HR2 Development - TRL 5 Update

Presented by: Brian Johnson, The Boeing Company

Prepared by: Yaw Agyei and Brian Johnson, both of The Boeing Company

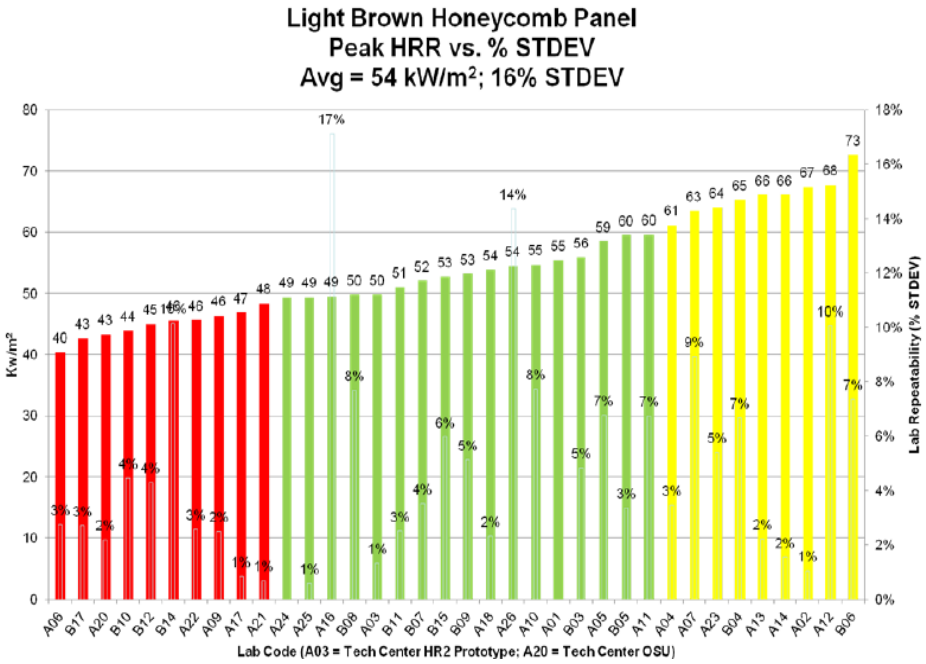
June 2019 MFTF

OSU Test Method

14CFR25.853(d)

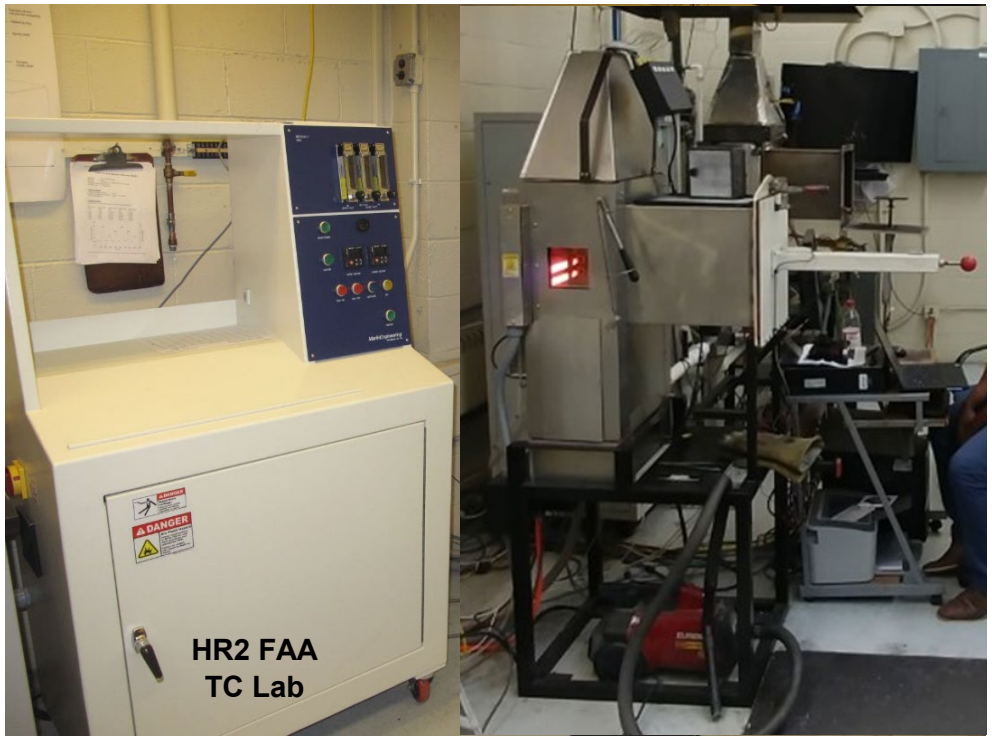
- Added in 1986
- Current FAR - Appendix F Part IV
- Applicable to interior exposed surfaces greater than 144 square inches
- Measure heat release as a function of time
- Test code: HR

