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G-27 Testing Apparatus Calibration Discussion

Overview analysis of key aspects of the testing chamber apparatus
(variables, best practices, moving toward consensus)

Robby Kinsala – CEO | Americase

G27 Test Chamber / Apparatus Design Elements:

Basic Overview

Key Variables – Lab to Lab Repeatability

Example Test Chambers

Marlin Engineering

Boeing

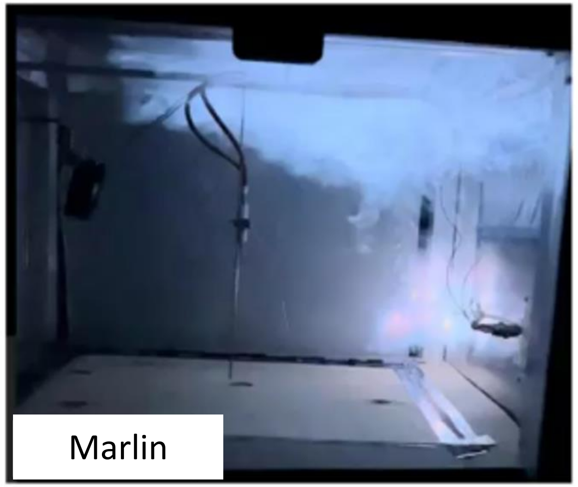
Transport Canada / NRC

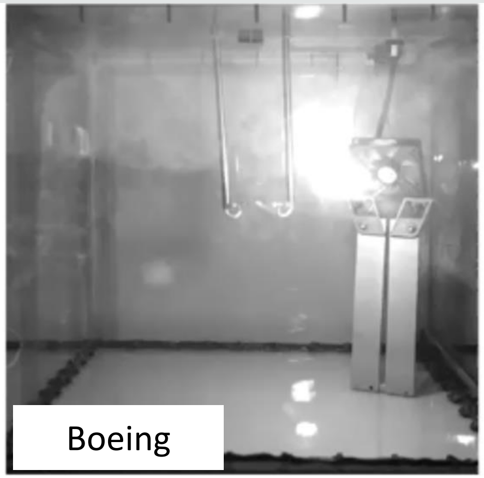
Fulcrum / Americase

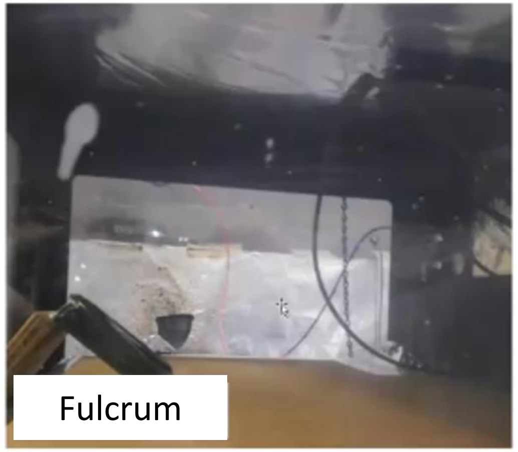
FAA Fire Tech Center

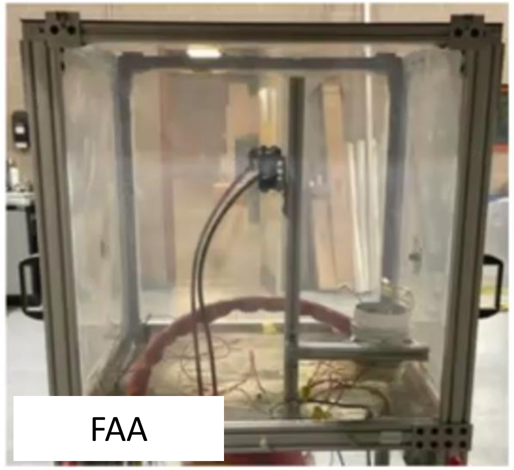
(Other Labs with chambers not shown in this presentation)

The chamber is specifically specified in the G27 (SAE AS6413) standard to verify flammable gasses exiting a package containing lithium battery(s) in TR will not ignite in a hazardous manner if in an aircraft cargo compartment.









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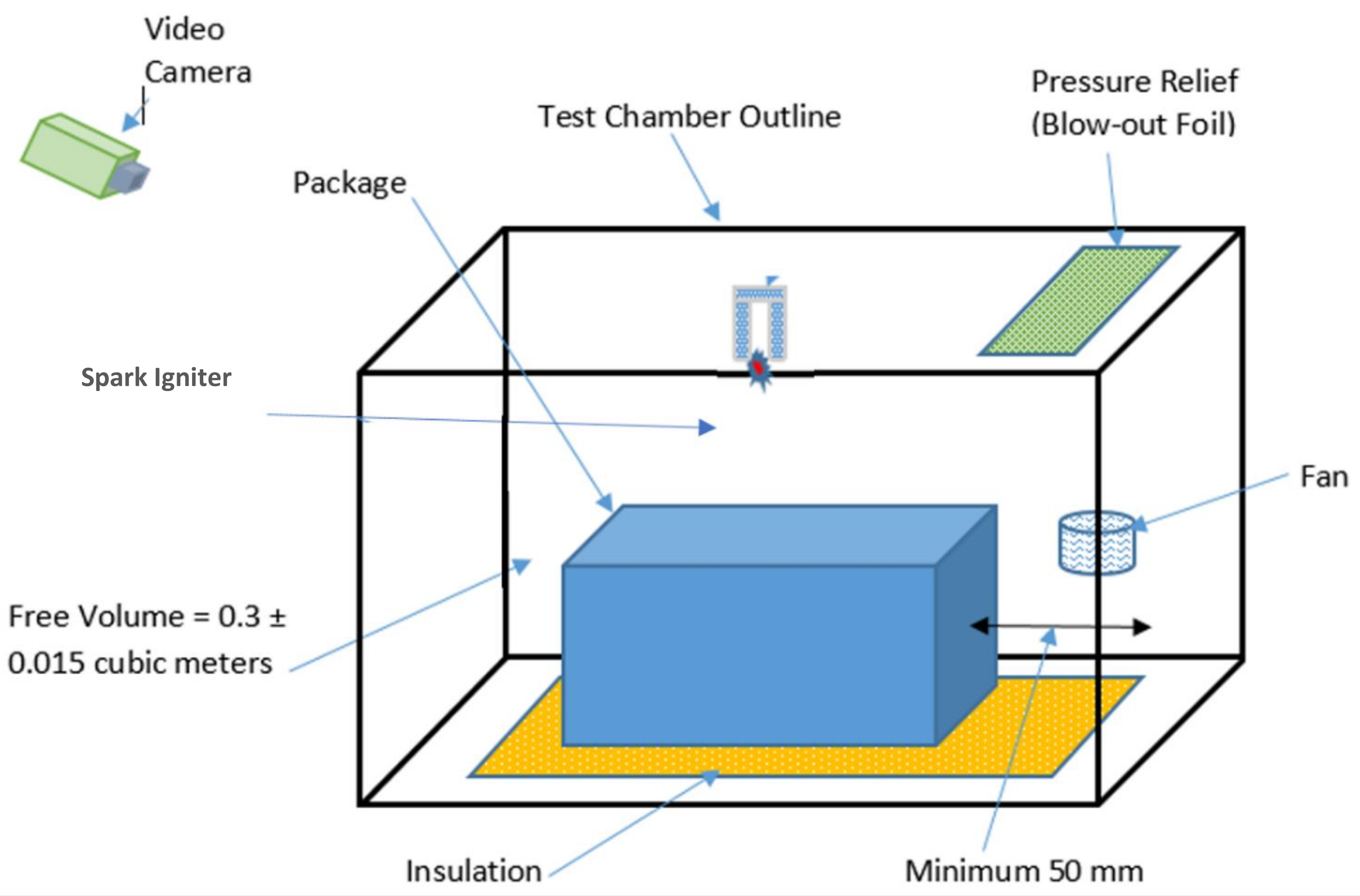
Design Features

