Discovery of Supply Voltage Variation:

Effect on Material Heat Release Measurements

A look inside the HR2 burn chamber

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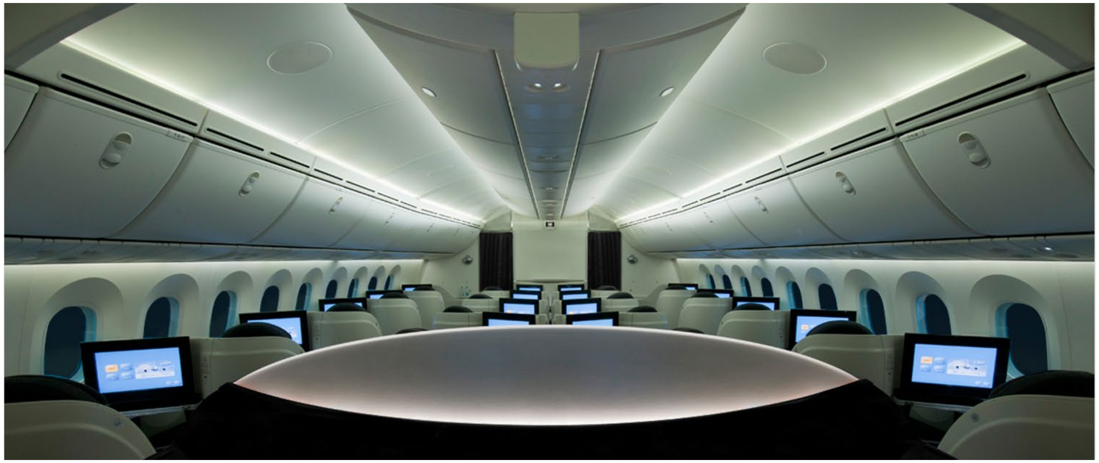
Material Heat Release Testing

Heat Release is the amount of heat energy created by a material when burned[1]

The heat release of materials used (in airplanes) drives occupant survivability …dictating how quickly the conditions progress to flashover[2].

The heat release rate test measures both total heat release and peak heat release rate.

Large surfaces in the passenger cabin, including partitions, ceilings, and wall panels must meet heat release rate (HRR) requirements.



787 business class interior illustrating multiple large surfaces requiring heat release testing

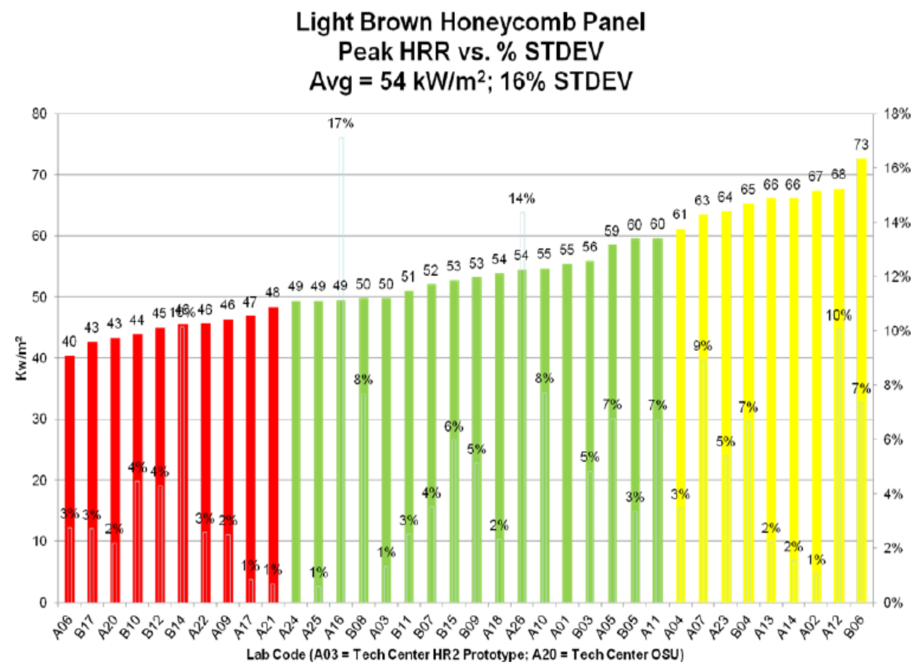
[1,2]**Federal Register** /Vol. 84, No. 128 /Wednesday, July 3, 2019 / Proposed Rules

OSU - Current Material Heat Release Test Method

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

14CFR25.853(d)

- 65/65 requirement added in 1990
- Current § 25.853(d) and Part IV of Appendix F to Part 25
- Applicable to large exposed interior surfaces
- Regulates heat release as a function of time



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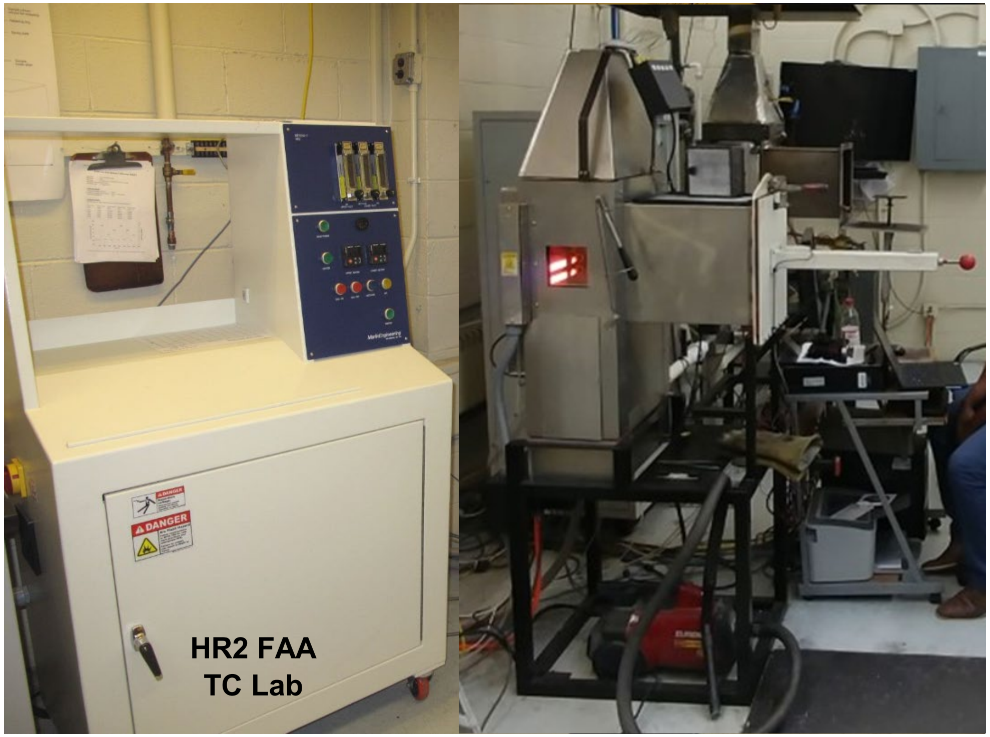
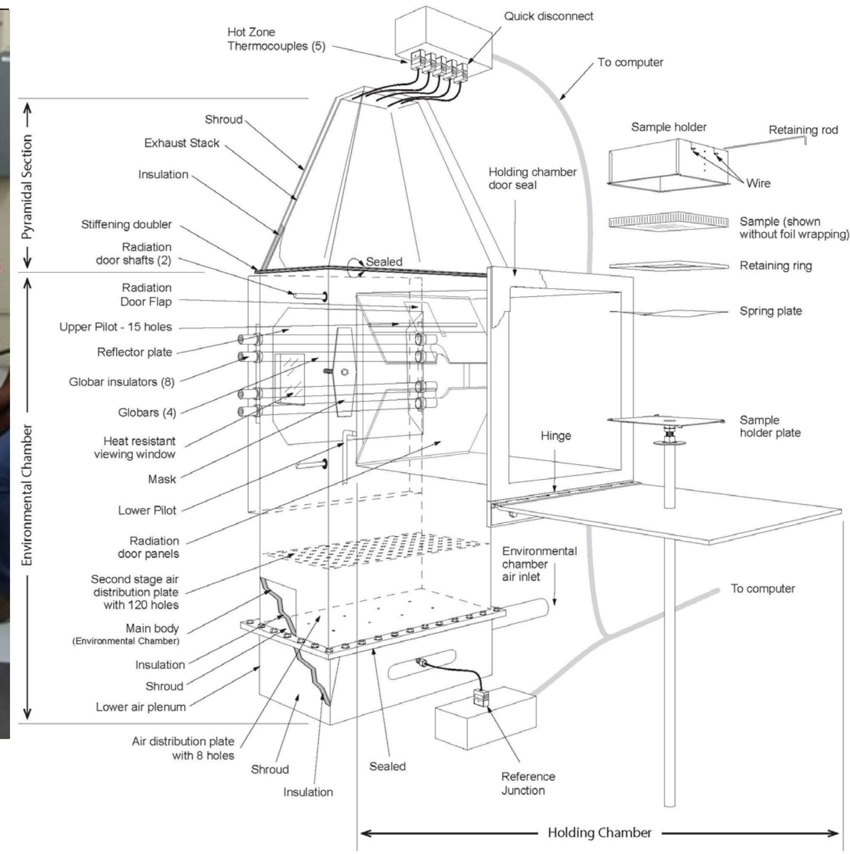
HR2 - Next Generation Material Heat Release Test Method





