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A Statistical Approach to OSU Variability Reduction

International Aircraft Materials & Fire Test Working Group
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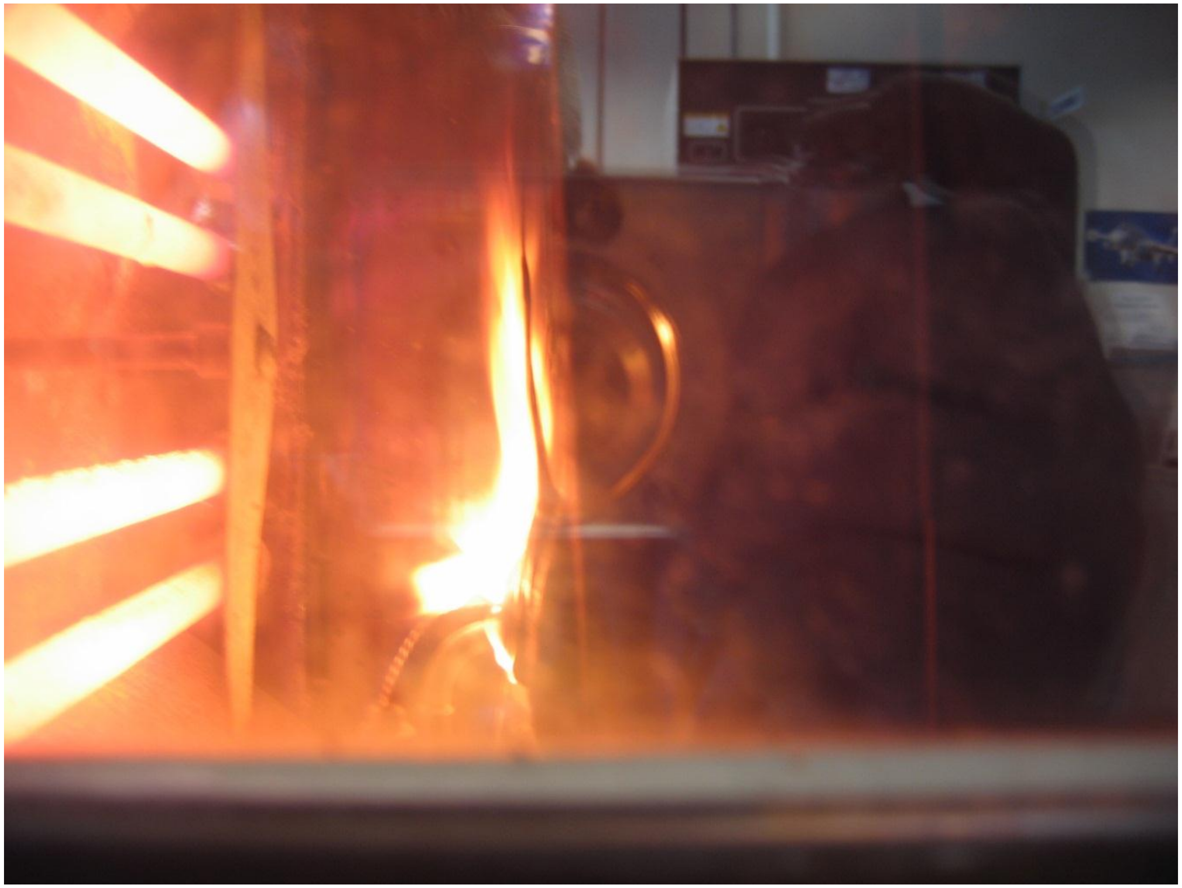

Boeing OSU Variability Reduction Project

- **In April 2010, Boeing began a project to better understand OSU variability between three machines at two labs**
- **The Boeing Flammability team identified 69 variables**
- **Key variables included:**
  - Sample position w/in the burn chamber
  - Machine insulation
  - Calorimeter (surface damage, position w/in calibration fixture)
  - Airflow through chamber
  - For additional variables, click here
- **Initial approach focused on evaluating high impact, easy to change variables – still insufficient for scope of project**
- **Each variable was then addressed through scientific Design of Experiments (DOE) with the help of Boeing Applied Math**

Boeing OSU Variability Reduction Project

- **The DOE Approach:**
  - What is a DOE
  - Why do we do it?
  - OSU Project Example

Boeing OSU Variability Reduction Project
- What is Design of Experiments (DOE) ?