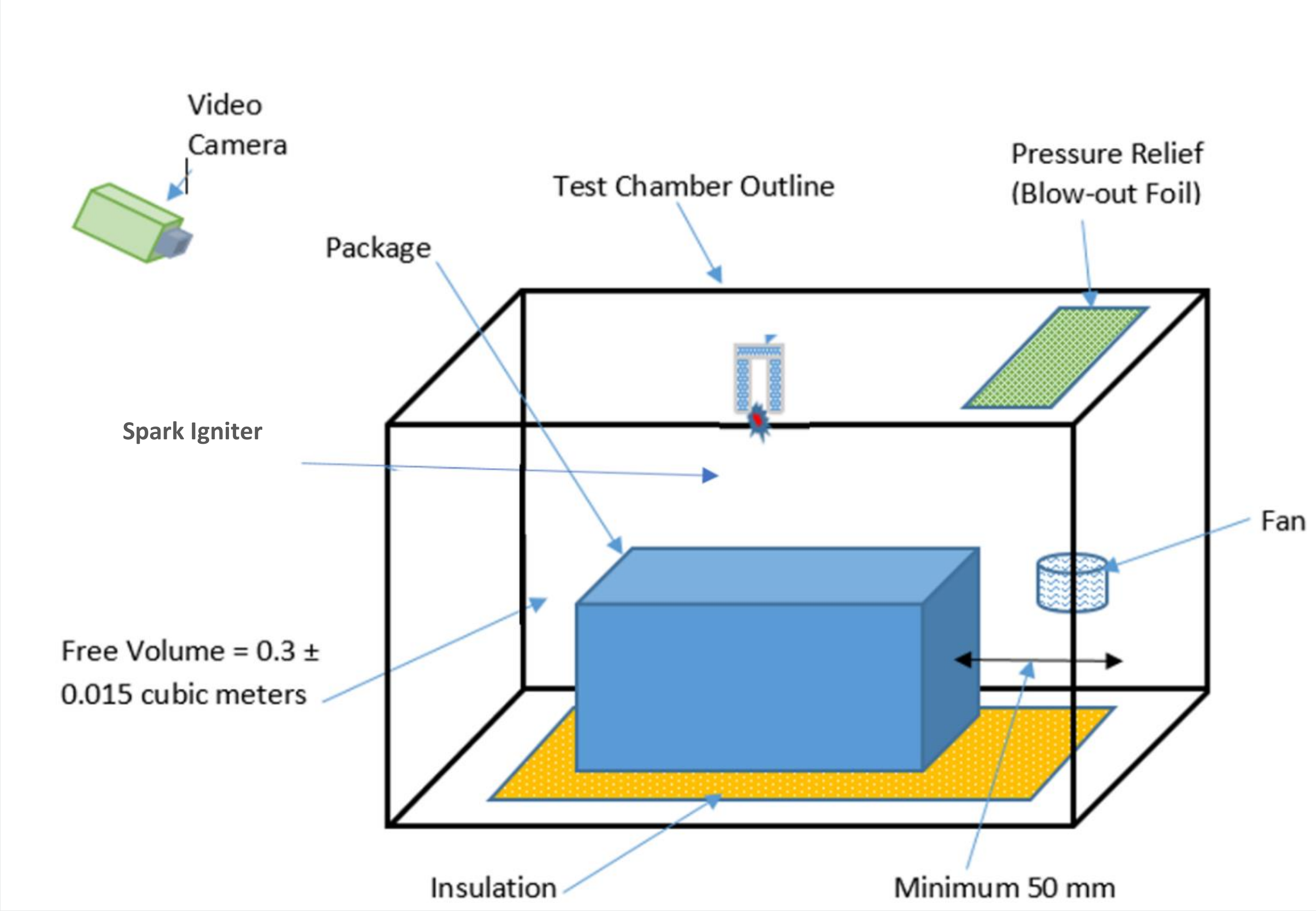
- Free Volume of air remaining in chamber = 0.3 cu meters
- Pressure Relief (Blow-Out) Panel
- 35 cfm mixing fan
- Ignition / Spark Ignitor
- Chamber Leak Rate Controlled
- Optional Video Camera(s)
- Optional Witness Panels (not shown)

Today's discussion concentrates on variables affecting gas ignition reproducibility (lab to lab).



Key Variables

- Ignition Source energy and location
- Fan location, orientation and flow rate
- Leak Rate / Leak Points



