Similarity Project Update

Presented to: International Aircraft Materials Fire Test Forum

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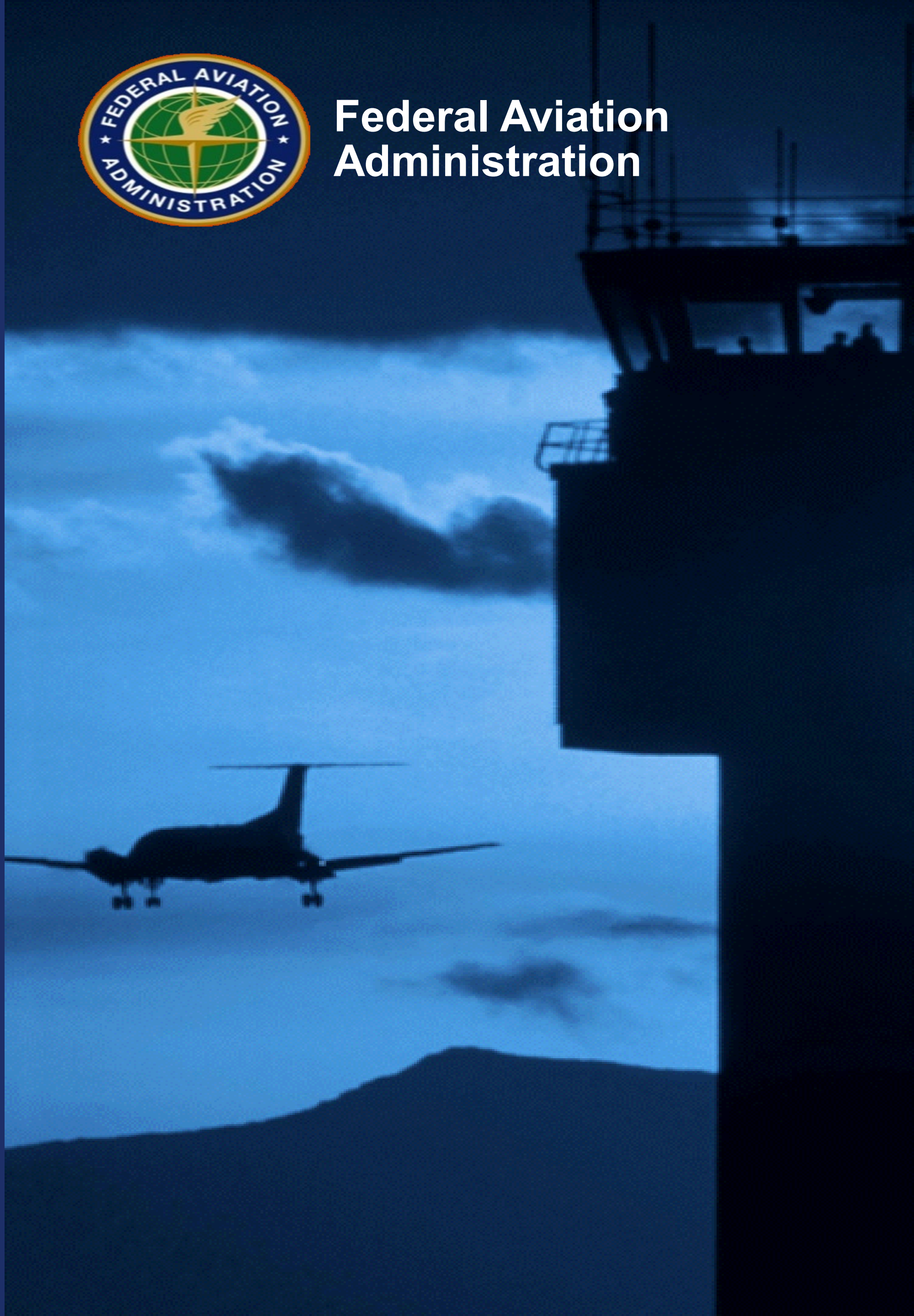
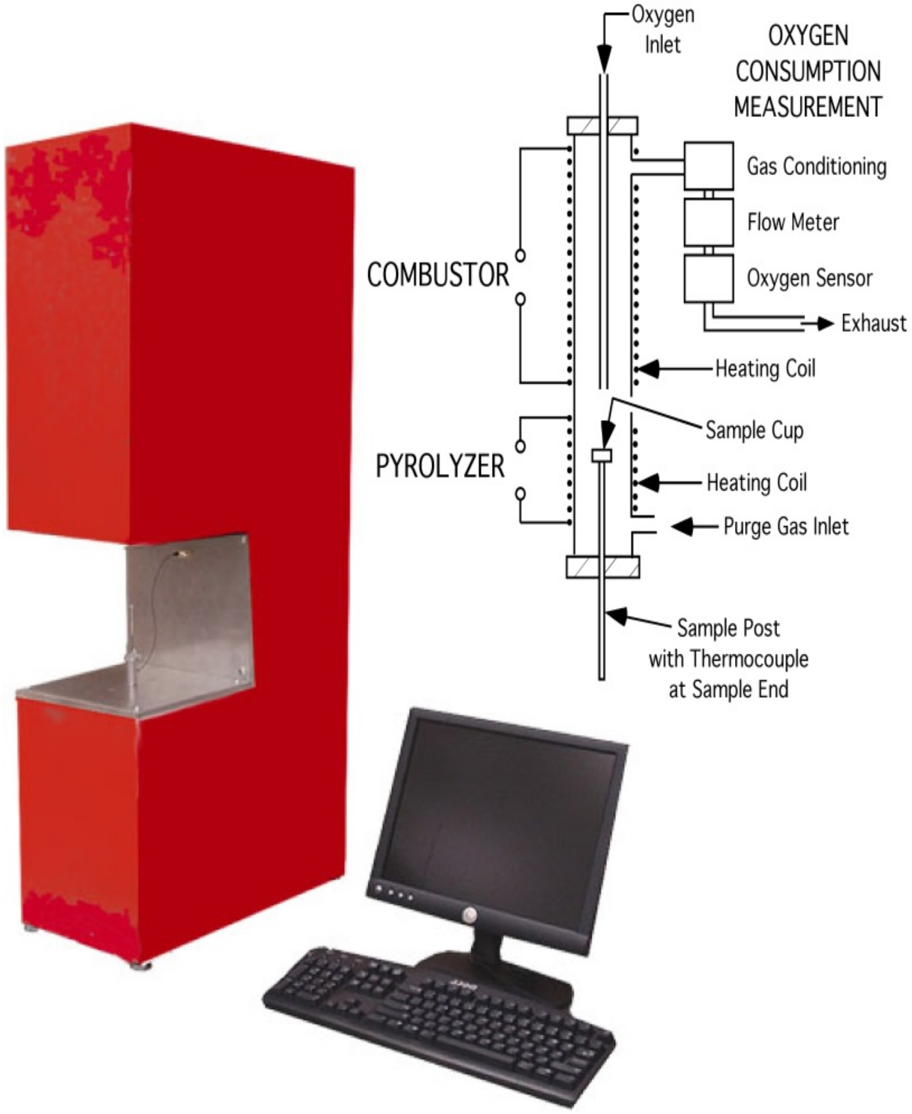


