



HR2 Development TRL 6 – Status Update



A look inside the HR2 burn chamber

Presented by: Brian Johnson, BCA Flammability

Prepared by: Brian Johnson, BCA Flammability
Yonas Behboud, BR&T

April 2023 MFTF - Congress Center Bremen

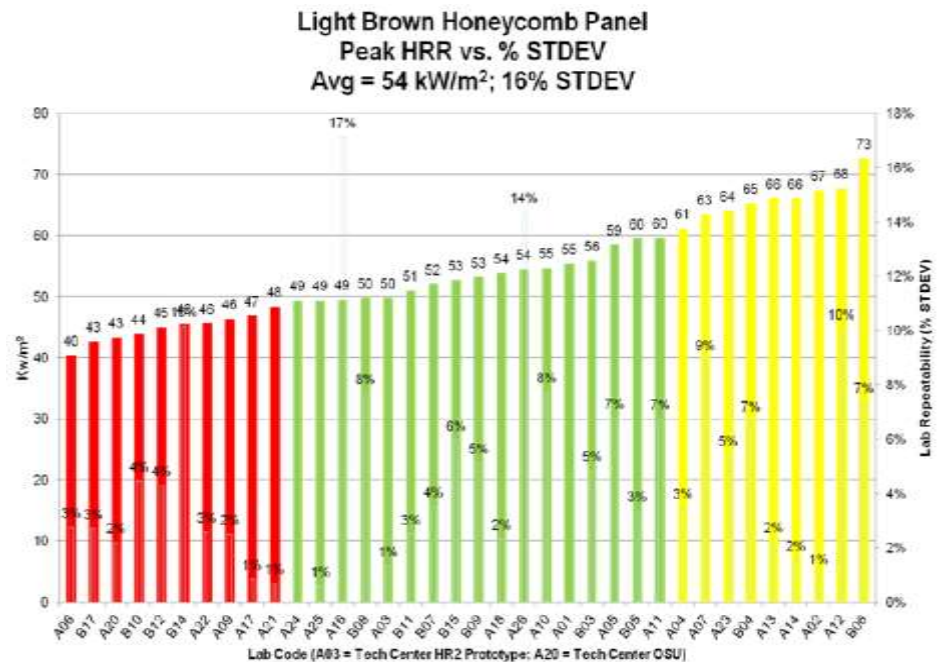
OSU Test Method



- Reproducibility challenges persist
- Specification does not tightly control some key parameters
- Decades of certification data in use

14CFR25.853(d)

- Added in 1986
- Current FAR - Appendix F Part IV
- Applicable to interior exposed surfaces greater than 144 square inches
- Measures heat release as a function of time
- Test code: HR



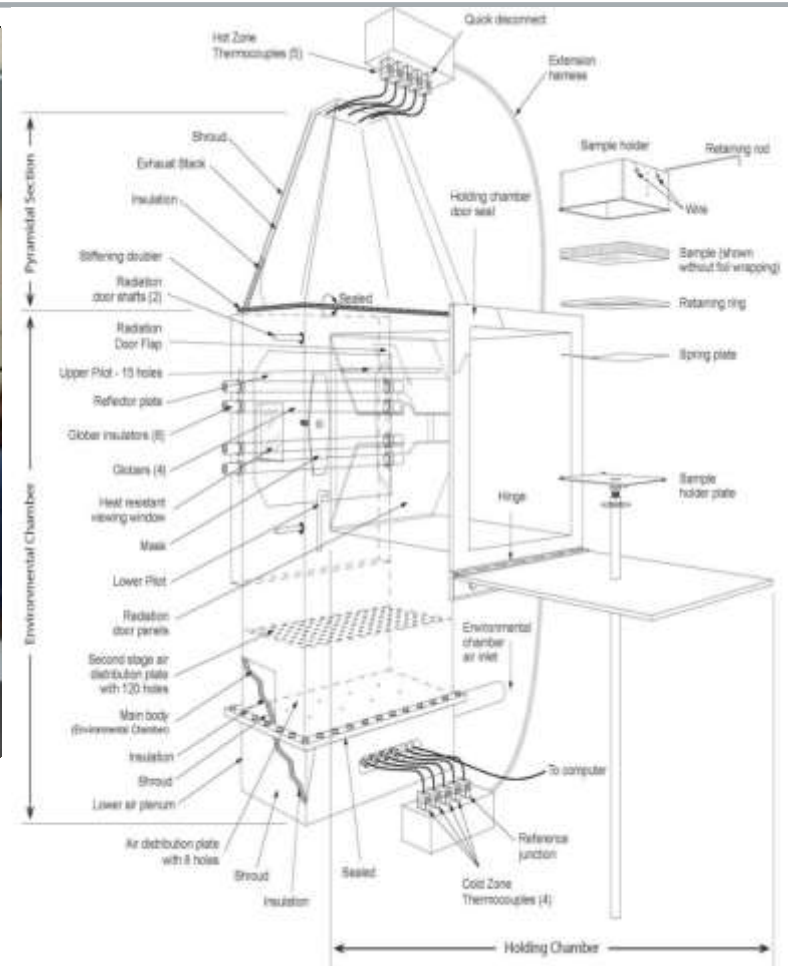
* Presented June 2012

HR2 - Next Generation OSU



Design and Other Changes

- Elimination of cooling flow / inner chimney
- Insulation / metal wall specification changes
- Coupon location in chamber specified
- Air and methane flows controlled via MFCs
- Single lower Tcouple - DAQ correction
- HFG calibration / limit changes (3.65 W/cm^2)
- Methane calibration and cal factor correction
- Multiple additional procedural changes



