 68 to 75 degrees F in increments of 1.0 deg F.

- Repeat step above with throat diameters of 0.207” and 0.209”

- Thank you Katy Wrenn, Boeing math group !

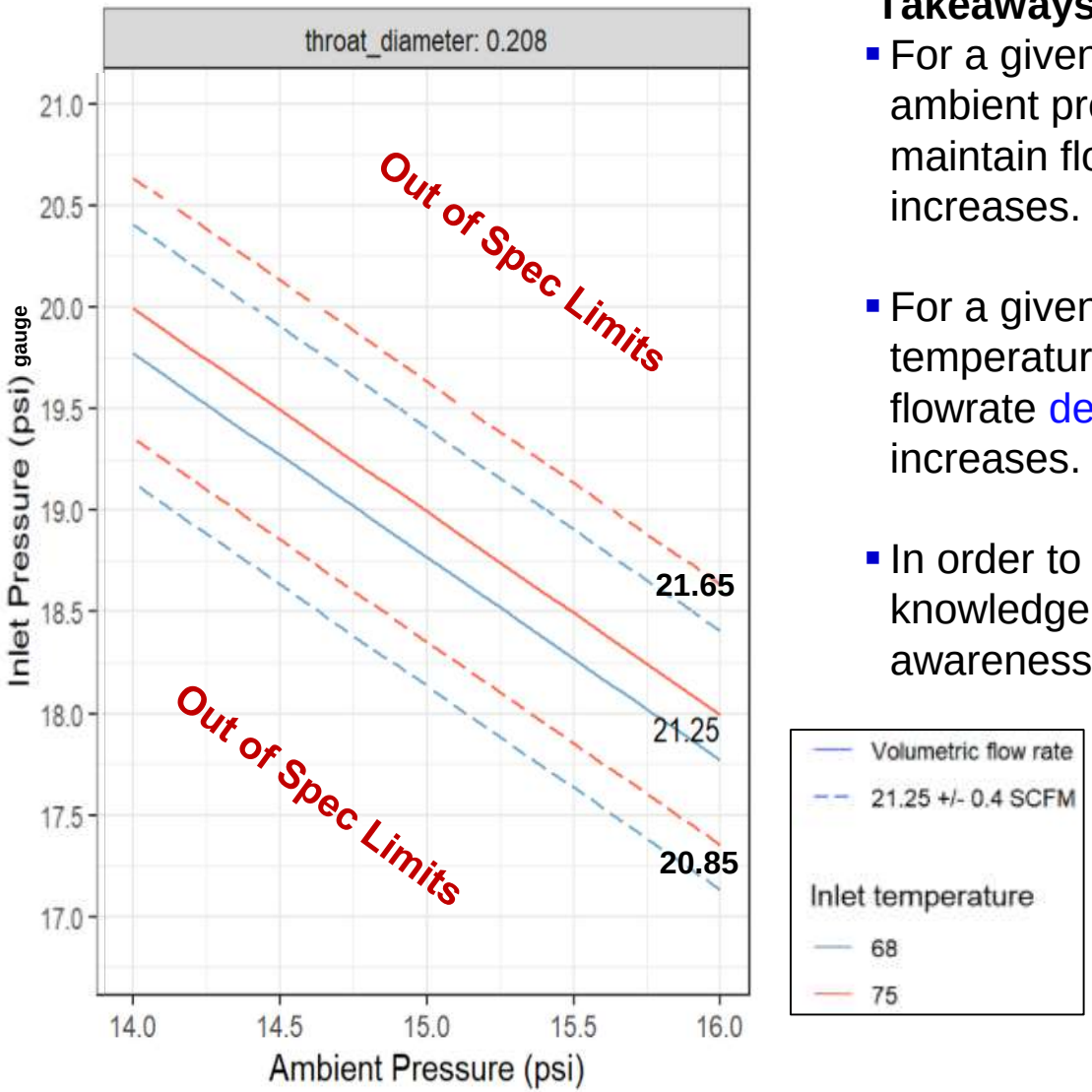
Parametric Study - Results



- There are interactive effects between throat diameter, inlet pressure, ambient pressure, and temperature. As throat diameter increases, the inlet pressure required to maintain a particular flowrate decreases.

- Extremely sensitive to throat diameter. A difference in throat diameter of 0.001 inch results in a need to adjust inlet pressure by about 0.25 psi to maintain a given flowrate.

Parametric Study - Results



Takeaways:

- For a given throat diameter, with constant ambient pressure, inlet pressure required to maintain flowrate increases as the temperature increases.
- For a given throat diameter, with constant temperature, inlet pressure required to maintain flowrate decreases as ambient pressure increases.
- In order to achieve a nominal flowrate, knowledge of the precise throat diameter and awareness of environmental factors is needed.

Example 1

Given:

- Both Charleston and Bremen laboratories have a sonic choke with a known throat diameter of 0.208 inch.
- Both laboratories have air temperatures of 72.5 deg F
- Both laboratories have a measured lower plenum pressure of 12.2 inch H_2O (0.44 psi)

Required:

What is the appropriate inlet pressure to achieve 21.25 SCFM?

Solution:

See next slides

Example 1

Procedure:

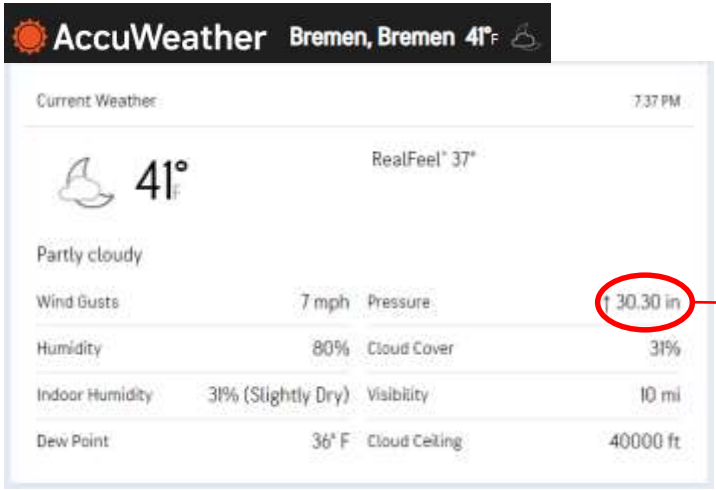
(1) Obtain lab ambient pressure (P_{LAB})