Apparatus Calibration: Methane LFL Ignition Test

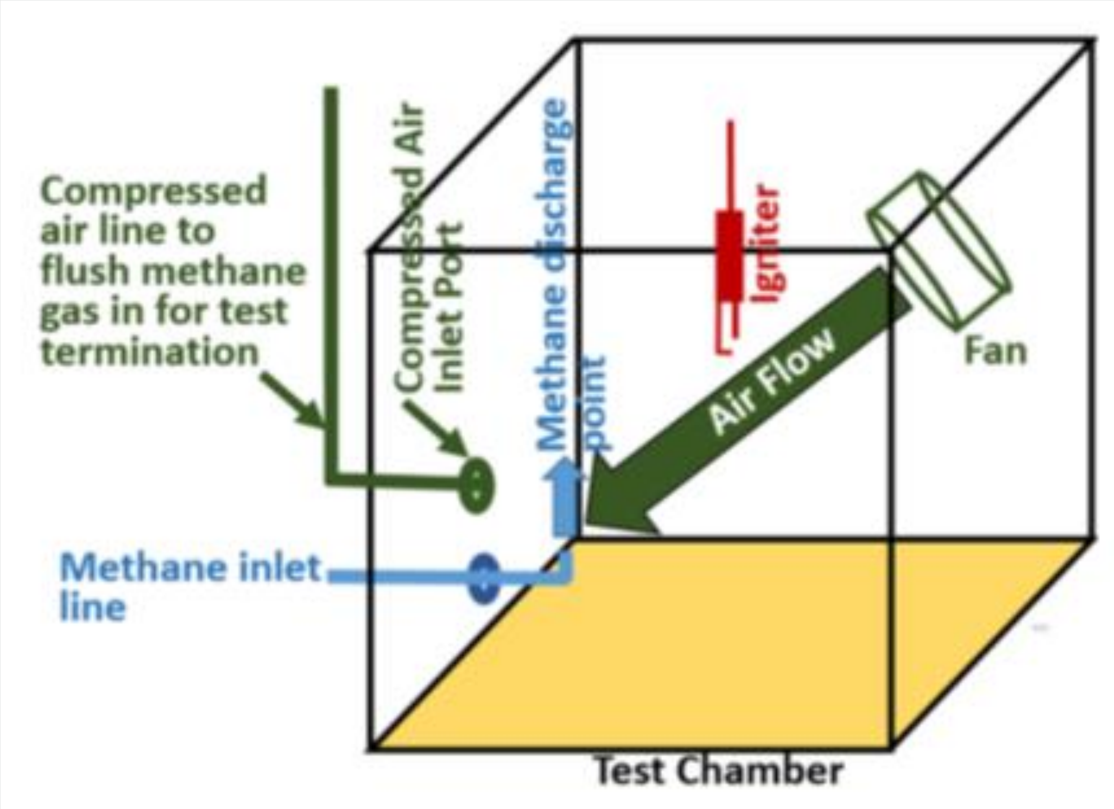
Goal of Methane LFL Test:

- Use an agreed upon pseudo-standardized ignition calibration test method across multiple test chambers.

- Verify ignition results are repeatable across all test chambers.

Methane Ignition Test

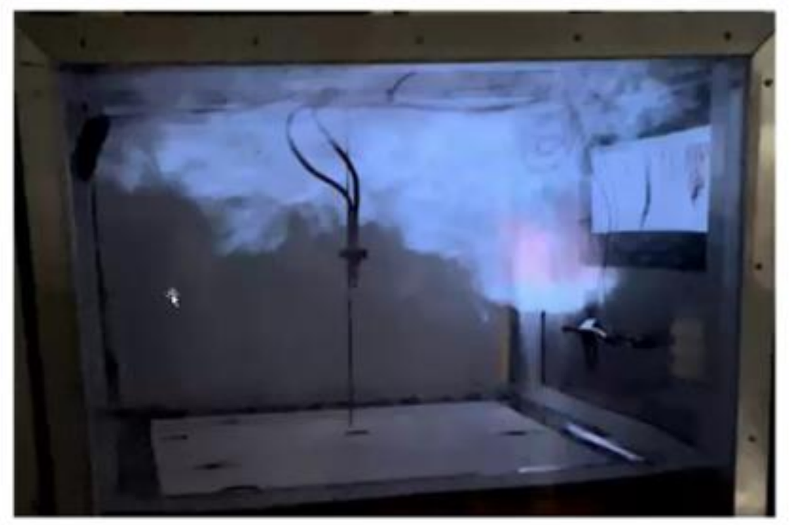
- Modify test chamber to include methane tube with flow rate of 2 liters/min
- Setup test chamber without a package; run ignition test per AS6413
- Analyze variance across Round Robin Test Labs
  - Isolate variables; test again.

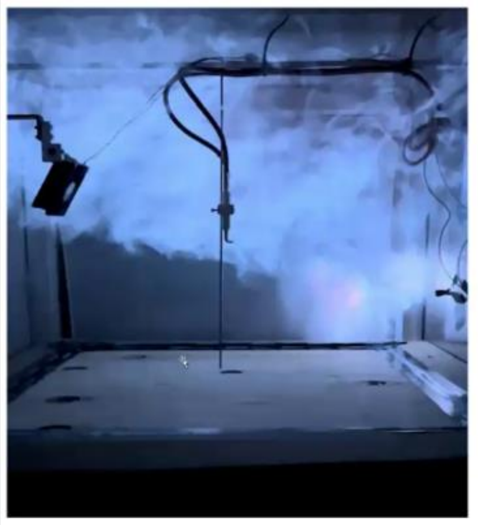


Methane Ignition Test

Preliminary Results:

- Significant stratification
- Unexpected early ignition
- Pre-ignition fuel “consumption”
- Delayed ignition





Apparatus Analysis 1: Ignition Source (power, location, frequency)

Ignition Source Power vs LFL Combustion

Optimal Location

Duration and Frequency potential issues

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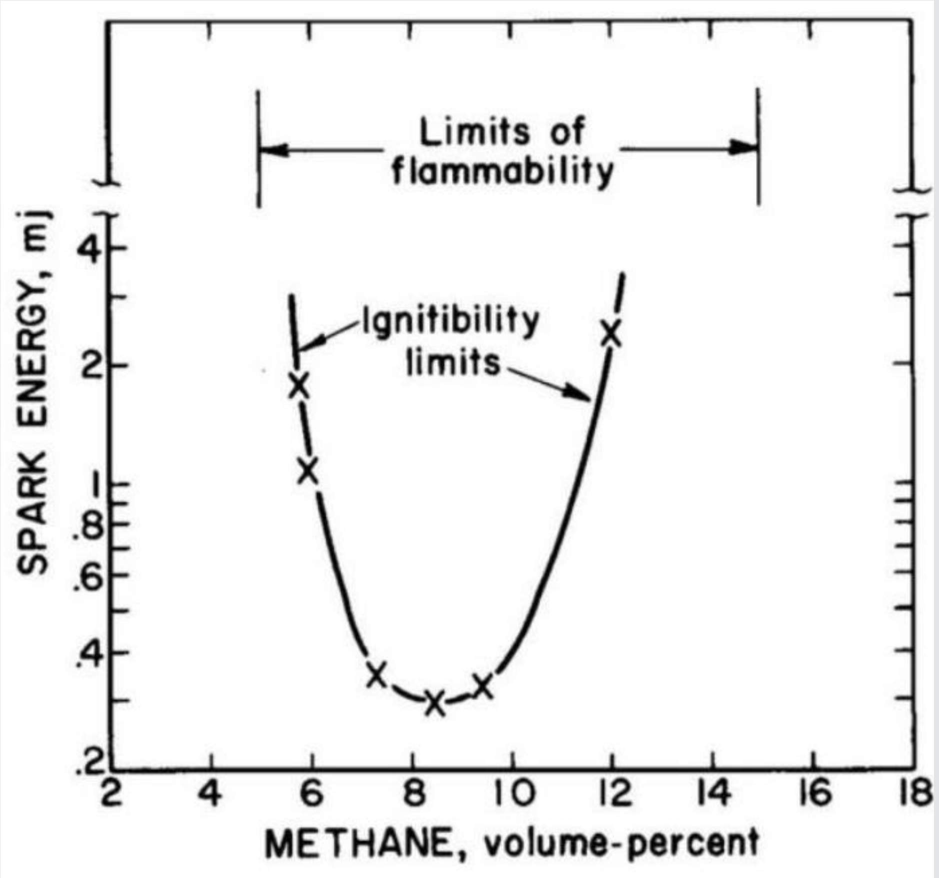
Energy of Spark Ignitor

- Targeting earliest possible ignition (LFL), therefore energy level of spark ignitor must meet a MINIUM energy threshold of 1mJ. (For Methane)
- Lower energy thresholds are not ideal for repeatability, particularly when testing ignition of cell gasses.