- **Design of Experiments involves the active, systematic, and controlled change of process (or product) inputs to induce and observe their effects on process (or product) outputs.**

- **A systematized collection of principles for valid experimentation (*Randomization, Blocking, Replication and Balance*)**

- **A rigorous science for linking "how it was done" to "what you can say."**

- **A technology that includes techniques for structuring very powerful experiments with relatively few runs.**

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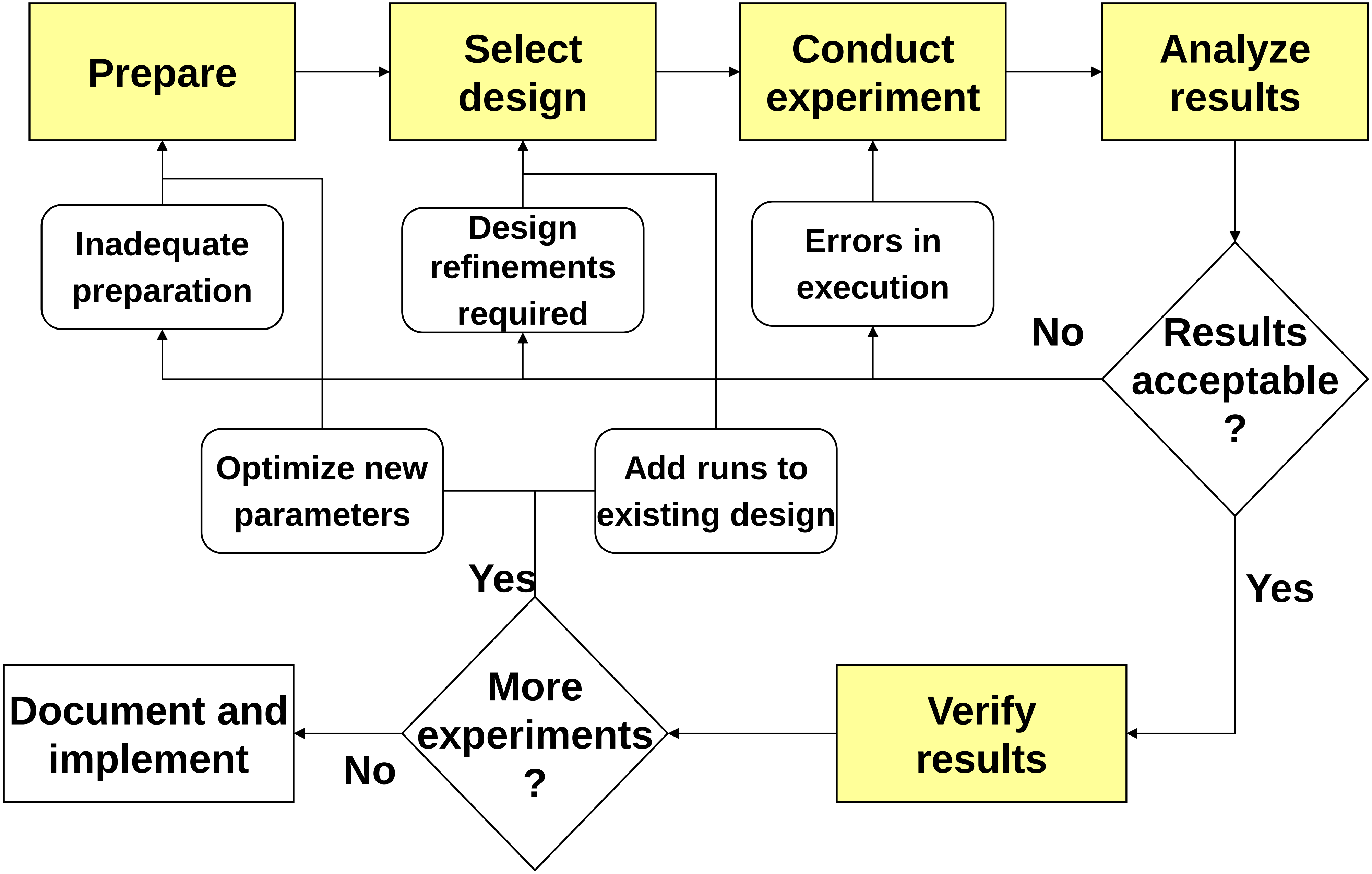
- Experimentation Process



