HR 2 Response Parameters Ranges and Sonic Choke Evaluation

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Contributors: HR 2 Development Team, Boeing Teams

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Support and Contributions

- HR 2 Development Team
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  - Martin Spencer - MarlinEngineering
  - Brian Johnson – Boeing
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- Boeing Applied Math
  - Lindsay Jones, PhD
  - Katy Wrenn

Contents

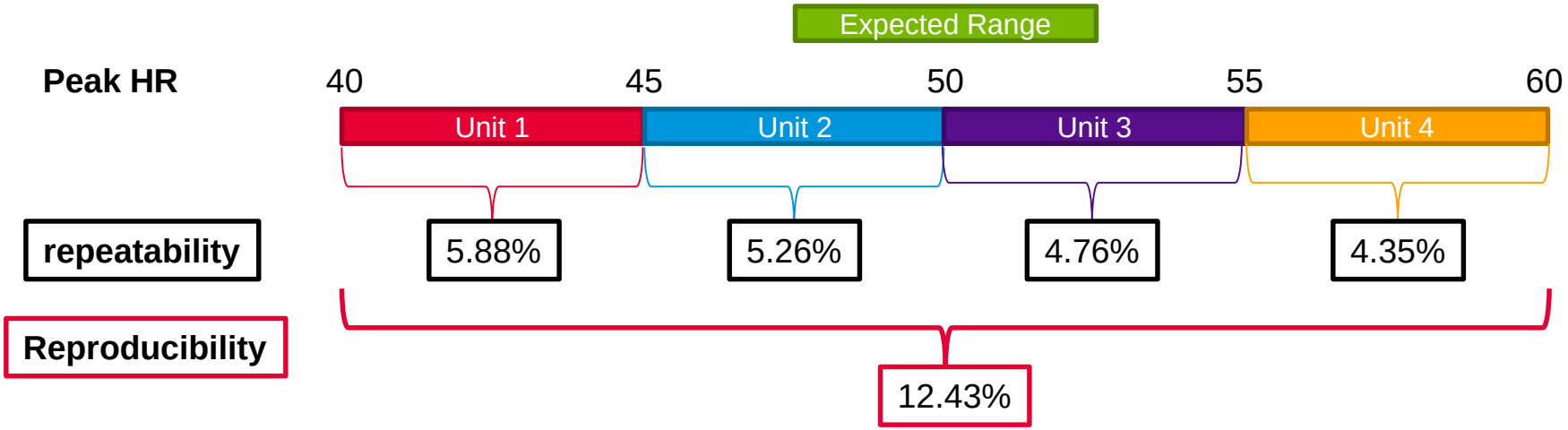
HR 2 Development Goal
Improving Reproducibility

HR 2 Goal

- Define a robust test method to determine peak and total heat release that improves repeatability and reproducibility when compared with OSU.
  - Measured by CoV = (Stdev/Mean)*100

Gold Standard Expected Range
47.5 – 52.5, Avg 50
5.00% Reproducibility

Gold Standard Theoretical Example



HR 2 Goal – Improving Reproducibility

HR 2 Key Characteristics – Nominal Operating Parameter Ranges

PARAMETER	DESCRIPTION	MIN	NOMINAL	MAX
Inlet Airflow Rate	SCFM	19.6	20	20.4
Inlet Air Temperature	°C	21.1	22.5	23.9
Inlet Air Relative Humidity	% RH	-	-	≤ 65
Heat Flux (W/cm^2)	Center	3.60	3.65	3.70
	Each Corner (4)	3.55	3.65	3.75
Average Baseline Exhaust Gas Temperature	No Flame (°C)	270	280	290
	Slope (L/°C)	0.0255	0.0289	0.0323
Calibration Factor Range	W/°C	15.00	17.00	19.00
	kW/m^2/°C	0.646	0.732	0.818
	3 SLPM ΔT (°C)	92.8	103.7	117.6
Interspace Pressure	inH2O	0.40	0.55	0.70
Lower Plenum Pressure	inH2O	11.0	12.5	14.0
Methane Gas Supply Pressure	PSIG	18	20	22
Main Air Supply Pressure	PSIG	18	20	22
Mixing Air Supply Pressure	PSIG	18	20	22
Thermal Stability Temperature (TST)	20 sec average (°C)	365	380	395
Specimen Conditioning	Temperature (°C)	18	21	24
	Relative Humidity (%)	45	55	65
Upper Pilot Gas Flow	Air (SLPM)	0.98	1.00	1.02
	Methane (SLPM)	1.47	1.50	1.53
Lower Pilot Gas Flow	Air (mL/min)	0.65	0.70	0.75
	Methane (mL/min)	115	120	125