Above: Ignitability curve and the flammability limits of methane & air

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Long duration/Long Arcs

Long Duration and Long Arc sparks result in a considerable quantity of CH5 burning (without causing an explosive ignition).

- Fan blowing directly across the spark causing a bend in the arc (see picture)
- In other examples (not shown) the fan direction was downward through the spark, which prevented “streamers” from igniting the flammable mixture near top of the chamber as the burning gas was pushed downwards.
- Both situations cause a delayed ignition due to CH5 being consumed pre-ignition.
- Ignition source must be pulsed rather than continuous, perhaps even less than 1 time per sec.

Above: Fan directed at Spark, causing a long arc

Long duration/Long Arcs

Long Duration and Long Arc sparks result in a considerable quantity of CH5 burning (without causing an explosive ignition).

- Continuous ignition source consumes methane prior to LFL ignition.
- Ignition source must be pulsed rather than continuous, perhaps even less than 1 time per sec.

Above: Low dimensional mixing; and continuous arc. Resulted in upward streamer of methane burning before ignition.

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Above: Continuous arc resulting in upward streamer of methane burning before ignition.

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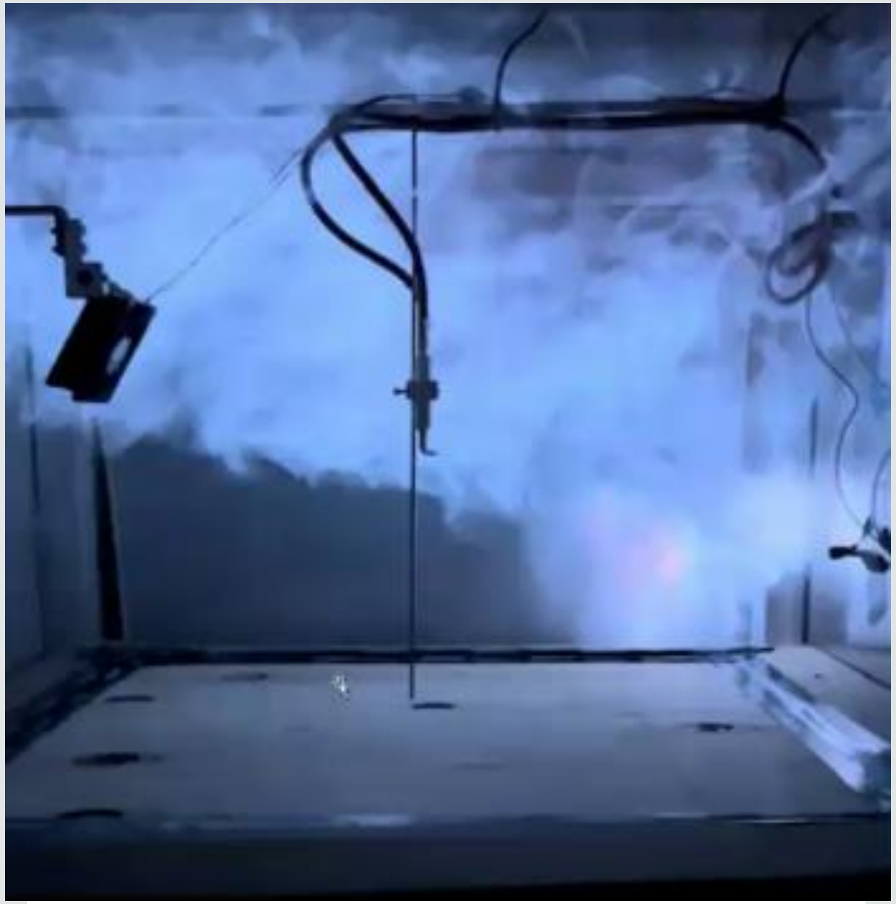
Ignition Source Take Aways

Consensus of G27 Round Robin Test group:

- Spark ignition source >10 mJ (<250 mJ)
- Non-continuous / pulsed at ~ once per second
- Centered in both planes for Methane Calibration
- Centered mid-way between chamber top and top of package for package tests



Above: Example of best-case ignition using methane

Apparatus Analysis 2: Mixing Fan Location

Tested Options

Result Deviations

Suggested Resolution

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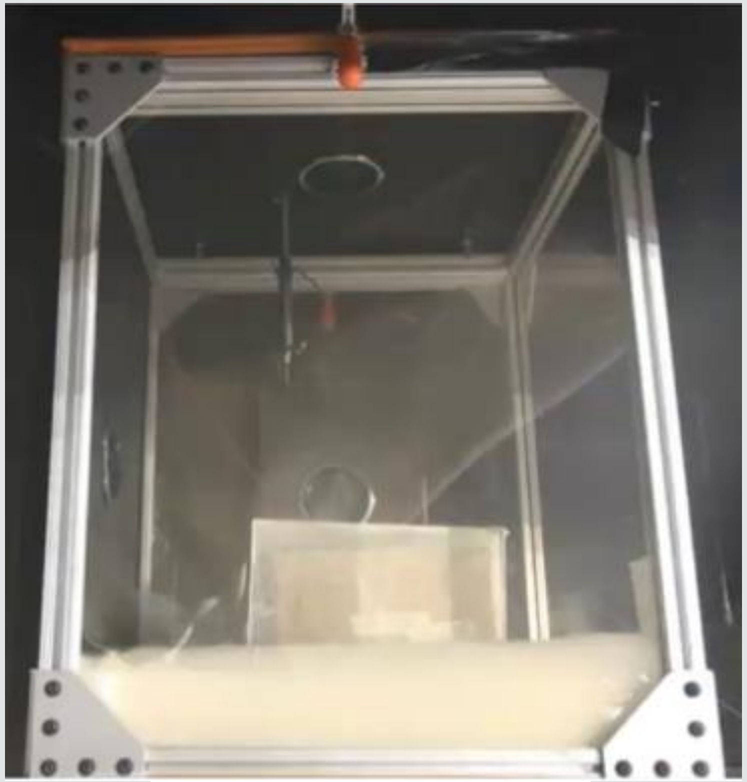
Fan or no fan?

