Methods for Characterizing Artificial Smoke Generators for Inflight Smoke Detection Certification

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Thank You!

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BOEING

BOMBARDIER

EMBRAER

TAMI

Kidde
Technology that saves lives

CONCEPT
smoke systems

Overview

– Section 1 Background

– Section 2 Previous studies

– Section 3 Method

– Section 4 Potential parameters

– Section 5 Conclusions

Test Apparatus

Background

- Due to health and safety concerns – artificial smoke generators are used for inflight certification testing
- Smoke generator aerosols must be similar to real smoke for the false alarm resistant smoke detectors to alarm
- Standardizing the artificial smoke generators necessary to ensure the reliability and integrity of the inflight smoke detection certification test

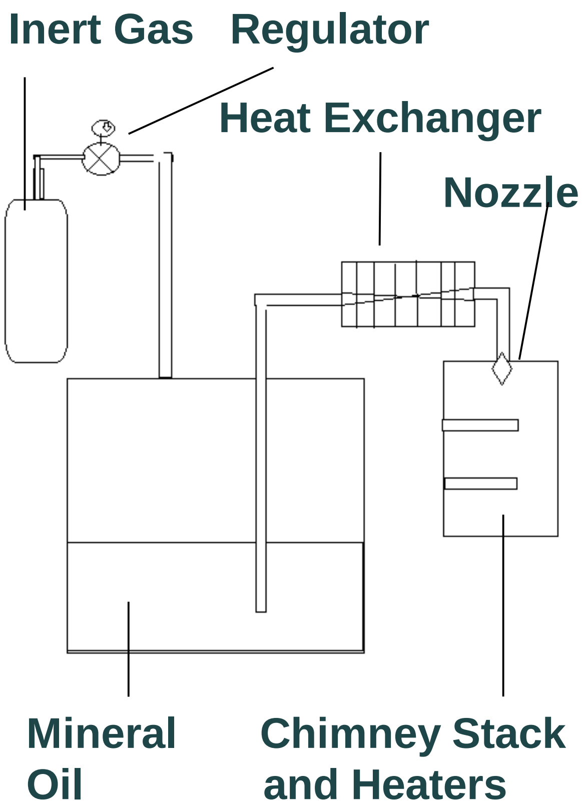
Background

- One minute cargo compartment detection requirement [1]
- Test is designed to demonstrate that the smoke detection system will detect a **smoldering fire** that produces a **small amount** of smoke [2]
- In an attempt to eliminate the frequency of **false alarms**, criteria for resisting alarms from nuisance sources [3]
- On average, there are 70 fire or smoke detector events for freighter and passenger aircraft annually [4]
  - Approximately 1% of flight deck warnings are a result of actual fire

1 Title 14 Code of Federal Regulations (CFR) Part 25.858, 2/10/1998
2 Federal Aviation Administration Advisory Circular 25-9A
3 TSO C1e, 8/19/2014
4 R.G.W. Cherry, "Research into Fire, Smoke or Fumes Occurrences on Transport Airplanes," FAA Report DOT/FAA/TC-16/49, March 2017

Smoke Generators

- Important variables of smoke generators
  - Gas propellant
  - Gas propellant pressure
  - Chimney heater temperature
  - Mineral oil characteristics
    - Viscosity and refractive index



Simplified Smoke Generator Schematic

Mie Scattering Theory

- **Mie Scattering Theory** governs light scattering by sub-micron particles
- A simplified approximation of Mie Scattering Theory is given by van de Hulst [5]

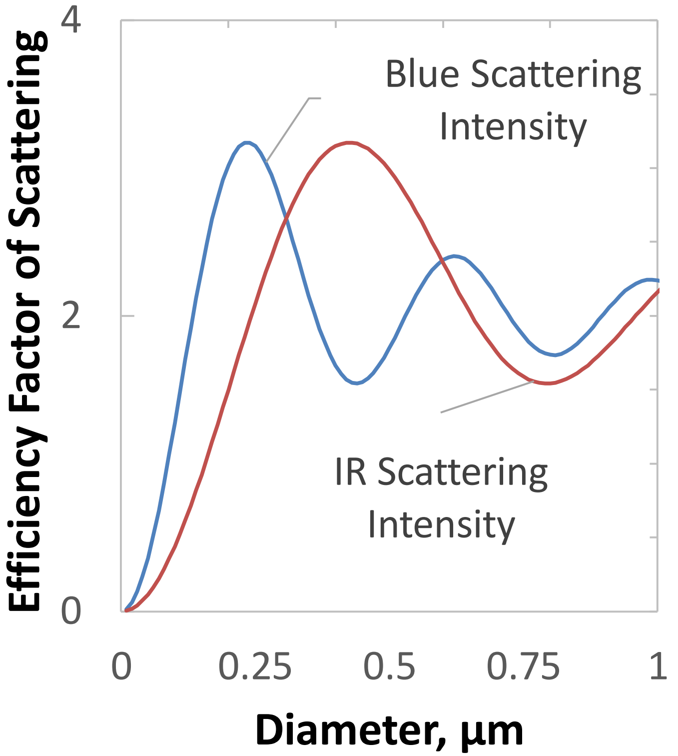
$$Q = 2 - \frac{4}{p}\sin(p) + \frac{4}{p^2}(1 - \cos(p))$$

- Where Q is the efficiency factor of scattering

$$p = \frac{4\pi a(n-1)}{\lambda}$$

This shows that the **scattering intensity** is a function of

n, **Refractive index of the particle**
a, radius of the particle
λ, Wavelength of the incident light