Similarity Project Goals

- **Develop** standardized guidance using the Microscale Combustion Calorimeter (MCC) to compare the flammability properties of combustible components of aircraft cabin materials.

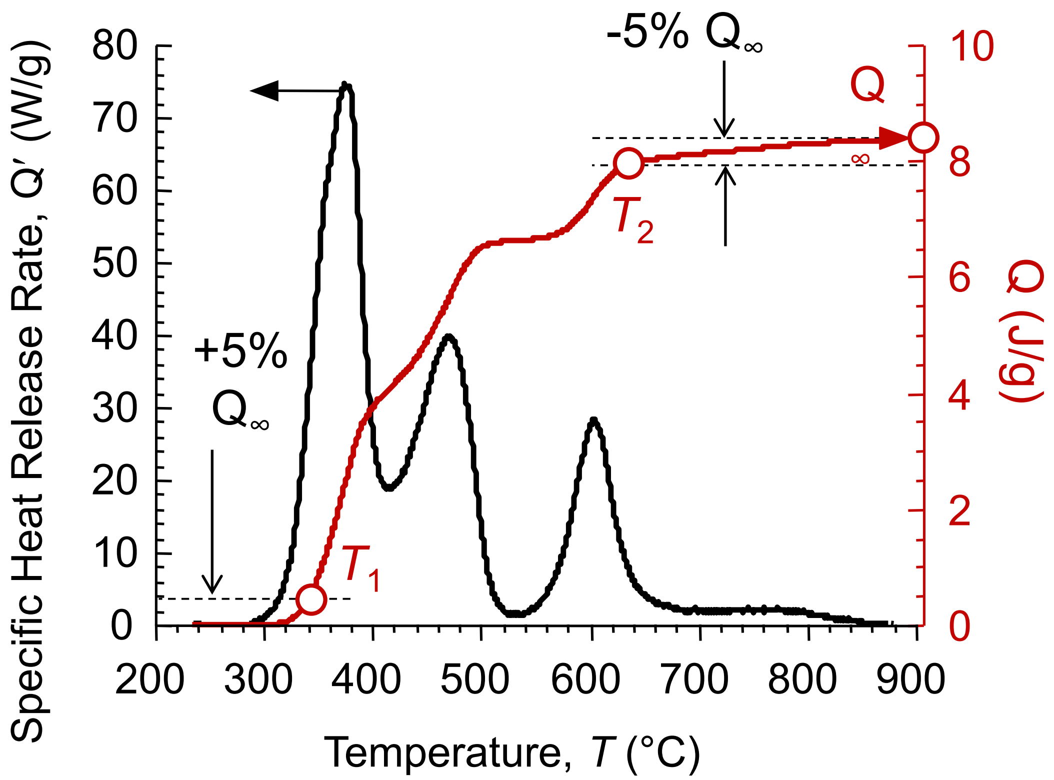
- **Validate** Similarity Process through case studies comparing FAA fire test results to physically-based MCC flammability parameter.