(2) Obtain lower plenum static pressure (P_{PLN})

(3) Calculate Total Pressure = (P_{LAB}) + (P_{PLN}) → This is what will be used in the following charts

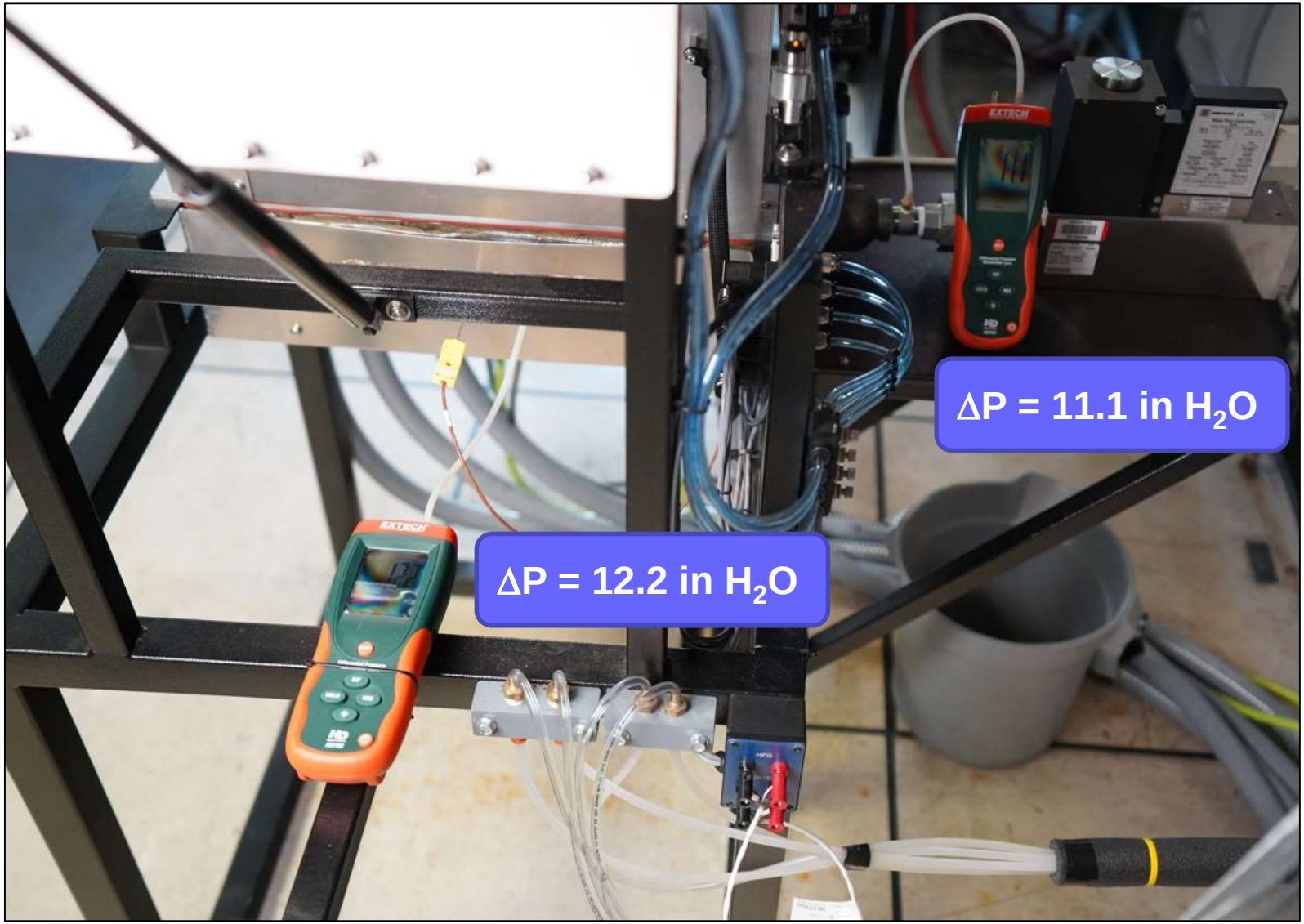
Step (1)