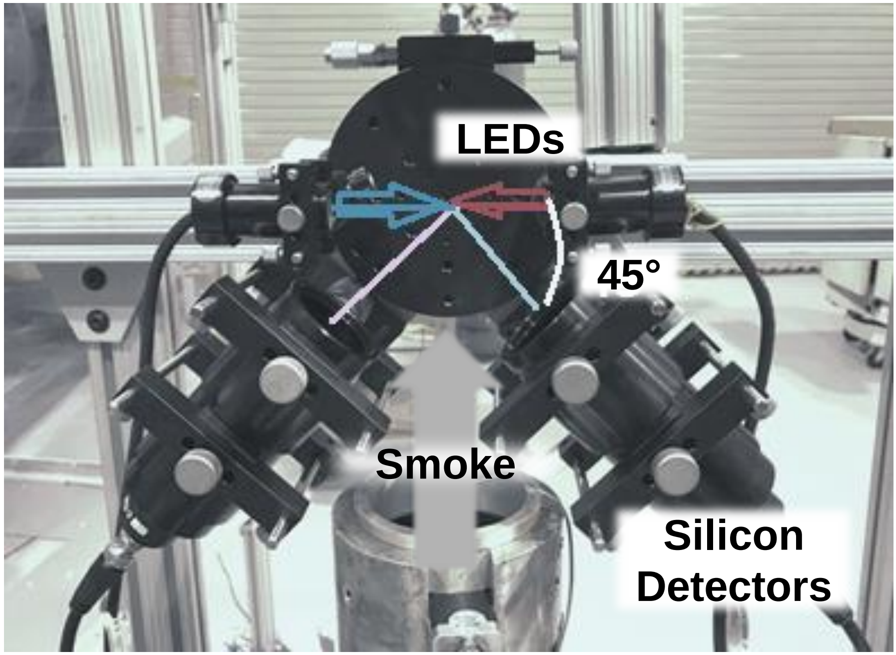


Maxwell's Equation plotted using 470nm and 850nm wavelengths, refractive index 1.5

[5] van de Hulst, H. C. (1957). *Light scattering by small particles*. New York: John Wiley and Sons. ISBN 9780486139753.

Electromagnetic Radiation Scattering Measurement (LSM)

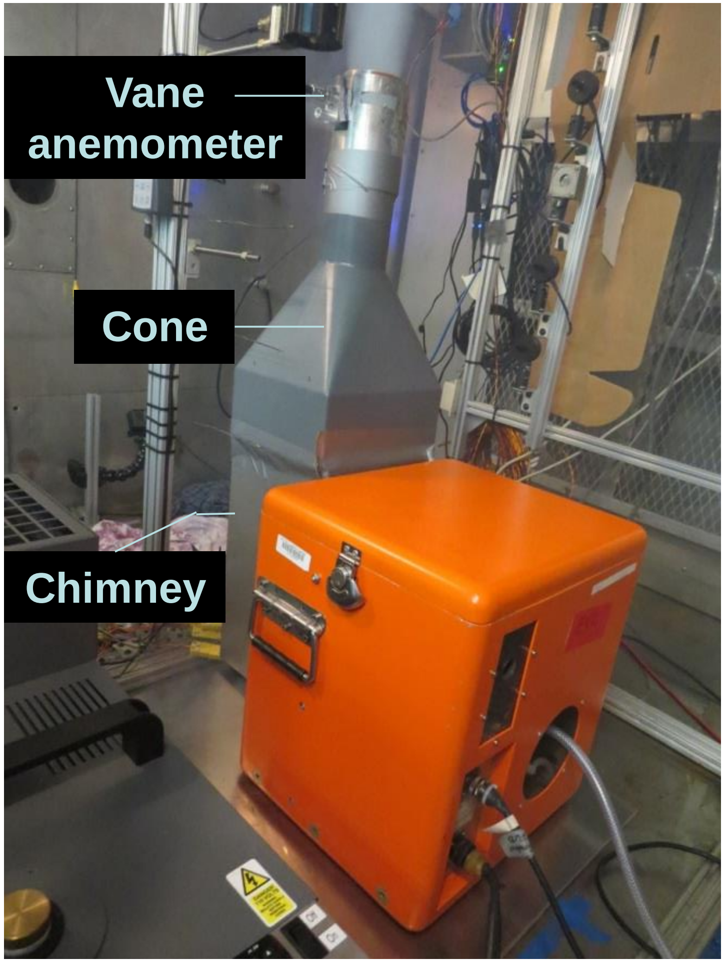
- **Two LEDs**
  - 470nm blue LED forward scattering angle of 135°
  - 850nm IR LED forward scattering angle of 135°
- **Measurements used to calculate:**
  - Percentage of blue to blue and IR light scattering intensity
  - Utilize van de Hulst approximation to characterize very small particles



Electromagnetic Radiation Scattering Measurement (LSM)

Smoke Transport

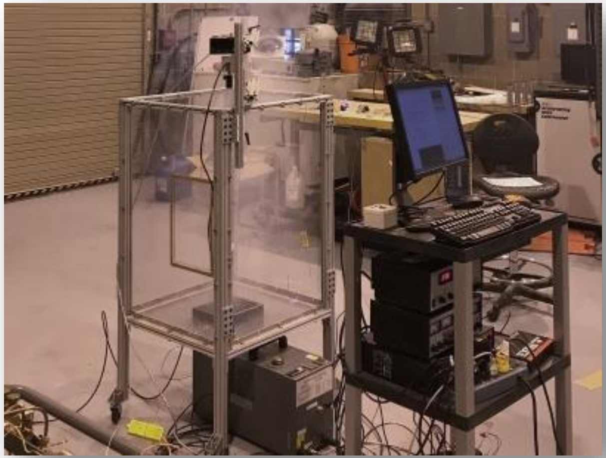
- A cone is connected to the smoke generator's chimney
- Attached to the cone is a vane anemometer to measure the **volumetric flow rate**
- The **volumetric flow rate is directly correlated with chimney heat output**