Response Parameters

270 – 290 °C
280 °C ± 3.6%

15 – 19 W / °C
17 W / °C ± 11.76%

Test Method Repeatability Capability Estimate

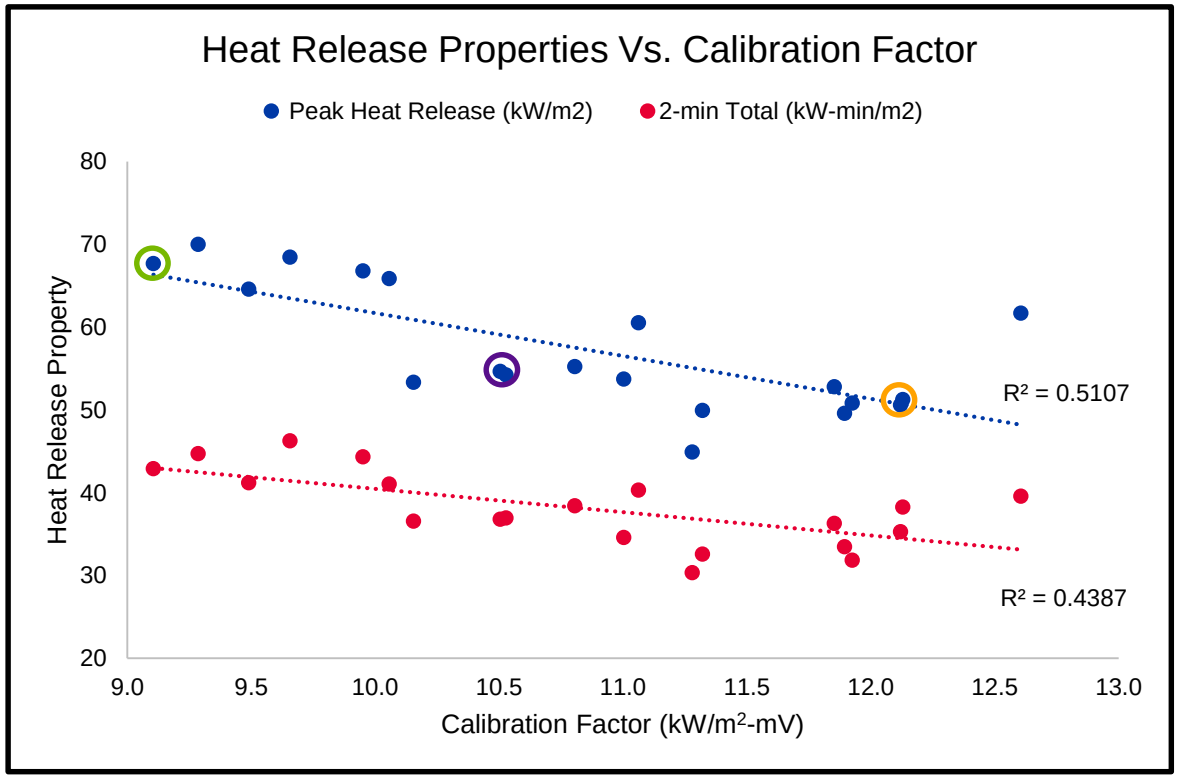
365 – 395 °C
380 °C ± 3.9%

All based on observations

HR 2 Goal – Improving Reproducibility
Importance of Calibration Factor

Calibration Factor (Boeing OSU Study)

- Most critical response, perfect state response
- Measured variation = inherent common cause variation
- Estimate HR 2 repeatability, reproducibility capability



20 Level Multi-Variable interaction study

Data Point	Total	Lower	Cooling	Split Ratio	Heat Flux
○	79.8	31.8	48.1	1.51	3.52
○	84.7	24.4	60.3	2.47	3.49
○	90.4	20.0	70.4	3.5	3.53

General Trend

Calibration Factor

Heat Release Properties

HR 2 Response Parameter Ranges
Calibration Factor Experiment

Objective

1. Conduct 100 methane gas calibrations on HR 2 prototype
2. Measure and record input and response parameters
3. Analyze data, calculate tolerance interval for response factors
   - 99-95% tolerance interval - 95% confidence that interval covers 99% of sample population