14.60 psi



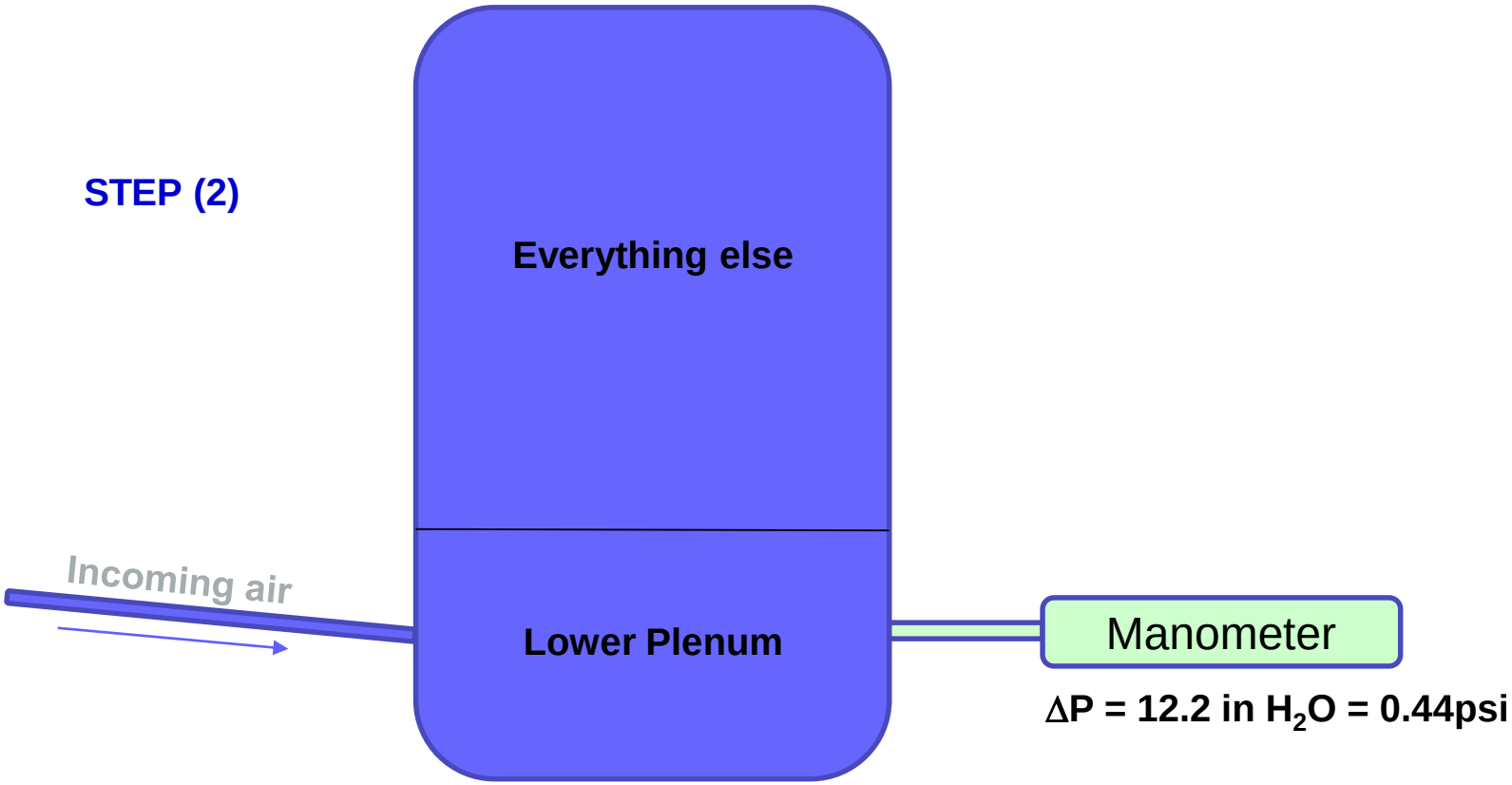
14.88 psi

HR2



Slide diagram of HR2 showing Lower Plenum

STEP (2)



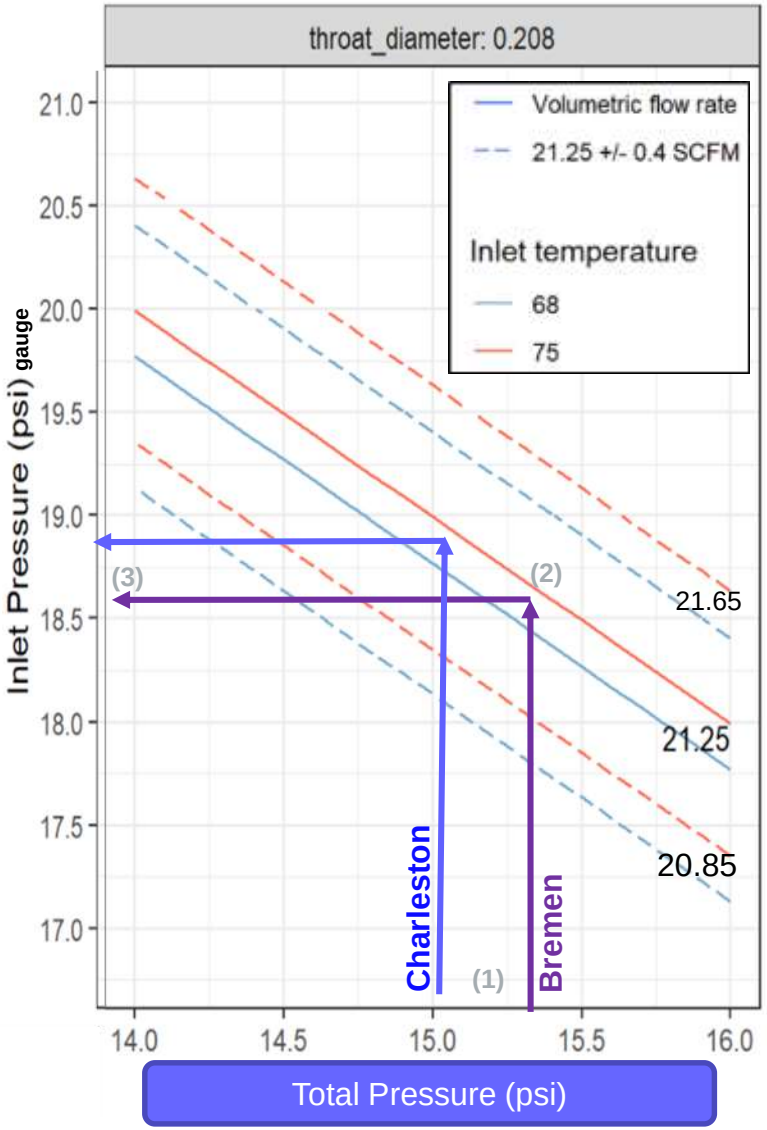
$\Delta P = 12.2$ in $H_2O = 0.44$psi

STEP (3)

$P_{TOT\ |\ CHS} = 0.44 + 14.60 = 15.04$ psi

$P_{TOT\ |\ BRE} = 0.44 + 14.88 = 15.32$ psi

Example 1



Procedure:

(1) Start at total pressure

(2) Draw vertical line to intersect temperature

(3) Draw horizontal line to find inlet pressure

Takeaway:

All else being equal, the two labs would have a 0.3 psi difference in inlet pressure in order to achieve a flowrate of 21.25 SCFM