Aircraft Materials Fire Test Handbook, Revision 3, Chapter A-4

Design and Other Changes

- Aircraft Materials Fire Test Handbook, Revision 3, Chapter A-4
- Elimination of cooling flow / inner chimney
- Construction & procedural improvements
- Mass flow controlled air and gas flows
- Tighter operating parameter ranges vs. OSU

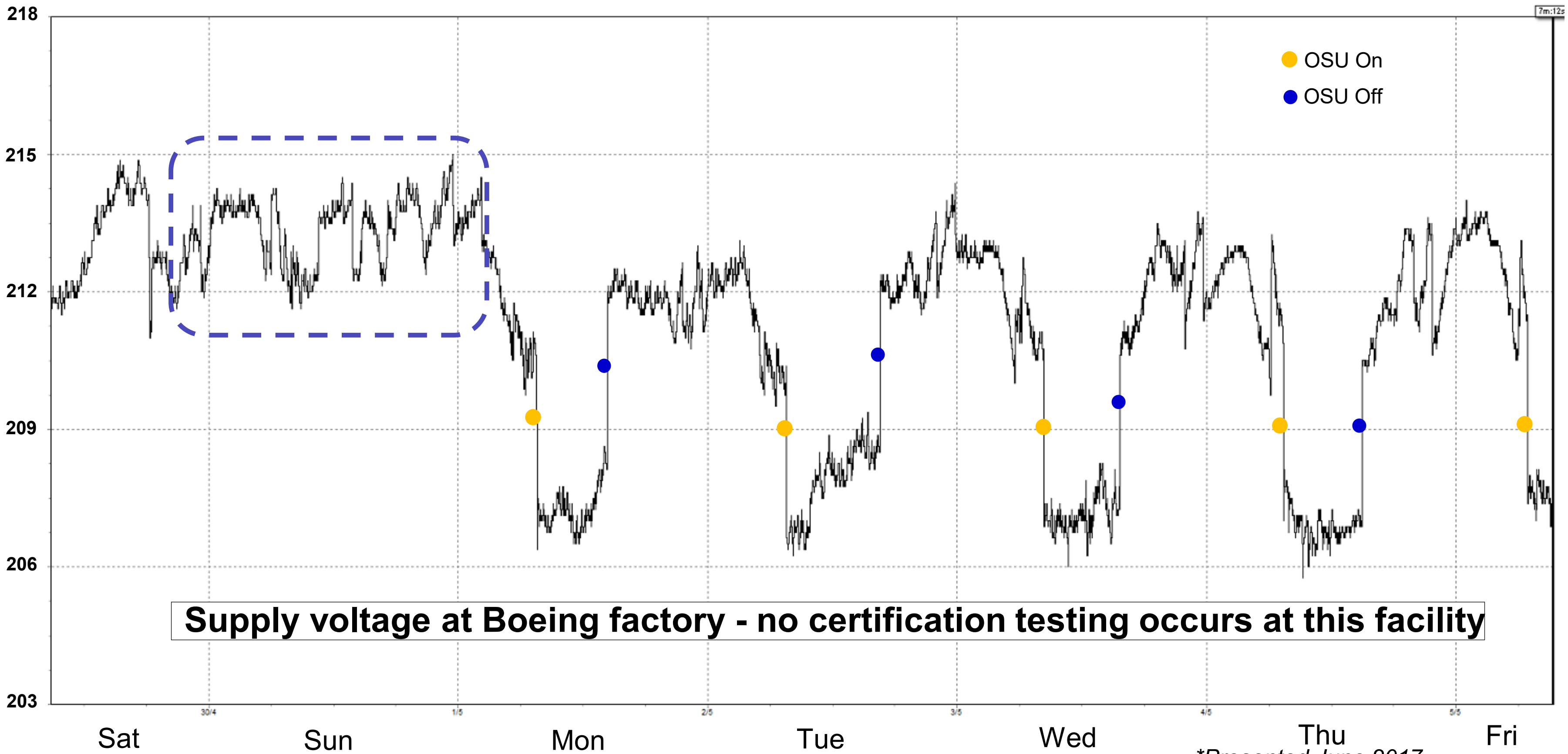
Anticipated Improvements

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

**Presented June 2017*

Voltage Variation Investigation Impetus

- Notional relationship between Globar calibration power and time of day
- Current OSU specifications control heat flux not **voltage variation**
  - ➢ Initial voltage monitoring conducted indicated a dynamic supply voltage…



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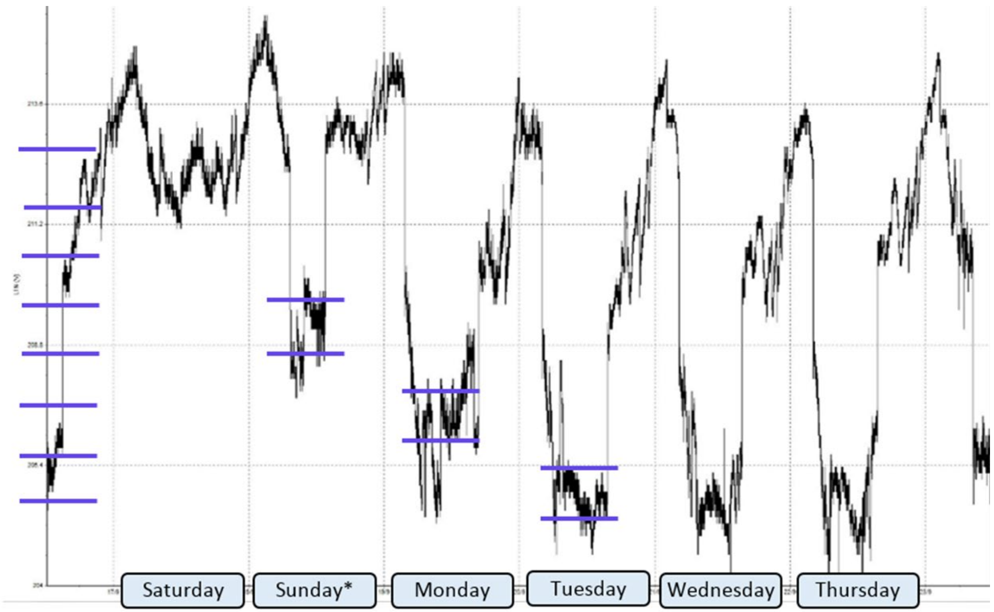
What Effect Could Voltage Change have on Heat Flux?

Method: measure and record heat flux over a range of supply voltages

- Turn on lab equipment to pull down supply voltage to OSU



Target Voltages (V)

Supply	w/Loads
209	208
207	206
205	204

- Lab equipment used to introduce an additional ~1 volt drop
  - **Despatch** Oven Model RFD1-42-2E 34.5A max load - set to 500°F
  - **Fischer Scientific** Isotemp Programmable Forced Draft Furnace - set to 600°F
  - **Wabash** Heated Press Model G30H-18-BCLPX 26A max load - set to 320°F
  - **Tetrahedron** Press Model SFP-13 28A max load - set to 510°F

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Procedure - Voltage vs. Heat Flux

1. At the beginning of each day, complete startup procedures and allow unit to stabilize for 2 hours.
2. Gather heat flux and environmental data at a given supply voltage value.
3. Engage laboratory loads and confirm voltage drop has occurred, then repeat step 2.
4. Disengage laboratory loads.
5. Monitor supply voltage and repeat steps 2-4 at varying voltage values over 3 days, Sunday-Tuesday.
6. At the end of each day, complete shutdown procedures.