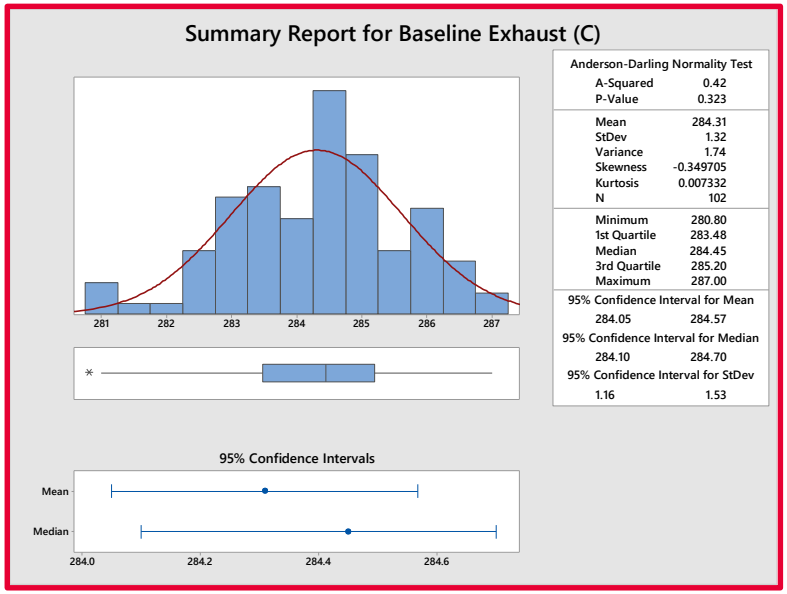
Goal

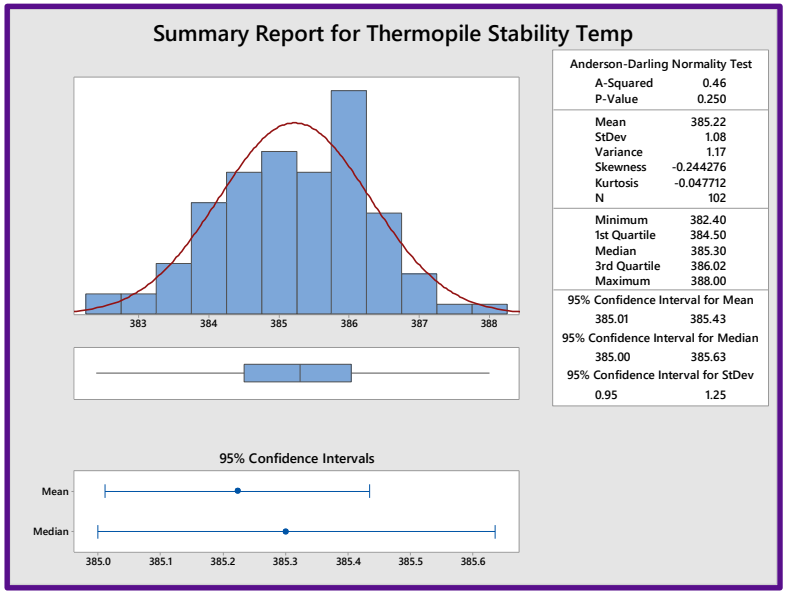
1. Set required response parameter ranges (control limits)
2. Estimate test method capability based on calibration factor range

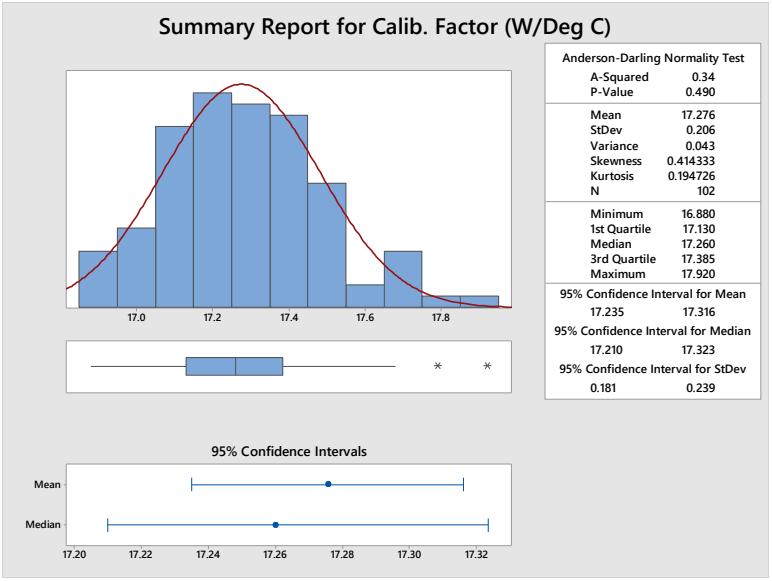
Experiment conducted by Mike Burns – FAA Tech Center

Analysis by Boeing

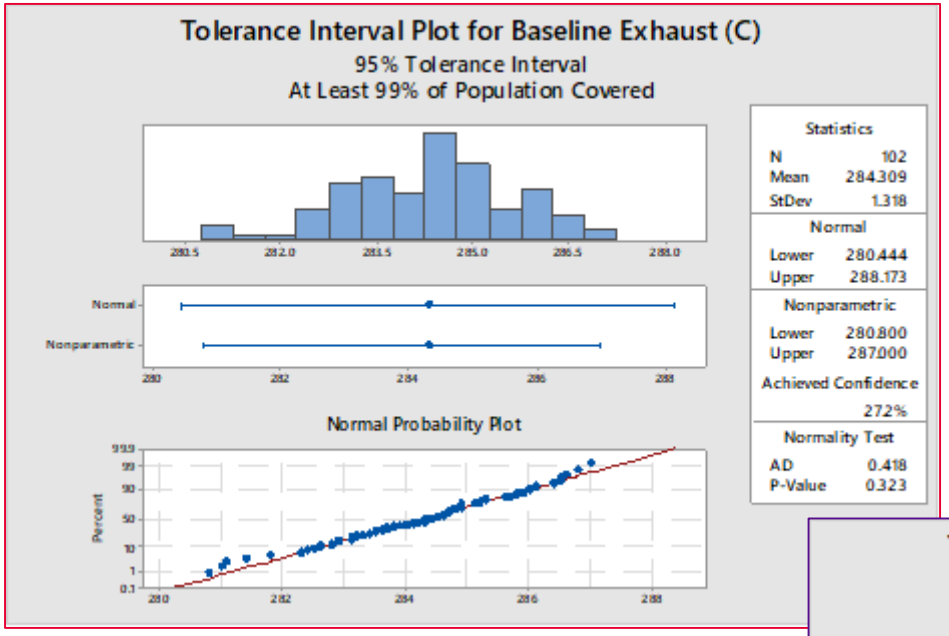
HR 2 Response Parameter Ranges
Calibration Factor Experiment – Graphical Summary







