



HR2 TRL 6 - Reproducibility Assessment



A look inside the HR2 burn chamber
AT coupon ignition

Test Results

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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 5 - Repeatability completed - CoV improvement demonstrated
 - Multiple changes to processes and equipment to reduce variation
 - Significant improvements demonstrated for both panel types
- HR2 is in **TRL Phase 6** - Reproducibility
 - Individual coupon type CoV and ANOVA evaluation

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

TRL 6 Test Plan

Approach

- Phase 1 - Evaluate units to ensure parameters fall within set ranges
- Phase 2 - Test 40 specimens and compare variation to reproducibility criteria
 - Revised to 24 specimens per sample type to accommodate instruments coming online

Instruments

Tested

- Marlin Engineering (ME) HR2 - FAA TC, Egg Harbor Township, New Jersey
- Deatak (DT) HR2 - FAA TC, Egg Harbor Township, New Jersey

Future Implementation

- Marlin Engineering HR2 - Airbus Fire Test Laboratory, Bremen, Germany
- Marlin Engineering HR2 - Boeing Test Laboratory, Seattle, Washington
- Marlin Engineering HR2 - Unit in construction at ME Facility, Bellingham, WA

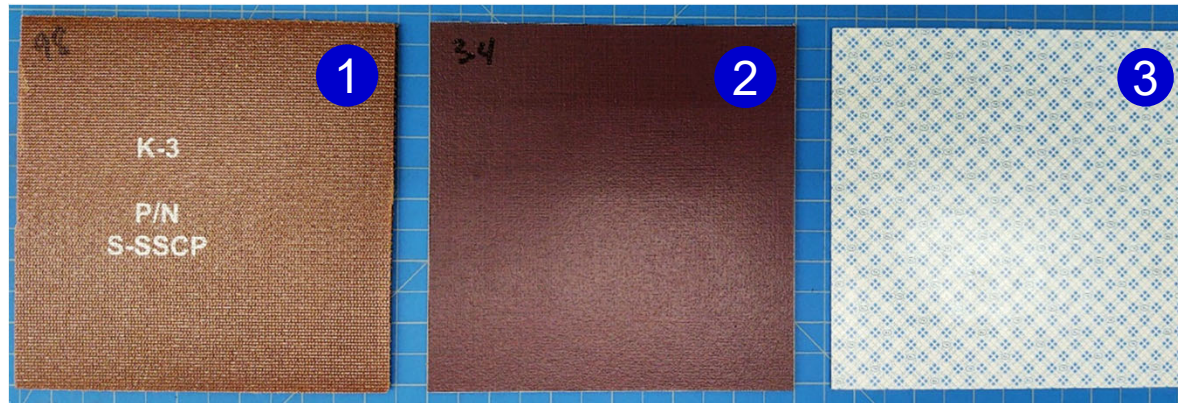
TRL 6 Test Plan

Test Coupons

- Coupons fabricated at Airbus (AT), Boeing (BPD), and Schneller (SPD)
- Panels shipped to Boeing for randomization and distribution
- Coupons stored in conditioning chamber (70°F, 50% RH) prior to test
- Develop plan to statistically evaluate variation due to storage effects*

24 randomized samples each of 3 homogenous coupon types per unit

1. Standard laminate panel (SPD) - provided by the FAA / Schneller
2. Boeing standard panel with decorative (BPD) - provided by Boeing
3. Aluminum panel with transfer tape (AT) - provided by Airbus



* Boeing panels exhibit very little additional variation when similarly stored

Phase 2 - Specimen Test Measurements

Test Procedure

- Detailed cold and hot start procedures were followed prior to testing
- Test per A4 Test Method in Aircraft Materials Fire Test Handbook Rev 3
- Specimens were tested in a randomized run order
- All specimens continuously conditioned from receipt until the time tested
- Coupons removed from conditioning in groups of threes, transferred into a sealed plastic bag, and removed from the bag just prior to testing
- Coupons weighed prior to wrapping
- Sample holders were marked and recorded prior to each run
- Loaded sample holders were weighed before and after testing
- Same materials and processes were used in sample preparation
- Thermopile stabilized to within 3% of baseline prior to specimen loading
- Ambient and supply air temp and humidity were recorded prior to each test
- Sample holders were cleaned with a wire brush after each test
- Thermocouples were cleaned after every five (5) runs