- Fan is needed to mix gasses.
- Cell gasses released from packages can settle, especially at lower SOC events.
- Methane is relatively difficult to mix with the 35-cfm fan, therefore placement is critical. (A higher cfm fan is potentially needed for Methane Calibration testing.)
- Cell gas is mixed relatively well when exiting a package. The addition of a 35-cfm fan is sufficient to minimize stratification of cell gas.

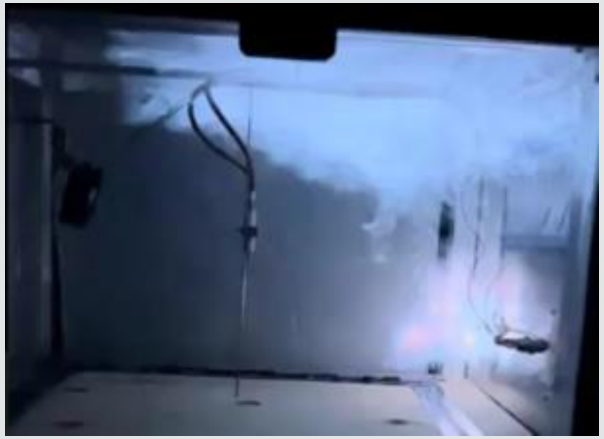


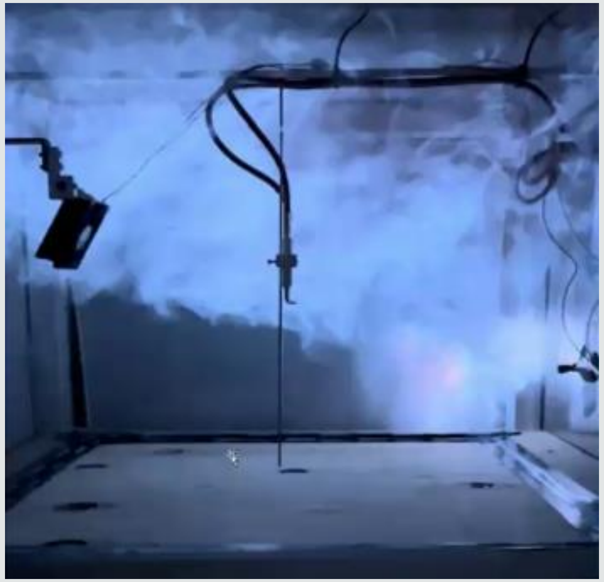
Heavier Cell Gas and Mist sinks to bottom

Methane Gas floats to top

Fan Location

- Fan locations and orientations were tested extensively
- If fan is pointed at the test package (not shown) it could skew the results of the package test
- If fan is pointed at spark ignitor it causes two things to happen:
  - 1) the arc is elongated (discussed in prior slides)
  - 2) streamers of flammable gasses occur without causing full ignition
  - Both cause consumption of gasses pre-ignition





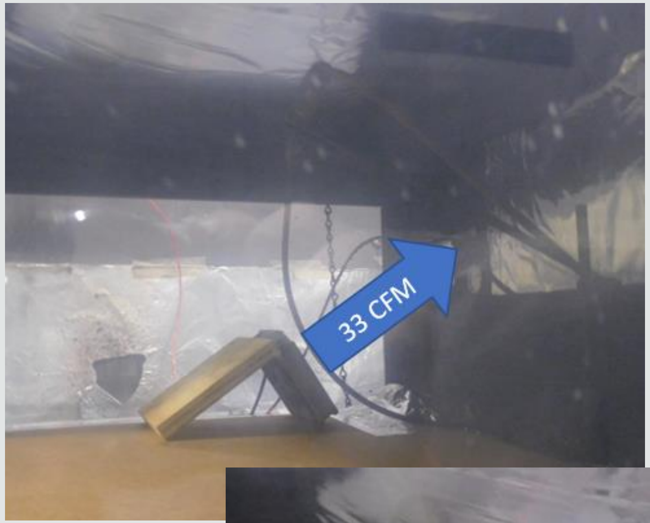
Fan Location

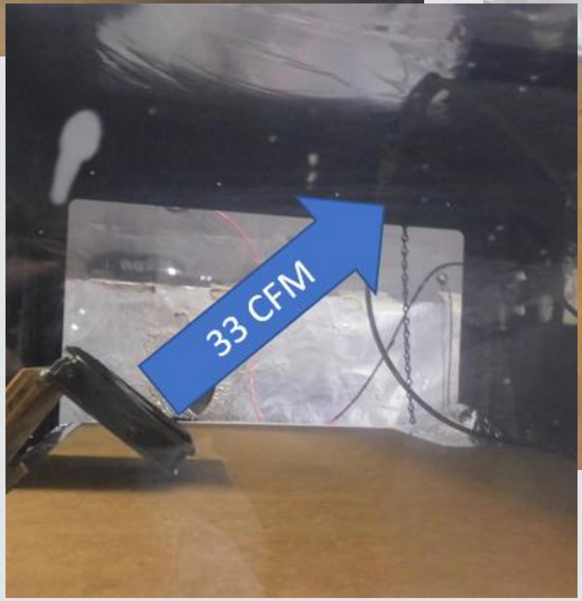
- Fan pointed at pulsed ignitor
- Streamers of flammable gasses occur without causing full ignition
    - LFL ignition is delayed due to methane consumption prior to full ignition

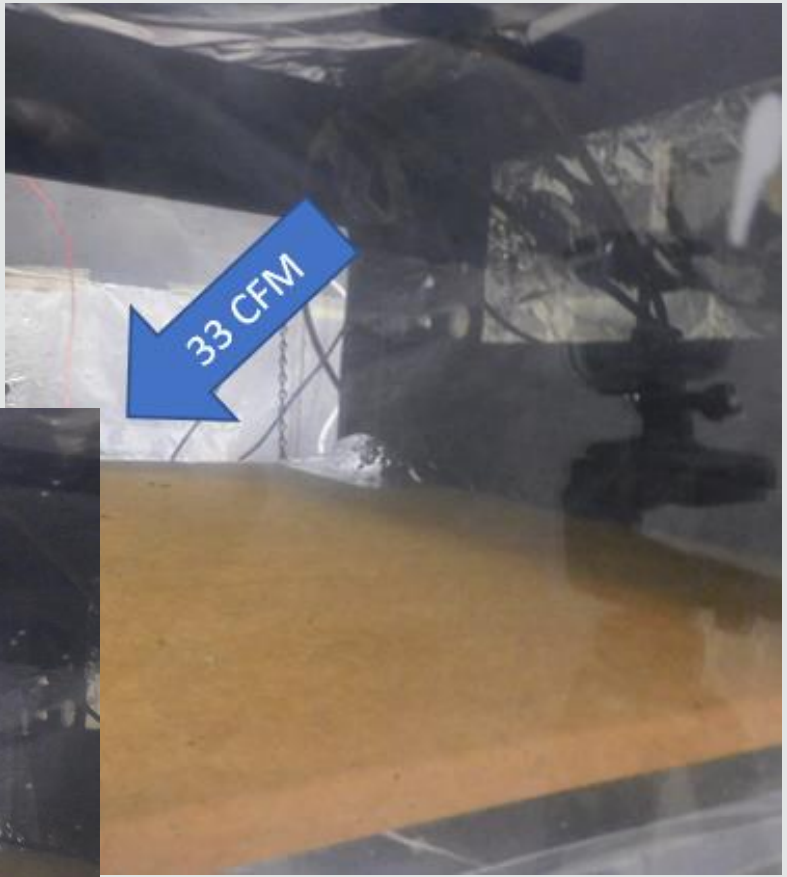
Marlin Engineering

Fan Location

- Best orientation is at ~45-degree angle from top to bottom parallel to one face, ensuring the fan does not point at the ignitor or at the package.
    - Example picture to far right