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- Example

- **Goal: Establish the thermopile baseline**
- **Four critical variables.**
  - Lower Flame Length
    - Nominal Length = Diameter (D) of the burner tube, 0.5D and 1.5D
    - 0.004 ft^3/min methane and an air supply adjusted to produce a flame such that the inner cone is approximately the same length as the diameter of the burner tube
  - Upper Flame length
    - Nominal 1”, also try 0.75” and 1.25”
    - Controlled by Methane mixed with air in a ratio of approximately 50/50 by volume. Flamelets should be approximately one inch long (0.25" tip appears yellow)
  - Heat flux (Center)
    - Nominal (3.5 W/cm^2) and the upper/lower ranges (± 0.05 W cm^2)
  - Airflow
    - Nominal (200mm Hg). Vary between 180mm Hg and 220mm Hg
- **Total combinations = 3 x 3 x 3 x 3 = 81**
- **Based on DOE principles, adequate data can be collected through 48 combinations with multiple operators**

Boeing OSU Variability Reduction Project

- **Results, after many iterations of DOE's:**
  - Understanding of impact of key variables, and how to control them
  - Standard Work Instructions created to control 'standardized' parameters – Daily Startup Checklist, Maintenance Checklist, process instructions
  - Checklists were developed based on weekly discussions on machine operation.
  - Updated regularly to ensure consistent operation of machines with multiple users
  - Standard Panel tested weekly to monitor and record progress on all machines – 5 panels per set
  - Control charts maintained, regularly reviewed by non-advocate reviews
  - Project continued for approximately one year
  - Decreasing trend in standard deviations show reduced variability
  - Ongoing testing to monitor OSU performance based on documented, standard procedures for setup, operation, and cleaning

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- **Results:**
  - Daily startup checklist & maintenance checklist
  - Have been provided to FAATC for inclusion in AC

	A	B	C
1	**DAILY OSU CHECKLIST** **Requirements per BSS7322 Rev A**	Fri	Sat
2	Date	1-Feb	2-Feb
3	Completed By	YONAS	
4	**COLD START**		
5	Ensure gas bottle is charged (change @ ≤250psi). Verify regulator pressure is at 20psi after flames are turned on.	1900/20	
6	Turn air hood on high	x	
7	Clean upper chimney and inner walls with brush. After cleaning, verify position of air-mixing plate in upper	x	
8	Brush soot and contaminates from thermocouples using a soft-bristled brush and properly position, ensure wires are separated.	x	
9	Clean upper pilot tube using wire brush, ensure flame length poke-yoke is properly positioned.	x	
10	Verify lower and upper pilot position using sample holder Poke-Yoke.	x	
11	Vacuum out chamber, visually check that air holes in floor of chamber are clear.	x	
12	Clean window and mirror.	x	
13	Check position of diamond (vertical).	x	
14	Check that doors close completely around sample insertion rod.	x	
15	Check condition of calorimeters - report and replace if indented or missing paint.	x	
16	Check that calorimeters are flush with frame of the holder.	x	
17	Check condition of sample holders, visually check wires on holders	rewire	
18	Turn on supply air - adjust regulator until manometer reads 200mm Hg	x	
19	**HOT START/CALIBRATION**		
20	Turn on power to OSU. Verify that buttons for radiant heater, smoke detection and sample insertion are all on.	X	
21	Time OSU is turned on	7:10	
22	Time OSU can be calibrated (1.5 hours after power on)	8:40	
23	Time OSU is calibrated: For calibration, insert the calorimeters and close doors. Record calorimeter output 10 seconds after insertion; allow cooling for a minimum of 30 seconds between measurements. Heat flux req. @ center position: 3.45 - 3.55 w/cm^2	9:00	
24	Center calibration factor (mV/W/cm^2)	1.726	1.726
25	Center reading (mV)	6.05	