Phase 2 - Calibration and Test Data Log

Unit	Day	Set	File Name	Order	Sample Holder #	Specimen n Typ	Specimen #	Specimen ID	Specimen Mass (Pre-test, g)	Specimen Holder Specimen Mass (Pre-test, g)	Specimen Holder Specimen Mass (Post-test, g)	Specimen Mass Loss (g)	Test Start Time	Room Temp (°F)	Room Humidity (%RH)	Supply Air Temp (°C)	Supply Air Humidity (%RH)	Tpile Baseline (°C)	Peak (kW/m²)	Peak Time (sec)	2-Min Total HR (kW-min/m²)	5-Min Total HR (kW-min/m²)
FAA-ME	1	1	FAA-ME-Day1-Set1	1	1	AT	6	AT-6	161	534.5	531	3.5	10:22 AM	69.8	23	22.4	3.1	337.40	55.71	163	0.07	30.67
FAA-ME	1	1	FAA-ME-Day1-Set1	2	2	SPD	102	SPD-102	25	398.5	390	8.5	10:28 AM	69.3	23	22.4	2	333.80	44.15	47	31.91	71.04
FAA-ME	1	1	FAA-ME-Day1-Set1	3	3	SPD	44	SPD-44	25	397	389.5	7.5	10:35 AM	69.8	23	22.6	2	335.60	42.86	46	30.84	66.44
FAA-ME	1	1	FAA-ME-Day1-Set1	4	1	BPD	102	BPD-102	38.5	415.5	405.5	10	10:41 AM	71.4	24	22.5	2.5	335.70	45.36	20	18.91	37.43
FAA-ME	1	1	FAA-ME-Day1-Set1	5	2	SPD	3	SPD-3	25.5	398.5	390.5	8						333.70	42.26	49	30.40	67.15
FAA-ME	1	1	FAA-ME-Day1-Set1	6	3	SPD	96	SPD-96	26	397.5	389	8.5	10:55 AM	72.5	24	22.6	3.1	335.30	44.67	47	32.12	69.39
FAA-ME	1	1	FAA-ME-Day1-Set1	7	1	AT	87	AT-87	161	534	531	3	11:02 AM	69.3	24	22.5	2.1	335.30	61.00	155	0.41	34.43
FAA-ME	1	1	FAA-ME-Day1-Set1	8	2	SPD	29	SPD-29	25.5	398.5	390.5	8	11:08 AM	72.5	24	22.6	1.8	333.00	44.52	48	32.26	71.36
FAA-ME	1	1	FAA-ME-Day1-Set1	9	3	BPD	94	BPD-94	38	410	401	9	11:15 AM	70.2	24	22.5	2.3	334.50	44.83	18	20.44	37.43
FAA-ME	1	1	FAA-ME-Day1-Set1	10	1	AT	104	AT-104	161	535	530.5	4.5	11:21 AM	72.1	25	22.5	2.6	332.70	55.86	161	0.19	33.04
FAA-ME	1	2	FAA-ME-Day1-Set2	11	2	BPD	114	BPD-114	38.5	412.5	402.5	10	11:28 AM	72.1	25	22.4	2.6	332.50	46.72	19	20.85	44.42
FAA-ME	1	2	FAA-ME-Day1-Set2	12	3	SPD	60	SPD-60	25.5	397.5	389.5	8	11:36 AM	68.9	25	22.4	2.6	332.20	42.48	46	30.37	68.21
FAA-ME	1	2	FAA-ME-Day1-Set2	13	1	SPD	53	SPD-53	25.5	403	394.5	8.5	11:43 AM	72.7	26	22.5	1.8	333.50	45.43	47	31.60	68.66
FAA-ME	1	2	FAA-ME-Day1-Set2	14	2	AT	64	AT-64	161.5	531	527.5	3.5	11:50 AM	71.6	26	22.5	2.2	334.60	58.81	160	0.26	32.48
FAA-ME	1	2	FAA-ME-Day1-Set2	15	3	BPD	2	BPD-2	39	401	401		11:59 AM	71.8	25	22.6	2.6	333.50	44.60	19	17.98	35.10