- Initial Globar power settings were not changed during data collection
- Air flow was constant during experimental procedures and data gathering

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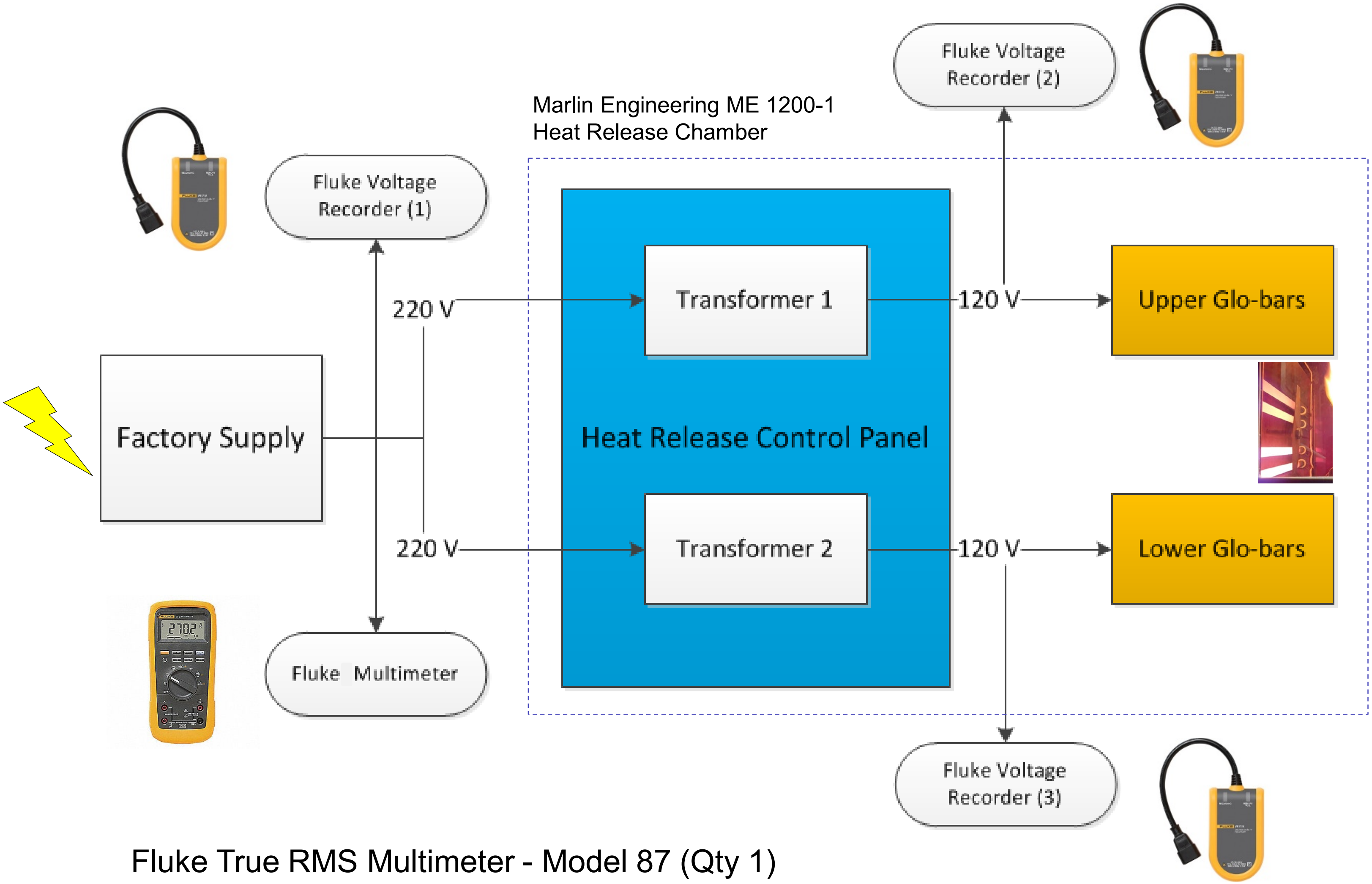
Voltage Measurement and Logging



Fluke True RMS Multimeter - Model 87 (Qty 1)

Fluke Voltage Quality Recorder - Model VR 1710 (Qty 3)

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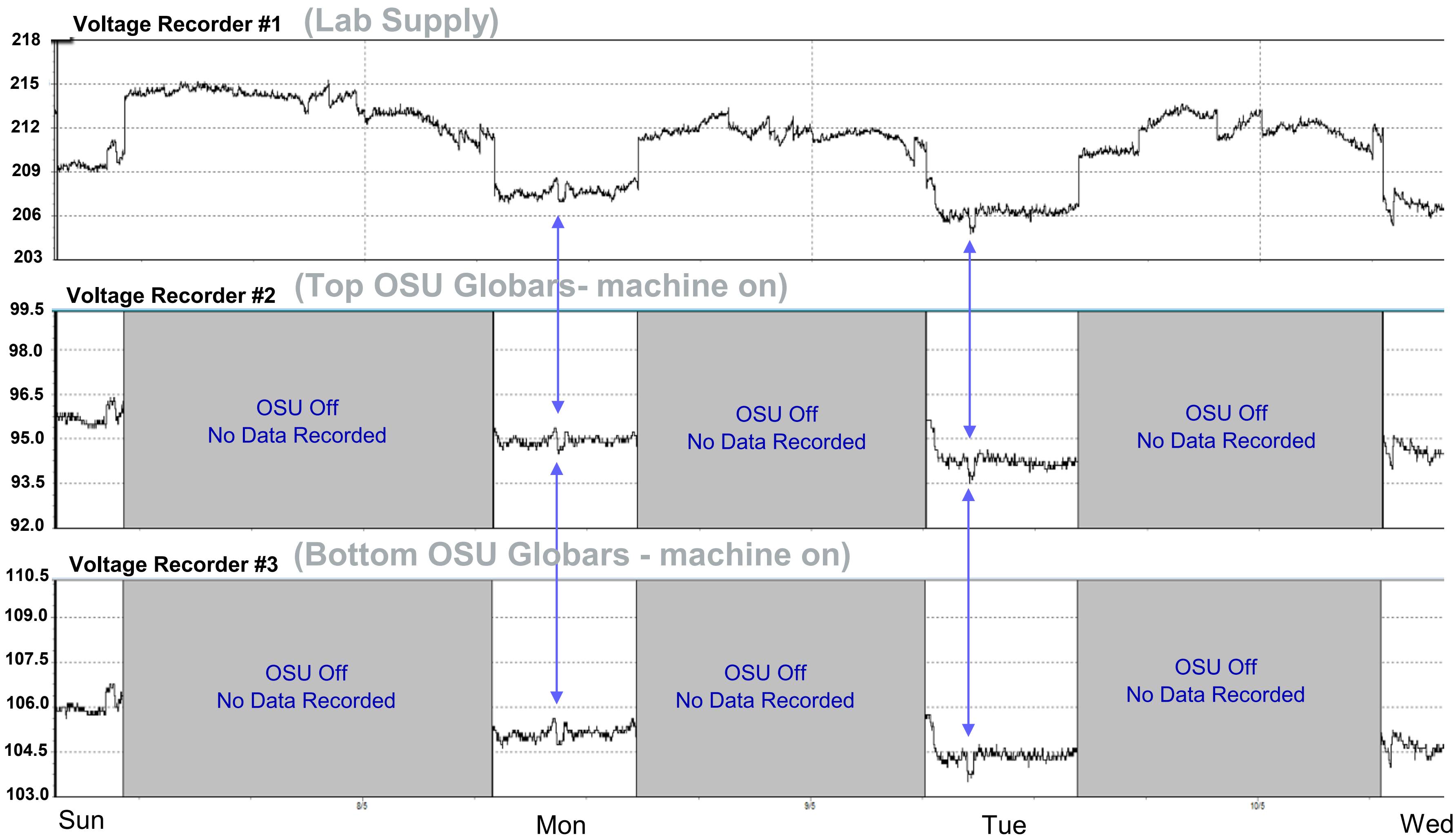
Actual Supply Voltage Behavior (Data Gathering)