- **Release** updated guidance documents.



Microscale Combustion Calorimeter (ASTM D7309-21)

- ❑ The MCC test measures materials properties related to flammability on a milligram size scale.
- ❑ One of the outputs: Fire Growth Parameter (FGC).
- ❑ The FGC is the ignitability and burning rate of the material, i.e., the **total fire hazard**



MCC procedure for FGC

1. Measure specific heat release rate Q′ versus temperature *T* as per ASTM D7309 (5 replicates)
2. Integrate Q′/β versus *T* to obtain Q versus *T*, i.e., Q(*T*)
3. Obtain total heat release $Q(T_\infty) = Q_\infty = h_c$(J/g)
4. Obtain T_1 at 5% deflection from Q(T) baseline, i.e., at $0.05Q_\infty$
5. Obtain T_2 at Q_∞ i.e., $0.95Q_\infty$.
6. Calculate Fire Growth capacity (FGC)

T_0 = 25°C (298K)

T_1 = Ignition temperature

T_2 = Burning temperature

$$FGC = \left(\frac{Q_\infty}{T_2 - T_1}\right)\left(\frac{T_2 - T_0}{T_1 - T_0}\right)$$

14 CFR Bench Scale Fire Tests (Pass/Fail)

OSU Rate of Heat Release Apparatus
(Large Area Materials)
- Peak HRR
- 2-min HR

Radiant Panel
(Thermo-acoustic Insulation)
- Flame propagation distance
- After flame time

Vertical Bunsen Burner
(All other materials)
- Flame time
- Flame drip time
- Burn length

Validation case studies

Twelve industry case studies completed to validate MCC Similarity guidance:

- Phenolic resin systems
- Adhesives & potting compounds
- Decorative laminates
- Thermoplastics
- Paints/coatings
- Insulation blankets

Similarity Criteria

Coupon Testing

$$\frac{|P_a - P_b|}{P_b} \leq \frac{|X_a - X_b|}{X_b}$$

Production Testing

$$\frac{|P_a - P_b|}{P_b} \leq \frac{2\sigma_{Xb}}{X_b}$$

P_a and P_b are FGC from ASTM D7309-21 (MCC)

X_a and X_b are bench-scale fire properties

σ_{Xb} is the standard deviation of FAA tests of a certified production material containing component B

Current focus

- Current efforts are focused on improving the **reproducibility** of the MCC test method by developing rules for baseline correction that can be automated to eliminate operator judgement.

- Goal is to make FGC_a and FGC_b as reproducible as possible so their difference, $|FGC_a-FGC_b|$, which is the basis for a similarity determination, is independent of testing laboratory.

Recent Progress

1. FAA Tech Note on Physical Basis for Using FGC as a microscale flammability metric - *Completed* (DOT/FAA/TC-20/35)
2. FAA Tech Note on Similarity Criterion and Industry Case Studies – *Completed* (DOT/FAA/TC-20/30)
3. Journal article on Theoretical Basis for FGC published April 1, 2021 (*Polymer Degradation & Stability*)
4. FAA Tech Note on MCC Baseline Correction for maximum accuracy of FGC – *Internal/External Review*
5. 2021 version of ASTM D7309 will include FGC *(balloted on March 4, 2021)*

Motivation for Developing MCC Baseline Correction Rules

- For low heat release aircraft materials, MCC data must be corrected for baseline drift to be accurate.