**Presented October 2016*

Anticipated Improvements

- **Repeatability** driven by design and cal changes
- **Reproducibility** increased via spec controls
- Cross industry variation greatly reduced

HR2 Development Goal and Status

- HR2 Goal: Define a robust method to determine peak and total heat release that improves repeatability and reproducibility when compared with OSU

History / Status

- NASA Technical Readiness Level (TRL) model adopted
- TRL 4 - Robustness completed - calibration factor variation < 5%
- TRL 5 - Repeatability completed - CoV improvement demonstrated
- HR2 development is in **TRL 6 - Reproducibility**
 - Individual coupon type CoV and ANOVA evaluation
 - Success criteria will be determined by the OSU / HR2 task group*

* Key members: Mike Burns (FAATC), Martin Spencer (MarlinEngineering), Mike Schall (Deatak), Jan Christian Thomas (Airbus), Yaw Agyei (Boeing BR&T), Kent Wenderoth (Herb Curry), Hiroaki Fujioka (Chemitox)

HR2 Tailored TRL Development Model

TRL 6 - *Reproducibility* - variation in measurements taken on the same specimens under the same conditions using different machines.

➔ Gate 6 / Enter **TRL 7**: Individual coupon type CoV and ANOVA evaluation

TRL 7 - *Range* - demonstrated ability to test a range of coupon materials and configurations. Establish pass/fail criteria for HR2 total and peak heat release.

➔ Gate 7 / Enter **TRL 8**: Results over a range of specimen types that are consistent with OSU empirical results.

TRL 8 - *Documentation* - Final drawings and methods released, equipment “qualified” through test and demonstration. Documented test guidance finalized.

➔ Gate 8 / Enter **TRL 9**: Final unit drawings and test methods released.

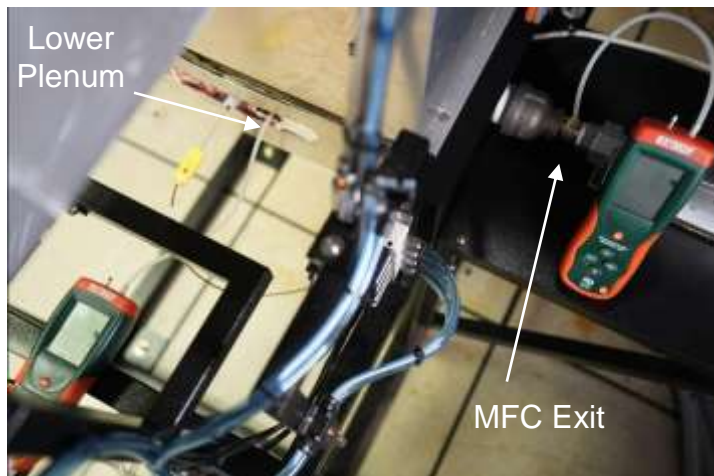
TRL 9 - *Round Robin* - multiple production units performance verified by successful round-robin testing.

➔ Gate 9 / **Completion**: Individual coupon type reproducibility verified on multiple production units.

*Presented October 2023

Boeing HR2 – Status Update

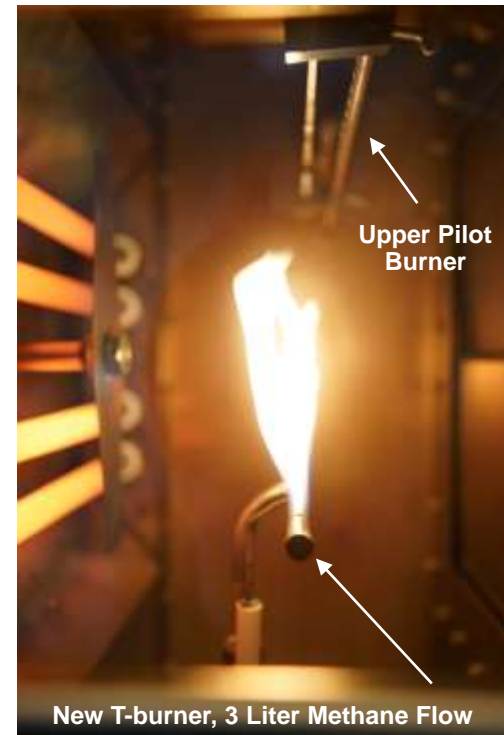
- Marlin HR2 unit installed in Seattle Flam lab
- Primary operator is Yonas Behboud
- Sierra and Alicat MFC's connected and functional
- Air pressure is measured in two locations
 - MFC exit – 11.1 inches of water
 - Lower plenum – 12.2 inches of water
- ✓ Pressures and operating parameters are aligning with the FAA TC data



Boeing HR2 – Status Update

- Recent change to 3-liter methane calibration flow location:
 - Was: Upper Pilot Burner
 - Is: Lower Pilot – New T-Burner*
- Software and hardware updated to accommodate changes
- New T-burner purchased from Marlin Engineering and installed
- Operating parameters data sets gathered per Chapter A4 updated document (March draft) for both MFCs (30 – Sierra, 15 – Alicat)
 - Average Baseline Gas Temperature
 - Thermal Stability Temperature (TST)
 - Calibration Factor