FAA-ME	1	2	FAA-ME-Day1-Set2	16	1	AT	90	AT-90	161	534	531	3	12:06 PM	69.1	26	22.6	2.9	332.40	54.20	164	0.07	32.24
FAA-ME	1	2	FAA-ME-Day1-Set2	17	2	AT	62	AT-62	161.5	530.5	528	2.5	12:12 PM	71.8	27	22.6	2.8	330.20	54.73	165	0.34	34.73
FAA-ME	1	2	FAA-ME-Day1-Set2	18	3	SPD	50	SPD-50	25	398	389.5	8.5	12:19 PM	70.0	27	22.5	1.9	328.50	44.83	45	32.47	73.23
FAA-ME	1	2	FAA-ME-Day1-Set2	19	1	AT	19	AT-19	161.5	534.5	531.5	3	12:25 PM	71.8	28	22.7	2.2	332.90	54.88	160	0.24	30.88
FAA-ME	1	2	FAA-ME-Day1-Set2	20	2	BPD	17	BPD-17	38	412	402.5	9.5	12:32 PM	71.6	28	22.7	2.5	330.20	43.31	22	17.01	36.64
FAA-ME	1	3	FAA-ME-Day1-Set3	21	3	BPD	50	BPD-50	38	410.5	400.5	10	12:40 PM	70.0	28	22.6	2.8	331.80	46.49	20	22.49	45.63
FAA-ME	1	3	FAA-ME-Day1-Set3	22	1	SPD	78	SPD-78	25.5	403	394	9	12:46 PM	72.9	29	22.6	3.1	331.00	44.30	48	33.02	72.50
FAA-ME	1	3	FAA-ME-Day1-Set3	23	2	AT	57	AT-57	161	530.5	527.5	3	12:53 PM	69.4	29	22.4	1.8	332.50	57.45	159	0.32	34.56
FAA-ME	1	3	FAA-ME-Day1-Set3	24	3	BPD	98	BPD-98	38	410	400.5	9.5	12:59 PM	72.5	30	22.6	1.9	330.40	44.52	20	25.35	47.40
FAA-ME	2	1	FAA-ME-Day2-Set1	25	1	SPD	82	SPD-82	25.5	402	394.5	7.5	9:57 AM	71.4	21	22.1	2.4	330.40	41.95	50	31.25	68.31
FAA-ME	2	1	FAA-ME-Day2-Set1	26	2	AT	53	AT-53	160.5	530	527	3	10:03 AM	68.9	21	22.2	2.7	332.60	55.11	160	0.15	31.87
FAA-ME	2	1	FAA-ME-Day2-Set1	27	3	BPD	110	BPD-110	38	411	401	10	10:09 AM	71.1	21	22.3	3	330.00	41.20	21	19.35	38.06
FAA-ME	2	1	FAA-ME-Day2-Set1	28	1	SPD	37	SPD-37	25.5	403	394.5	8.5	10:17 AM	72.3	21	22.3	3.2	329.70	39.76	49	28.16	61.54
FAA-ME	2	1	FAA-ME-Day2-Set1	29	2	SPD	79	SPD-79	25	398.5	390	8.5	10:23 AM	68.7	21	22.3	2	331.70	40.90	50	30.23	64.51
FAA-ME	2	1	FAA-ME-Day2-Set1	30	3	BPD	37	BPD-37	39	411.5	401	10.5	10:31 AM	72.0	20	22.5	2.4	334.20	47.02	19	19.72	37.81
FAA-ME	2	1	FAA-ME-Day2-Set1	31	1	BPD	82	BPD-82	38.5	416	405.5	10.5	10:38 AM	72.3	21	22.4	2.7	331.70	45.43	20	26.03	50.53
FAA-ME	2	1	FAA-ME-Day2-Set1	32	2	SPD	51	SPD-51	26	399.5	391	8.5	10:44 AM	68.5	21	22.3	3	331.30	43.77	47	31.29	68.57
FAA-ME	2	1	FAA-ME-Day2-Set1	33	3	AT	44	AT-44	160.5	529	525.5	3.5	10:51 AM	72.9	21	22.4	2.5	333.20	55.11	157	0.14	30.54