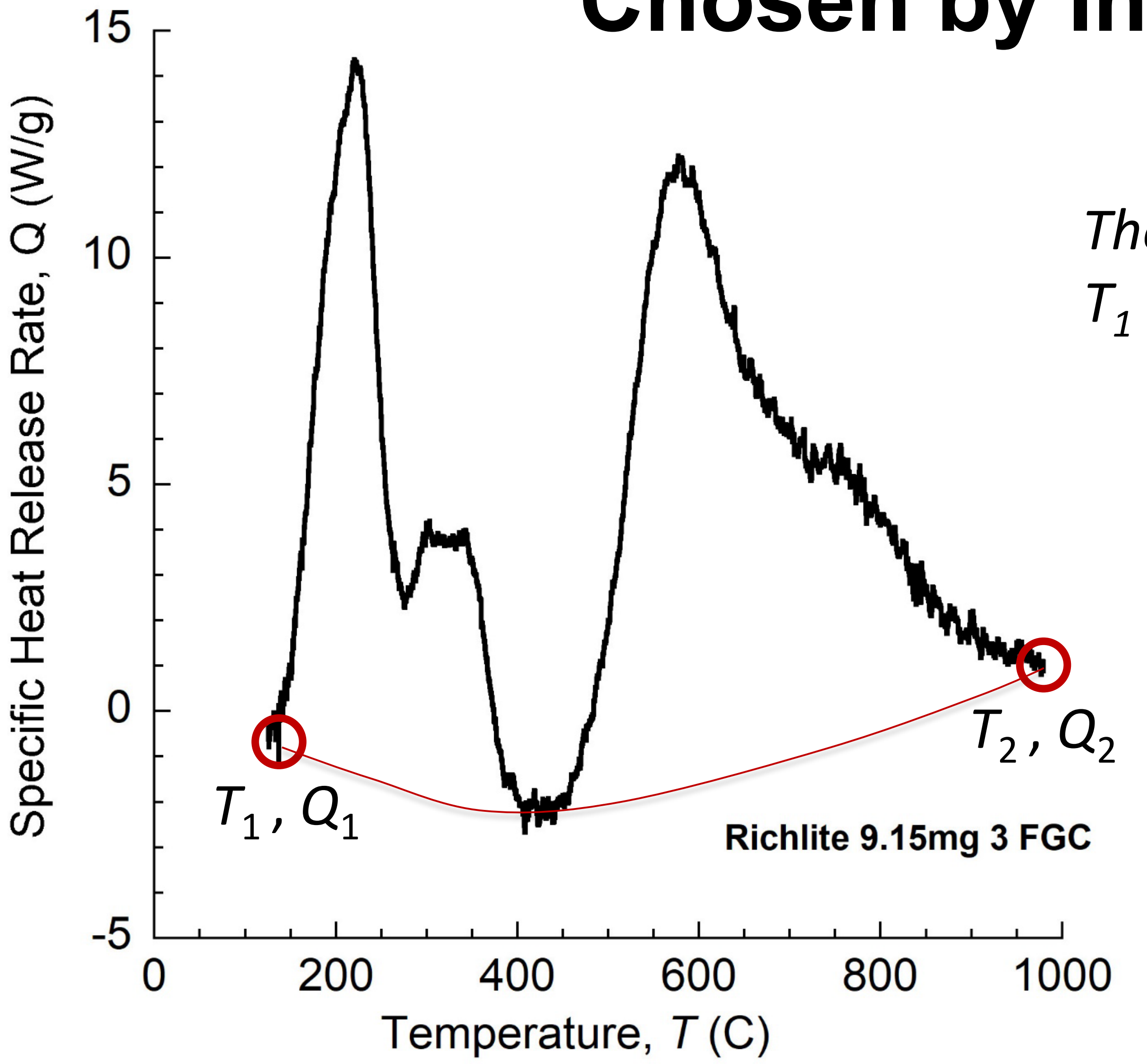
- MCC baseline correction is currently a user-dependent process.

- Standardized rules for baseline correction will improve reproducibility of FGC measurements in ASTM D7309 by taking the user out of the loop.

- Baseline correction rules can be automated in software.

- Only non-proprietary rules can be included in ASTM D7309 for calculation of FGC.

Baseline Endpoints T_1 and T_2 Currently Chosen by Inspection



The user chooses baseline endpoints T_1 and T_2 based on a best guess that maximizes total heat release.

This is an arbitrary process may include spurious data and not be accurate.

T_1/T_2 ≡ First/Last Temperature (Method #1)