*Rationale explained in M. Spencer's presentation



Chapter A4 - Operating Parameter Updates

Table A4-2. Nominal Operating Parameters/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)	275	285	295
Calibration Factor Ranges	SLPM	2.85	3.00	3.15
	W/°C	19.0	20.0	21.0
	3 SLPM ΔT (°C)	85.3	89.6	94.3
Interspace Pressure	inH2O	0.40	0.55	0.70
Lower Plenum Pressure	inH2O	11.0	12.5	14.0
Methane Gas Supply Pressure	PSIG	20	25	30
Main Air Supply Pressure	PSIG	20	25	30
Mixing Air Supply Pressure	PSIG	20	25	30
Thermal Stability Temperature (TST)	20-sec average (°C)	360	370	380
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)	650	700	750
	Methane (mL/min)	105	120	135

Prior Ranges
(Ref. Only)

270 – 290 °C

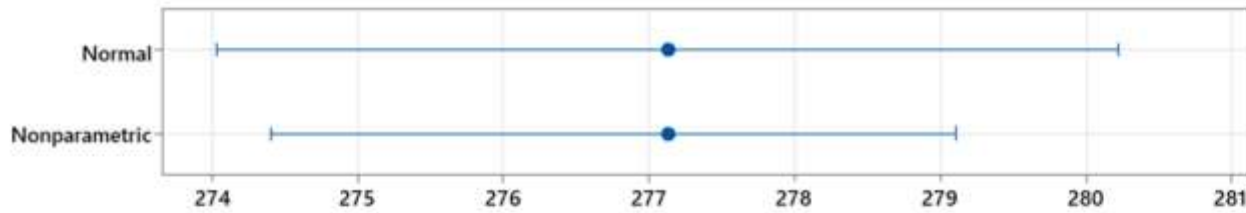
15 – 19 W / °C

365 – 395 °C

Sierra Operating Parameter Data - Baseline

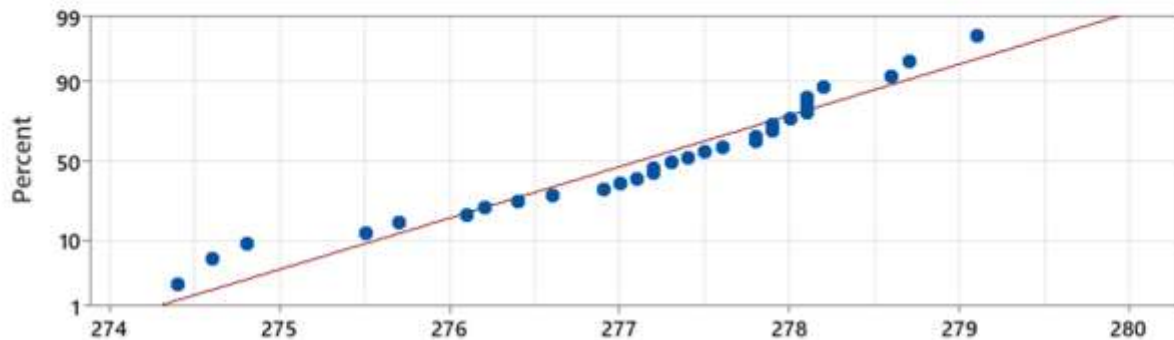
Tolerance Interval Plot for Baseline (°C)

95% Tolerance Interval
At Least 95% of Population Covered



Statistics	
N	30
Mean	277.127
StDev	1.212
Normal	
Lower	274.031
Upper	280.222
Nonparametric	
Lower	274.400
Upper	279.100
Achieved Confidence	44.6%
Normality Test	
AD	0.693
P-Value	0.063

Normal Probability Plot

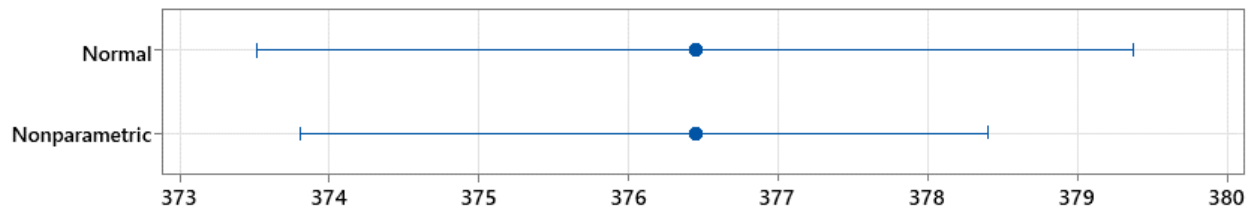
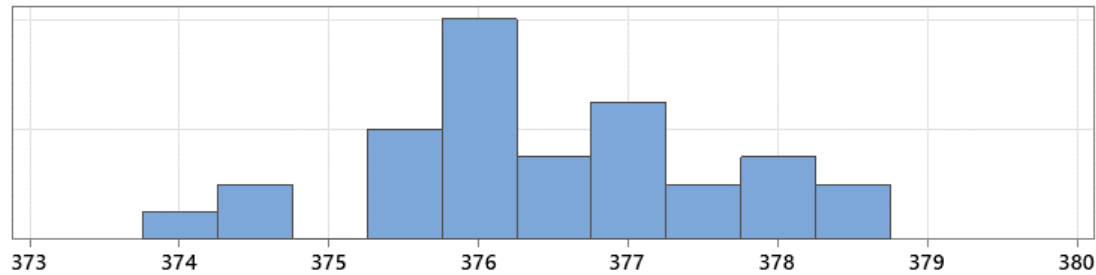


Average Baseline Exhaust Gas Temperature	No Flame (°C)	275	285	295
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Sierra Operating Parameter Data – TST Stability