Siemens Cerberus with Volumetric Flow Rate Cone

Section 2
Previous Studies

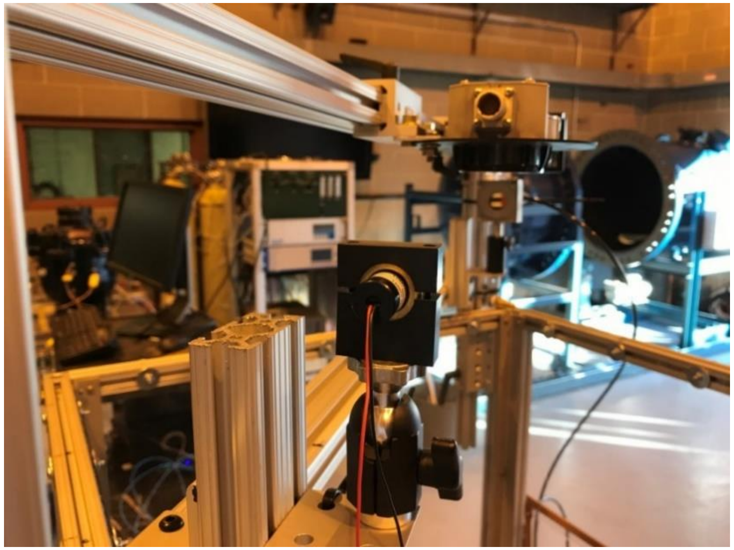
- Small Scale Testing
  - 2’ x 2’ x 3’ open top Plexiglas test chamber



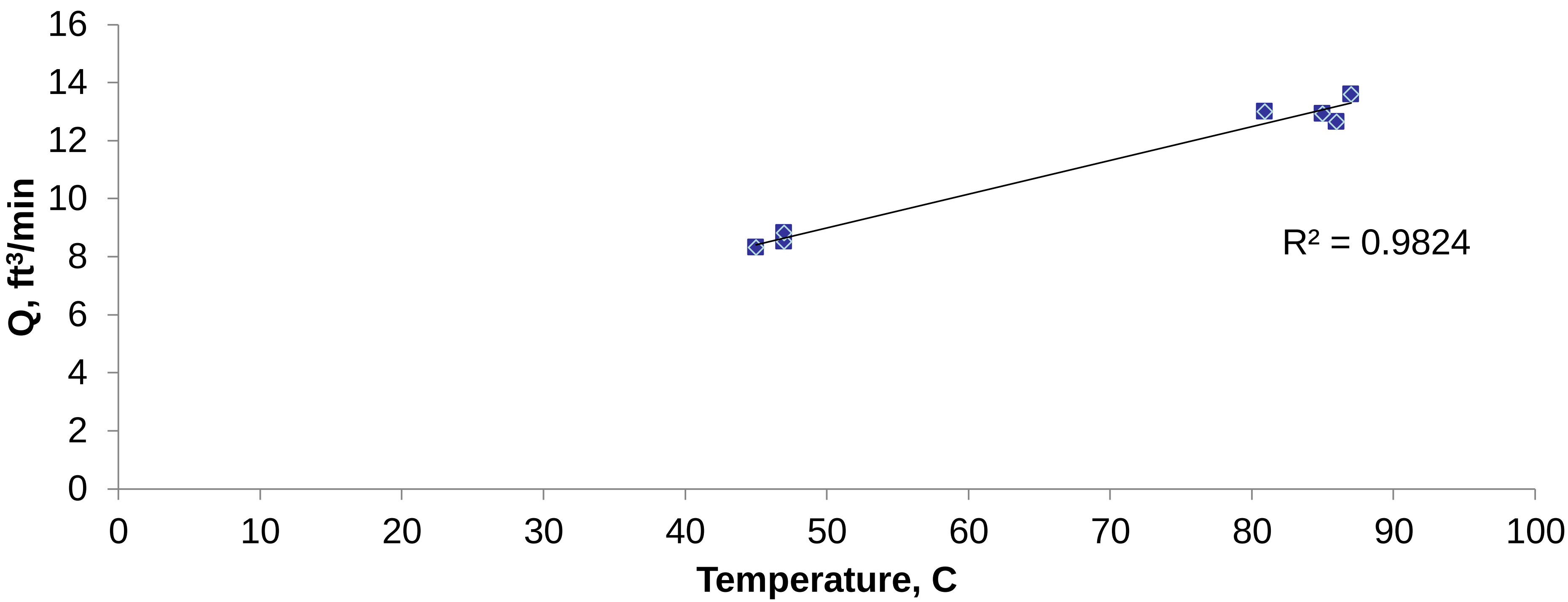
- Large Scale Testing
  - Aft cargo compartment of DC-10

Small Scale Test Results

- Varying the gas propellant, gas propellant pressure and heater setting on a single smoke generator can affect:
  - Aerosol particle size and/or refractive index
  - Total and rate of aerosol production
    - **Parameters affect detection alert level and overall detection time!**



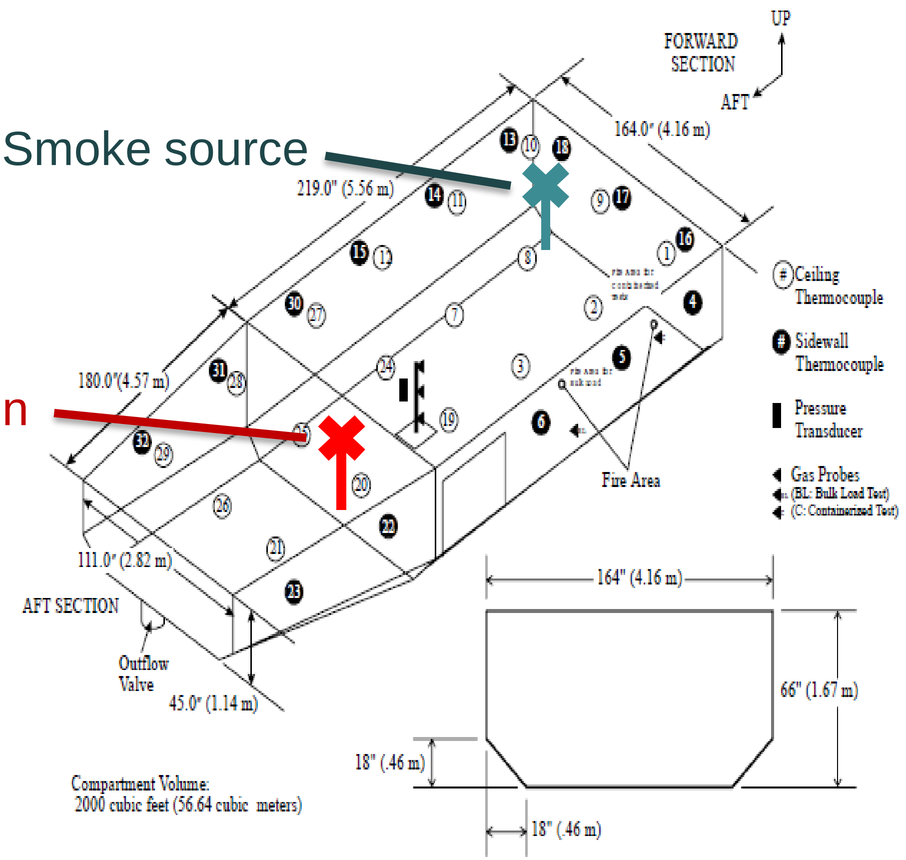
Smoke Transport



- Testing conducted on a single smoke generator
- Chimney geometry could affect smoke transport