➢ Supply voltage changes transfer directly to the globars

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Raw Data Collection

LINE VOLTAGE VS. RADIATED HEAT FLUX - DATA COLLECTION LOG																				
Metadata						*Variable*				*Constants*						*Output*				
Data Tags						Voltage (V)				Controller Settings		Ambient Conditions		Air Pressure (mmHg)		Flux (W/cm^2)				
Data Point	Run #	Load?	Day	Date	Test Time	Target Voltage	Initial Voltage	Final Voltage	Average Voltage	Upper Bars	Lower Bars	Temp (°F)	Humidity (%RH)	Initial Pressure	Final Pressure	Center Heat Flux@	Top Right Flux	Top Left Flux	Bottom Right Flux	Bottom Left Flux
V_0	1				9:43am		209.2	209.2	209.328	52.8	64.7	71.2	36	203	201	3.56	3.56	3.72	3.54	3.66
	2	No			9:54am	209.0	209.2	209.4	209.297	52.8	64.7	71.4	35	202	203	3.56	3.58	3.73	3.53	3.66
	3				9:59am		209.3	209.5	209.359	52.8	64.7	71.3	35	200	202	3.56	3.58	3.70	3.53	3.67
	4				10:07am		209.1	209.1	209.250	52.8	64.7	71.4	35	203	202	3.55	3.59	3.71	3.53	3.67
	5				10:14am		210.5	210.6	210.609	52.8	64.7	71.4	35	200	203	3.59	3.63	3.76	3.58	3.70
	6	No	Sunday	5/7/2017	10:21am	211.0	210.6	210.8	210.719	52.8	64.7	71.5	35	201	200	3.59	3.63	3.77	3.58	3.72
	7				10:28am		210.9	210.7	210.969	52.8	64.7	71.5	35	200	200	3.60	3.62	3.76	3.58	3.70
	8				10:44am		209.6	209.6	209.672	52.8	64.7	71.7	34	201	200	3.57	3.59	3.74	3.56	3.68
	9	Yes			10:52am	210.0	210.0	210.0	209.906	52.8	64.7	72.0	34	201	203	3.57	3.62	3.75	3.56	3.68
	10				11:00am		210.1	210.1	210.219	52.8	64.7	72.1	34	202	203	3.58	3.62	3.75	3.56	3.70
V_2	1				9:50am		207.6	207.8	207.563	52.8	64.7	68.7	38	200	203	3.54	3.55	3.70	3.52	3.65
	2	No	Monday	5/8/2017	9:59am	208.0	207.7	207.9	207.844	52.8	64.7	68.8	38	202	202	3.53	3.56	3.69	3.50	3.65
	3				10:10am		208.3	208.5	208.406	52.8	64.7	68.7	38	203	203	3.56	3.59	3.71	3.53	3.67
V_3	1				10:25am		207.1	206.9	207.063	52.8	64.7	68.9	38	200	202	3.51	3.52	3.66	3.48	3.63
	2	Yes	Monday	5/8/2017	10:32am	207.0	207.1	207.2	207.047	52.8	64.7	69.0	38	201	201	3.51	3.53	3.65	3.46	3.60
	3				10:39am		207.0	207.7	207.125	52.8	64.7	68.9	38	201	203	3.50	3.53	3.66	3.48	3.62
V_4	1				8:02am		206.0	206.4	205.953	52.8	64.7	66.8	47	200	200	3.45	3.49	3.61	3.43	3.57
	2	No	Tuesday	5/9/2017	8:09am	206.0	206.6	206.2	206.438	52.8	64.7	67.3	46	203	201	3.46	3.50	3.65	3.43	3.56
	3				8:16am		206.3	206.4	206.156	52.8	64.7	67.5	46	201	201	3.46	3.49	3.64	3.43	3.56
V_5	1				8:24am		205.5	205.0	205.531	52.8	64.7	67.8	46	202	200	3.44	3.46	3.58	3.39	3.51
	2	Yes	Tuesday	5/9/2017	8:31am	205.0	205.2	204.7	205.172	52.8	64.7	68.0	45	200	202	3.42	3.45	3.59	3.39	3.53
	3				8:38am		205.1	205.4	205.156	52.8	64.7	68.3	45	202	202	3.42	3.44	3.58	3.40	3.51

@Note: Center Heat Flux is an average of three readings. Corner values are a single reading.

***Note:** Despatch Circulation Oven used for load; once set temp reached, load drawn cycled to keep at set point. This caused ~0.8V fluctuation in the supply voltage for the runs noted above.

- ➢ Center Heat Flux Varied from 3.42 to 3.60 W/cm^2 over a 6 Volt Supply Range

Specified range is 3.45 to 3.55 W/cm^2

**Presented June 2017*

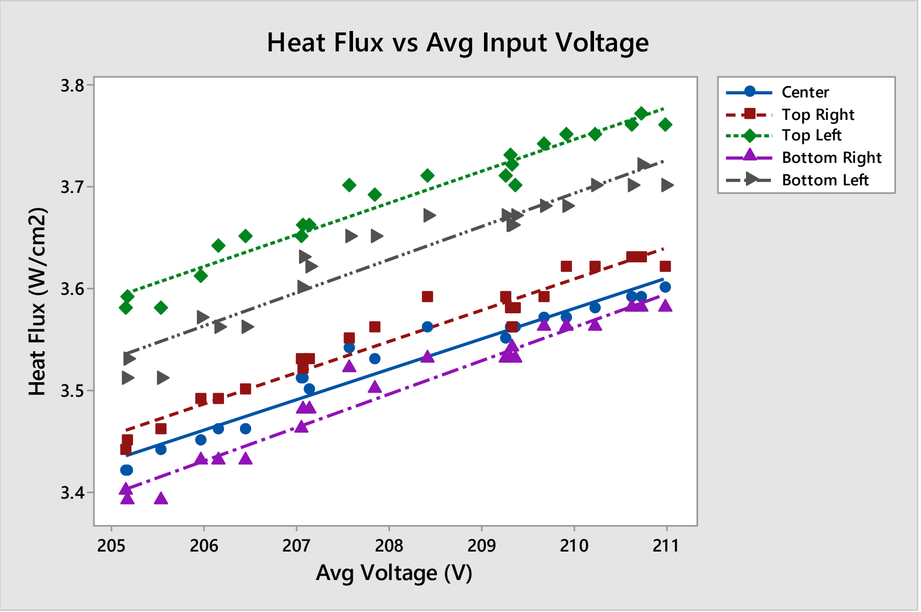
Results: Heat Flux Variation

Supply (Input) Voltage vs. Heat Flux

- Regression model for “Average Center Heat Flux” used in calculations

Heat flux density changes linearly with voltage

- 1V change in Supply Voltage resulted in 0.024 to 0.033 W/cm^2 in radiated heat flux



Post-calibration changes in supply voltage affect radiated heat flux.

➢ OSU supply voltage needs to be regulated to within ± 1.5 V to keep center heat flux value of 3.5 W/cm^2 within specification

**Presented June 2017*

Impact of Changing Heat Flux on Material Heat Release

Method: Study the effects of varying heat flux on HR peak, total, and peak time results. Conduct 27 total tests across three heat flux levels:

- $\leq 3.25\ W/cm^2$
- $3.5\ W/cm^2$
- $\geq 3.75\ W/cm^2$

Equipment

- OSU heat release unit
- Standard test panels (honeycomb phenolic sandwich panel)
- Voltage logger installed and recording (10 sec sample interval)
- Multimeter monitoring real-time supply voltage

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Procedure - Heat Flux vs. Material Heat Release

1. Standard OSU startup – allow 1.5 hours for mV output to stabilize
2. Heat flux calibration at 3.5 W/cm^2
3. Run 3 standard panels (prepreg / honeycomb sandwich)
4. Vary heat flux settings to produce ≤3.25 W/cm^2, 3.5 W/cm^2, and ≥3.75 W/cm^2 following a random order
5. At each heat flux level, run 3 standard panels before moving to the next level until a total of 27 tests results are generated – 9 at each of the three heat flux settings