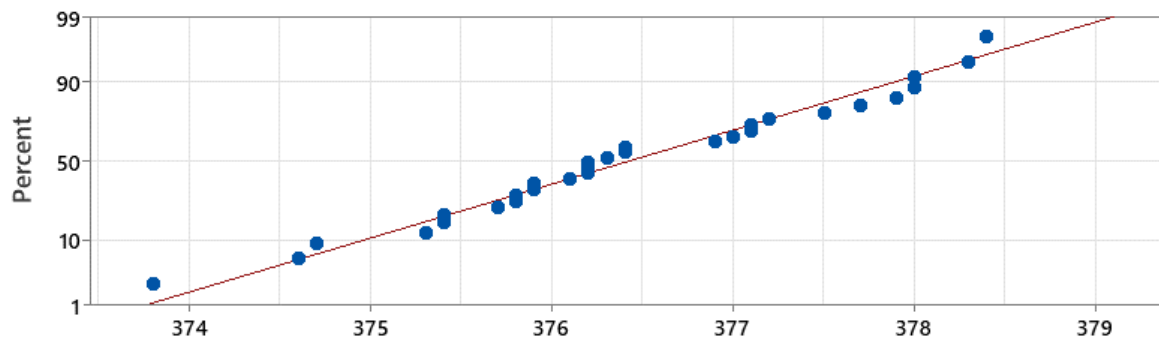
Tolerance Interval Plot for TST (°C)

95% Tolerance Interval
At Least 95% of Population Covered



Statistics	
N	30
Mean	376.440
StDev	1.146
Normal	
Lower	373.512
Upper	379.368
Nonparametric	
Lower	373.800
Upper	378.400
Achieved Confidence	44.6%
Normality Test	
AD	0.281
P-Value	0.617

Normal Probability Plot

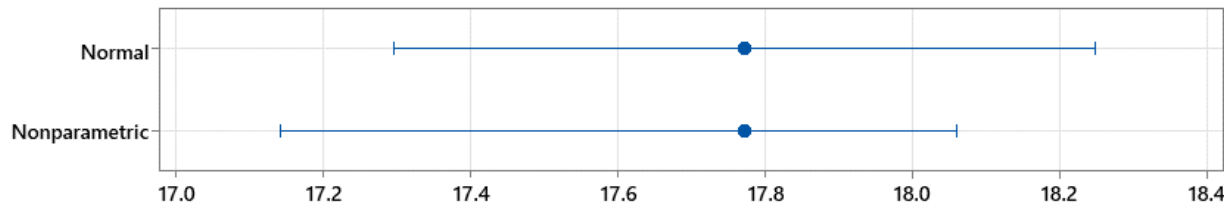
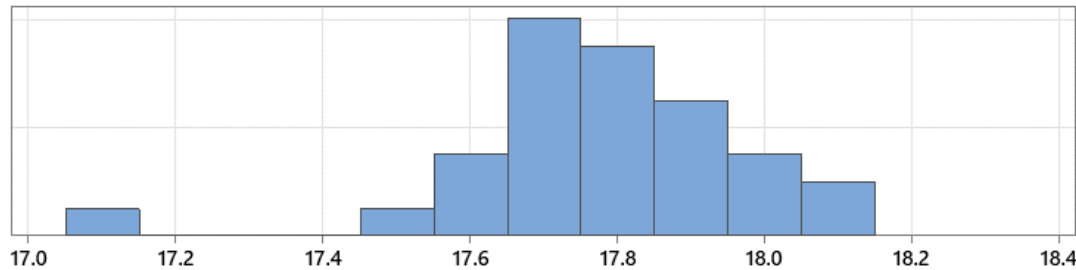


Thermal Stability Temperature (TST)	20-sec average (°C)	360	370	380
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Sierra Operating Parameter Data – Cal Factor

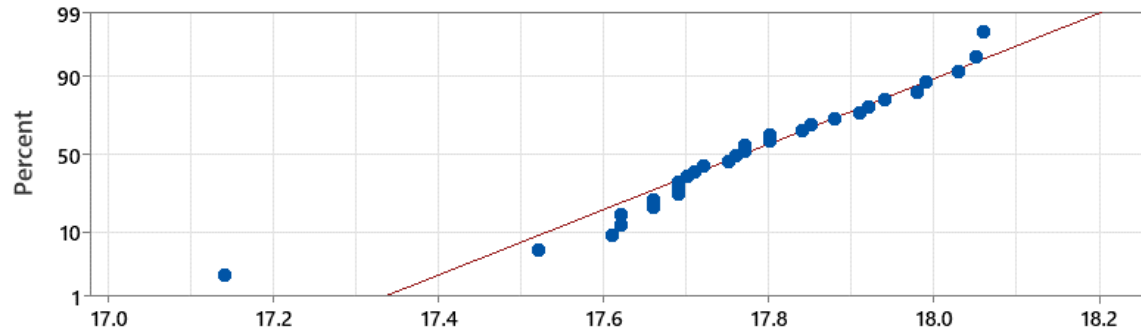
Tolerance Interval Plot for Calibration Factor (W/°C)

95% Tolerance Interval
At Least 95% of Population Covered



Statistics	
N	30
Mean	17.771
StDev	0.186
Normal	
Lower	17.296
Upper	18.246
Nonparametric	
Lower	17.140
Upper	18.060
Achieved Confidence	44.6%
Normality Test	
AD	0.522
P-Value	0.170

Normal Probability Plot



Calibration Factor Ranges	SLPM	2.85	3.00	3.15
	W/°C	19.0	20.0	21.0
	3 SLPM ΔT (°C)	85.3	89.6	94.3