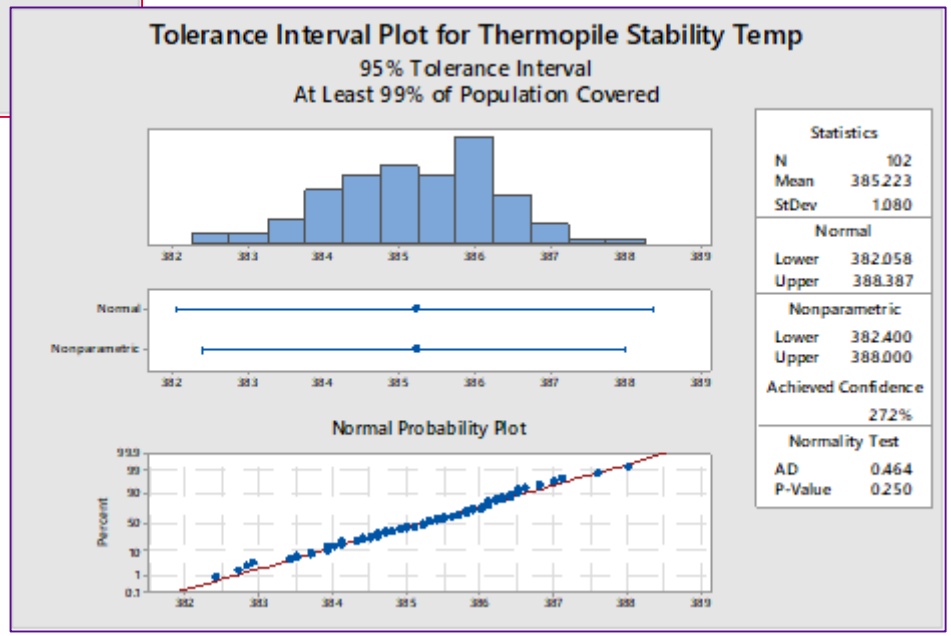
HR 2 Response Parameter Ranges
99-95% Tolerance Intervals



Baseline Exhaust

280.4 – 288.2 °C, **± 1.4%**

Was: ± 3.6%

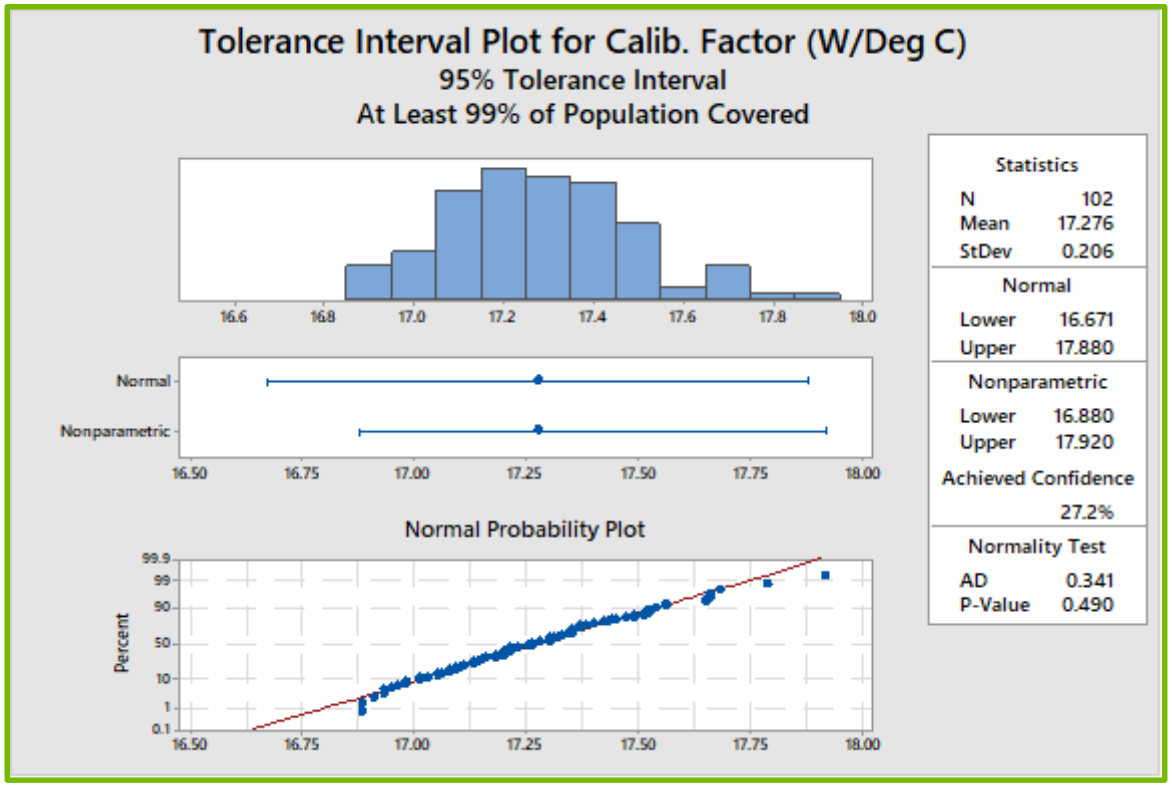


Thermopile Stability Temperature

382.0 – 388.4°C, **± 0.8%**

Was: ± 3.9%

HR 2 Response Parameter Ranges
99-95% Calibration Factor Tolerance Interval



Calibration Factor

17.28 ± 0.60 W/°C

16.68 – 17.88, **± 3.47%**

Was: ± 11.76%

HR 2 Test Method Repeatability Capability

± 3.47%

Sonic Choke Evaluation
Purpose

Background

- Fall 2019 meeting - Mike Burns introduced sonic choke as a possible alternative to Mass Flow Controllers to distribute HR 2 air.
  - Passive component that controls air to the chamber
  - Lower initial cost - $950
  - Lower maintenance cost
  - MFC also operating at high end of range