Example 2

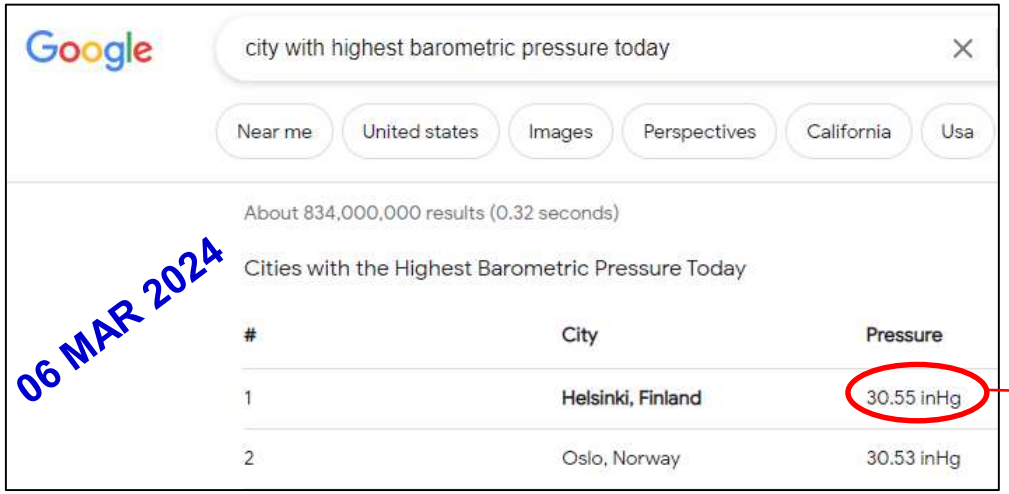
Given:

- A laboratory in Helsinki, Finland has a sonic choke with a known throat diameter of 0.209 inch, air temperature of 68.0 deg F, and lower plenum pressure of 0.46psi.
- A laboratory in Dunedin, New Zealand has a sonic choke with a known throat diameter of 0.207 inch, air temperature of 75.0 deg F, and lower plenum pressure of 0.42 psi.

Required:
What is the appropriate inlet pressure to achieve 21.25 SCFM?