January | February | March | April | May

	A	B
1		**OSU Maintenance Log**
2		Initial when complete
3	1	Measure position of the sample holder in the chamber using C-clamp poke-yoke. (100mm from inner door, centered on diamond)
4	2	Measure position of the calibration fixture in the chamber using C-clamp poke-yoke. (100mm from inner door, centered on diamond)
5	3	Carefully inspect seal of outer doors and replace gasket if the seal is torn or leaking
6	4	Inspect seal of maintenance hatch and replace gasket if the seal is torn or leaking
7	5	Visually inspect condition of insulation - if insulation is degrading, replace it
8	6	Clean environmental chamber floor pan (120 holes) and ream with a #28 drill (.1405")
9	7	Clean the T-bar calibration burner (.116")
10	8	Visually inspect globar wires - if worn, discolored, or brittle, replace
11	9	Remove the upper pilot burner and ream holes with a #59 drill (.041")
12	10	Remove lower pilot burner tube and clean, reposition tube in correct vertical orientation with flamelet perpendicular to the diamond
13	11	Visually inspect sample holder mounting fixture, diamond, and reflector plate. If badly warped, replace as needed

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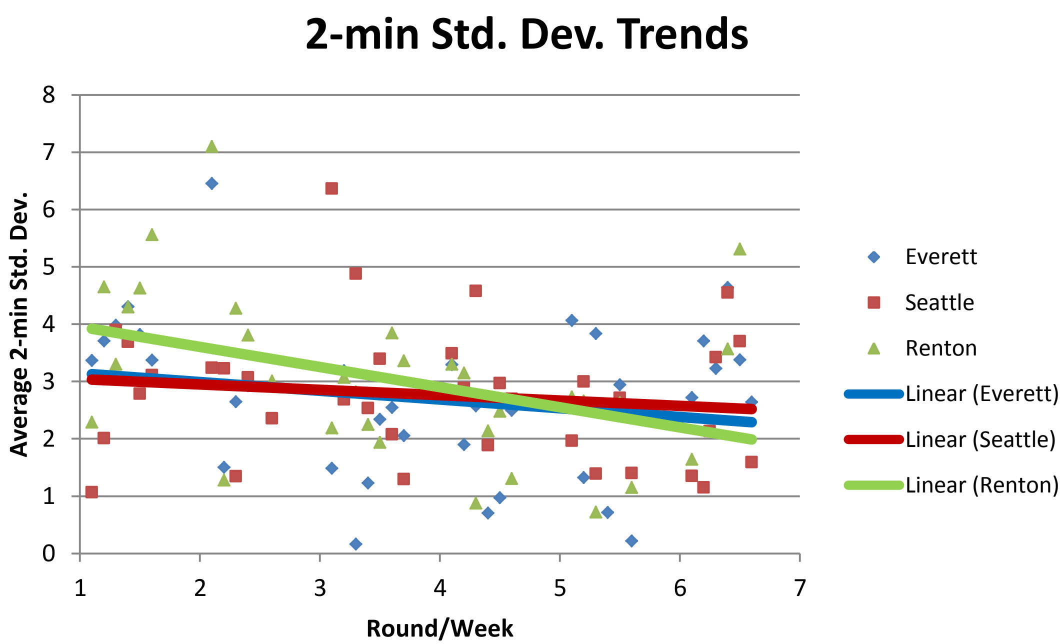
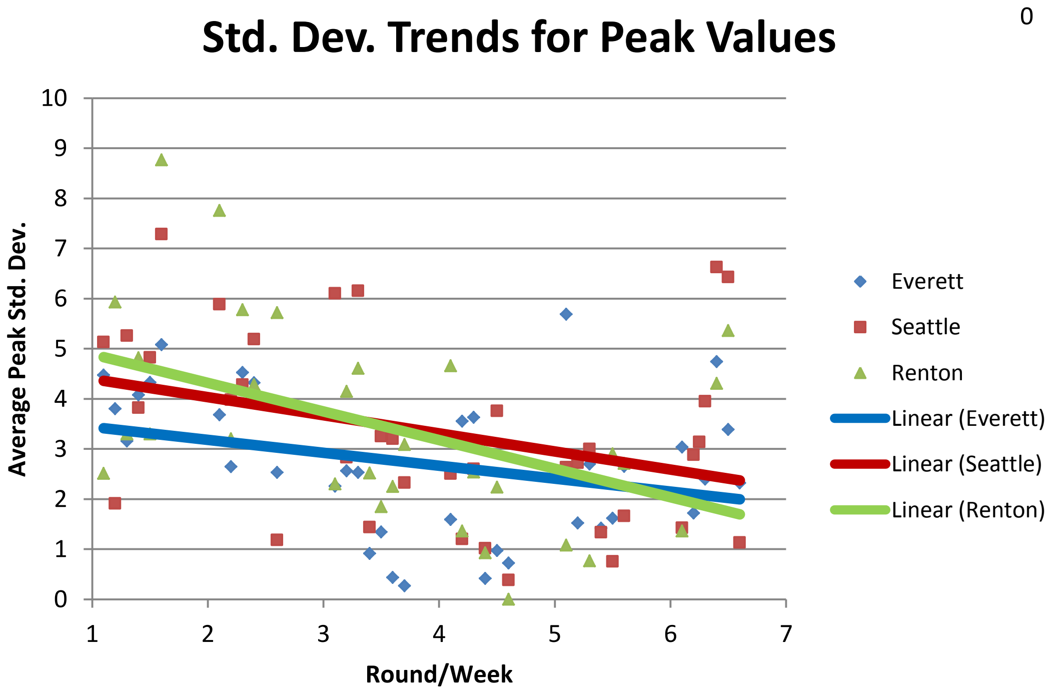
- **Results:**
  - 2.2 point decrease in peak Std. Dev.
  - 1.1 point decrease in 2-min Std. Dev.





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- **Conclusion:**
  - Methodical approach successfully identified key parameters that contribute to variability
  - DOE approach validated importance of standard work instructions, checklists, etc.
  - Boeing's OSU machines providing consistent, repeatable data
  - Even with using established controls, there is "inherent" variability within the OSU