Large Scale Testing McDonnell Douglas DC-10

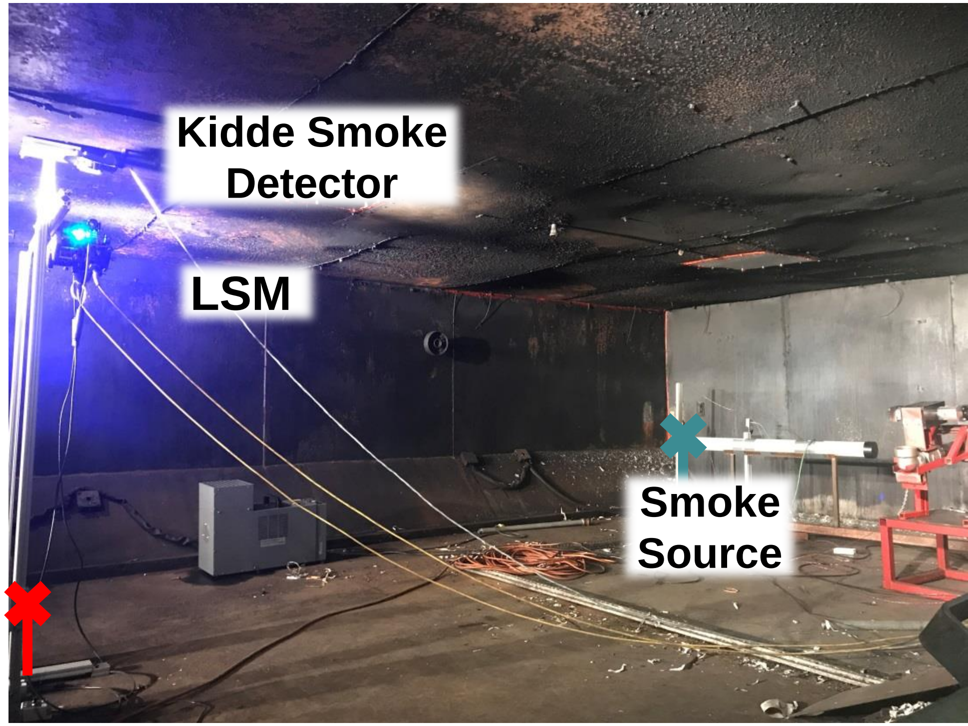
- Aft Cargo Compartment [6]
- Volume- 2000 ± 100 CU FT
- Distance is 19.5ft



[6] Reinhardt, J.W., Blake D., and Marker, T., "Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems," FAA report DOT/FAA/AR-00/28, September 2000.

Large Scale Testing

- **Kidde smoke detector**
  - 2” from ceiling
- **LSM**
  - 6” from ceiling
- **Optical density meter**
  - 1” above smoke source
- **Aviator UL**
  - 1 and 4 heater bars (160W and 640W)
  - 15, 30 and 50psi
- **MPS fire load**
  - Cardboard box 18” x 18” x 18”
  - filled with 2.5 lb. of paper



Large Scale Test Results

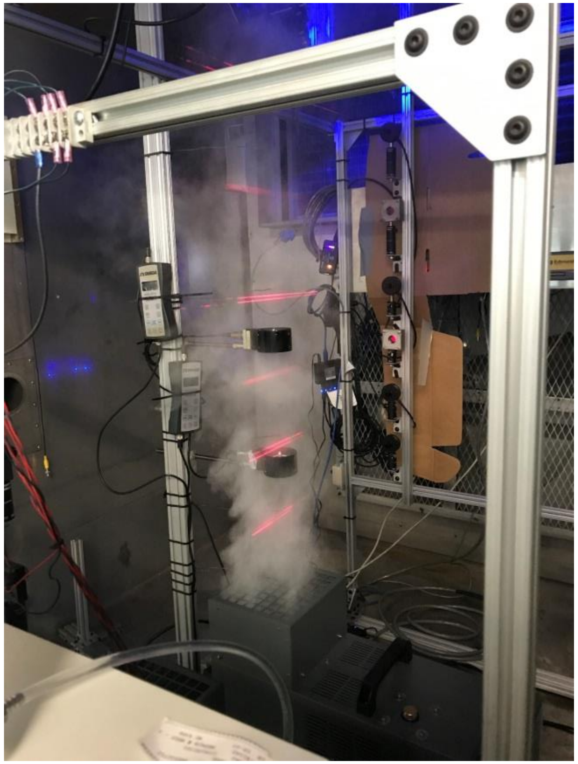
- Detection time depends on:
  - Thermal buoyancy
    - Heater wattage
  - Aerosol production and particle size
    - Blue signal, IR signal and the percentage of blue signal

	%Blue	Blue+IR	Time to Detection
15psi 160W Heater	0.65	0.25	105
15psi 640W Heater	0.5	0.18	63
30psi 160W Heater	0.67	0.42	81
30psi 640W Heater	0.52	0.37	62
50psi 160W Heater	0.69	0.59	71
50psi 640W Heater	0.53	0.57	46
Cardboard Fire	0.57	0.82	23
Cardboard Smolder	0.53	0.18	57