- Heat Release task group agreed to possible change if sonic choke is shown to be accurate and precise

- Mike and HR 2 Development Team tasked with gathering evidence to evaluate performance

Sonic Choke Evaluation
Experiment Design

Experiment Goal

1. Gather evidence to assess sonic choke performance
2. Replace mass flow controller with sonic choke if performance criteria is met
   - **Performance criteria:** Sonic choke able to achieve flow rates comparable to theoretically calculated flows (Christian Thomas - Airbus)

Experiment Objectives

1. Design and conduct an experiment that varies air temperature, inlet pressure through sonic choke, measured via mass flow meter downstream of choke.
2. Conduct statistical analysis to compare theoretical flow rates with actual flow rates

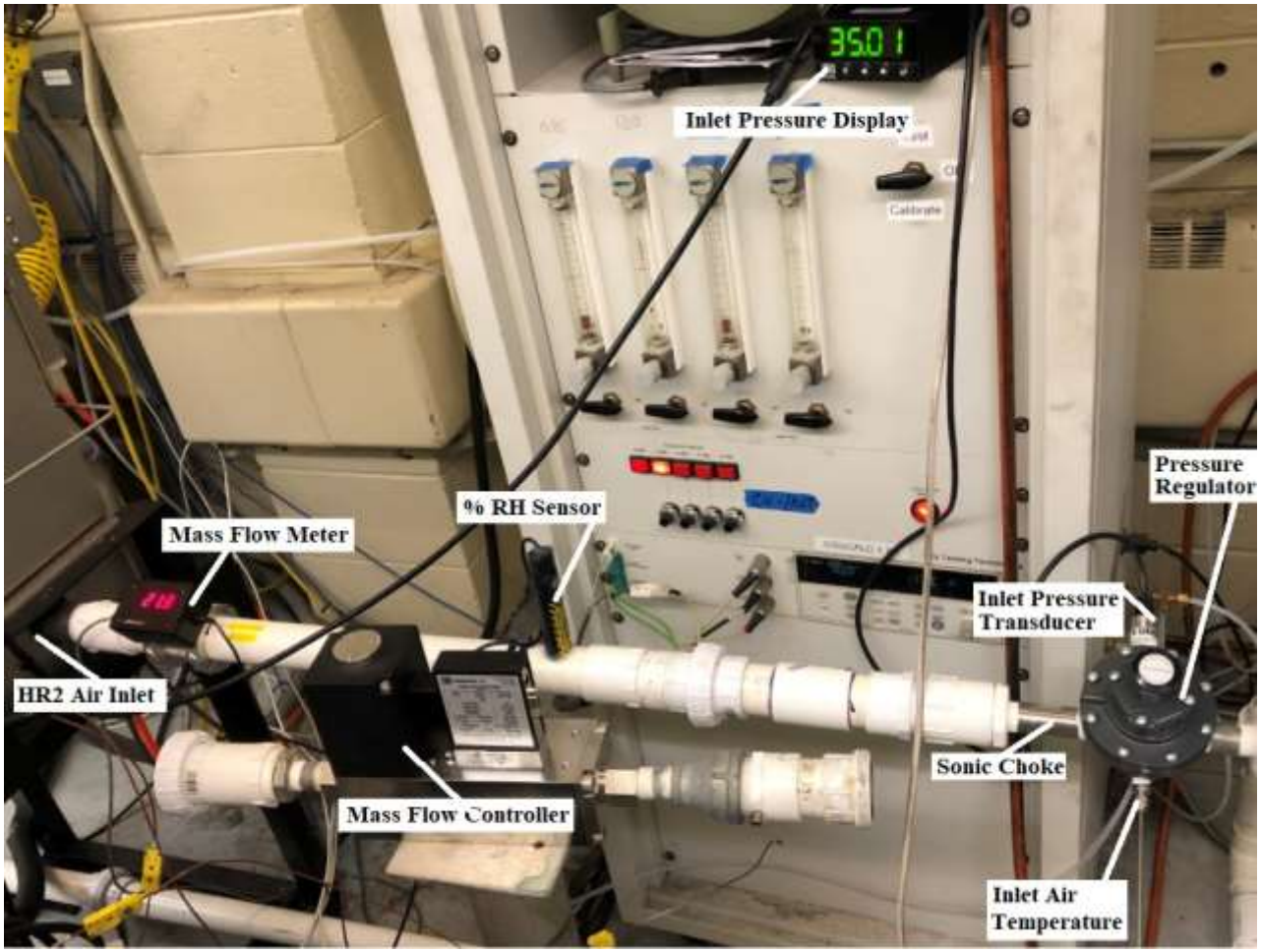
- Control Factors
  - Temperature: 65 – 80 F
  - Inlet Pressure: 30 – 40 PSIA