Solution:
See next slides

Example 2



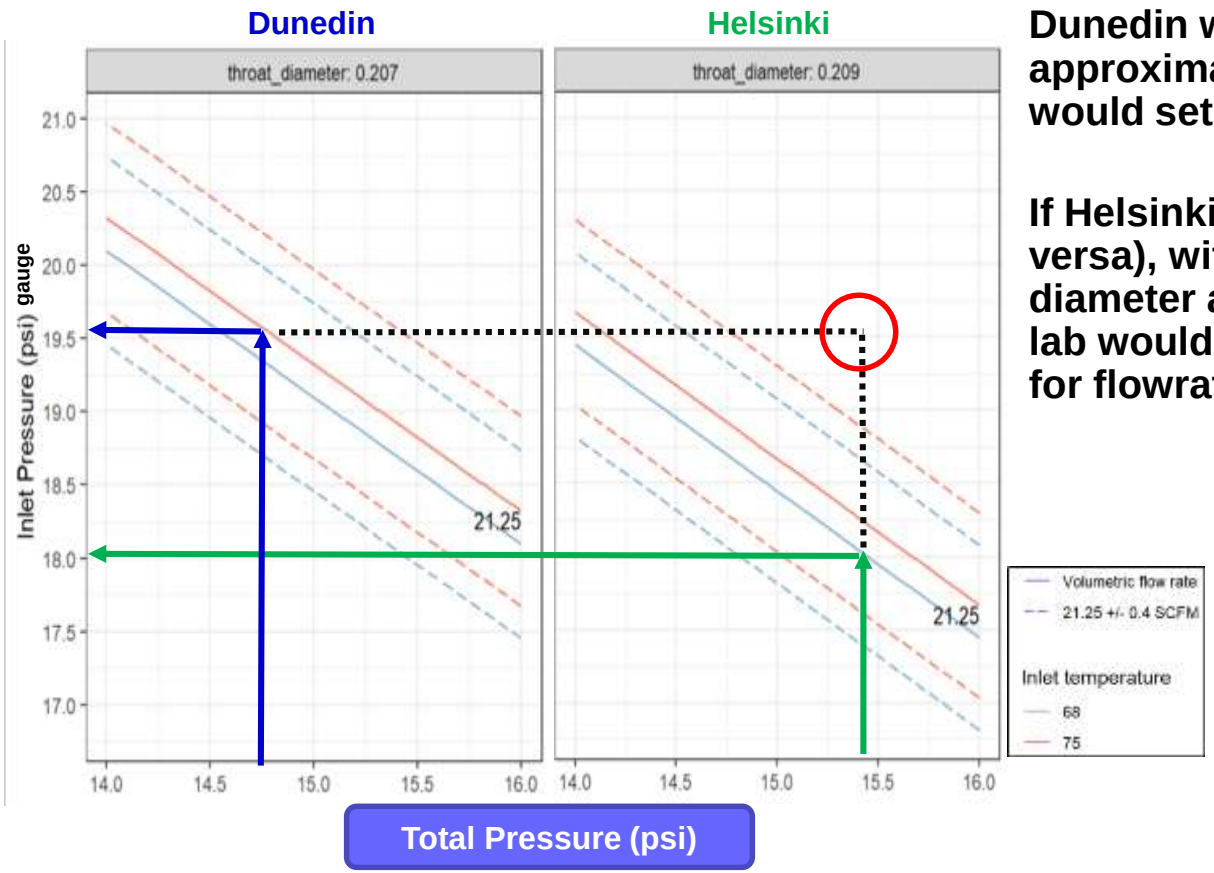
15.00 psi

14.28 psi

$P_{TOT\,|\,HEL} = 0.46 + 15.00 = 15.46$ psi

$P_{TOT\,|\,DUN} = 0.42 + 14.28 = 14.70$ psi

Example 2



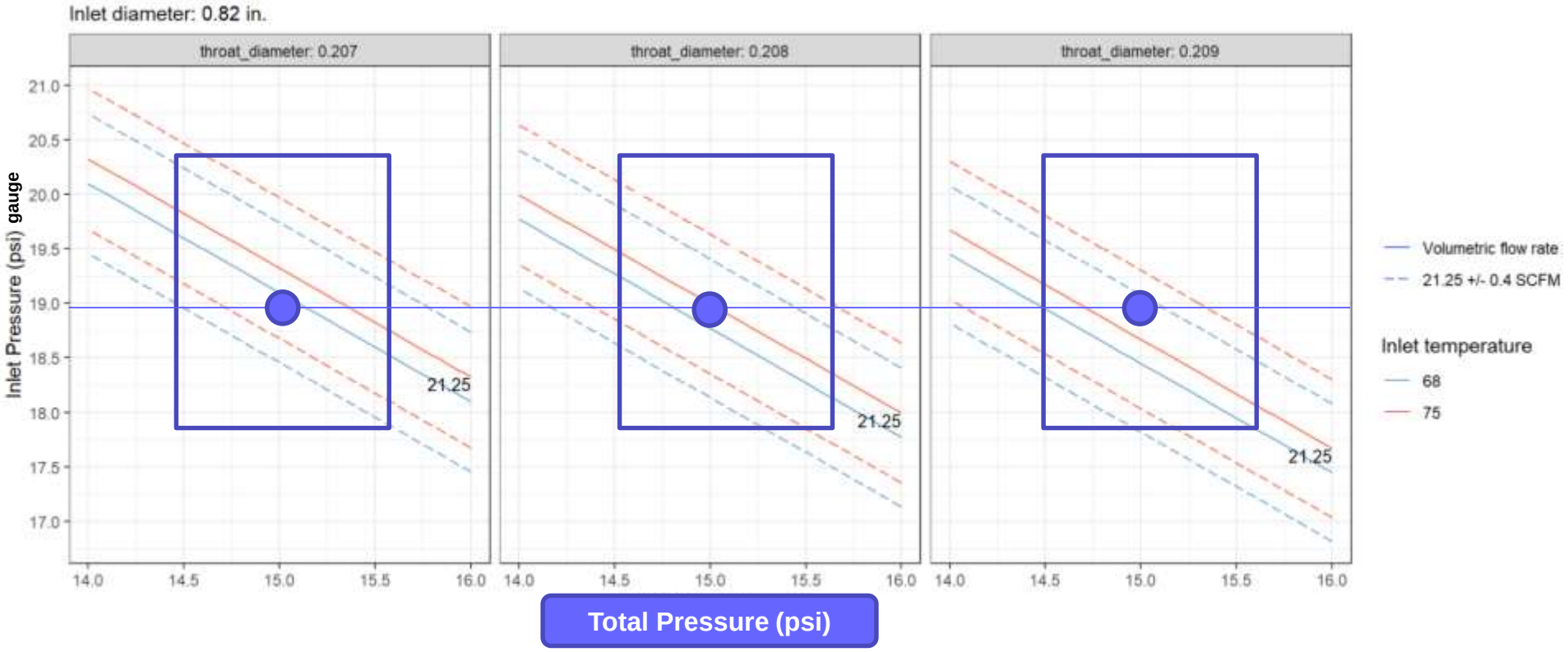
Observation:

Dunedin would need to set inlet pressure at approximately 19.6 psi, whereas Helsinki would set at approximately 18.0 psi.

If Helsinki were to mimic Dunedin (and vice versa), without accounting for throat diameter and environmental conditions, the lab would be exceeding specification limits for flowrate.

Set it and forget it?

- Is it possible to be completely passive? …… Almost.



- Setting inlet pressure to 19.0 psi, would give approximately nominal results.
- Highly recommend checking lab conditions to ensure target airflow achieved.

If not….

- There is a likelihood of introducing airflow variability if environmental conditions and throat diameter are not accounted for.

- What effect this may have on heat release results is unknown at this time.

- Looking forward to the round robin…… (joking!)……. Or…….. ☺

Summary

- Parametric study conducted using piping of 0.82” inner diameter (3/4 inch schedule 40). Equations are not dependent on piping diameter.

- Critical input parameters to volumetric flowrate at exit are inlet pressure, ambient pressure, inlet temperature, and throat diameter.

- Sonic Choke provides effective passive airflow control with lower costs and lower maintenance, provided the input parameters are understood and accounted for.

Questions

Danke Sehr !
bis Oktober !