Testing conducted with Aviator UL
Average of two tests

Section 3
Method

- Testing is conducted in a 7.8m^3 environmental chamber
- Blue and infrared, light scattering measurement (LSM)
- Scanning mobility particle sizer (SMPS)
- 6 vertically aligned light obscuration meters
- Four aircraft manufacturer's smoke generators
  - Annotated as: MFR 1a, MFR 1b, MFR 1c, MFR 2a, MFR 2b, MFR 3, and MFR 4
- Vane anemometers characterize smoke transport



Test Apparatus

Method

- A smoke generator is turned on to produce an aerosol for 60 seconds (14 CFR 25.858)
  - Compared with
- Smoldering foam, smoldering wood, and lithium-ion battery thermal runaway vent-gas are

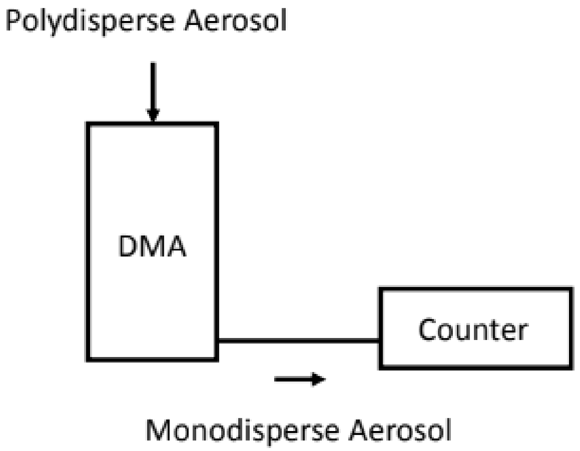
- Continuous light obscuration and scattering measurements

- Single SMPS measurement at 210s

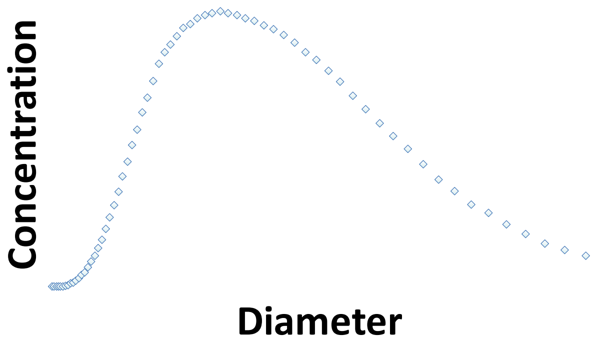
Altitude Chamber

Scanning Mobility Particle Sizer (SMPS)

- **How does the SMPS work?**
  - An impactor removes large particles and measures flow.
  - A neutralizer creates a well-characterized charge distribution on the particles.
  - Inside a Differential Mobility Analyzer (DMA), the charged particles experience an electrical field that separates particles based on their **electrical mobility** and outputs a monodisperse aerosol.
    - Electrical mobility is inversely related to particle size
  - The condensation particle counter (CPC) counts the monodispersed particles as they exit the DMA.



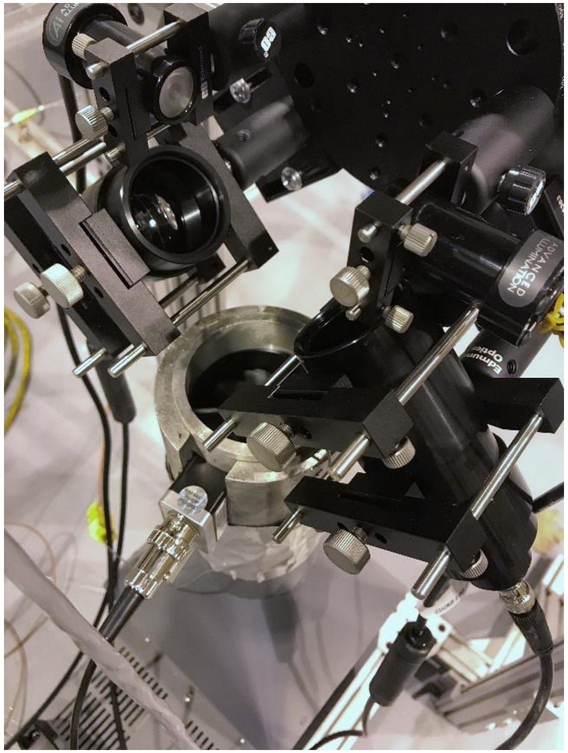
SMPS Simplification



SMPS Output

Section 4
Potential Parameters

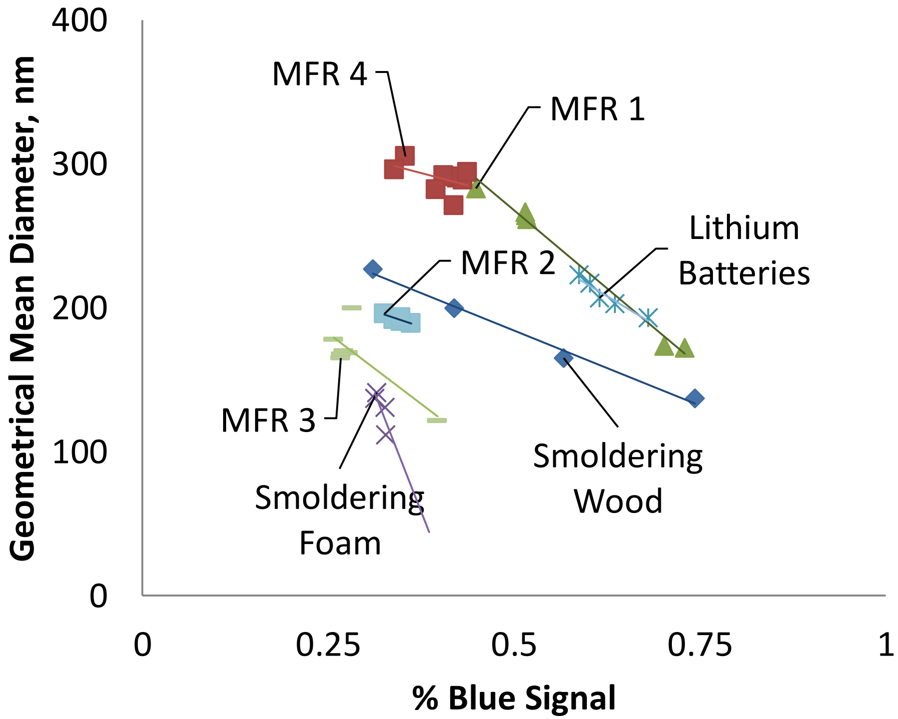
- Particle characterization
  - LSM
  - SMPS
- Light obscuration
  - Transient obscuration
  - Steady state obscuration
  - Repeatability
- Ambient environment
- Smoke transport