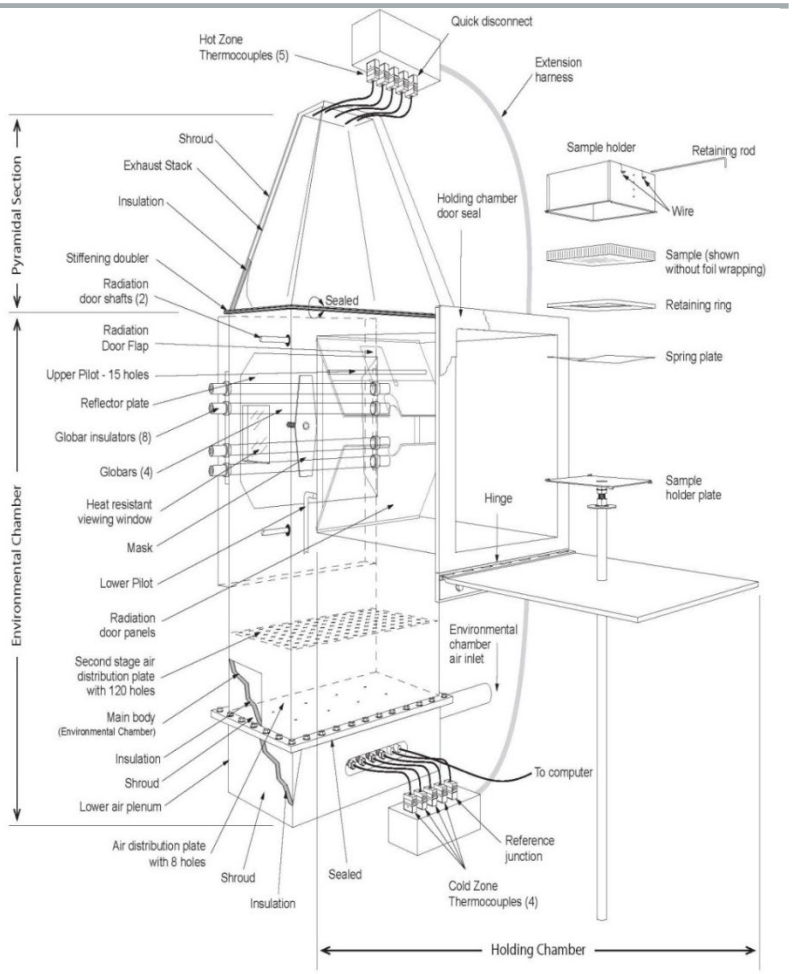
- Reproducibility challenges persist
- Specification does not tightly control some key parameters
- Decades of certification data in use



**Presented June 2012*

HR2 - Next Generation OSU





**Presented October 2016*

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

Anticipated Improvements

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

Introduction

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

Status

- NASA Technical Readiness Level (TRL) model adopted
- TRL 4 - Robustness completed - DOE defined key parameters and variation
  - Identification of Key Parameters influence levels
  - Reduced variation in Calibration Factors
  - Improved uniformity of Stability Runs
- HR2 is in TRL phase 5 - Repeatability
  - Phase I completed in Fall 2018 - inconclusive, indicated more work was needed

HR2 Development TRLs & Gates

TRL 5 - *Repeatability* - variation in measurements taken on the same item under the same conditions. Homogenous coupon tested multiple times using one unit.