- Response Factors
  - Flow rates, SCFM

Experiment conducted by Mike Burns – FAA Tech Center

Analysis by Boeing

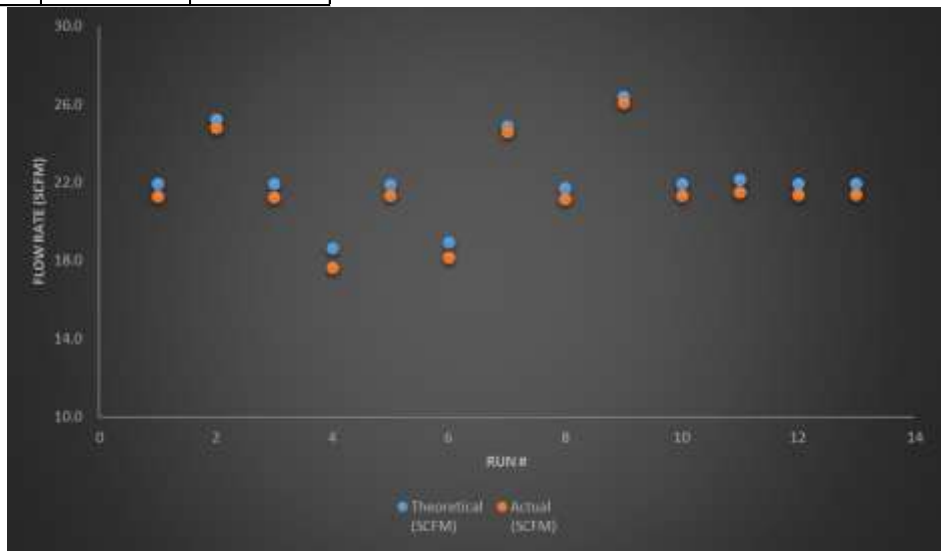
Sonic Choke Evaluation
Experiment Set-Up



Mike Burns set-up at FAA Tech Center

Sonic Choke Evaluation
Analysis

Run Order	Control Factor (Actual)		Response Factor			
	Air Temperature (F)	Inlet Pressure (PSIA)	Theoretical (SCFM)	Actual (SCFM)	Response Difference	% Difference
1	72.2	35.0	21.94	21.30	0.64	3.0%
2	65.6	40.0	25.23	24.81	0.42	1.7%
3	73.1	35.0	21.92	21.25	0.66	3.1%
4	80.4	30.0	18.66	17.64	1.01	5.7%
5	73.4	35.0	21.91	21.33	0.58	2.7%
6	64.4	30.0	18.94	18.16	0.78	4.3%
7	79.6	40.0	24.90	24.59	0.31	1.2%
8	83.2	35.0	21.71	21.17	0.54	2.6%
9	72.5	42.1	26.38	26.11	0.27	1.0%
10	72.5	35.0	21.93	21.32	0.61	2.9%
11	61.7	35.0	22.16	21.52	0.63	2.9%
12	73.2	35.0	21.92	21.37	0.55	2.6%
13	72.9	35.0	21.92	21.39	0.53	2.5%
~~14~~	~~72.9~~	~~27.9~~	17.47	16.55	~~0.92~~	~~5.6%~~
				Average	0.58	2.8%



Sonic Choke Evaluation
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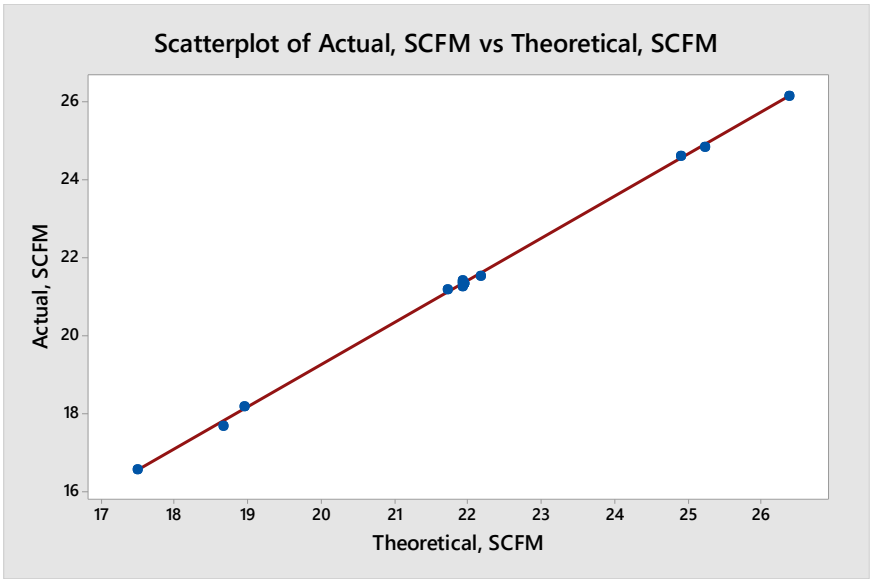
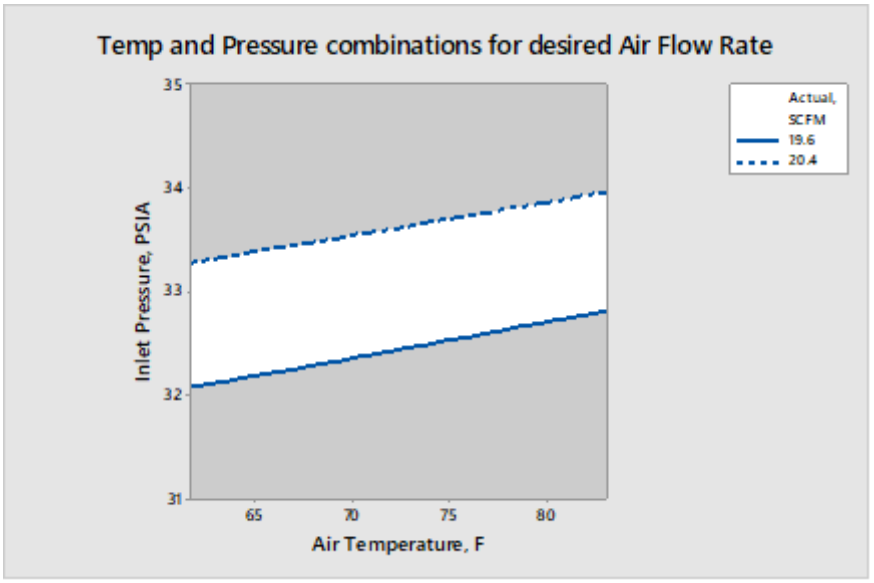