LSM and Vane Anemometer Cone

Particle Size - LSM and SMPS

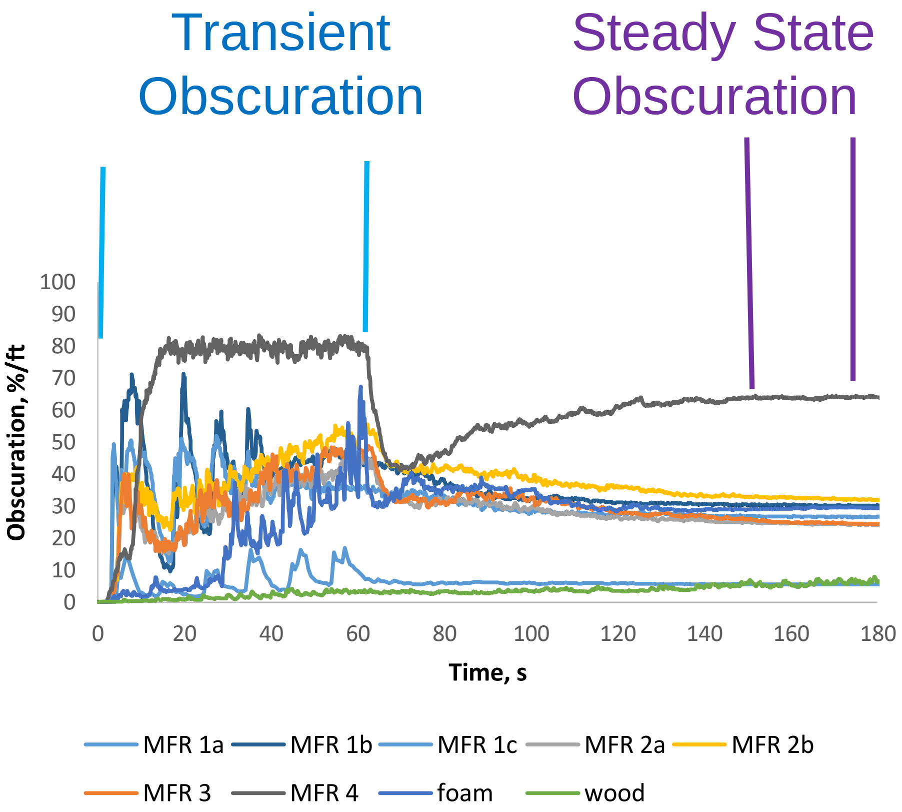
- Strong negative correlation between light scattering measurements and mean diameter for individually sourced particles
- Strong correlation diminishes when comparing particles from multiple sources
  - Potentially because varying refractive indexes
- **Smoke generator aerosols and real smoke sources overlap**



LSM %blue signal vs SMPS diameter

Light Obscuration

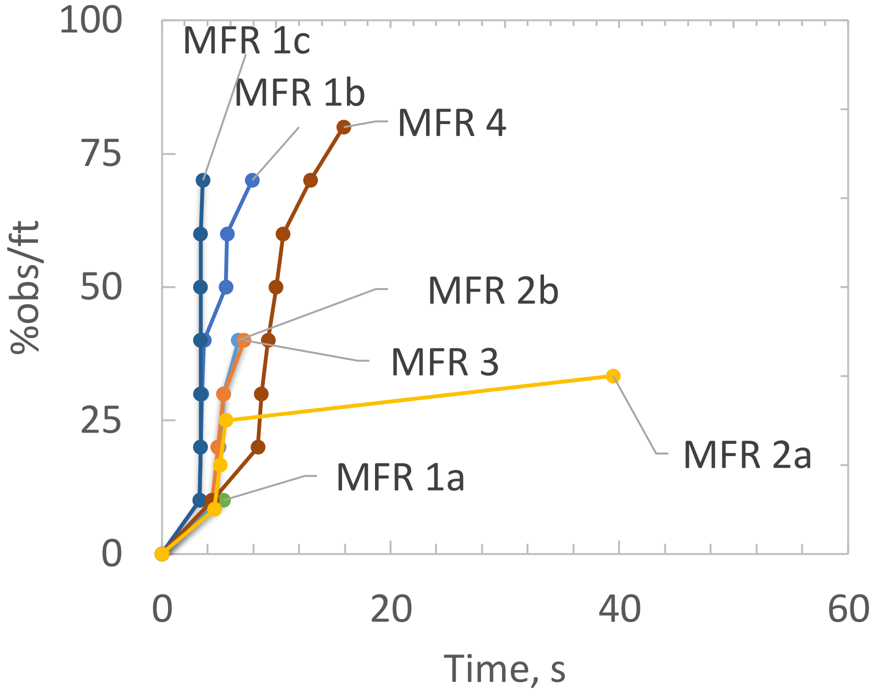
- **Transient Obscuration**
  - Initial 60 seconds
  - Characterizes **rate** of aerosol production
- **Steady State Obscuration**
  - After 120 seconds when the aerosol **fully mixes**
  - Characterizes **total** aerosol production
- **Repeatability**
  - Relative deviation between tests over 10 second increments