Sierra MFC - Operating Parameter Data

Statistics

Variable	Mean	StDev	CoefVar	Minimum	Median	Maximum	Range
Baseline (°C)	277.13	1.21	0.44	274.40	277.35	279.10	4.70
TST (°C)	376.44	1.15	0.30	373.80	376.25	378.40	4.60
Calibration Factor (W/°C)	17.771	0.186	1.05	17.140	17.765	18.060	0.920
Delta T	99.313	1.025	1.03	97.700	99.450	102.500	4.800

New Spec
275 -295
360 - 380
19 - 21
85.3 - 94.3

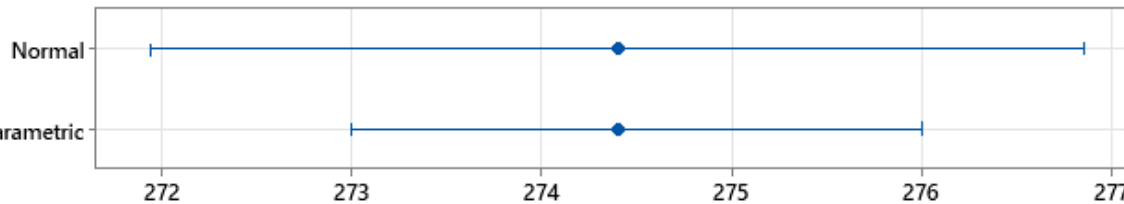
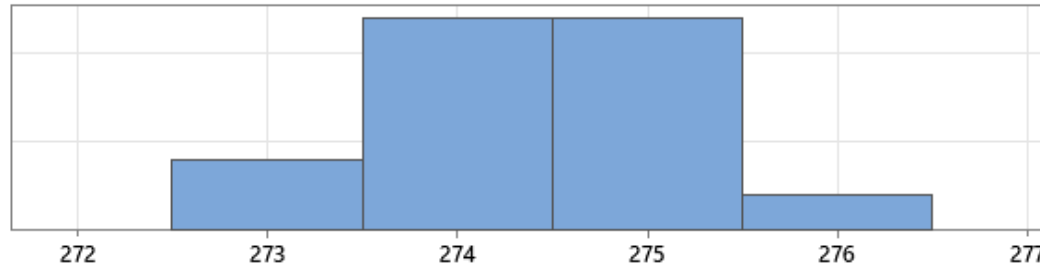
- Average Baseline Gas Temperature is within range (277°C)
- Thermal Stability Temperature is within range (377°C)
- Calibration Factor is outside of range (below low end by 1.23)
- Delta T is outside of range (over high end by 5°C)

- Adjusted Calibration Factor Mean 18.04

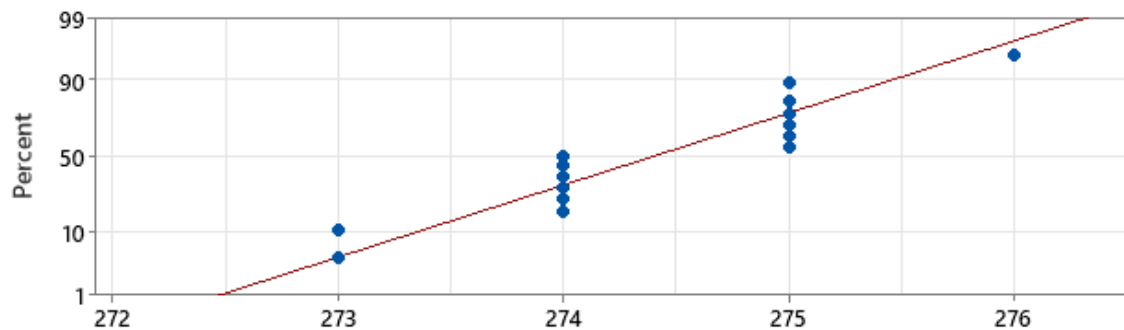
Alicat Operating Parameter Data - Baseline

Tolerance Interval Plot for Baseline (°C)

95% Tolerance Interval
At Least 95% of Population Covered



Normal Probability Plot

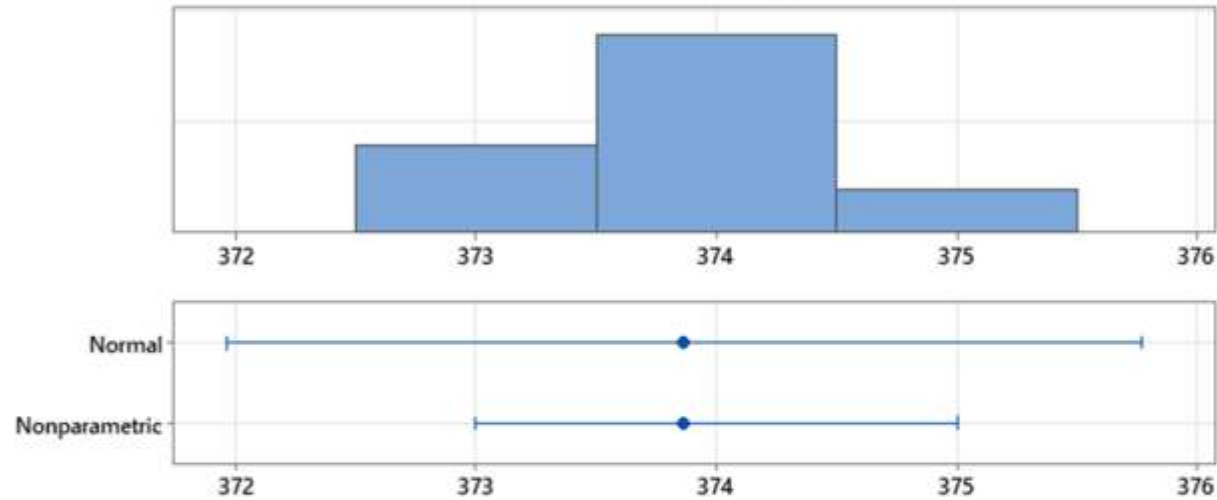


Statistics	
N	15
Mean	274.400
StDev	0.828
Normal	
Lower	271.945
Upper	276.855
Nonparametric	
Lower	273.000
Upper	276.000
Achieved Confidence	17.1%
Normality Test	
AD	0.933
P-Value	0.013