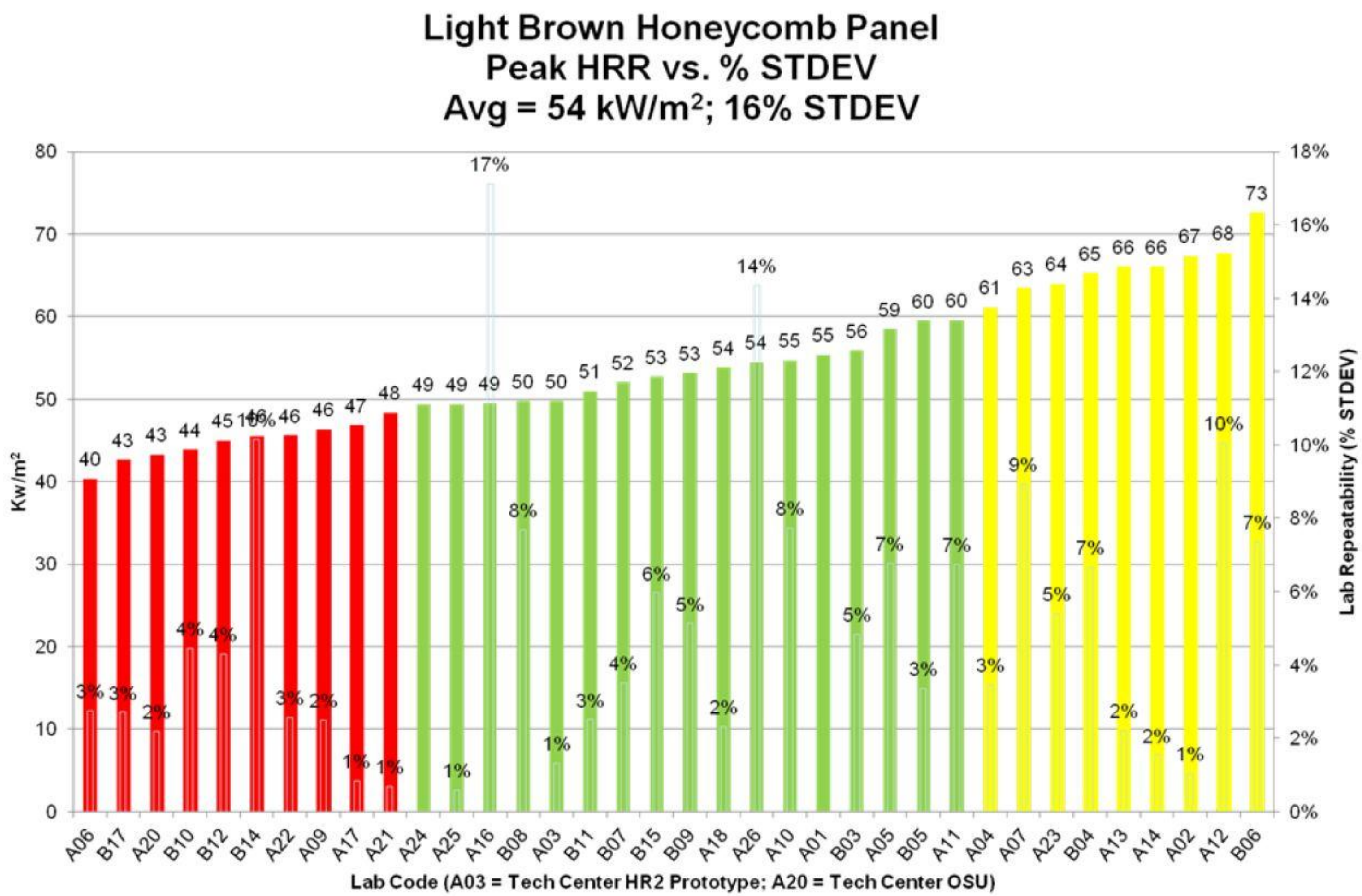
- **This method required up-front effort with data collection – many samples were tested over many months**
- ***BUT* - the benefits from this approach were realized in a statistically significant body of data**

Applying Boeing’s Approach to the 2012 FAA Round Robin

- **Background:**
  - Test Approach
    - 36 OSU’s participated in testing
    - Key equipment/setup information surveyed
    - Testing conducted per individual lab standards
  - Analysis Approach
    - Results plotted to show side-by-side comparison (FAA)
    - Operational variables statistically analyzed independently of test results (Boeing)
    - Test results statistically analyzed to determine correlation between labs (Boeing)

Applying Boeing's Approach to the 2012 FAA Round Robin

- **Side-by-side plot shows a substantial body of data, with clearly variable data in both the test results and standard deviations**



http://www.fire.tc.faa.gov/pdf/materials/June12Meeting/Burns-0612-OSU_HR2_Prototype_Data.pdf