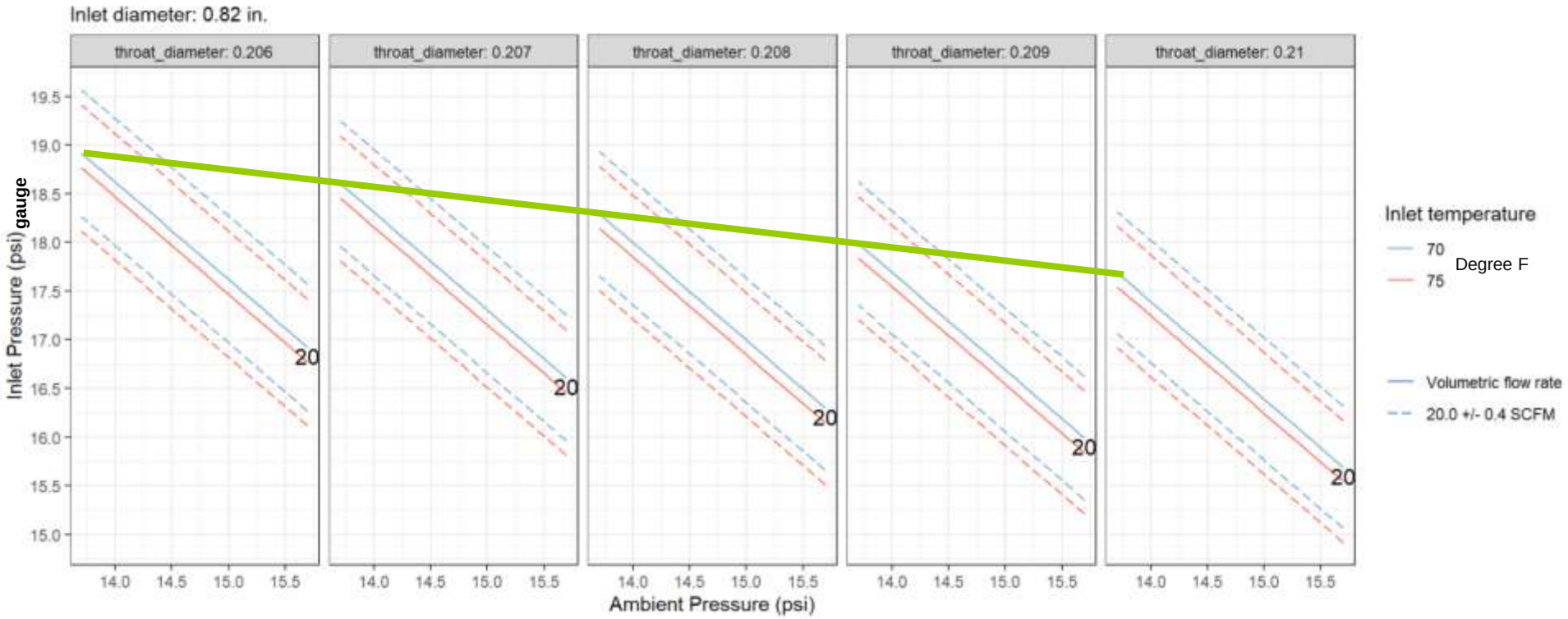
Contact Information:

Theodoros A. Spanos
Email: theodoros.a.spanos2@boeing.com
Tel: (+001) 843-469-8722

Backup

Parametric Charts

Backup – extra charts



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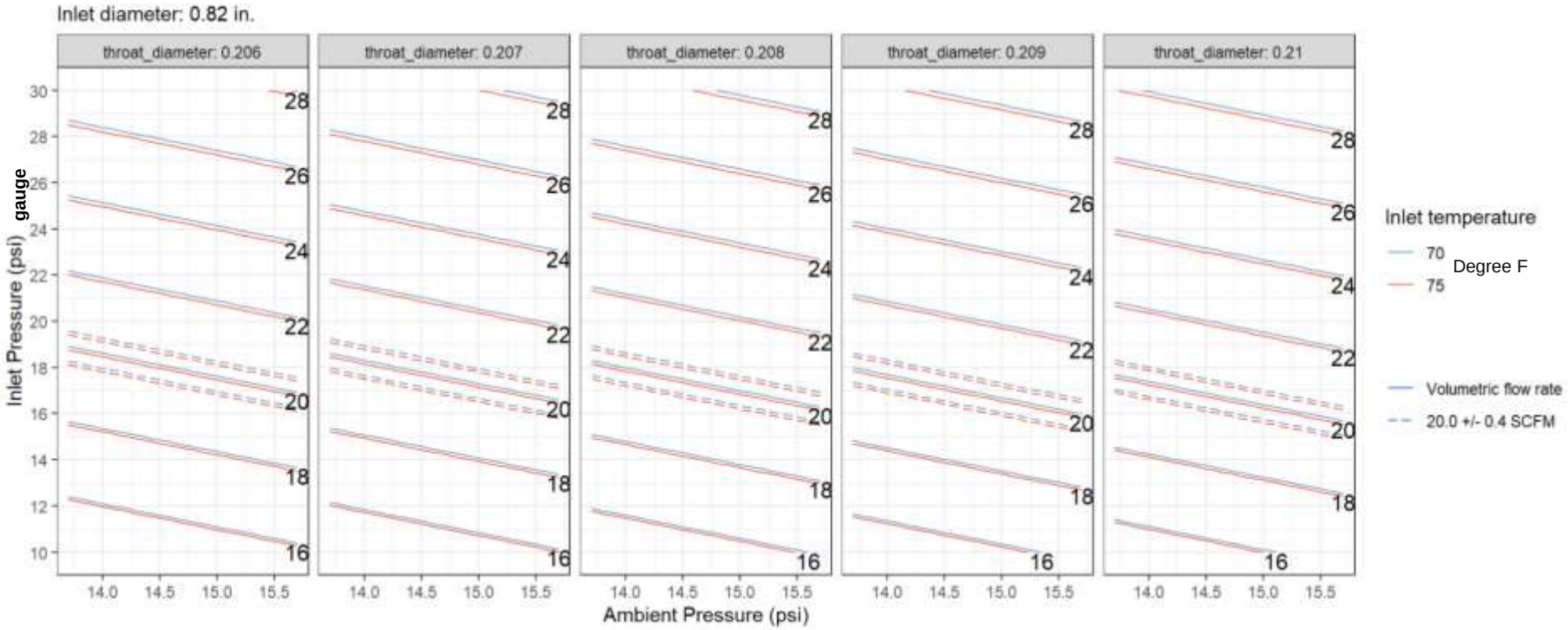