➡ Gate 5 / Enter **TRL 6**: Coefficient of Variation (CoV) improvement vs. OSU

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

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

TRL 7 - *Range* - Finalized prototype equipment demonstration on range of production configurations. HR2 pass/fail criteria (peak/total) established.

➡ Gate 7 / Enter **TRL 8**: Consistent results over a range of sample types

TRL 8 - *Guidance* - drawings release, equipment built to standards, 'qualified' through test and demonstration.

➡ Gate 8 / Enter **TRL9**: Qualification criteria and test guidance established

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

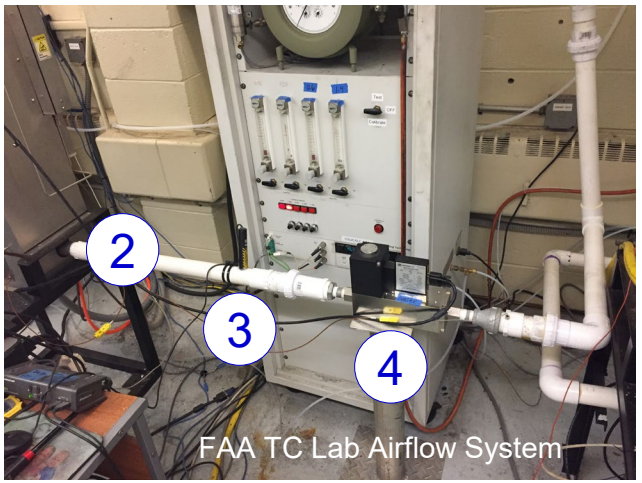
➡ Gate 9 / **Production Readiness**: Significant R&R improvements vs. OSU

HR2 Changes Prior to TRL 5 Phase Two

Equipment and Process Changes to Improve Repeatability

- Marlin prototype voltage control system installed on OSU and HR2
  - Active monitoring and control of globar voltage and current
- Standard coupon preparation process, materials, and tools[1]
- Mass flow controller calibration verified[4], downstream meter installed[2]
- Airflow humidity gauge installed and monitored[3]
- Daily cleaning and calibration prior to testing
- Standard operating process and intervals

FAA TC Lab Coupon Prep Station

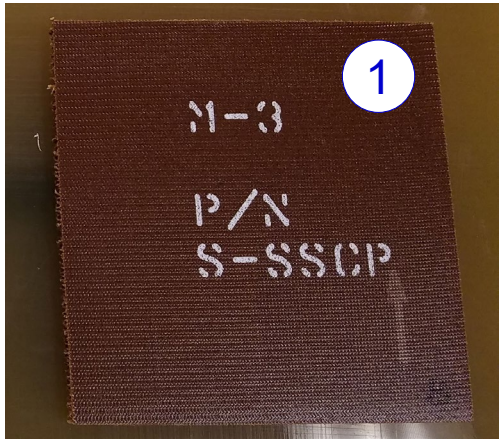


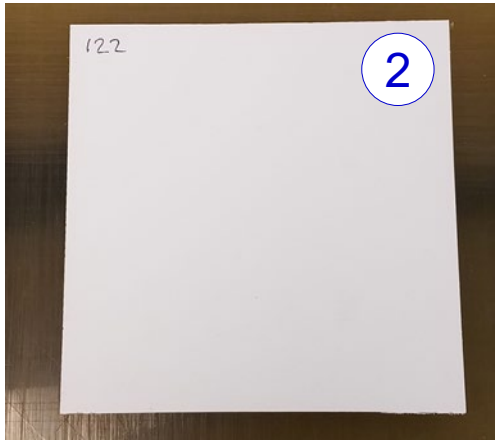
FAA TC Lab Airflow System

TRL 5 - Phase Two Test Plan

100 randomized samples of 2 homogenous coupon types

1. Honeycomb Sandwich Panel (Schneller) - provided by Schneller
2. Honeycomb Sandwich Panel with Decorative (HPD) - provided by Boeing