FAA-ME	2	1	FAA-ME-Day2-Set1	34	1	BPD	69	BPD-69	38.5	415.5	405.5	10	10:57 AM	72.1	21	22.5	2.1	331.30	42.94	20	18.94	38.09
FAA-ME	2	2	FAA-ME-Day2-Set2	35	2	AT	82	AT-82	161.5	531	527.5	3.5	11:38 AM	70.5	20	22.5	2.6	336.10	58.51	163	0.07	31.95
FAA-ME	2	2	FAA-ME-Day2-Set2	36	3	BPD	85	BPD-85	38.5	411	401	10	11:43 AM	73.4	20	22.6	2.8	332.50	46.34	18	21.45	42.96
FAA-ME	2	2	FAA-ME-Day2-Set2	37	1	AT	73	AT-73	161.5	535	531	4	11:50 AM	69.3	20	22.6	2.6	331.90	58.13	159	0.41	34.79
FAA-ME	2	2	FAA-ME-Day2-Set2	38	2	BPD	34	BPD-34	38	412.5	402	10.5	11:57 AM	71.1	20	22.6	1.9	330.60	41.80	19	38.87	63.88
FAA-ME	2	2	FAA-ME-Day2-Set2	39	3	SPD	98	SPD-98	25.5	397.5	389	8.5	12:03 PM	72.0	20	22.6	2.4	330.70	41.27	45	30.51	68.09
FAA-ME	2	2	FAA-ME-Day2-Set2	40	1	AT	88	AT-88	161	534.5	531	3.5	1:07 PM	70.3	20	22.8	3	337.30	61.53	161	0.09	31.68
FAA-ME	2	2	FAA-ME-Day2-Set2	41	2	SPD	24	SPD-24	25.5	399	391	8	1:15 PM	71.1	20	22.8	1.8	332.90	44.75	51	33.64	73.82
FAA-ME	2	2	FAA-ME-Day2-Set2	42	3	SPD	55	SPD-55	25.5	398	389.5	8.5	1:21 PM	70.0	20	22.8	2.1	334.70	45.13	45	31.71	68.64
FAA-ME	2	2	FAA-ME-Day2-Set2	43	1	BPD	13	BPD-13	38.5	416	406	10	1:28 PM	72.5	20	22.9	2.5	335.70	49.97	38	43.78	65.39
FAA-ME	2	2	FAA-ME-Day2-Set2	44	2	BPD	61	BPD-61	38	412	402.5	9.5	1:35 PM	73.2	20	22.7	2.9	334.10	45.28	20	24.98	43.48
FAA-ME	2	3	FAA-ME-Day2-Set3	45	3	SPD	14	SPD-14	25	397.5	389.5	8	1:42 PM	70.9	20	22.6	1.9	333.00	43.62	44	31.15	69.00
FAA-ME	2	3	FAA-ME-Day2-Set3	46	1	BPD	118	BPD-118	38.5	416	406	10	1:49 PM	70.7	20	22.7	2.2	333.80	46.41	21	25.54	46.68
FAA-ME	2	3	FAA-ME-Day2-Set3	47	2	SPD	33	SPD-33	26	399.5	391	8.5	1:55 PM	72.1	20	22.6	2.5	332.40	44.83	45	32.21	71.12
FAA-ME	2	3	FAA-ME-Day2-Set3	48	3	SPD	15	SPD-15	25.5	398	389.5	8.5	2:02 PM	74.3	20	22.8	2.9	333.50	42.79	47	30.50	65.78
FAA-ME	3	1	FAA-ME-Day3-Set1and2	49	1	SPD	61	SPD-61	25.5	402	394	8.5	10:00 AM	73.9	20	22.5	2.6	334.80	43.01	45	30.69	64.74
FAA-ME	3	1	FAA-ME-Day3-Set1and2	50	2	BPD	97	BPD-97	38.5	412	401.5	10.5	10:07 AM	76.8	20	22.5	3.1	335.40	46.04	20	24.38	41.94
FAA-ME	3	1	FAA-ME-Day3-Set1and2	51	3	SPD	92	SPD-92	25.5	398	390	8	10:13 AM	72.3	20	22.5	2.2	331.40	40.74	47	30.56	67.53