➢ Air flow was constant during experimental procedures and data gathering

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Raw Data Collection

Data Tags					Heat Flux (W/cm2)						Supply Voltage (V)			Ambient Conditions		Air Pressure (mmHg)		Heat Release			
Data Point	Run #	SH	Date	Start Time	Initial Heat Flux	Target Heat Flux	Upper Bar Setting	Lower Bar Setting	Final Heat Flux	Average Heat Flux (i+f)/2	Initial Voltage	120s Final Voltage	Average 120s Logged Voltage	Temp (°C)	Humidity (%RH)	Initial Pressure	120s Final Pressure	Thermo-pile Baseline (mV)	Peak Heat Release (kW/m^2)	Peak Time (s)	Total Heat Release (kW min/m^2)
V_0	0		8/30	7:17 AM	3.49	3.50	53.5	65.0		*3.49*	206.9	206.7	206.6	22.7	56	197	198	26.2	53.81	46	33.55
V_1	1			7:27 AM	3.49						206.8	206.9	206.6	22.7	56	199	199	25.9	56.03	44	38.03
	2		8/30	7:48 AM		3.50	53.5	65.0		*3.49*	206.4	206.5	206.2	22.7	56	200	197	26.0	51.89	45	33.64
	3			7:56 AM					*		206.6	206.5	206.4	22.7	55	199	197	25.9	60.50	45	39.70
V_2	4	1		8:44 AM	3.10						207.1	207.0	207.0	22.8	55	200	199	24.1	49.40	75	26.62
	5	2	8/30	8:52 AM		3.25	49.2	59.8		3.09	206.9	207.2	206.9	22.7	55	198	201	23.9	52.50	76	28.17
	6	3		8:59 AM					3.08		207.2	207.4	207.1	22.7	55	200	200	23.9	50.77	67	28.87
V_3	7	4		10:04 AM	3.48						207.0	207.2	206.8	22.9	55	200	201	25.9	58.78	44	38.47
	8	1	8/30	10:11 AM		3.50	53.5	65.0		3.51	206.5	206.6	206.7	22.9	55	201	198	25.9	58.13	45	39.10
	9	2		10:18 AM					3.54		207.2	207.2	207.0	22.9	54	198	199	26.1	54.87	47	34.16
V_4	10	3		11:04 AM	3.86						206.2	206.4	206.1	23.1	54	200	202	27.4	49.35	43	33.61
	11	4	8/30	11:12 AM		3.75	57.8	70.2		3.86	206.1	206.2	206.0	23.1	54	202	202	27.2	58.37	39	39.99
	12	1		11:19 AM					3.86		206.1	205.9	206.0	23.1	55	202	200	27.2	62.90	38	39.22
V_5	13	2		12:16 PM	3.85						205.9	205.9	205.8	23.0	55	202	199	26.8	60.71	40	39.41
	14	3	8/30	12:22 PM		3.75	57.8	70.2		3.85	205.9	205.8	205.8	23.1	55	200	201	27.1	63.46	41	39.01
	15	4		12:29 PM					3.85		205.6	205.8	205.6	23.2	54	201	202	27.1	63.22	40	42.35
V_6	16	1		1:03 PM	3.12						206.2	206.0	206.0	23.4	55	198	200	24.4	50.22	78	25.91
	17	2	8/30	1:09 PM		3.25	49.2	59.8		3.08	205.8	205.9	205.6	23.4	55	200	201	24.2	52.36	75	26.31
	18	3		1:16 PM					3.03		205.7	206.1	205.8	23.2	55	200	202	24.1	47.71	70	29.66
V_7	19	4		2:05 PM	3.45						205.9	206.0	205.9	23.3	55	201	200	26.0	54.32	47	35.88
	20	1	8/30	2:12 PM		3.50	53.5	65.0		3.48	206.2	206.2	206.1	23.2	55	199	202	26.1	63.17	43	36.79
	21	2		2:18 PM					3.52		206.4	206.2	206.1	23.3	55	202	202	26.0	53.76	46	36.63
V_8	22	3		3:04 PM	3.82						206.0	206.0	205.8	23.3	55	203	200	27.2	53.73	40	37.91
	23	4	8/30	3:11 PM		3.75	57.8	70.2		3.85	205.8	205.6	205.6	23.3	55	200	200	27.2	60.68	39	40.07
	24	1		3:17 PM					3.88		205.7	207.0	205.4	23.2	55	201	202	27.4	60.88	40	38.16
V_9	25	2		4:16 PM	3.04						206.5	206.7	206.5	23.1	55	200	200	24.2	49.12	78	28.40
	26	3	8/30	4:22 PM		3.25	49.2	59.8		3.06	206.8	206.5	206.6	23.1	55	200	200	24.4	47.06	64	26.84
	27	4		4:29 PM					3.08		206.7	206.8	206.6	23.2	55	201	202	24.3	52.31	64	31.22

* Data point V_1 final heat flux not measured due to voltage jump of approx. 1V at end of 3rd run (did not affect results – occurred after measurement period)

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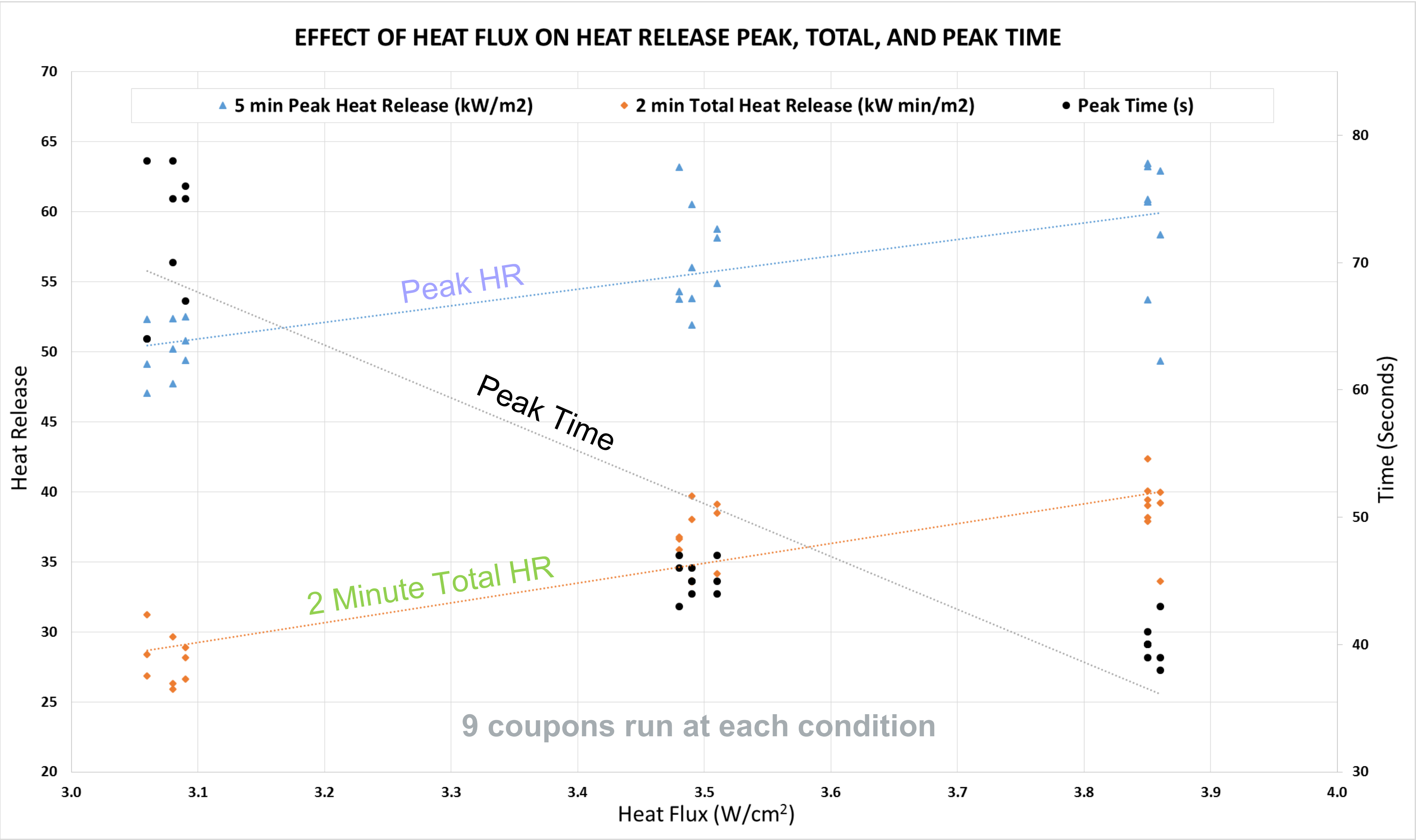
Data Analysis - Raw Data Scatterplot