$$\textit{Thermal Baseline},\ Q_0 = \frac{C_1}{T} - C_2$$

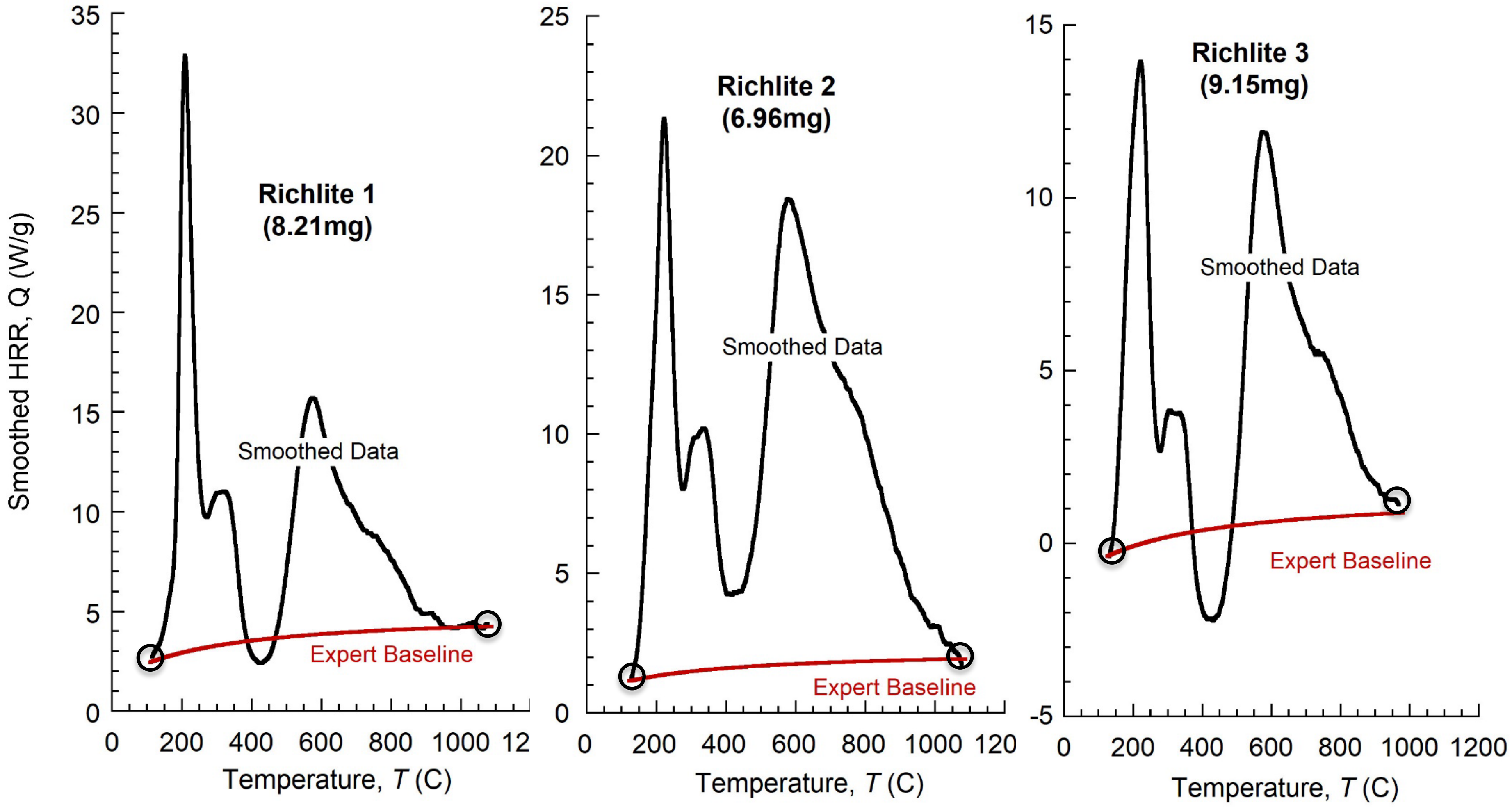
Step 1: Smooth acquired data using a 20 K/β second window to remove sampling noise at beginning and end. First Point = (T_1, Q_1), Last Point = (T_2, Q_2).

Step 2: Calculate and subtract baseline from T_1 to T_2 in a single step.