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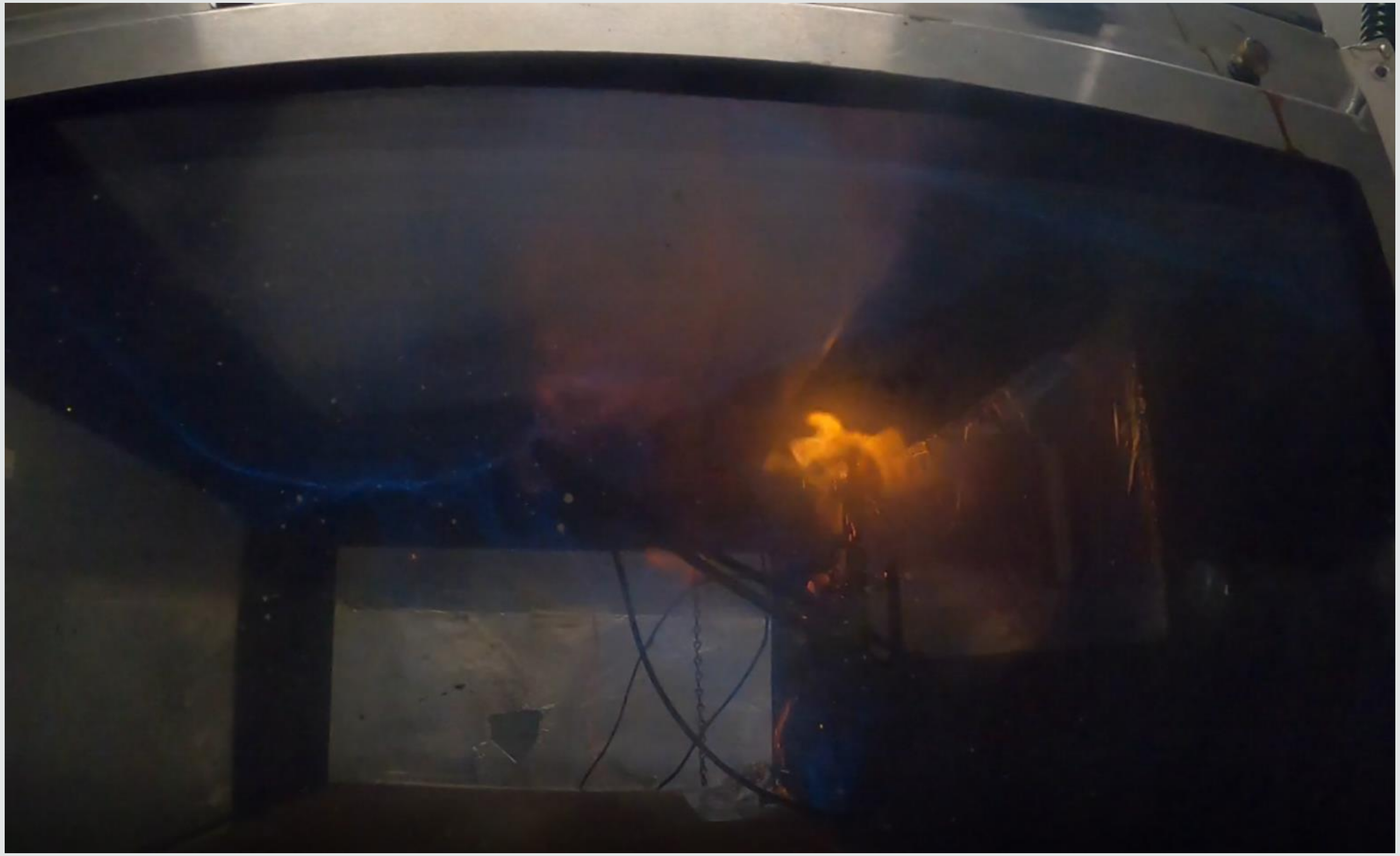
Fan Location

- Best orientation is at ~45-degree angle from top to bottom parallel to one face, ensuring the fan does not point at the ignitor or at the package.

Test Setup, Description, Results:

- Fan Location: In line with and above Methane inlet approx. 8 inches away
- Fan orientation: Blowing downward and away from Methane inlet, angle of approx. 40°
- Chamber Free Volume: 300 liters
- Methane Flow Rate: 2 liters / min
- Time of Ignition: 6m 36s
- Ignition Pattern: Stronger Ignition than in previous tests, approx. 2/3 of chamber