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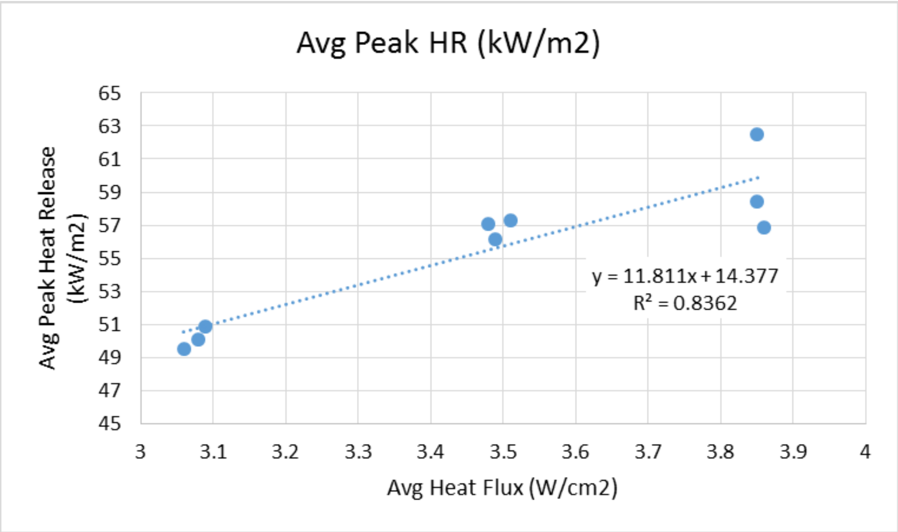
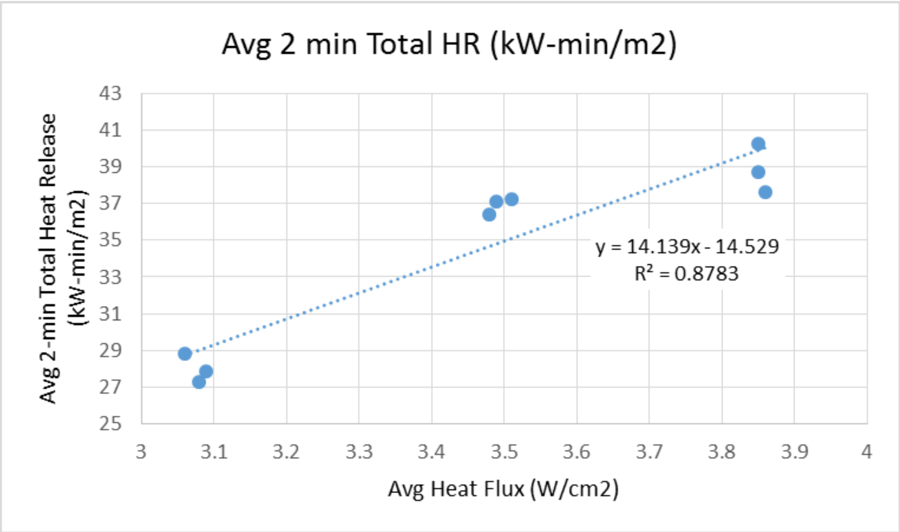
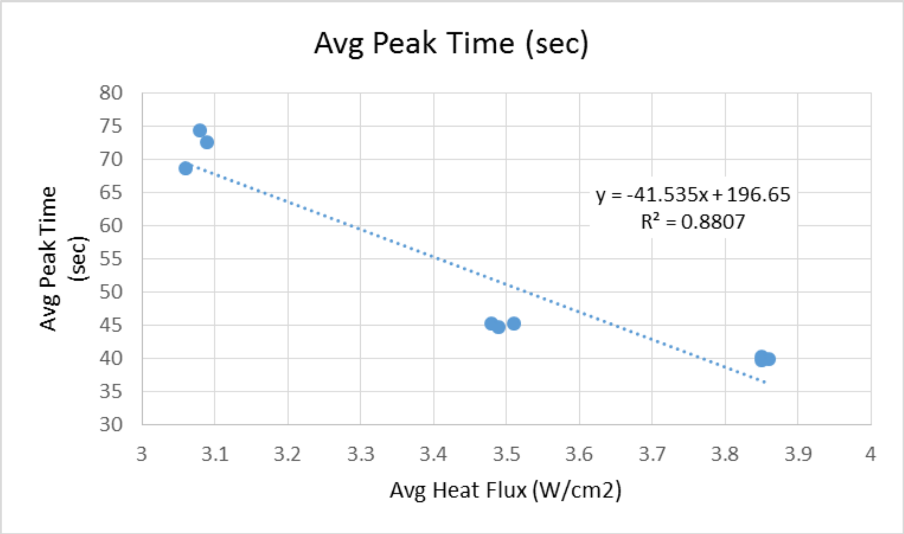
Regression Using 3 Point Data Averages







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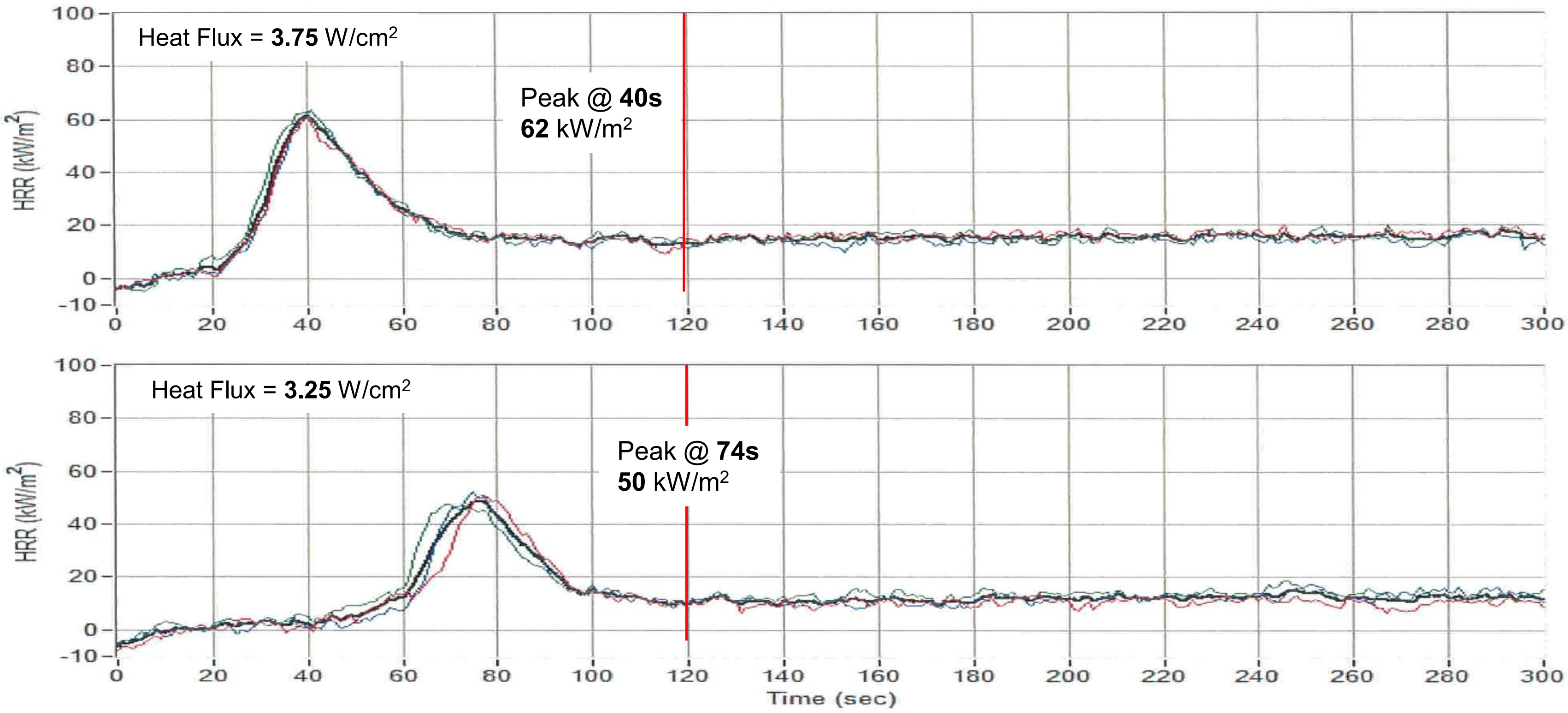
Heat Release Change Due to Supply Voltage Variation

Peak Shape / Timing



General Observations with Decreasing Heat Flux

- Lower peak values
- Lower 2 min total values
- Peaks shift right (starts and ends later)
- Wider peaks

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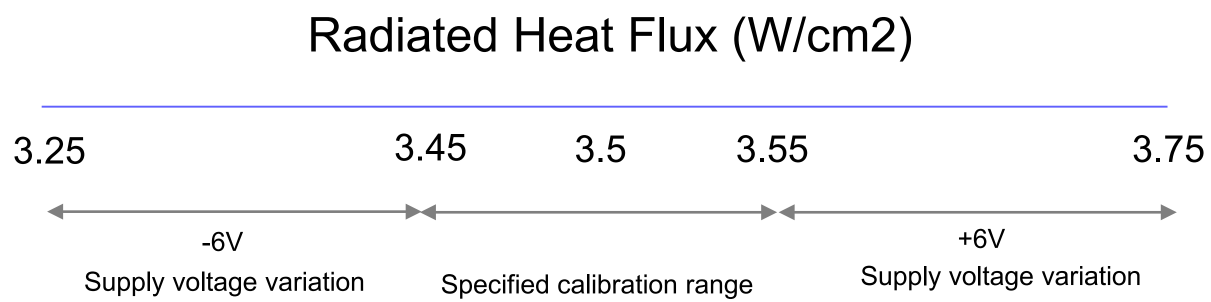
Heat Release Change Due to Supply Voltage Variation



What impact could this have on coupon test results?