Two test locations - two instruments

- Marlin Engineering OSU - tested May 6 - 10th at Boeing, Everett, WA <baseline>
- Marlin Engineering HR2 - tested May 20 - 24th at FAA TC, Egg Harbor Twp, NJ

Repeatability evaluated using the coefficient of variation (CoV = σ/μ)

- Anticipated HR2 CoV improvement versus OSU baseline - no exact target defined

TRL 5 Phase II Test Matrix - OSU and HR2

Unit	Day	Set	Order	Coupon ID	Dec Delam	Coupon Type	File Name	Week Day	Test Start Time	Room Temp (°F)	Room Humidity (% RH)	Supply Air Temp (°C)	Supply Air Pressure (mmHg)	Air Flow / Split Ratio	Sample Holder #	Peak (kW/m2)	Peak Time (sec)	2-Min Total HR (kW-min/m2)	Tpile Baseline (mV/°F)
OSU	1	1	4	HPD-118	X	HPD	OSU-Day1-Set1	M	2:45 AM	68.0	50	22	198	2.5	1	47.59	17	42.12	26.84
OSU	1	1	6	HPD-5		HPD	OSU-Day1-Set1	M	2:59 AM	68.1	50	22	198	2.5	3	39.08	19	46.69	26.57
OSU	1	2	8	HPD-134		HPD	OSU-Day1-Set2	M	3:15 AM	68.1	50	22	198	2.4	1	45.48	15	45.57	26.94
OSU	1	2	9	HPD-55	X	HPD	OSU-Day1-Set2	M	3:22 AM	68.0	49	22	198	2.4	2	43.27	17	43.00	26.67
OSU	1	2	12	HPD-26		HPD	OSU-Day1-Set2	M	3:45 AM	68.0	50	22	198	2.4	1	45.57	16	44.21	26.60
OSU	1	2	13	HPD-75		HPD	OSU-Day1-Set2	M	3:52 AM	68.1	50	22	198	2.4	2	42.00	17	45.24	26.46
OSU	2	1	15	HPD-27		HPD	OSU-Day2-Set1	T	9:42 AM	68.4	47	21	198	2.4	2	47.42	16	48.28	26.69
OSU	2	1	16	HPD-38		HPD	OSU-Day2-Set1	T	9:50 AM	68.5	47	21	197	2.4	3	33.53	21	40.92	27.04
OSU	2	1	17	HPD-111	X	HPD	OSU-Day2-Set1	T	9:58 AM	68.4	46	21	197	2.4	4	38.73	18	41.49	26.78
OSU	2	1	21	HPD-52		HPD	OSU-Day2-Set1	T	10:31 AM	68.6	46	21	197	2.5	4	38.53	20	44.61	26.58
OSU	2	2	23	HPD-80		HPD	OSU-Day2-Set2	T	10:47 AM	68.2	48	21	197	2.5	2	41.07	17	47.28	27.04
OSU	2	2	26	HPD-135		HPD	OSU-Day2-Set2	T	12:42 PM	68.4	47	22	198	2.4	1	45.21	14	46.61	26.80
OSU	2	2	29	HPD-44		HPD	OSU-Day2-Set2	T	1:12 AM	68.4	48	22	198	2.4	4	43.79	17	44.64	26.71
OSU	2	3	31	HPD-58	X	HPD	OSU-Day2-Set3	T	1:33 AM	68.3	48	22	199	2.4	2	41.66	17	42.94	27.04