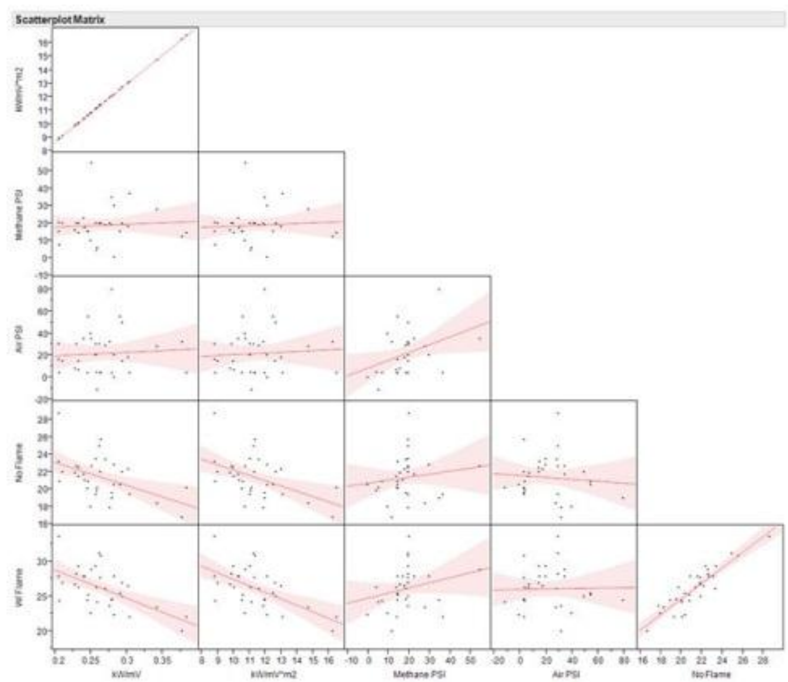
Applying Boeing's Approach to the 2012 FAA Round Robin

- **Each lab operated based on its normal practices**
- **Machine operating parameters were reported**
- **Boeing analysis took operating parameters into account**
- **Correlations drawn between each independent parameter**
  - Equipment manufacturer
  - Inlet pressures
  - Compressor vs. blower
  - Etc.
- **Machine parameters then analyzed in reference to test data**

Link to FAA Presentation

Applying Boeing's Approach to the 2012 FAA Round Robin

- **Boeing equipment/setup analysis shows:**
  - Correlation between kW/mv and kW/mV*m^2 parameters (r=1, as expected)
  - Strong positive correlation (r=0.8981) between flame off and flame on baselines (as expected)
  - Negative correlation between calibration variables and baseline variables: a high Kh machine will have a lower baseline (r=-0.47/-0.58, not expected)



Applying Boeing’s Approach to the 2012 FAA Round Robin

- **Conclusion:**
  - The statistical analysis identifies several equipment/setup parameters that significantly affect variability
    - Machine Type
    - Blower vs. Compressor
    - Gas Pressure
  - Not all variation is explained by observed parameters
    - These factors explain less than 50% of the variability ($R^2 \leq 0.5$)
  - There are too many uncontrolled parameters and too little data to explain the variability
  - Better control needs to be exercised over future Round Robin testing if variation is going to be explained

Applying Boeing's Approach to the 2012 FAA Round Robin

- **Recommendation:**
  - Conduct another focused Round Robin (5-10 machines)
    - Much discussion needed in task group to define plan
    - Cross section of machines – principle of balance
  - Control parameters
    - All labs set up to the same parameters: air/methane pressure, etc.
    - Calibrate using the same process
    - Calibrate using a single, shared calorimeter
    - Collect a larger dataset – 10 to 50 panels tested at each lab
  - Statistical analysis of collected data
  - Use this standard approach in future development of the HR2