Average Baseline Exhaust Gas Temperature	No Flame (°C)	275	285	295
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Alicat Operating Parameter Data – TST Stability

Tolerance Interval Plot for TST (°C)
95% Tolerance Interval
At Least 95% of Population Covered



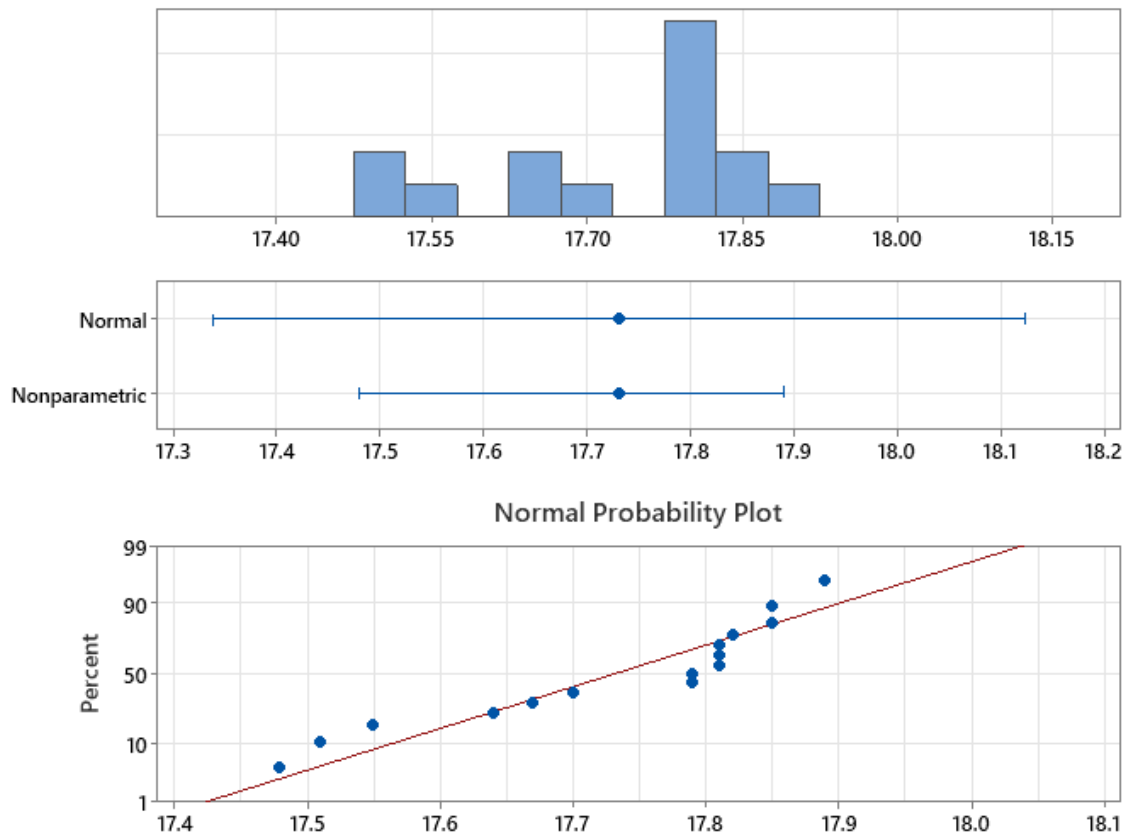
Statistics	
N	15
Mean	373.867
StDev	0.640
Normal	
Lower	371.969
Upper	375.764
Nonparametric	
Lower	373.000
Upper	375.000
Achieved Confidence	17.1%
Normality Test	
AD	1.573
P-Value <	0.005

Thermal Stability Temperature (TST)	20-sec average (°C)	360	370	380
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Alicat Operating Parameter Data – Cal Factor

Tolerance Interval Plot for Calibration Factor (W/°C)

95% Tolerance Interval
At Least 95% of Population Covered



Statistics	
N	15
Mean	17.731
StDev	0.132
Normal	
Lower	17.339
Upper	18.123
Nonparametric	
Lower	17.480
Upper	17.890
Achieved Confidence	17.1%
Normality Test	
AD	0.847
P-Value	0.022

Calibration Factor Ranges	SLPM	2.85	3.00	3.15
	W/°C	19.0	20.0	21.0
	3 SLPM ΔT (°C)	85.3	89.6	94.3

Alicat MFC - Operating Parameter Data

Statistics

Variable	Mean	StDev	CoefVar	Minimum	Median	Maximum	Range
Baseline (°C)	274.40	0.828	0.30	273.00	274.00	276.00	3.00
TST (°C)	373.87	0.640	0.17	373.00	374.00	375.00	2.00
Calibration Factor (W/°C)	17.731	0.132	0.75	17.480	17.790	17.890	0.410
Delta T	99.533	0.743	0.75	99.000	99.000	101.000	2.000

New Spec
275 - 295
360 - 380
19 - 21
85.3 - 94.3

- Average Baseline Gas Temperature is outside of range (below low end by 1°C)
 - Thermal Stability Temperature is within range (374°C)
 - Calibration Factor is outside of range (below low end by 1.27)
 - Delta T is outside of range (over high end by 5°C)
-
- Adjusted Calibration Factor Mean 18.00