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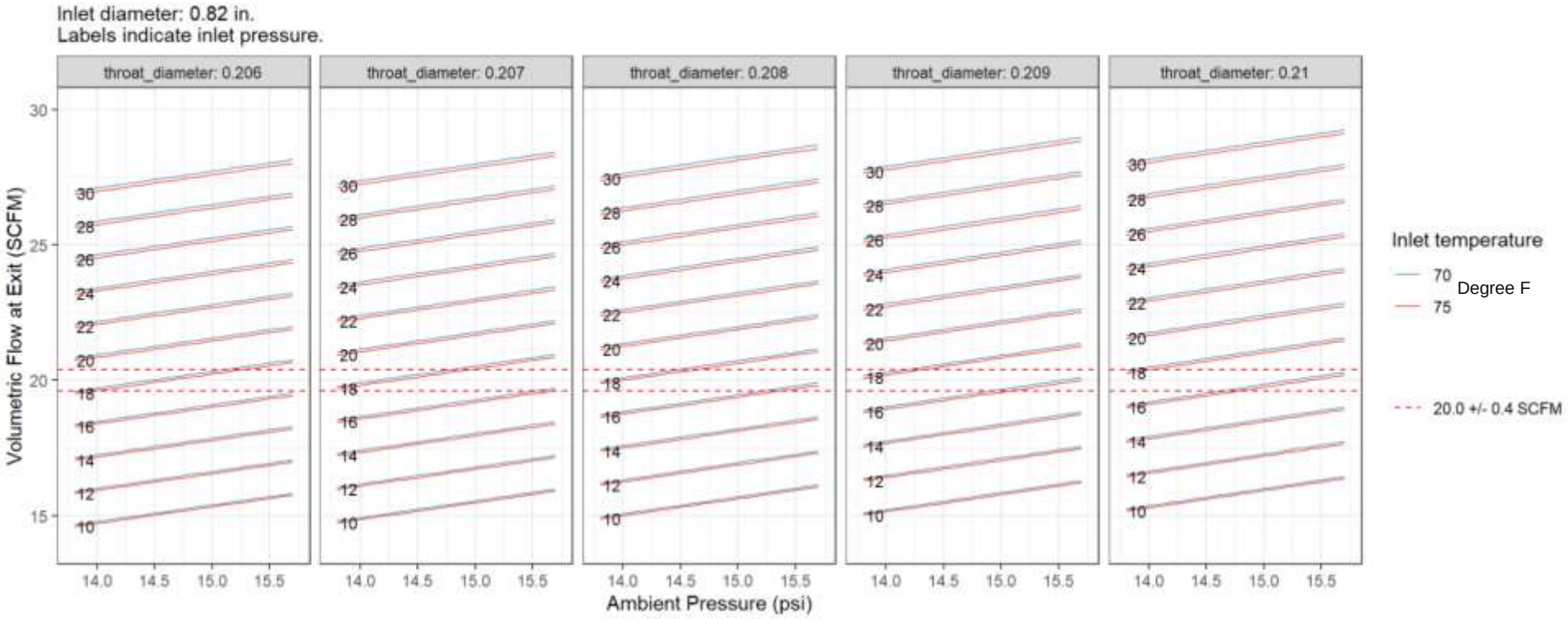

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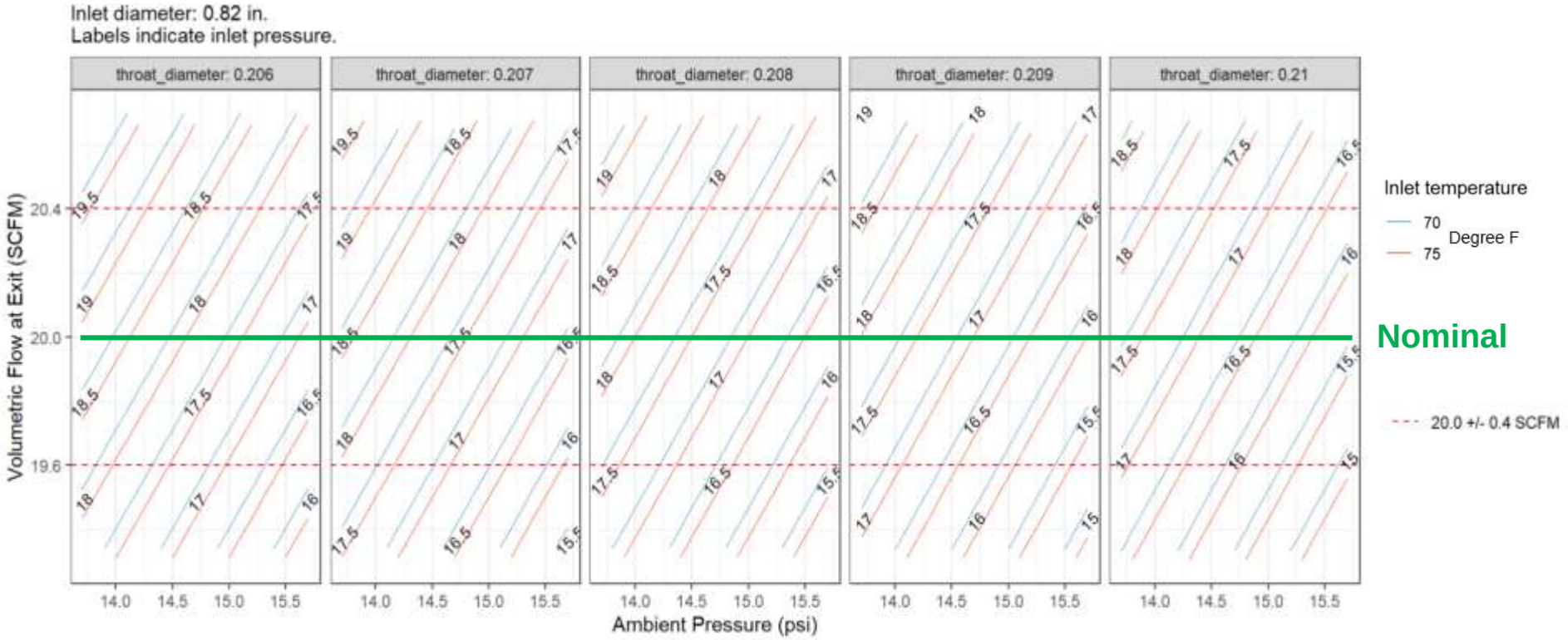