- **Thank you for your time**

- **Good luck OSU Task Group!**

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Row	#	Variable	Fa, Fi, C	FA Values	Fa Difficulty	High = 3	Medium = 2	Low = 1	Difficult = 1	Medium = 2	Easy = 3	Total
5						Impact			Ease of Correction			
6												
7	10	Conditioning of the coupon	Fa	12h, 24h, 36h,	E			1			3	#VALUE!
8	22	Distance coupon goes into chamber	C		D	3					3	6
9	23	Seal of the inner chamber doors	Fi			3					3	6
10	24	Seal of outer door	Fi			3					3	6
11	40	The welded bead size of the TC wires	Fi			3					3	6
12	41	Type of insulation used behind the back	Fi	nonstandard ,		3					3	6
13	42	Condition of insulation behind the back plate	Fi	New, useable, replace		3					3	6
14	45	Condition of electrical wires attached to the glow bars	Fi			3					3	6
15	48	Hole size of bottom plate in the bottom of the chamber	Fi			3					3	6
16	49	Hole size of the upper 15 pilots	Fi			3					3	6
17	6	Visually Ck Position of Diamond	Fi	Vertical, angled		3					3	6
18	1	Coupon Build	CV			3					3	6
19	3	Air Pressure	CV / FA	In tolerance, high, low		3					3	6
20	4	Air Flow	CV / FA	In tolerance, high, low		3					3	6
21	8	Distance of the lower flame from the coupon	Fi	In tolerance, vertical spacing off, horizontal spacing off		3					3	6
22	12	Foil wrap on coupon	Fi	Correct foil/no, TF clear/no		3					3	6
23	13	Cleanliness of Thermopile	FA	contaminated		3					3	6
24	14	Different Calorimeters	Fi			3					3	6
25	17	Wait time between tests	FA	30 sec, more, less	E	3					3	6
26	18	Cleanliness of chimney	Fa	Clean, contaminate		3					3	6
27	20	Length of upper flames	Fa	To spec, long, short		3					3	6
[illegible]		[illegible]	[illegible]									

Row	#	Variable	Fa, Fi, C	FA Values	Fa Difficulty	High = 3	Medium = 2	Low = 1	Difficult = 1	Medium = 2	Easy = 3
						Impact			Ease of Correction		
	10	Conditioning of the coupon	Fa	12h, 24h, 36h,	E			1			3
	21	Length of lower flame	Fi	To spec, long, short		3					3
	25	Distance calorimeter goes into chamber	Fi			3					3
	26	Measurement device (Plotter or Multi meter) (Calibration of	Fi	device, nominal calibration,		3					3
	27	Wet Test Meter	Fi	required/no?		3					3
	31	Wet test meter is level	Fi	level/angled		3					3
	32	Wet test meter water level	Fi	too high, just right, too low		3					3
	33	Thermopile Baseline Reading	C			3					3
	34	Preconditioning of chamber	CV/FA	constant temp/warming up/too hot		3					3
	35	Heat flux to the correct 3.5+/- 0.05 W/cm sq	CV/FA	nominal or fringe calibration		3					3
	38	Visual Cleanliness of lower chamber	Fi	clean/no		3					3
	46	Positioning of the TC wires	Fi	correct/outside of fixture setting		3					3
	47	Temperature of the air going into the chamber 73 deg.	CV	Nominal, too hot, too cold		3					3
	50	Condition of calorimeters. Are they indented or missing paint	FI	Good condition, must be replaced		3					3
	53	calibrating to nominal or just within the range	Fa	nominal/fringe calibration		3					3
	54	Regulators for the upper pilots to achieve 50/50 by volume	Fi			3					3
	56	Cleanliness and hole size of the t-burner when calibrating	Fi			3					3
46	60	Visually ck Wires on holders	Fi	correct/outside of fixture setting		3					3
47	61	Condition of sample holders	Fi	good/poor condition		3					3
48	63	Are the calorimeters flush with the frame of the holder	Fi	level with frame, not properly seated		3					3