OSU	2	3	33	HPD-72	X	HPD	OSU-Day2-Set3	T	1:48 AM	68.3	48	22	199	2.4	4	36.67	17	42.23	26.83
OSU	2	4	38	HPD-24		HPD	OSU-Day2-Set4	T	2:25 AM	68.0	49	22	199	2.4	1	37.29	16	43.70	27.02
OSU	2	4	41	HPD-117		HPD	OSU-Day2-Set4	T	2:49 AM	68.1	49	22	198	2.4	4	40.62	17	44.76	26.82
OSU	2	5	43	HPD-120		HPD	OSU-Day2-Set5	T	3:06 AM	68.0	49	22	198	2.5	2	42.67	17	47.59	26.99
OSU	2	5	46	HPD-31		HPD	OSU-Day2-Set5	T	3:26 AM	67.8	49	22	198	2.4	1	44.21	16	49.03	26.69
OSU	2	5	47	HPD-59		HPD	OSU-Day2-Set5	T	3:33 AM	68.0	49	22	198	2.5	2	33.44	19	43.26	26.74
OSU	3	1	52	HPD-110	X	HPD	OSU-Day3-Set1	W	8:31 AM	68.4	47	21	200	2.5	1	43.38	17	46.03	26.88
OSU	3	2	60	HPD-69		HPD	OSU-Day3-Set2	W	9:41 AM	68.6	46	21	200	2.5	1	38.83	19	43.84	26.87
OSU	3	2	62	HPD-65		HPD	OSU-Day3-Set2	W	9:56 AM	68.4	46	21	200	2.5	3	37.74	20	42.91	26.79
OSU	3	2	63	HPD-48	X	HPD	OSU-Day3-Set2	W	10:03 AM	68.5	46	21	200	2.4	4	40.51	17	45.41	26.62
OSU	3	3	65	HPD-35	X	HPD	OSU-Day3-Set3	W	10:19 AM	68.2	47	21	200	2.4	2	44.89	17	45.55	27.01
OSU	3	3	66	HPD-46		HPD	OSU-Day3-Set3	W	10:25 AM	68.2	47	21	200	2.4	3	40.53	17	44.63	26.87
OSU	3	3	69	HPD-53		HPD	OSU-Day3-Set3	W	10:48 AM	68.1	48	21	199	2.4	3	35.25	23	42.63	26.64
OSU	3	4	73	HPD-126	X	HPD	OSU-Day3-Set4	W	12:30 PM	68.5	48	22	199	2.5	1	40.96	18	40.86	26.79
OSU	3	5	78	HPD-61	X	HPD	OSU-Day3-Set5	W	1:07 AM	68.4	49	22	199	2.4	2	44.56	16	46.00	26.79
OSU	3	5	79	HPD-136	X	HPD	OSU-Day3-Set5	W	1:15 AM	68.4	48	22	199	2.4	3	54.56	15	51.30	26.78
OSU	3	5	80	HPD-139		HPD	OSU-Day3-Set5	W	1:21 AM	68.5	48	22	199	2.4	4	39.05	17	47.67	26.55
OSU	3	5	82	HPD-93	X	HPD	OSU-Day3-Set5	W	1:35 AM	68.5	49	22	199	2.4	2	40.84	18	45.62	26.47
OSU	3	6	86	HPD-84		HPD	OSU-Day3-Set6	W	2:10 AM	68.2	49	22	200	2.4	1	35.09	19	39.99	27.02

Actual number of coupons tested: <*OSU*> Schneller - 101, HPD - 72

<*HR2*> Schneller - 99, HPD - 72

TRL 5 Test Results

General Observations

OSU vs HR2 Peak Time and Shape

- HR2 peak times were equivalent to OSU peak times
- Peak and 2-min total HR2 values were slightly lower than OSU*