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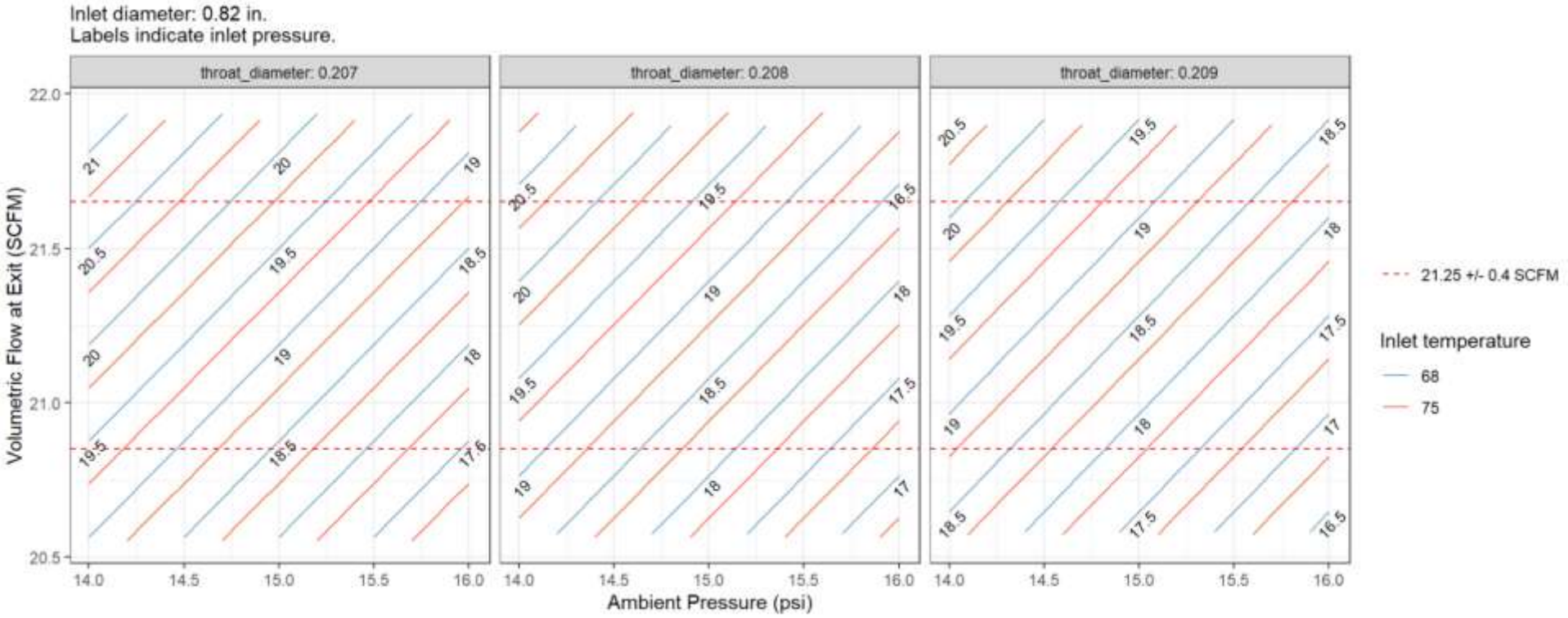

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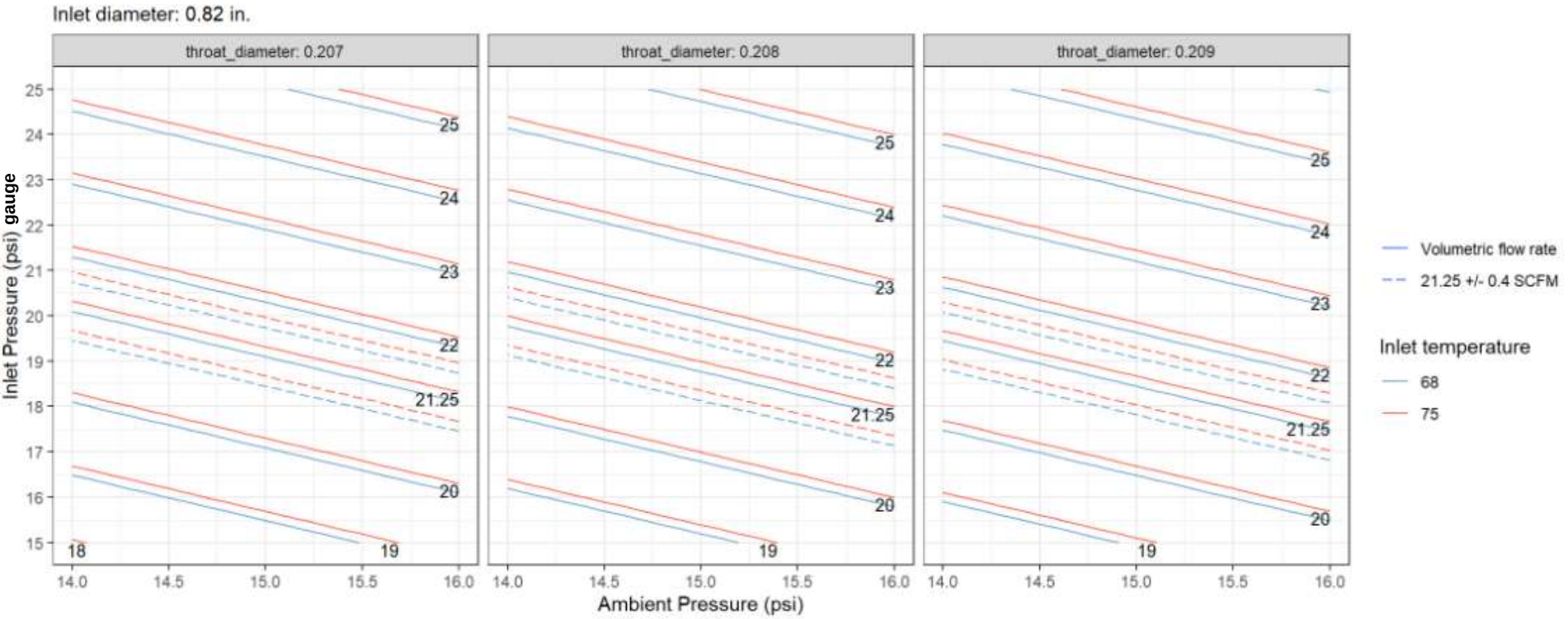

Backup – extra charts