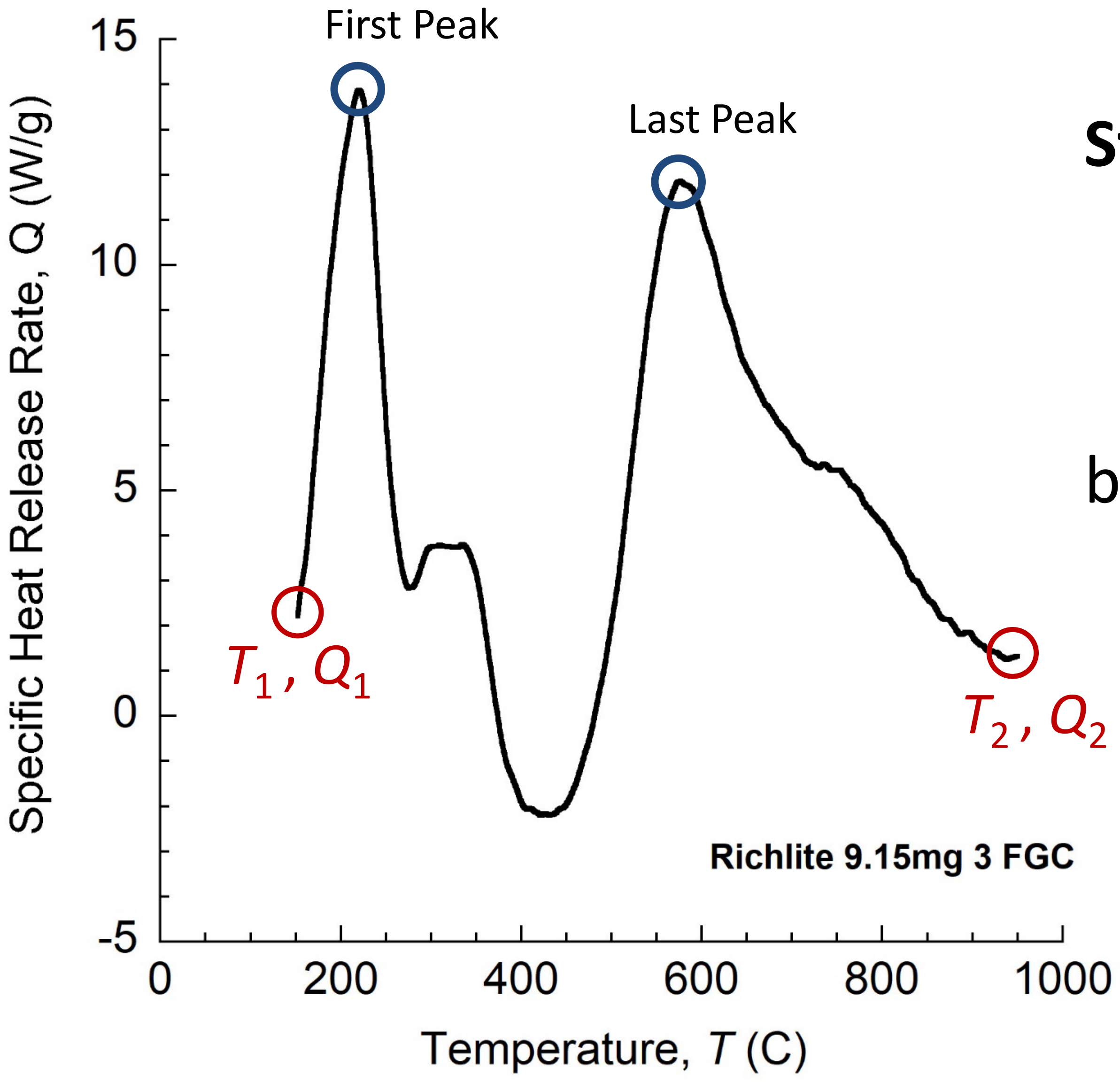
Global correction includes Q noise before and after the combustion event that can affect THR and FGC.

T_1/T_2 = First/Last Temperature is Simplest Approach

Entire range of data (including noise) is analyzed



T_1/T_2 from First/Last Peak (Method #2)