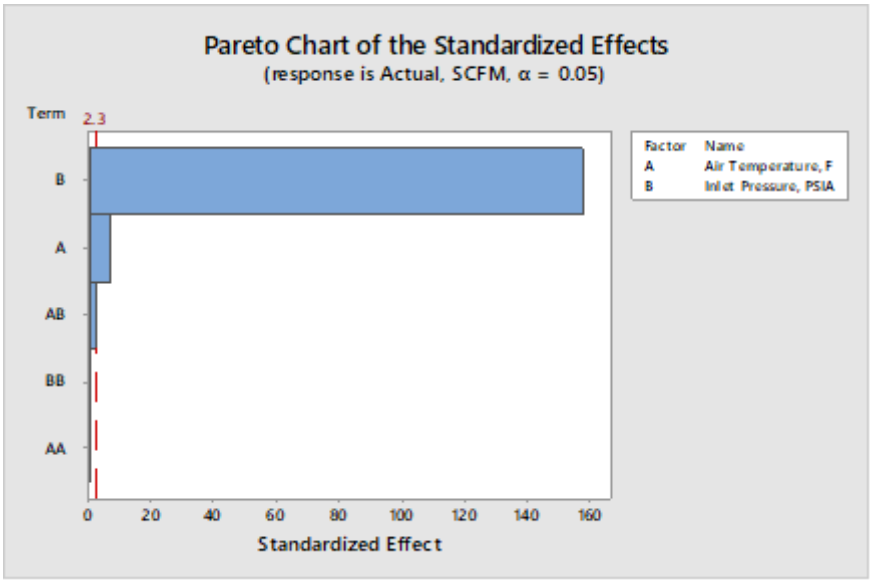


Regression Equation

Actual, SCFM = -2.343 + 1.07930 Theoretical, SCFM

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0702324	99.94%	99.93%	99.91%



Conclusion / Next Steps

HR 2 Response Parameter Ranges

- Prototype unit repeatability capability estimated at ± 3.47%
- Opportunity to significantly reduce acceptable response parameter ranges → contributes to better test method reproducibility
- Response parameter ranges, reproducibility capability will be determined using TRL 6 Phase 1 unit assessment data
  - 4 units at this time (FAA – 2 units, Airbus, Boeing)

Sonic Choke Performance Evaluation

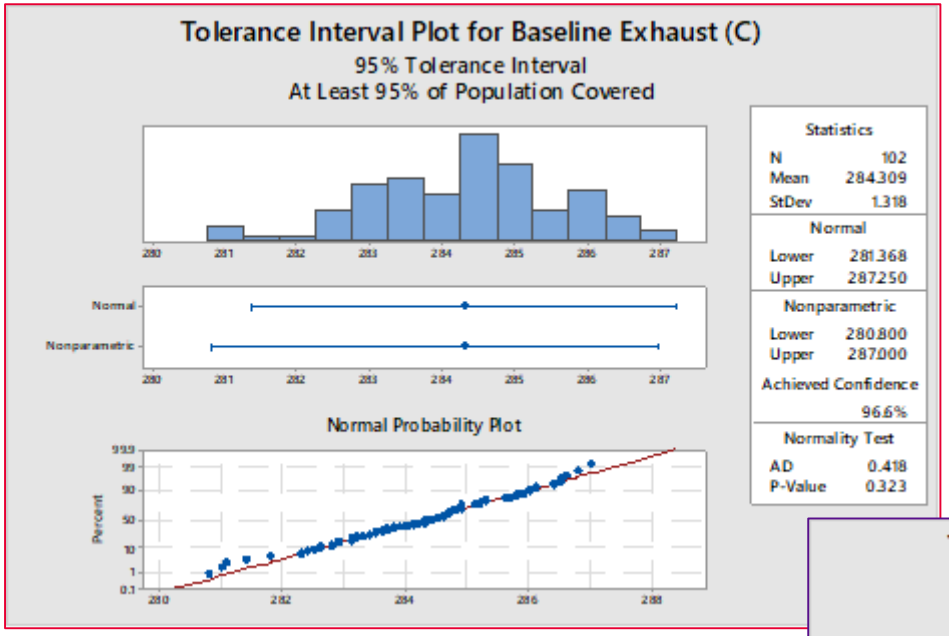
- Actual measurements comparable to theoretical
- Air flow rates heavily affected by pressure, little influence from temperature
- Task group discussion on potentially replacing MFC with Sonic Choke
  - Considering performance, capability, cost

Questions / Thoughts?

What goes around the world but stays in a corner?