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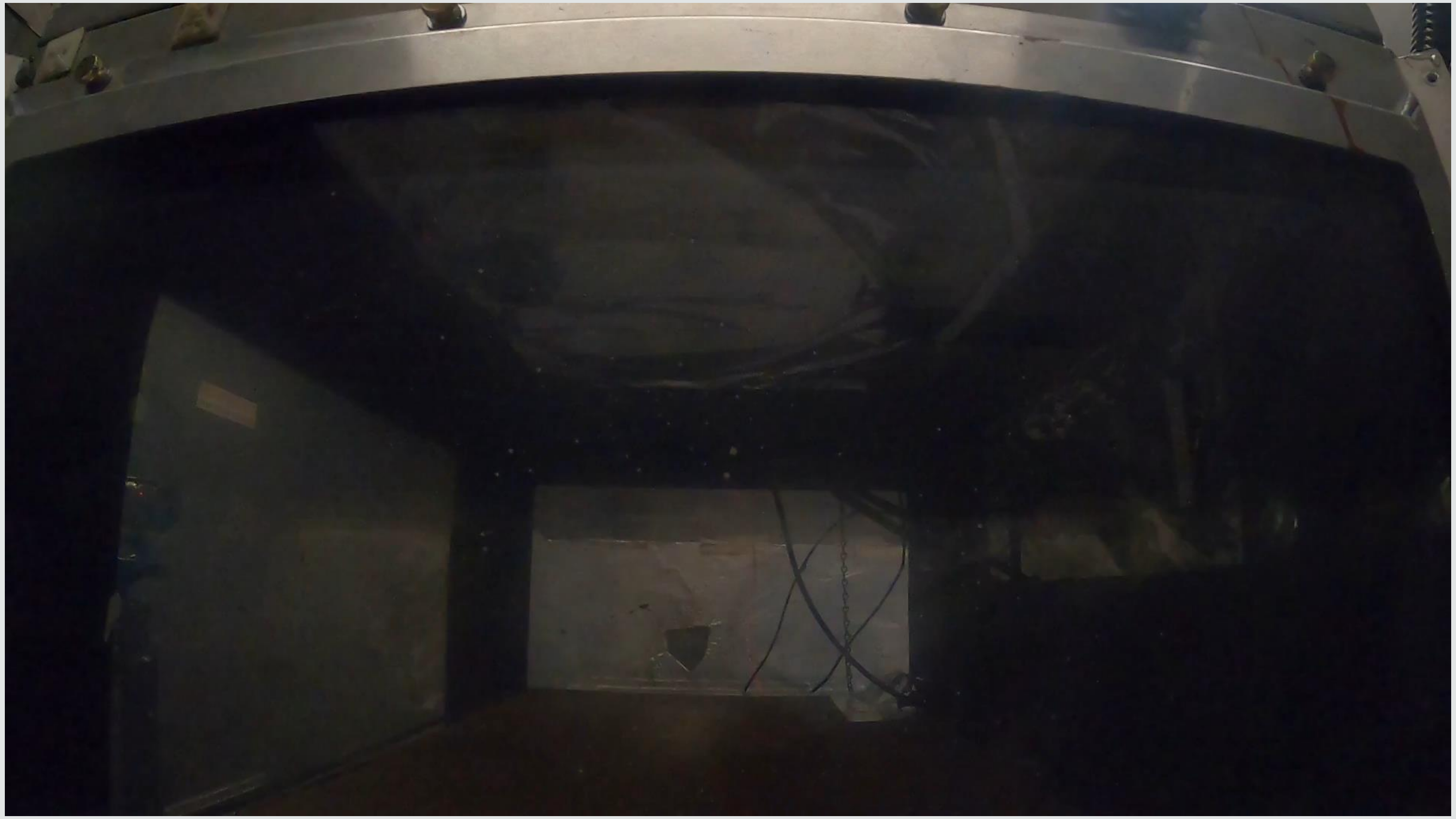


Apparatus Analysis 3: Test Chamber Leak Rate (ACH)

Leak Rate Test Method

Result Deviations

Suggested Leak Rate Range

Air Exchange Rate
“Fireplace Method”

- Connect one side of chamber through sealed opening to an air hose through a flow meter and an air compressor
- Connect the other side of chamber through sealed opening to a manometer
- Force air into chamber until manometer reads 0.1” (29.4 kPa) above atmospheric pressure, stabilize in-flow to maintain pressure
- Record total air flow rate through flow meter after 1 hour

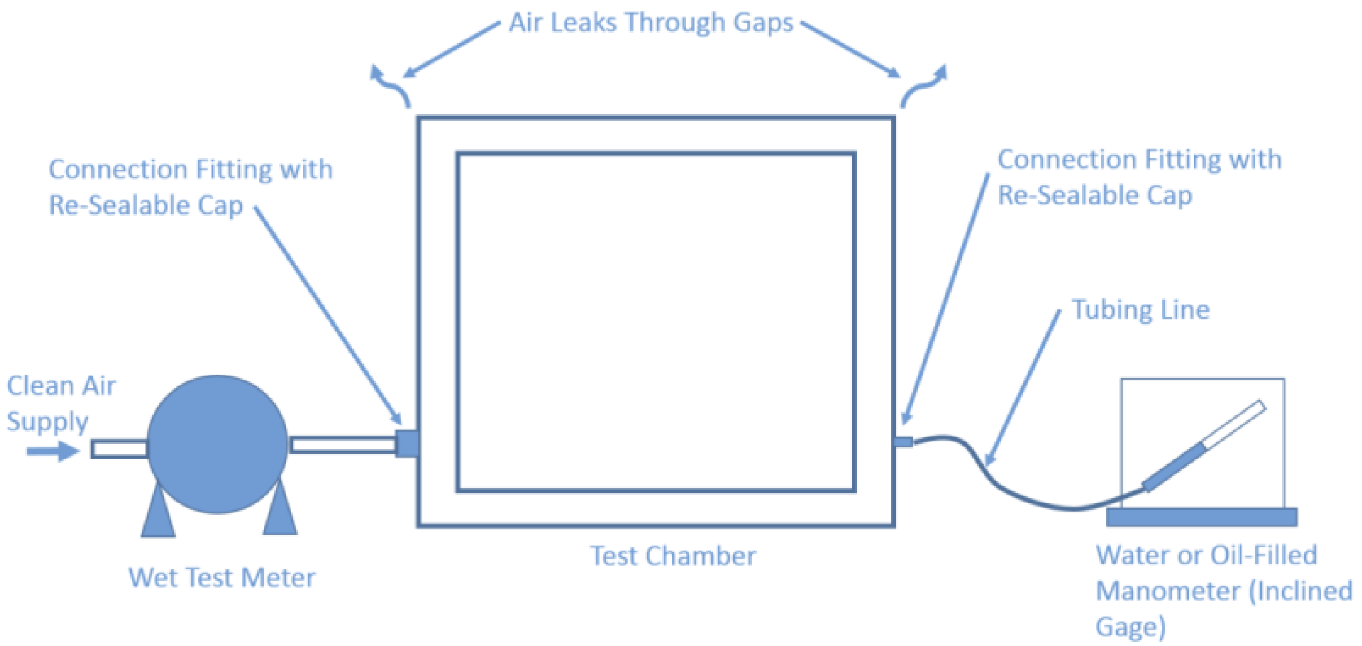
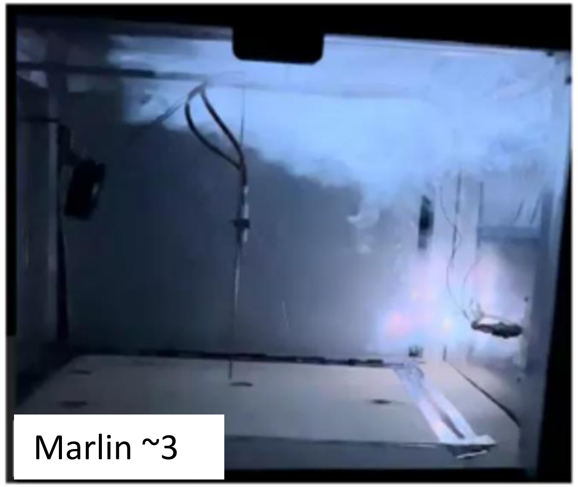
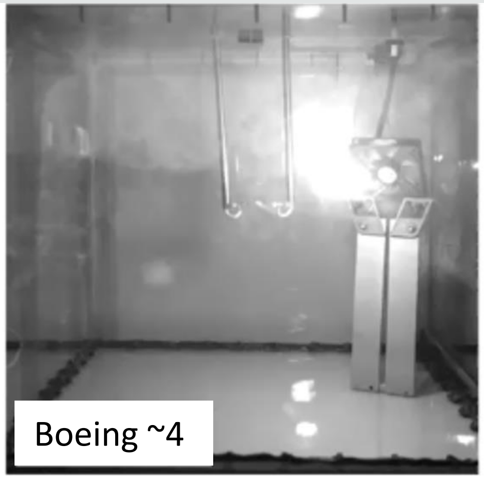