- Actual number of coupons tested: 24 of each type per unit
- Tested for 3 days on ME unit, followed by 3 days on the DT unit
- Calibration factor determined on test day 1 only for each unit (ME, DT)
- Heat flux was measured, calibrated each day prior to testing (center, corners)

TRL 6 Test Results

General Observations

AT HR2 Peak Time

- AT HR2 peak times was ~ 160 seconds, almost fully outside of 2-minute total
- Calculated 5-minute total heat release for all coupon types as a result

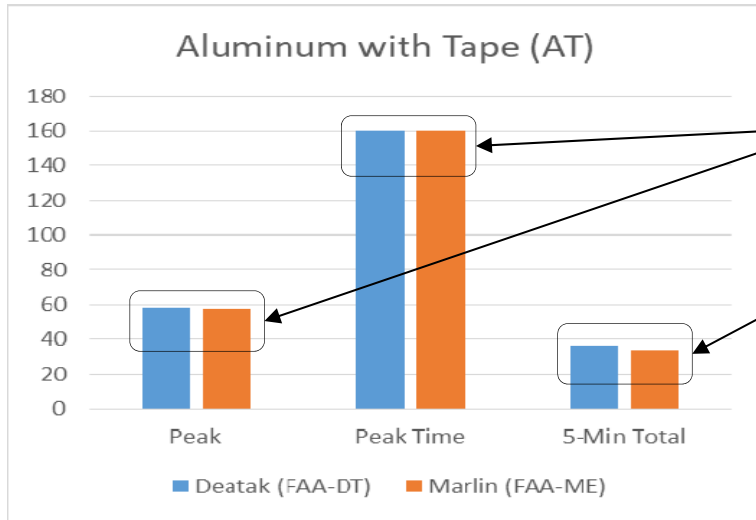
Boeing Panel with Decorative (BPD) - Upper Pilot Extinguishing

- Several BPD coupons extinguished the upper pilot flames
- DT unit: partial extinguishing for less than 3 seconds, no invalid tests
- ME unit : >3 flames extinguished beyond 3 second limit, several invalid tests

ME Upper Pilot Extinguishing with BPD Coupons



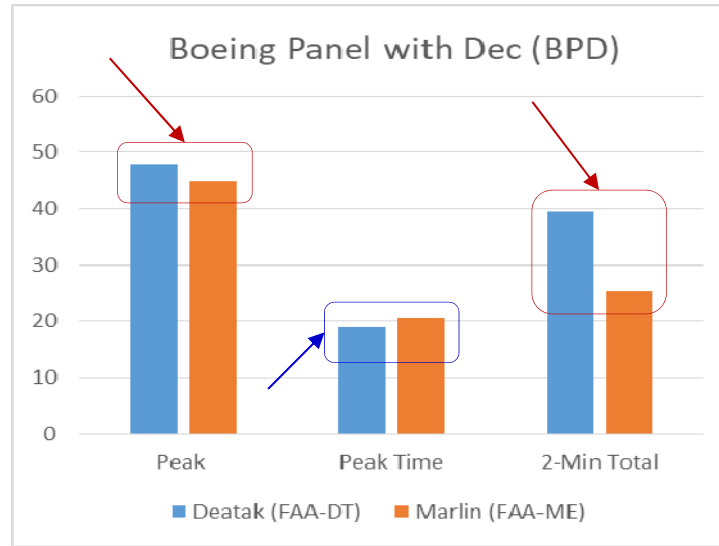
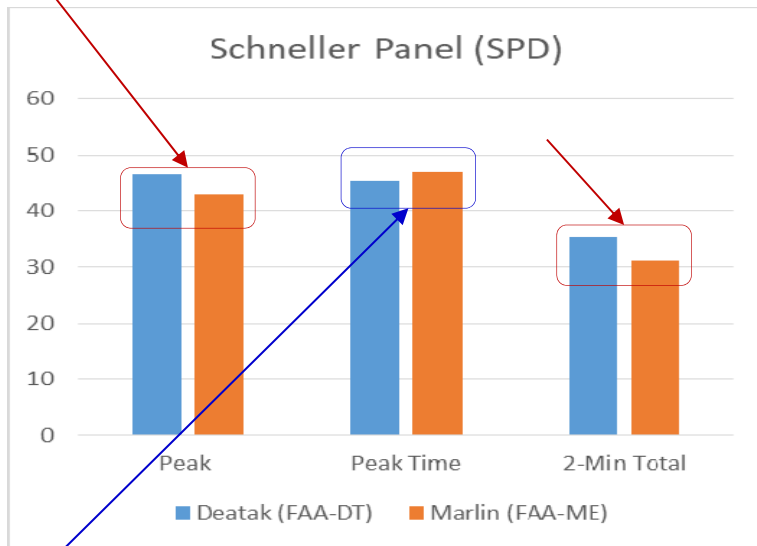
TRL 6 Test Results