A. Postage stamp

HR 2 Response Parameter Ranges
95-95% Tolerance Intervals



Baseline Exhaust

281.4 – 287.3 °C, **± 1.0%**

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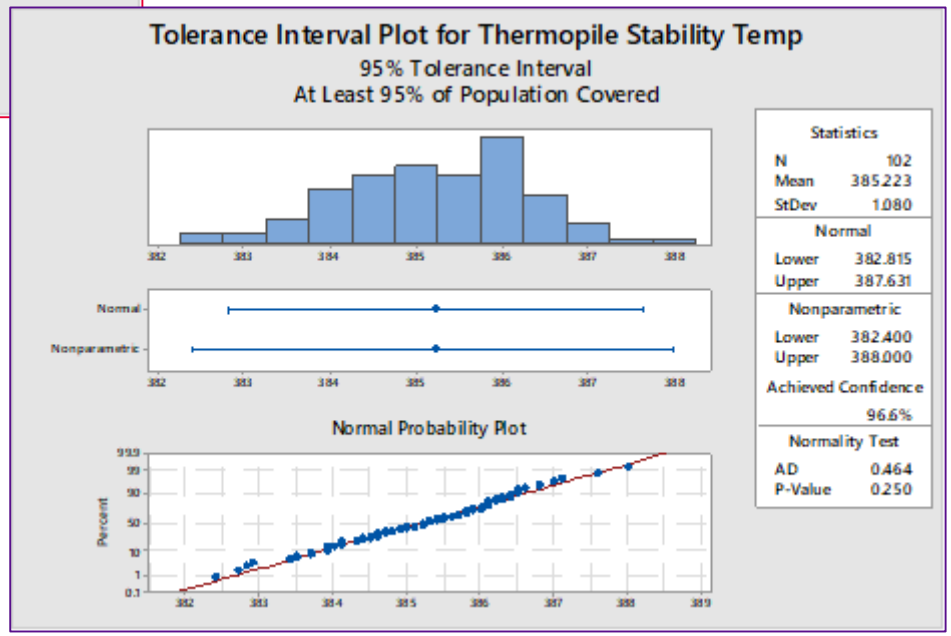

Thermopile Stability Temperature

382.8 – 387.6°C, **± 0.6%**

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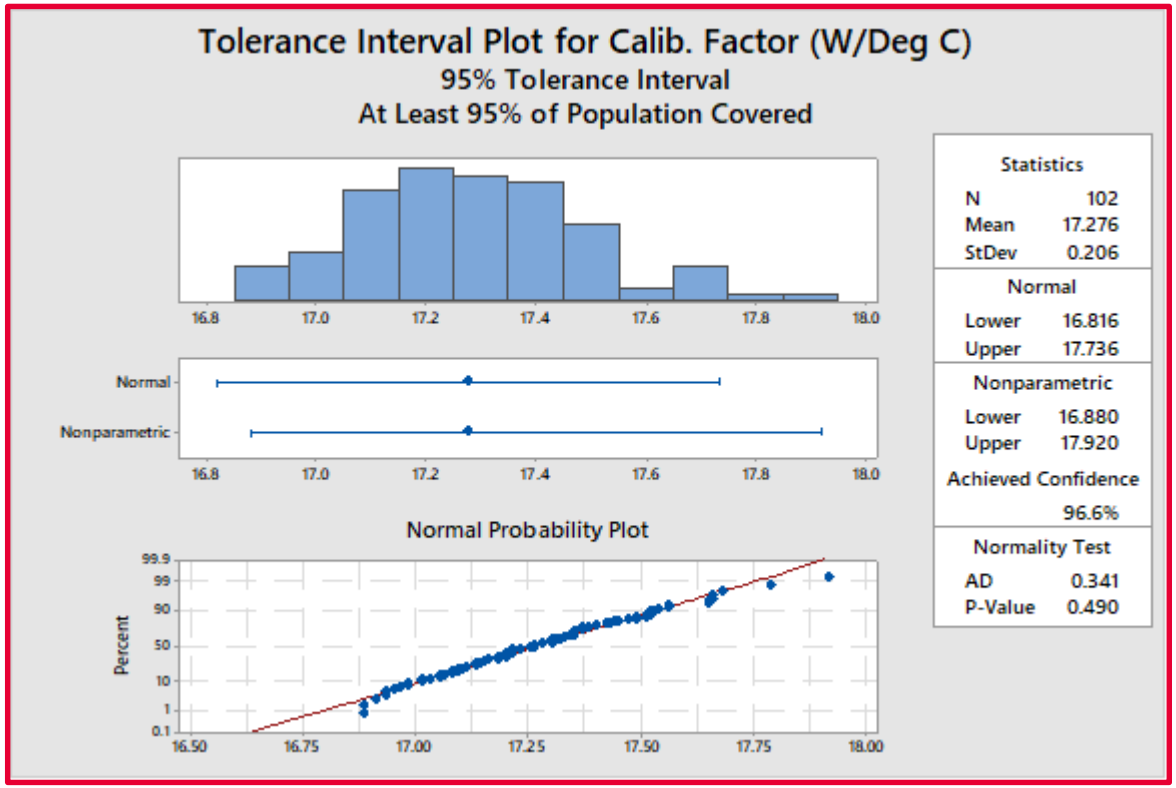
HR 2 Response Parameter Ranges
95-95% Calibration Factor Tolerance Interval



Calibration Factor

17.28 ± 0.46 W/°C

16.82 – 17.74, **± 2.66%**

Was: ± 11.76%

HR 2 Test Method Reproducibility Capability

± 2.66%