Time vs light obscuration
Various manufacturer smoke generator settings

Transient Obscuration

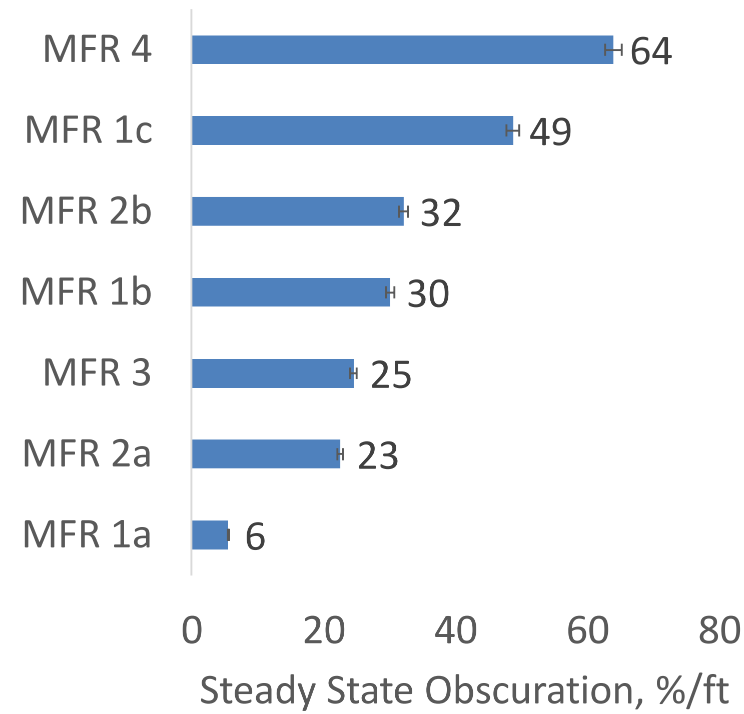
- Transient obscuration characterizes the rate of aerosol production
- The steeper the curve, the more rapid the aerosol production rate
- The highest point on the curve represents the maximum light obscuration reached
- **There is a wide range of aerosol production rates used for smoke detection certification testing**



Time vs light obscuration
Used to determine transient light obscuration

Steady State Obscuration

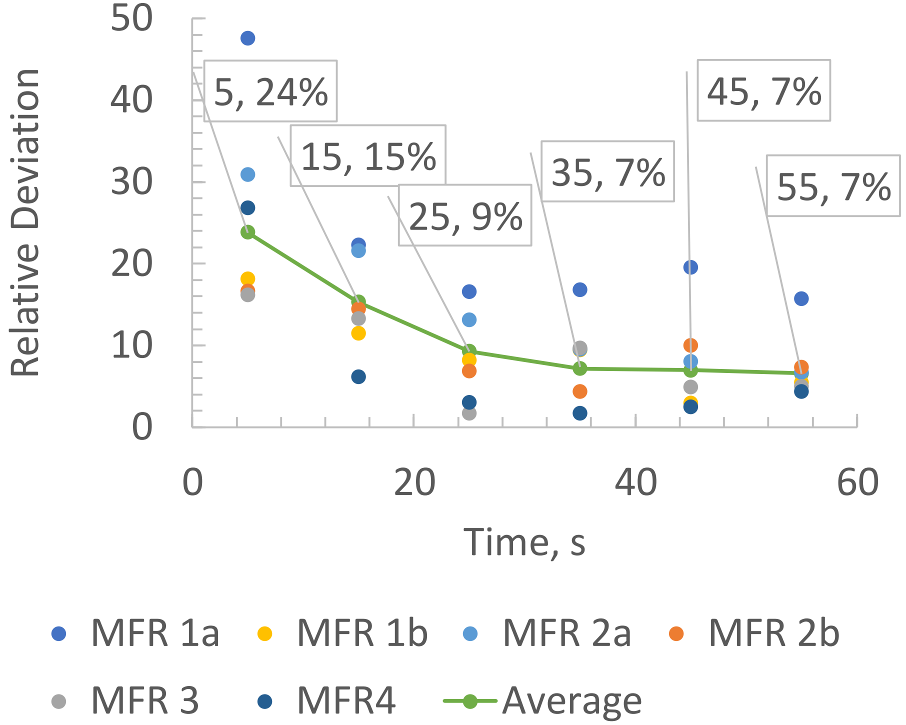
- Steady state obscuration characterizes the total aerosol production
- The average steady state obscuration is 32%/ft with a standard deviation of 17 %/ft
- **There is a wide range of total aerosol production used for smoke detection certification testing**
  – Two perspectives
    - This is ok, because of the varying size of aircraft cargo compartments
    - This is not ok, because a fires beginning does not discriminate against aircraft size



Time vs light obscuration
Used to determine steady state light obscuration

Repeatability

- The relative deviation is calculated to determine test repeatability
  - 10 second increments
- The most significant initial 10 seconds are the least repeatable
- **The first 10 seconds have an average of 24% deviation between tests from an individual smoke generator**



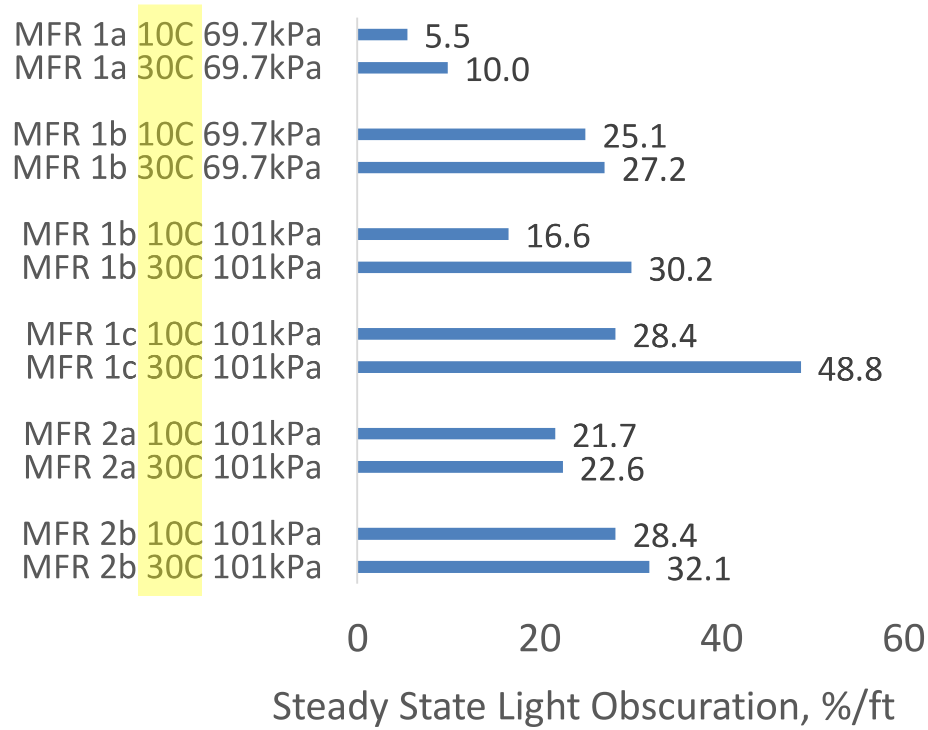
Time vs percent deviation
Used to determine repeatability