Heat Flux		Peak Heat Release
3.25	W/cm^2	62.1
3.45	W/cm^2	64.4
3.50	**W/cm^2**	**65.0**
3.55	W/cm^2	65.6
3.75	W/cm^2	68.0

6 point range

Heat Flux		2 min Total Heat Release
3.25	W/cm^2	61.5
3.45	W/cm^2	64.3
3.50	**W/cm^2**	**65.0**
3.55	W/cm^2	65.7
3.75	W/cm^2	68.5

7 point range

- Voltage fluctuations may cause significant variations in HR results
- Draft Handbook (HR2) voltage control limits are +/- 1% (Chapter A4)

➢ A power conditioner or controller may be needed to stay within spec limits

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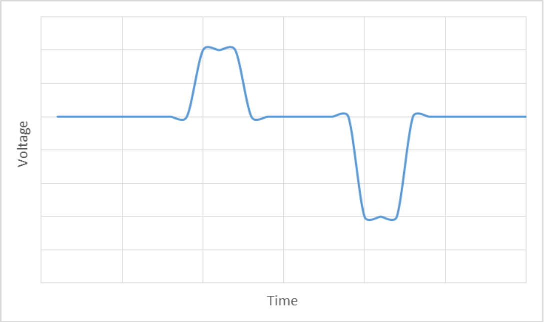
How to Control Supply Voltage Variation

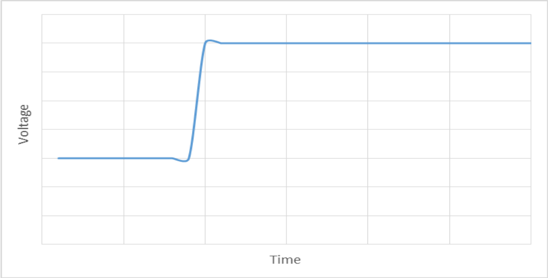
Voltage Variation Classification

Three general event classes

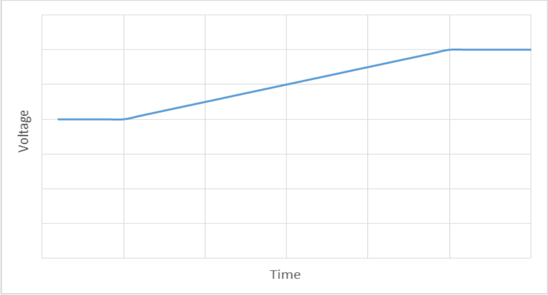
Spike - transient gain or loss followed by a return to the prior baseline



Step - short-term sustained change creating a new baseline voltage level

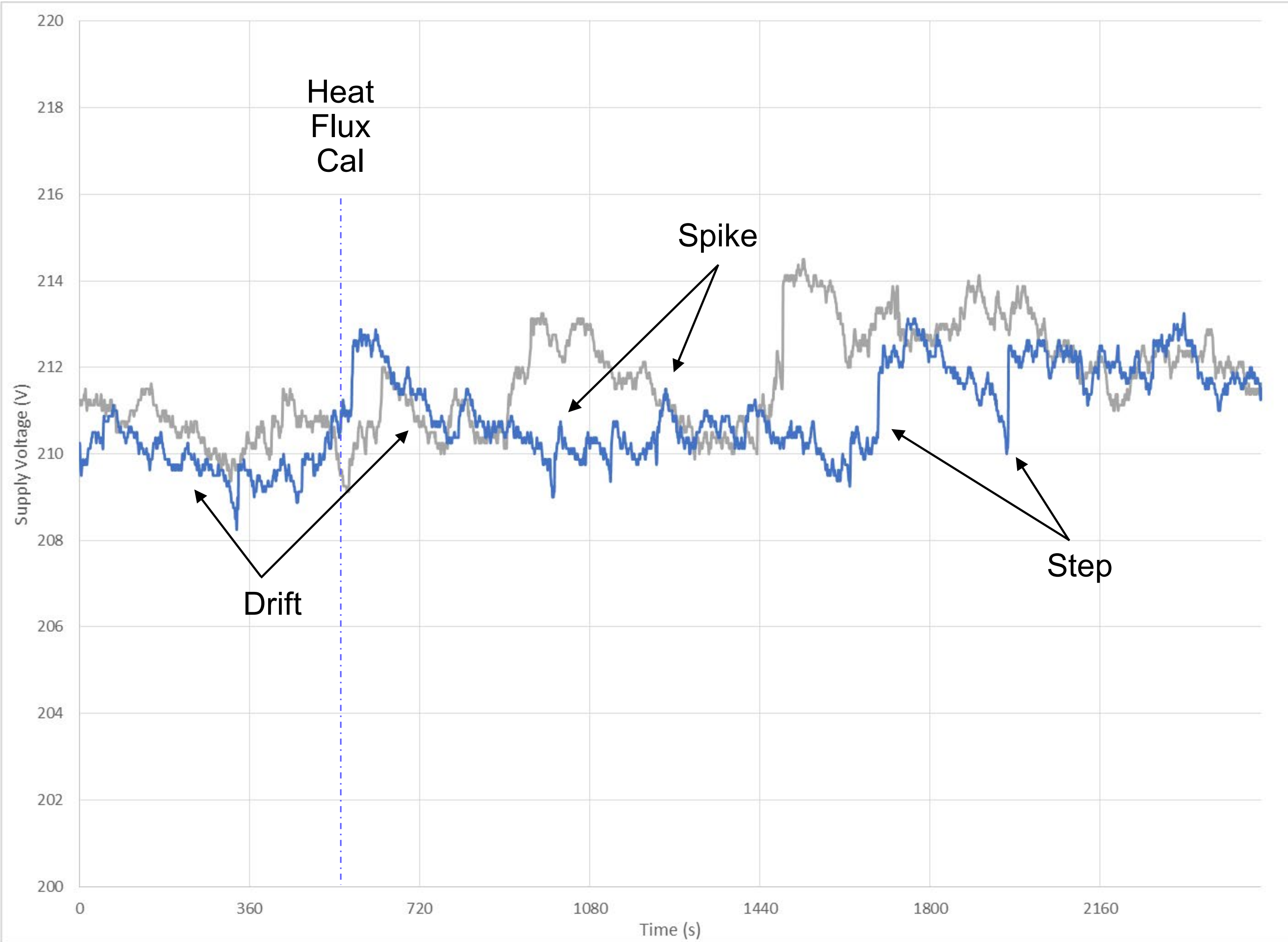


Drift - longer term increase or decrease of supply voltage



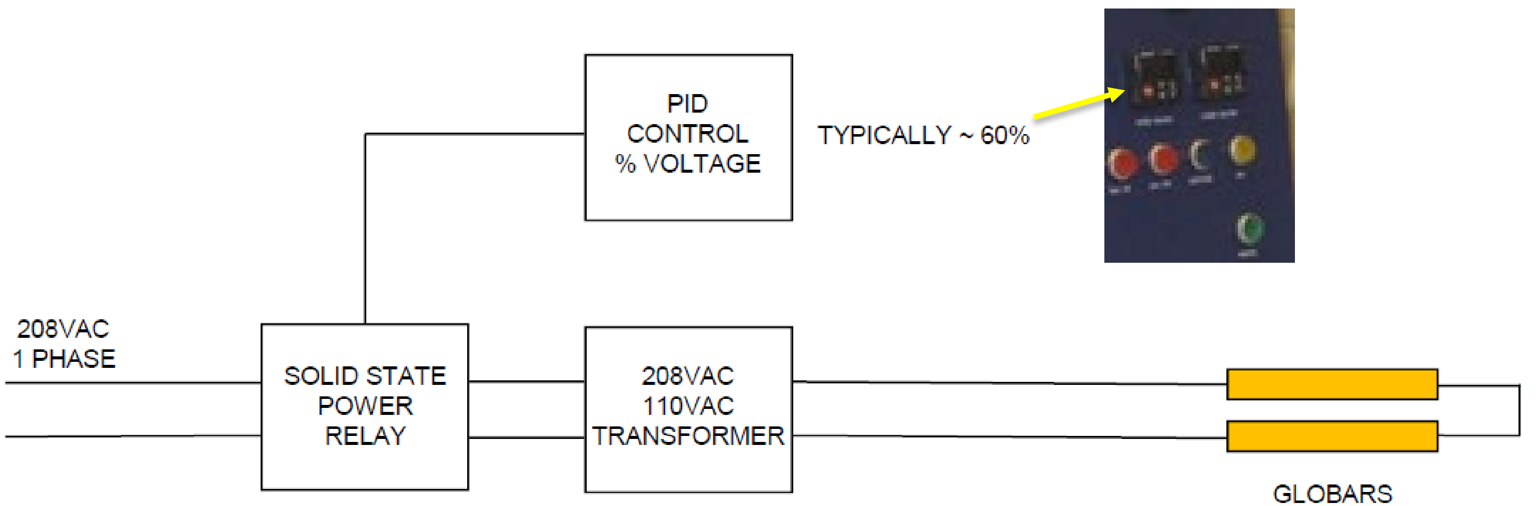
Event characteristics - change > 0.5V, timescale differentiates step vs. drift