(AT) Peak time and magnitude were comparable

Appeared after 2-min - use 5-min total

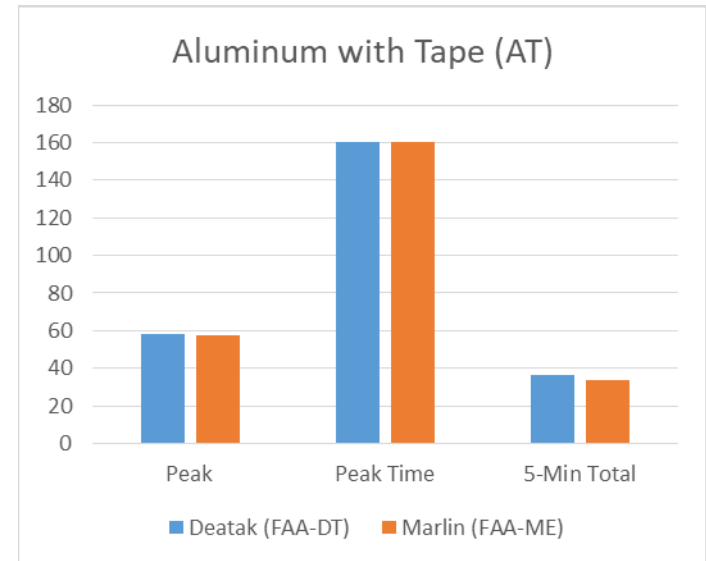
(SPD, BPD) Peak, 2-Min Total HR values were larger on DT vs. ME



(SPD, BPD) Peaks appeared sooner on average

Aluminum with Tape (AT)

		Mean	Std Dev	CoV
Peak Heat Release (kW/m^2)	FAA-DT	58.07	1.83	3.14%
	FAA-ME	57.33	2.33	4.08%
Peak Time (s)	FAA-DT	160.6	5.26	3.27%
	FAA-ME	160.6	2.58	1.61%
5-Min Total Heat Release ($kW*min/m^2$)	FAA-DT	36.64	2.78	7.49%
	FAA-ME	33.52	2.50	7.37%

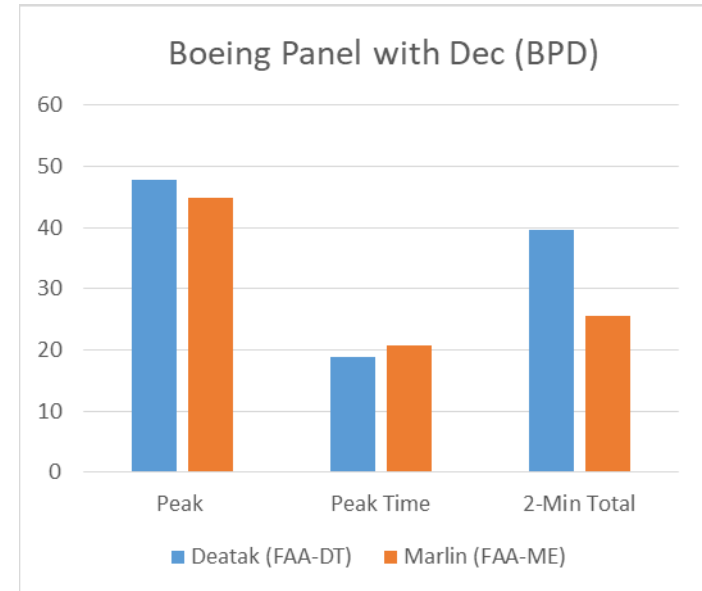


Statistically Significant Difference (95% Confidence)
 No Significant Difference (95% Confidence)

- The mean peak heat release and peak time are not significantly different
- The mean 5-min total heat release is significantly different between the two instruments

Boeing Panel with Decorative (BPD)

		Mean	Std Dev	CoV
Peak Heat Release (kW/m ²)	FAA-DT	47.75	2.74	5.74%
	FAA-ME	44.92	2.19	4.87%
Peak Time (s)	FAA-DT	18.91	4.43	23.4%
	FAA-ME	20.65	3.93	19.0%
2-Min Total Heat Release (kW*min/m ²)	FAA-DT	39.55	5.68	14.4%
	FAA-ME	25.47	6.55	25.7%