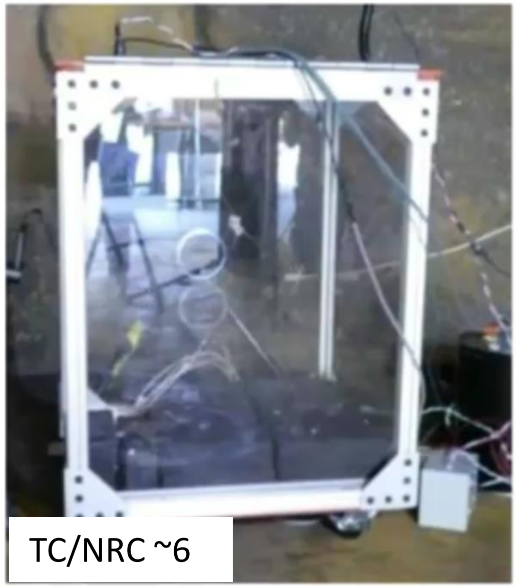
Figure 1: Test Set-up Sketch

Air Changes / Hr

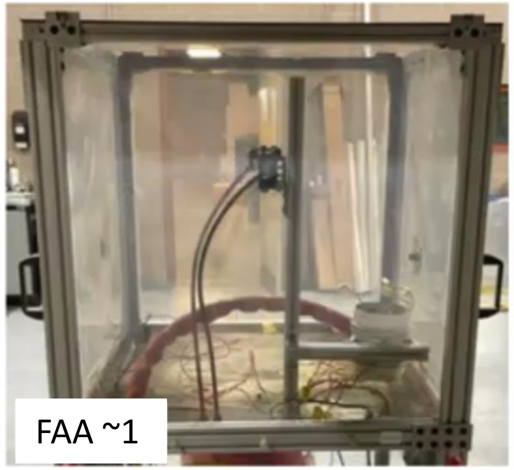
Marlin Engineering	~3 ACH
Boeing	~4 ACH
Transport Canada / NRC	~6 ACH
Fulcrum / Americase	~3 ACH
FAA Fire Tech Center	~1 ACH


Marlin ~3


Boeing ~4


TC/NRC ~6


Fulcrum ~3


FAA ~1

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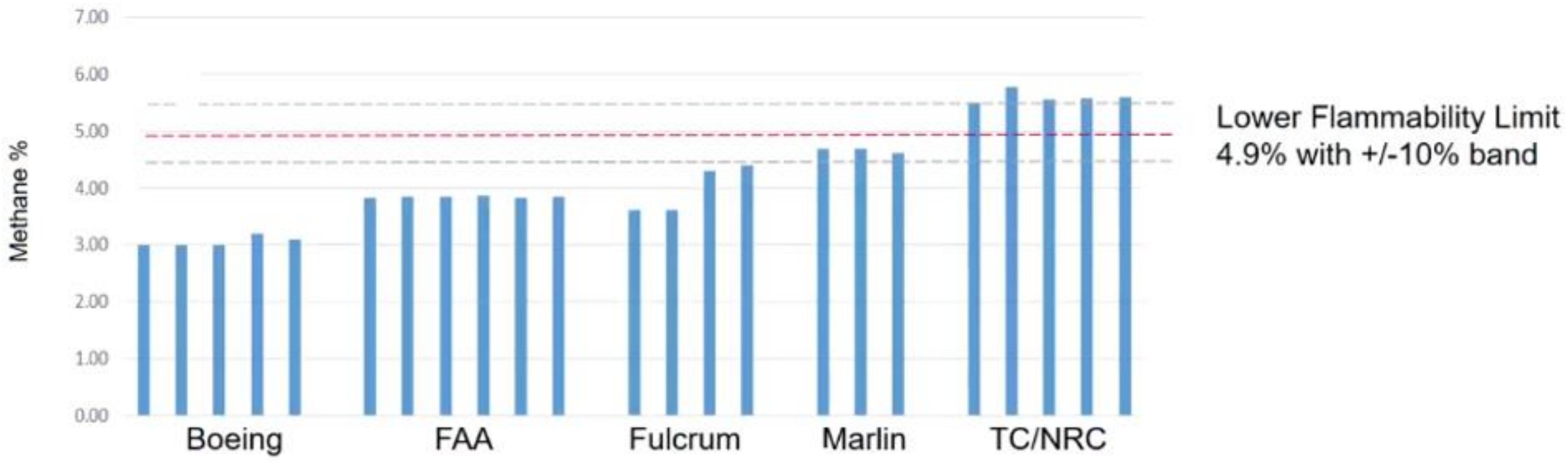
Summary of Methane Calibration Round Robin Testing Results



Key Takeaways From Round Robin Testing

- Ignition Source
  - Well documented preferred location
  - Minimum energy important, but also a pulse frequency that is not too high
- Mixing Fan
  - Significant factor – most likely variable that could prevent repeatable results
  - Orientation top to bottom same face, not across spark ignitor, was proven best practice so far
  - Chamber Aspect Ratio also contributes to mixing issues
- Leak Rate
  - Later testing performed by Boeing and TC/NRC indicates leak rate variance has less of an impact on LFL ignition
  - Consensus required for acceptable leak rate range, recommend 1 to 6 ACH
  - Uniform leakage is also important; leaking only from top or bottom will impact mixing
- Chamber Calibration
  - Calibration from chamber-to-chamber among round robin committee labs using cell gas (vs. methane) is most likely next step for calibration verification. Purpose would be to prove that ignition time using cell gas (certain # of identical cells) with the agreed upon chamber variables mitigated as discussed today is equal across all labs.
  - If so, future labs <u>may</u> only need to perform calibration on specific features: ignitor, fan, chamber leak rate.

Data provided to G27 Committee by Round Robin Test Lab Group

Methane Calibration Test data by:

- Marlin Engineering – Martin Spencer
- Boeing – James Russell
- Transport Canada / NRC – Kiran Shoib, Manuel Hernandez
- Fulcrum / Americase – Robby Kinsala, Raymond James, Chris Egloff
- FAA Fire Tech Center – Matt Karp, Steven Rehn

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