Ambient Environment and Steady State Obscuration

- Positive correlation between ambient temperature and the total aerosol production
  - Significance varies with smoke generator and setting

- Must either
  - Make guidelines for cargo compartment temperature

  Or
  - Use smoke generators that will not vary with ambient temperature

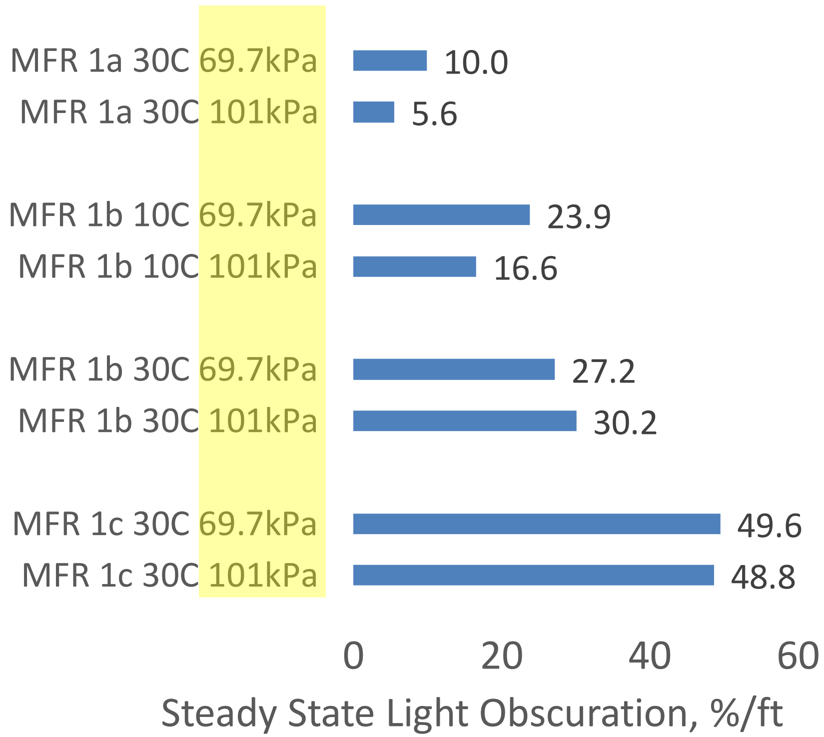


Steady State Light Obscuration by Ambient Temperature

Ambient Environment and Steady State Obscuration

- Weak negative correlation between ambient pressure and the total aerosol production

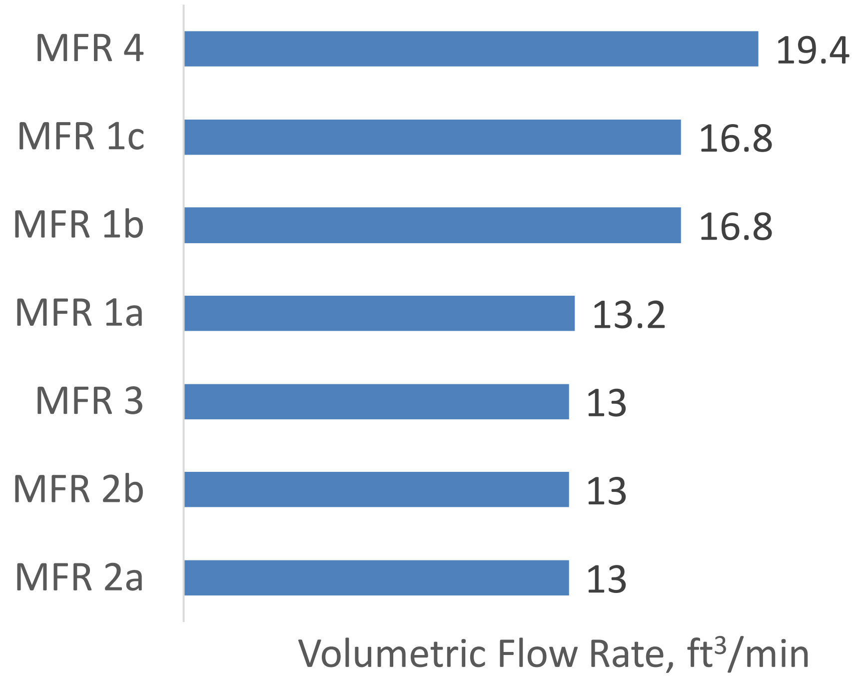
- Increasing the ambient pressure can, but does not always, decrease the total aerosol production



Steady State Light Obscuration by Ambient Pressure

Smoke Transport

- Volumetric flow rate characterizes the smoke transport
- The volumetric flow rate is directly correlated with chimney heat output
- **There is a range of volumetric flow rates used for smoke detection certification testing**



Volumetric flow rate
Comparison volumetric flow rate of various smoke generator settings

Section 4
Conclusions

- Smoke generators are capable of producing an aerosol with similar particle size distributions and light scattering characteristics to real smoke sources
  - **Parameters affect detection time of false alarm resistant detectors!**

- Smoke generators used by major aircraft manufacturers for certification testing have measurable differences
  - Total aerosol production
  - Tate of aerosol production
  - Smoke plume velocity between
  - **Parameters directly affect detection time!**

Contact Information

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