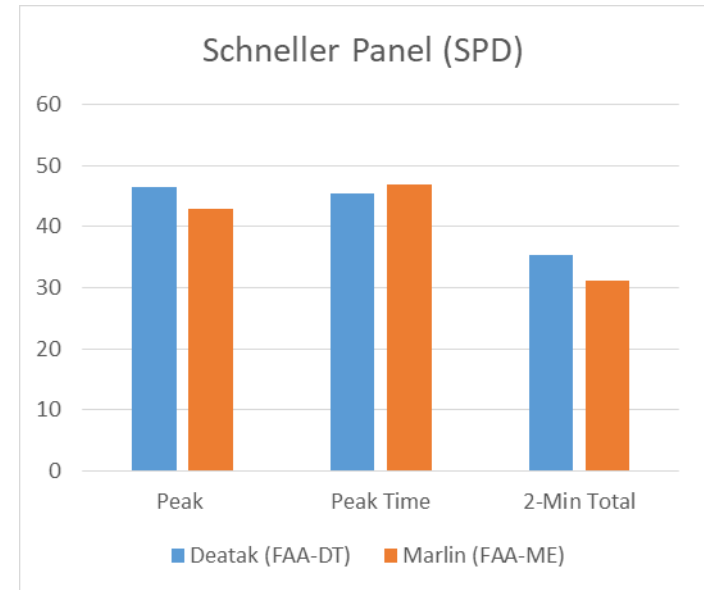


Statistically Significant Difference (95% Confidence)
 No Significant Difference (95% Confidence)

- All results were included in the data presented, including when upper pilots were out
- The mean peak time is not significantly different between the two instruments
- The mean peak and 2-min total heat release is significantly different

Schneller Panel (SPD)

		Mean	Std Dev	CoV
Peak Heat Release (kW/m ²)	FAA-DT	46.34	1.75	3.78%
	FAA-ME	42.80	1.71	3.97%
Peak Time (s)	FAA-DT	45.41	1.44	3.17%
	FAA-ME	46.90	1.85	3.95%
2-Min Total Heat Release (kW*min/m ²)	FAA-DT	35.40	1.85	5.24%
	FAA-ME	31.11	1.16	3.71%



Statistically Significant Difference (95% Confidence)
 No Significant Difference (95% Confidence)

- The mean peak time, peak and 2-min total heat release are all significantly different

Post Testing Actions

- ME Schneller panel mean results are 3 - 4 points lower than expected
 - DT Schneller panel results are very close to TRL 5 results
 - ~ 1 point difference in mean peak and mean 2-min total HR
 - Indicates lower air flow or heat loss during TRL 6 testing
- Suspected issue with ME unit due to this and BPD upper pilot extinguishing
 - ME unit had not had major maintenance since installation (7 years)
 - Pressure and flow measurements were taken prior to disassembly
 - Lower plenum pressure was low (11" WC vs 13" WC in DT)
 - No leaks discovered in the lower plenum area
 - Hardware joining lower plenum, main air distribution plate and main body were loose enough to be turned by hand

Post Testing Actions (continued)

- ME unit was completely torn down in the weeks after testing
 - Insulation was significantly deteriorated (left, right, & rear of unit)
 - All unit insulation was replaced
 - Upper, inner door mechanism bushings were burned out
 - Mechanisms were replaced
 - Gaskets / seals worn out - replaced with high temp 1/8" graphite
 - Exhaust stack
 - Viewing window
 - Rear global pan
 - Holding chamber
- Mike is currently calibrating heat flux and preparing to assess operating parameters
- Spare **SPD** and **BPD** coupons will be tested to assess performance

Next Steps

Anticipated Schedule

FAA TC ME rebuild, coupon assessment	Apr 2021
FAA TC ME operating parameter run	May 2021
New coupons finalized, produced, shipped	Jun 2021
Boeing HR2 delivery and installation	Jul 2021*
Boeing HR2 unit response experiment	Aug 2021*
Boeing testing and data analysis complete	Sep 2021*
Airbus HR2 upgrades	Sep 2021+
Airbus HR2 unit response experiment	Oct 2021+
Airbus testing and data analysis complete	Nov 2021+
FAA TC HR2 TRL 6 retest	Oct 2021
FAA TC data analysis complete	Nov 2021

* Contingent upon unit installation and setup timing

+ Contingent upon upgrade availability and timing

Questions?