Honeycomb Panel with Decorative (HPD) - Delamination

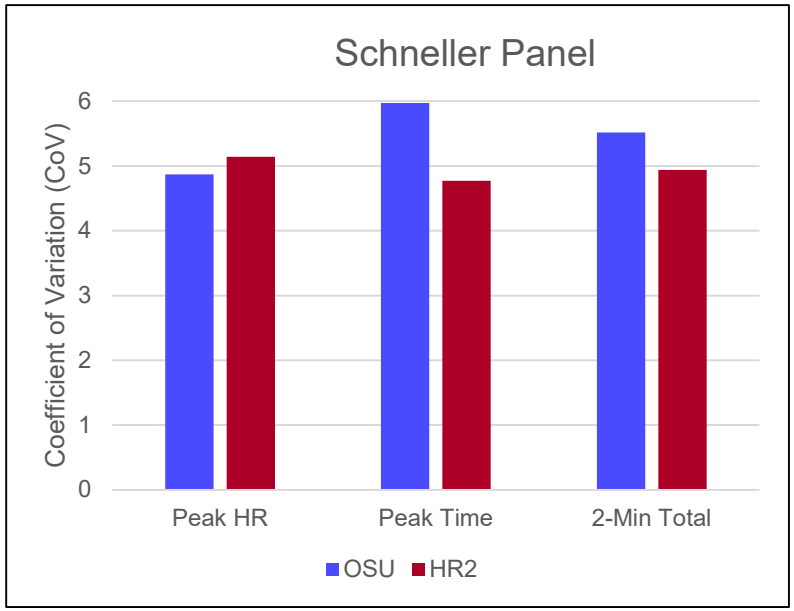
- Several HPD coupons exhibited varying degrees of decorative delamination
- Delamination effected peak, peak time and 2-min total heat release values

➢ For these reasons, we should rely primarily on Schneller panel data for comparison of OSU and HR2 repeatability

* May be due to airflow differences that will be discussed in the Breakout Session

Schneller Panel - Mean, Std Dev & CoV

		Mean	Std Dev	CoV
Peak Heat Release (kW/m^2)	OSU	48.65	2.37	4.87%
	HR2	45.49	2.34	5.14%
		Mean	Std Dev	CoV
Peak Time (sec)	OSU	45	2.66	5.97%
	HR2	43	1.95	4.51%
		Mean	Std Dev	CoV
2-Min Total Heat Release ($kW*min/m^2$)	OSU	41.32	2.28	5.51%
	HR2	36.77	1.82	4.94%



No Significant Difference (95% Confidence)

Statistically Significant Improvement (95% Confidence)

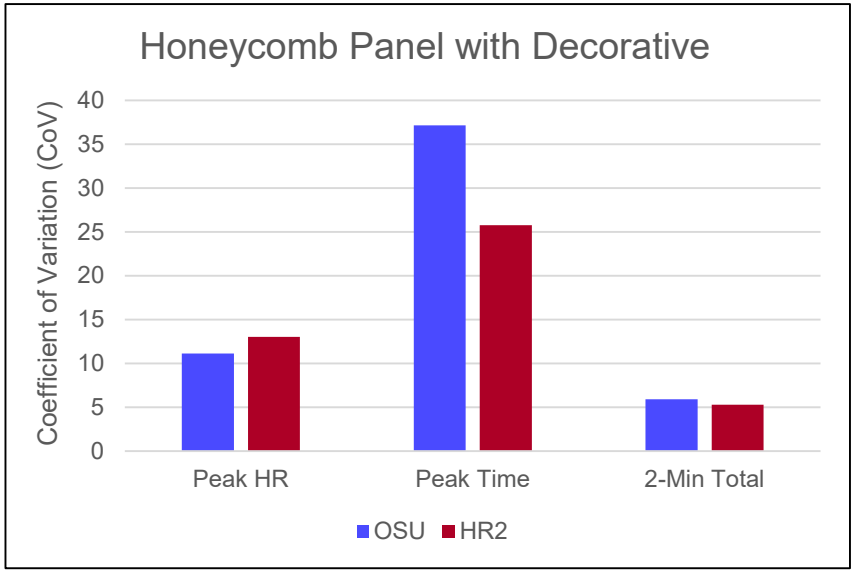
- HR2 standard deviation is lower than OSU for Peak, Peak Time, and 2-Min Total HR
- HR2 Peak Heat Release CoV is not significantly different than OSU
- HR2 Peak Time CoV and 2-Min Total CoV show a significant improvement vs. OSU