Voltage Variation - Real Data Example



OSU - Current State

Current System



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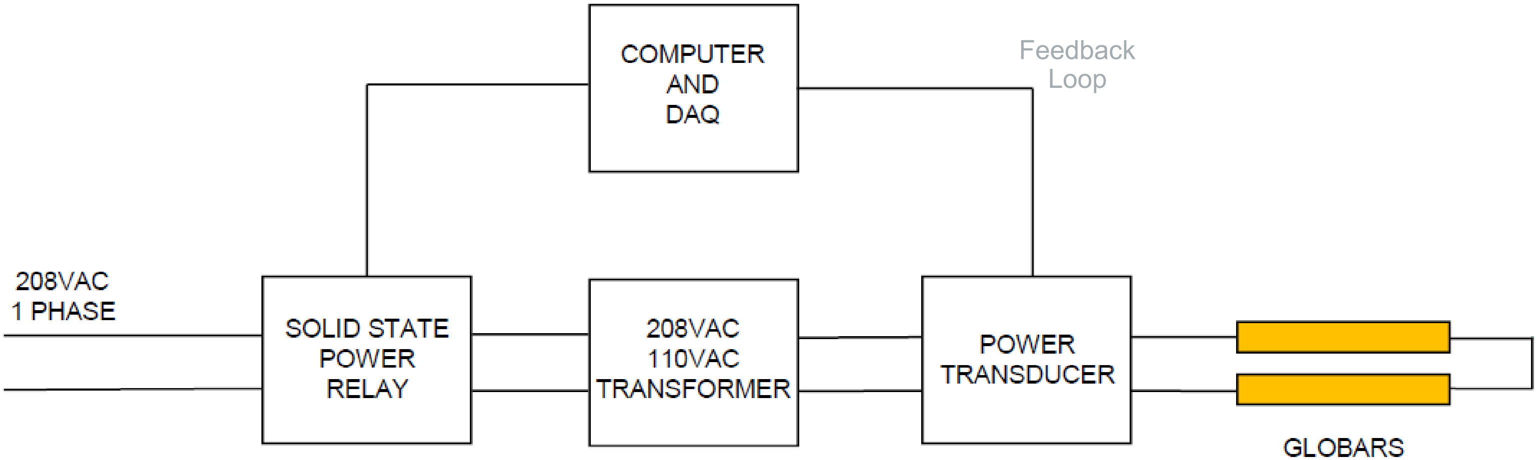
MarlinEngineering

MarlinEngineering Voltage Control System Prototype

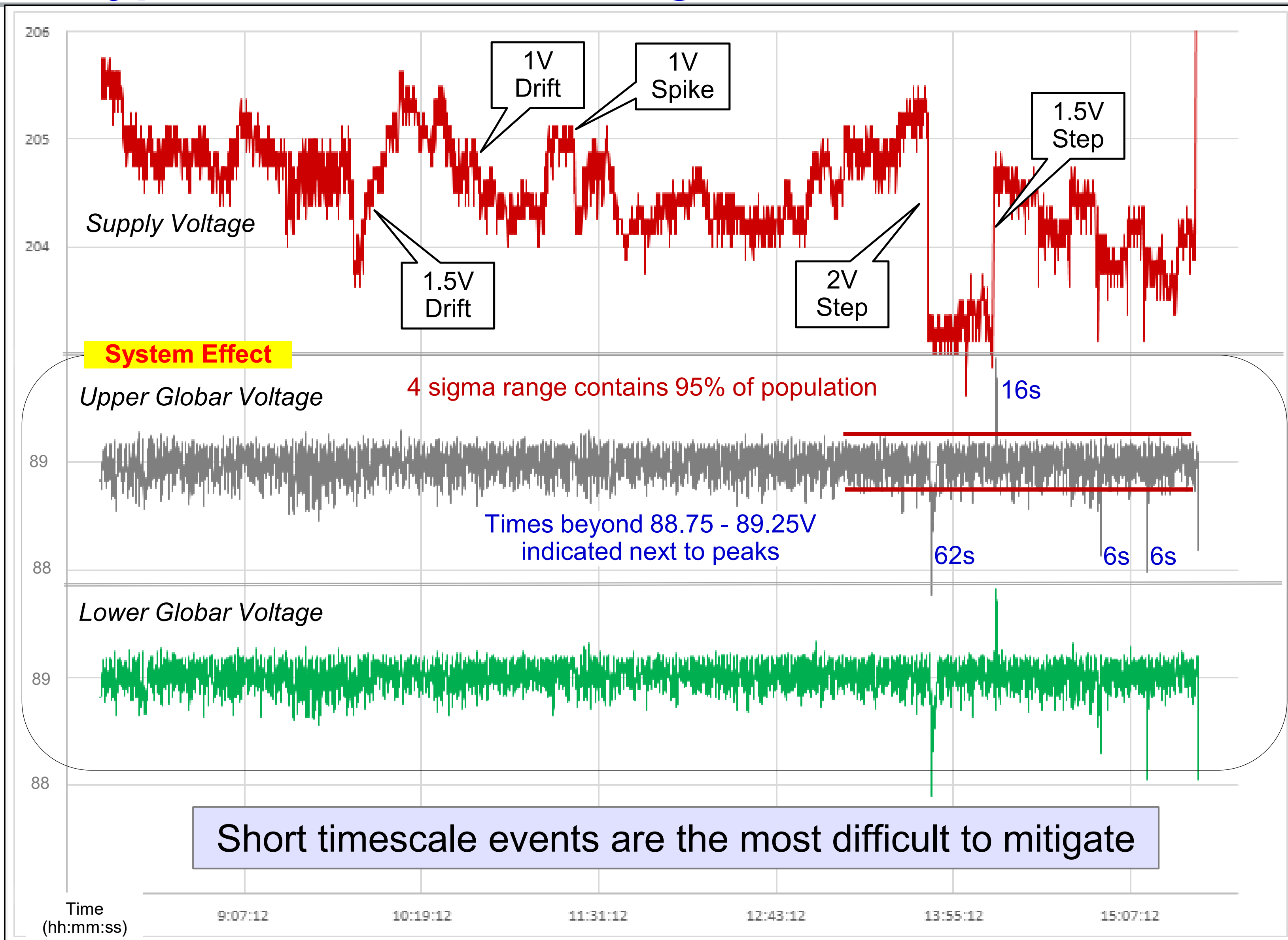
Heat Release Supply Voltage Control
Proposed System



DEMONSTRATED THAT POWER CAN BE HELD TO +/-0.5% AND RETURN TO STABLE SETTING WITHIN 10 SECONDS

MarlinEngineering

Prototype Performance During a Standard Run



Next Steps

Assess and Develop Voltage Conditioning (OSU and HR2)

- Initial solution greatly improves variation in heat flux but requires assessment
- Can short timescale and noise filtering performance be improved?
- Deatak designing and installing a conditioning system
- Develop case-specific targets from voltage round robin data
- Optimize algorithms and re-deploy
- Evaluate efficacy versus test cases
- Finalize algorithm design

Evaluate HR2 Specification Limits and Requirements

- Assess sufficiency and feasibility of current +/- 1% supply voltage control
- What magnitude and duration of voltage change can be tolerated?
- Design will likely be a balance of noise level versus response time capabilities
- Review wording versus ideal performance and propose updates

Lessons Learned

Potential for Broad Applicability

- Significant natural supply voltage variation discovered
  - Supply voltages vary broadly day to day and within days
  - Local loads can have a large influence as well
- Variation can have a proportional impact on test results
  - May be an unrecognized source of error in many measurements…
    - Non-flammability related test methods
    - Any equipment using A/C supply is potentially vulnerable
  - Very likely contributor to increased costs and required retesting
- Recommend review of specifications and power supply designs
  - Investigate requirements and manufacturer specific solutions
  - Inquire as to how control is executed and what the limits are

Questions?