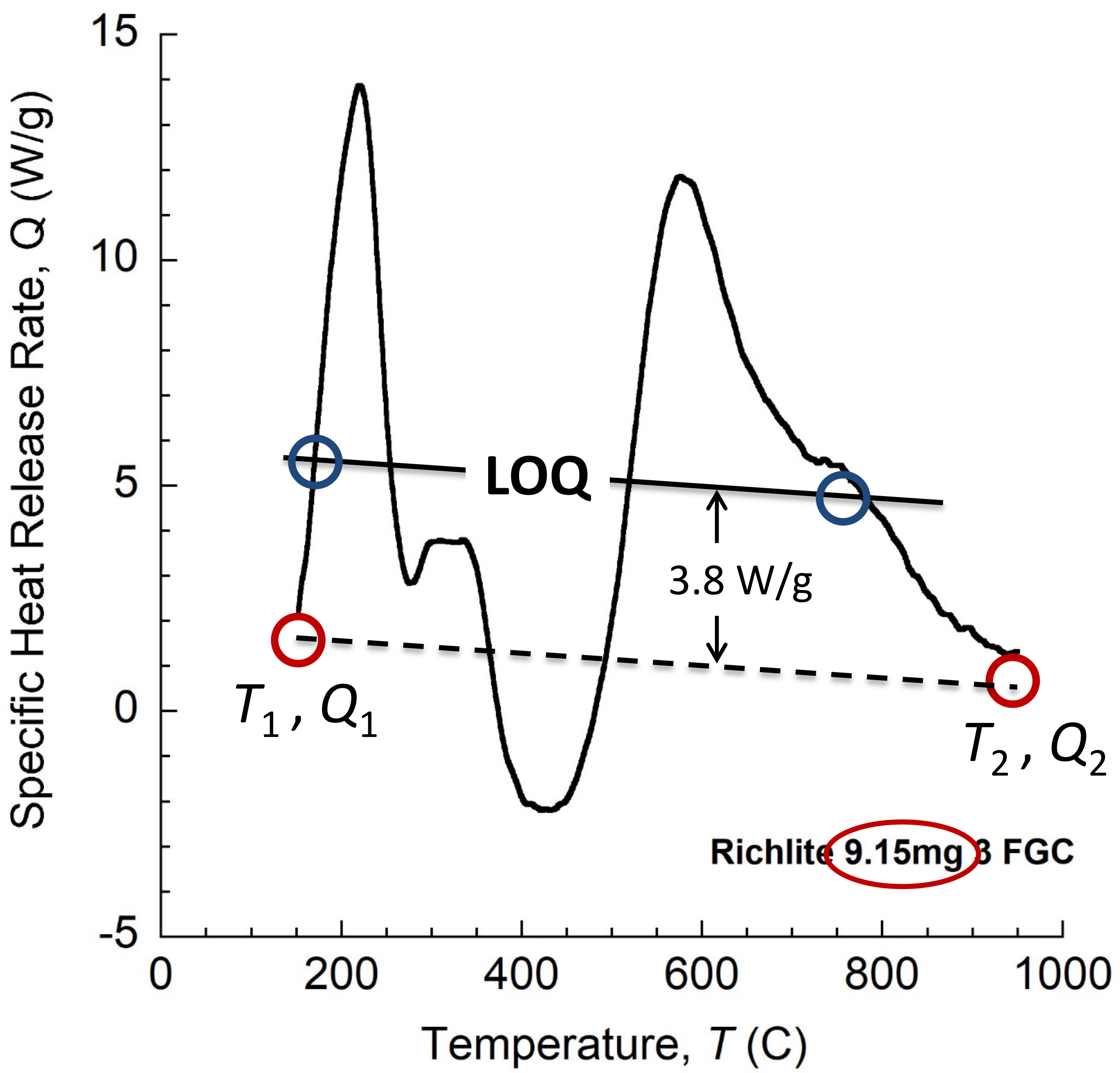


Step 1: Smooth acquired data using a 20 K/β second window

Step 2: Select T_1, T_2 at Q minima before first peak and after last peak

Peak detection software is proprietary or rarely documented and cannot be included in ASTM D7309

T_1/T_2 from LOQ Threshold (Method #3)



Step 1: Smooth acquired data using a 20 K/β second window

Step 2: Find T_1/T_2 at Q minima before first/after last intersection of Q with Limit of Quantification (LOQ = 35mW/m_0)

LOQ (W/g) = 35 mW/9.2mg = 3.8 W/g

T_1/T_2 by Moment-Area Method* (Method #4)

- Subtract 20K of data from the beginning and end of the test
- Calculate mean time from absolute value of specific heat release rate |Q| history

$$\bar{t} = \frac{\int_{-\infty}^{\infty} |Q|\, t\, dt}{\int_{-\infty}^{\infty} |Q|\, dt} = \frac{\sum |Q|\, t}{\sum |Q|}$$