HPD Panel - Mean and CoV Comparison

		Mean	*Std Dev*	*CoV*
Peak Heat Release (kW/m^2)	OSU	41.44	4.62	11.16%
	HR2	41.04	5.35	13.04%

		Mean	Std Dev	CoV
Peak Time (sec)	OSU	18	6.82	37.17%
	HR2	20	5.05	25.76%

		Mean	Std Dev	CoV
2-Min Total Heat Release $(kW*min/m^2)$	OSU	45.23	2.68	5.93%
	HR2	41.68	2.21	5.29%



- Extent of delamination varied widely, but was not recorded nor considered in randomization
- Peak and peak time standard deviation and CoV are much larger than expected, this is probably due to delamination issues
- 2-Min Total Heat Release standard deviation values are comparable to the Schneller data Like the Schneller data, it shows a statistically significant improvement in HR2 CoV

TRL 5 Follow Up Activity - Air Flow

- Flow rate difference between OSU and HR2 during TRL 5 testing

TRL5 OSU Schneller Panels at 25.4 SCFM

	Peak	Peak Time	2-Min	n=101
Mean	48.65	45	41.32	
Std dev	2.37	2.66	2.28	
CoV	4.87%	5.97%	5.51%	

TRL 5 HR2 Schneller Panels at 23.0 SCFM

	Peak	Peak Time	2-Min	n=99
Mean	45.49	43	36.77	
Std dev	2.34	2.06	1.82	
CoV	5.14%	4.77%	4.94%	

Would mean values be closer if HR2 airflow was increased?

Post TRL 5 HR2 Schneller Panels at 25.0 SCFM

	Peak	Peak Time	2-Min	n=7
Mean	50.06	44	38.79	
Std dev	2.05	2.07	1.62	
CoV	4.10%	4.75%	4.17%	

- Positive correlation between airflow and heat release numbers

Next Steps

Evaluate Gate 5 Exit Criteria

Coefficient of Variation (CoV) improvement vs. OSU

Criteria to be defined and evaluated relative to OSU coupon CoV and be consistent with our stated goal of improving repeatability when compared to the OSU results.

- Criteria met in 2 of the 3 response factors measured (peak time, 2-min total)
- Peak heat release CoV was not significantly different

Potential Paths Forward

1. Proceed to TRL 6 - recognize significant repeatability improvements captured in current design and procedures. Focus efforts on improving reproducibility.
2. Stay in TRL 5 - continue to make incremental changes to improve repeatability - repeat HR2 testing once sufficient improvements are complete.

TRL 6

Reproducibility - variation in measurements taken on the same items under the same conditions using multiple HR2 machines.

- Gate 6 / Enter TRL 7: Individual CoV and ANOVA analysis
  - Coefficient of Variation (Std dev/mean) evaluated for each coupon type tested on each HR2 instrument independently - similar to TRL 5
  - Analysis of Variance (One-Way ANOVA) - one factor design addresses the question:

Does the instrument used effect the mean peak or total heat release for each coupon type?

- Two instruments minimum (FAATC Marlin, FAATC Deatak, others?)
- 2 - 3 coupon types (recommend same type used in TRL 5)
- Number of coupons per instrument (30 - 50?) - resolution, confidence desired?

Breakout Session Topics

- Next steps and direction for HR2 development
  - Activity plan
  - Timeline / schedule development
- Additional data discussion & lessons learned during phase two testing
  - Honeycomb panel with dec results and analysis
  - Airflow investigation - impact on mean values
  - Voltage conditioning system function and improvements
  - High current connection challenges and potential improvements

Questions?