TRL 7 – Plan

SPECIMEN FAMILIES

Honeycomb Core Panels		Description	Provider	Contact	Average Peak	Peak Std Dev	Average Total HR	Total HR Std Dev
1	Thin Core	AerFilm LHR HA211 Adhesive on S-SSCP	Schneller	David Baker	40.2	4.7	45.5	5.4
2	Thick Core	0.75" core, 4 ply/4ply with dec lam on both sides	Boeing	Yonas Behboud				
3	Honeycomb Core / Al plys	0.40" core, 1 ply/1 ply, with Airbus deco foil (or painted)	AIRBUS (Diehl, Laubheim)	C. Thomas/G. Hansen				
Thermoplastic Panels								
4	KYDEX FST	PC copolymer 0.080" thick, integrally colored, opaque	Sekisui KYDEX	Michael Miler	41	7	36	10
5	Boltaron 9850E	PVC/PMMA 0.08" thick	Boltaron/Simona	Jessica Moore				
6	Polyphenyl Sulphone	PPSU 0.080" thick, one side primed and painted	Solvay/Mankewicz	W. Hamm/G. Hansen				
7	Ultem 9085	PEI 0.080"	Sabic	Ralph Buoniconti				
8	Lexan F6000	PC 0.080" thick, integrally colored (anticipated fail)	Rohm (ex-SABIC)	Ralph Buoniconti				
9	Decorative Laminate	AerForm 0.065"	Schneller	David Baker	50.9	5.3	47.2	10.9
Laminate								
10	Phenolic Glass Laminate	4 ply pre-preg, with Airbus deco foil	AIRBUS (Diehl, Laubheim)	Christian Thomas				
Alternate Thermoplastic Panels								
5a	*Boltaron 9815N	PVC/PMMA 0.08" thick	Boltaron/Simona	Jessica Moore				
5b	**KYDEX 6565	PVC/PMMA 0.08" thick, integrally colored	Sekisui KYDEX	Michael Miler	44	11	26	15

* Option to #5 - 9850E

** Option to #5 - Boltaron

Number of coupons needed (per row) 10 samples for the OSU, 10 samples for HR2, 10 samples for buffer

Mike B. can store specimens at TC conditioning chamber

30 samples per construction

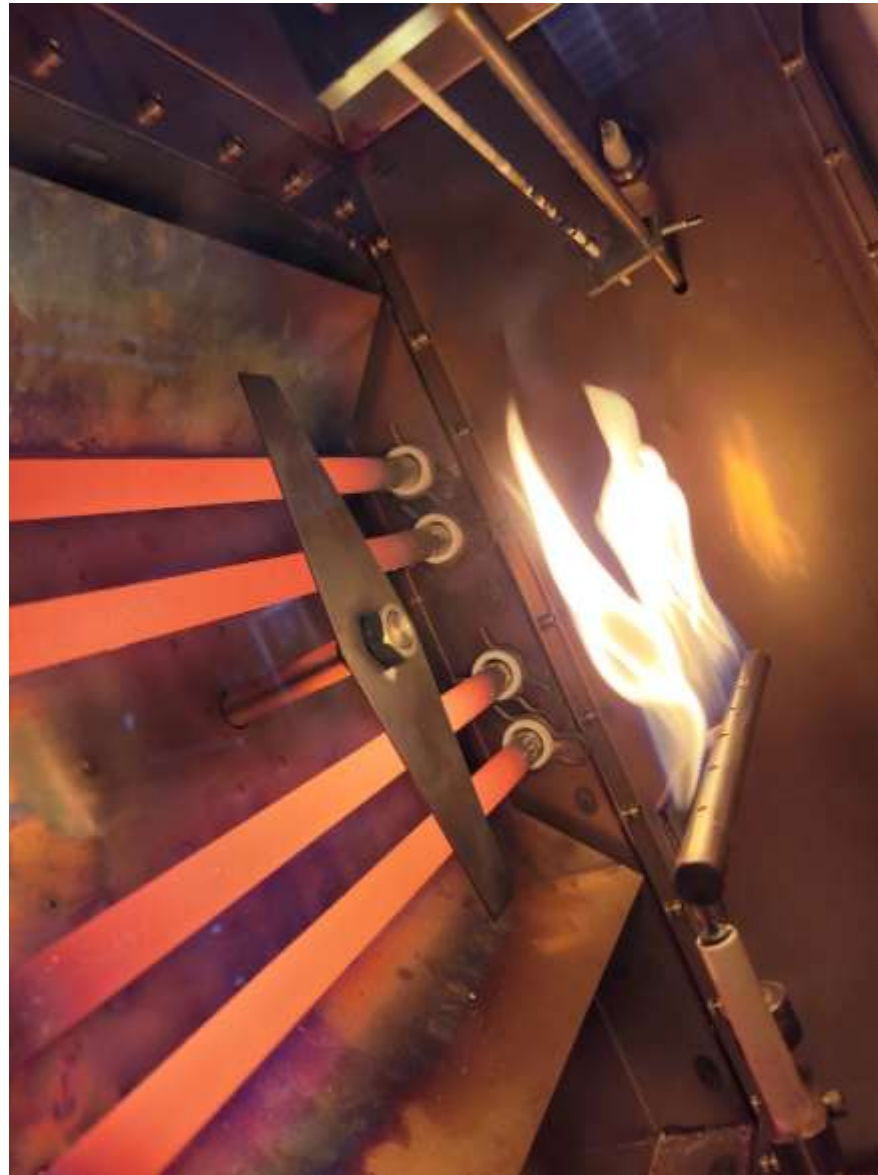
- Test 10 coupons each on 1 - OSU ('golden unit') and 1 - HR2 unit
- Thank you to those who are supporting this activity!