Equal sampling interval, Δt

- Compute the variance of time for Q(t) history

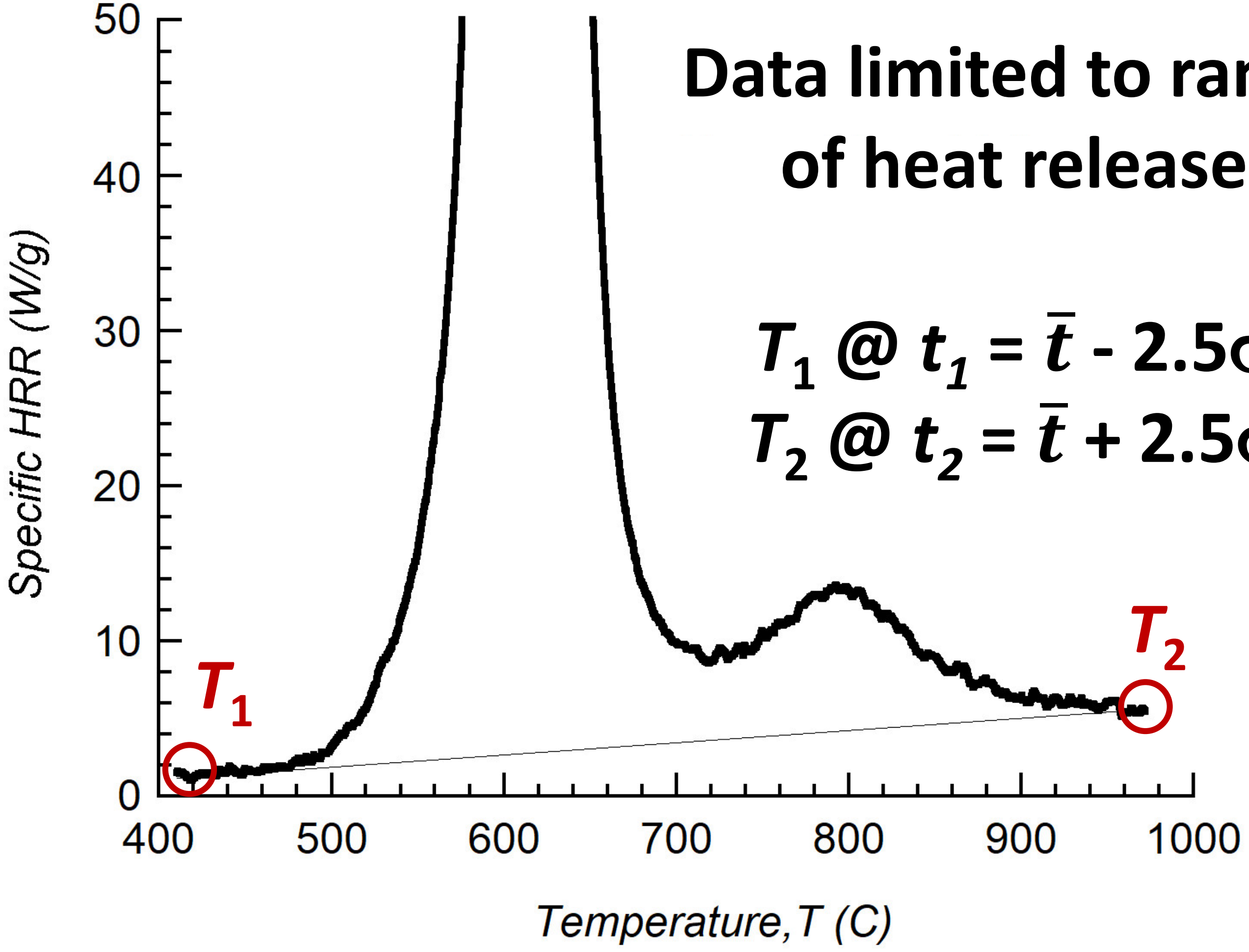
$$\mathrm{Var}(t) = \sigma^2 = \frac{\int_{-\infty}^{\infty} |Q|\, (t-\bar{t})^2 dt}{\int_{-\infty}^{\infty} |Q|\, dt} = \frac{\sum |Q| (t-\bar{t})^2}{\sum |Q|}$$

- T_1 is the temperature at $t = \bar{t} - k\sigma$
- T_2 is the temperature at $t = \bar{t} + k\sigma$

k = coverage factor

*R.E. Lyon, S. Crowley and R.N. Walters, Steady Heat Release Rate by the Moment Area Method, *Fire and Materials*, 32, 199-212 (2008).

Moment-Area Method (PPSU)



Data limited to range of heat release

$$T_1 \ @ \ t_1 = \bar{t} - 2.5\sigma$$
$$T_2 \ @ \ t_2 = \bar{t} + 2.5\sigma$$

Summary of Baseline Endpoint Selection Methods (Thermal Baseline)

Rank	BL Endpoints Method	Accuracy		Repeatability	
		THR	FGC	THR	FGC
1	Inspection by expert	1	1	0.95	0.94
2	First/Last Peak (#2)	1.00	0.99	0.92	0.91
3	LOQ Threshold (#3)	1.00	0.98	0.92	0.91
4	Moment-Area (±2.5σ) (#4)	0.99	0.97	0.92	0.90
5	First/Last Temperature (#1)	0.99	0.97	0.89	0.86
6	**No** baseline correction	0.96	0.93	0.87	0.82

(Thermal Baseline fit, n = 3 replicates of 90 materials (N = 278 files) with emphasis on low HR aircraft interiors)

Summary of Baseline Endpoint Selection Methods (Linear Baseline)

Rank	BL Endpoints Method	Accuracy		Repeatability	
		THR	FGC	THR	FGC
1	Inspection by expert	1	1	0.95	0.94
2	First/Last Peak (#2)	1.00	0.99	0.94	0.92
3	LOQ Threshold (#3)	1.00	0.99	0.94	0.92
4	Moment-Area (±2.5σ) (#4)	0.99	0.98	0.93	0.92
5	First/Last Temperature (#1)	1.00	0.99	0.92	0.88
6	**No** baseline correction	0.96	0.93	0.87	0.82

(Linear Baseline fit, n = 3 replicates of 90 materials (N = 278 files) with emphasis on low HR aircraft interiors)

Summary

- FAA-industry working group has developed a process to compare flammability of materials at the molecular (milligram) level using MCC.
- Approach is to use Pass/Fail criteria for Fire Growth Capacity (FGC) in ASTM D7309-2021 (MCC) to determine similarity.
- Good agreement between MCC tests and fire tests in numerous case studies validate this approach.
- Current work is focused on improving the reproducibility of FGC by automating the baseline correction to eliminate operator judgement/laboratory bias.
- Next steps: Draft updated guidance for review by FAA regulatory officials for approval and release.