Next Steps

Anticipated Schedule

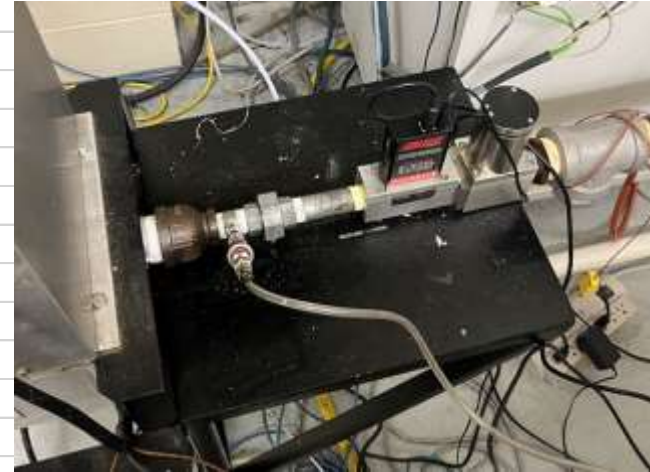
Boeing HR2 Delivery and Installation	Complete
Boeing HR2 Unit Response Experiment	In Progress
Boeing HR2 Airflow Evaluation (MFC, Sonic Choke)	May 2024
Boeing HR2 TRL 6 Testing and Data Analysis Complete	June 2024
Herb Curry Delivery and Installation	In Progress
Herb Curry Unit Response Experiment	June 2024
Herb Curry TRL 6 Testing and Data Analysis	July 2024
Chemitox HR2 Delivery and Installation	Complete
Chemitox HR2 Unit Response Experiment	TBD
Chemitox TRL 6 Testing and Data Analysis Complete	TBD
Airbus HR2 Upgrades	TBD
TRL 7	TBD

Burning Questions?



Operating Parameter Data – FAA TC Comparison

	Baseline	TST	Delta T	Cal. Factor	Lower Plenum Static Pressure (inwc)	Line Static Pressure (inwc)	Lab Temp (Deg F)
Run 1	291	388	97	18.48	12.2	11.45	69
Run 2	289	386	97	18.46			
Run 3	288	388	100	17.89			
Run 4	289	387	98	18.33			
Run 5	290	387	97	18.46			
Run 6	290	387	97	18.43			
Run 7	289	387	98	18.20			
Run 8	289	387	97	18.41			
Run 9	289	387	98	18.22			
Run 10	287	387	100	18.00			
AVG	289	387	98	18.29			
STDEV	1.1	0.6	1.1	0.2			
% STDEV	0.4%	0.1%	1.1%	1.1%			



<FAA TC Data: Marlin HR2 – Alicat MFC (Boeing Alicat Data)>

- Lower plenum pressure 12.2 in H₂O (Boeing 12.2 in H₂O)
- Average Baseline Gas Temperature 289°C (Boeing 276°C)
- Thermal Stability Temperature is within range 387°C (Boeing 375°C)
- Delta T is 98°C (Boeing 99°C)
- Calibration Factor is 18.29 (Boeing 18.02)

New Spec

275 -295

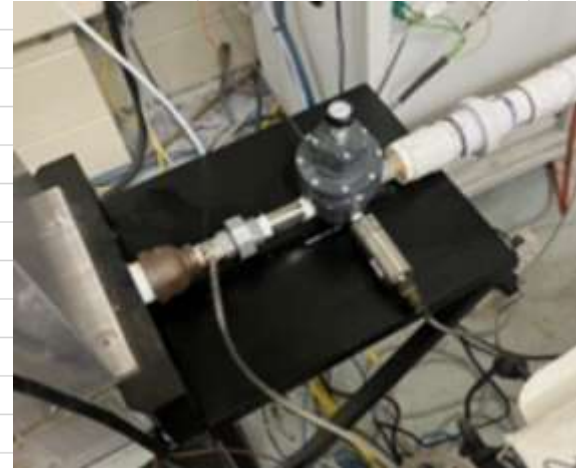
360 - 380

19 - 21

85.3 - 94.3

Operating Parameter Data – FAA TC Comparison

	Baseline	TST	Delta T	Cal. Factor	Lower Plenum Static Pressure (inwc)	Line Static Pressure (inwc)	Lab Temp (Deg F)
Run 1	287	384	98	18.37	12.2	11.45	71
Run 2	288	384	95	18.83			
Run 3	287	384	97	18.46			
Run 4	288	385	96	18.60			
Run 5	289	387	98	18.26			
Run 6	290	385	95	18.81			
Run 7	288	387	99	18.13			
Run 8	292	388	96	18.71			
Run 9	289	386	97	18.52			
Run 10	290	387	97	18.50			
AVG	289	386	97	18.52			
STDEV	1.5	1.5	1.3	0.2			
% STDEV	0.5%	0.4%	1.4%	1.2%			



<FAA TC Data: Marlin HR2 – Sonic Choke (Boeing Alicat Data)>

- Lower plenum pressure 12.2 in H₂O (Boeing 12.2 in H₂O)
- Average Baseline Gas Temperature 289°C (Boeing 276°C)
- Thermal Stability Temperature is within range 386°C (Boeing 375°C)
- Delta T is 97°C (Boeing 99°C)
- Calibration Factor is 18.52 (Boeing 18.02)

New Spec

275 -295

360 - 380

19 - 21

85.3 - 94.3