Smoke Generator Standardization Handbook

Presented to: Tenth Triennial International Aircraft Fire and Cabin Safety Research Conference

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Date: October 2022

Federal Aviation Administration

Background

- **One minute detection requirement**
  - Federal Aviation Administration (FAA) regulations require that a commercial aircraft cargo compartment smoke detection system must provide visual indication to the flight crew within one minute after the start of a fire [1].
- **Smoke detector sensitive enough for a small smoldering fire**
  - Further FAA guidance states that the smoke detection certification test is designed to demonstrate that the smoke detection system will detect a smoldering fire that produces a small amount of smoke [2].
- **False alarm resistant smoke detectors**
  - In an attempt to eliminate the frequency of false alarms, the FAA issued a Technical Standard Order to adopt the Minimum Performance Standards of smoke detector equipment, which includes criteria for resisting alarms from nuisance sources such as water vapor, insecticide aerosols, dust and light [3].

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

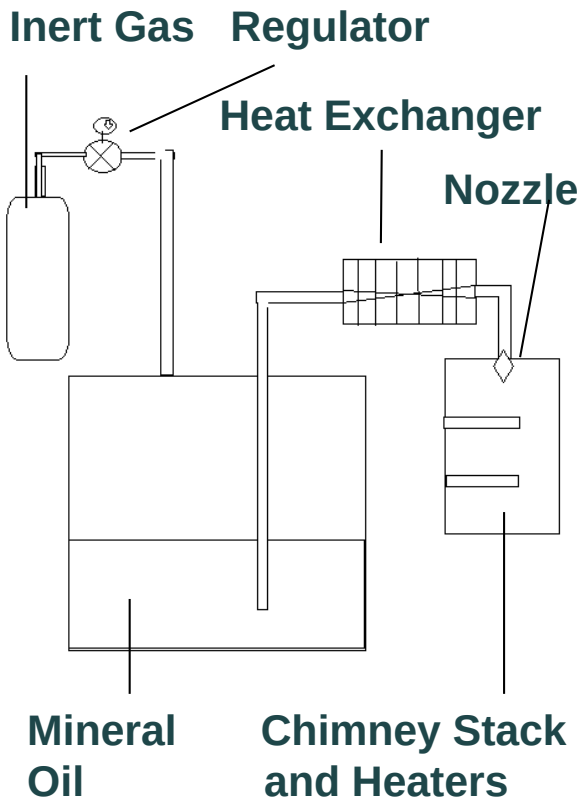
Federal Aviation Administration

Background Continued

- **In flight certification**
  - False alarm resistant smoke detectors must pass the inflight smoke detection certification test in order to be implemented in aircraft.
- **Use of artificial smoke generators**
  - Due to health and safety concerns – artificial smoke generators are used for inflight certification testing
- **False alarm resistant smoke detectors are sensitive to particle size**
  - Aerosols created by artificial smoke generators must have similar size distributions and light scattering characteristics in order for the false alarm resistant smoke detectors to alarm
- **Standardizing smoke source is important**
  - standardizing the artificial smoke generators for the total quantity of aerosol production, rate of aerosol production and repeatability of aerosol production is necessary to ensure the reliability and integrity of the inflight smoke detection certification test

Smoke Generators

- Theatrical smoke generators use an inert gas to propel mineral oil into a heat exchanger, where the solution is vaporized to create a nontoxic aerosol
- The aerosol exits through a chimney incorporated with heaters to create a thermally-buoyant plume
- Important variables of smoke generators
  - Gas propellant
  - Gas propellant pressure
  - Chimney heater temperature
  - Mineral oil characteristics
    - Viscosity and refractive index



Simplified Smoke Generator Schematic

Approved Smoke Generator Tests

- Aircraft Certification Offices have approved these smoke generators and settings as acceptable means of compliance for certifying cargo compartment smoke-detection systems

Manufacturer Symbol	Chimney Heater Wattage	Smoke Generator Manufacturer
MFR 1a	575	Siemens Cerberus
MFR 1b	1000	Siemens Cerberus
MFR 1c	1000	Siemens Cerberus
MFR 2a	640	Concept Aviator 440
MFR 2b	640	Concept Aviator 440
MFR 3	640	Concept Aviator 440
MFR 4	1125	Modified Concept Aviator 440

Purpose and Goals

- Smoke generators are used in the certification of aircraft smoke detectors
- Currently no standardization concerning the use of these generators
  - Quantify important smoke generator parameters for smoke detection
  - Analyze smoke generators used by airframe manufacturer
  - Quantify requirements in handbook for future smoke detection certification
  - Create list of smoke generators and prescribed settings that adhere to requirements

Purpose and Goals

- Outline important parameters for artificial smoke generators:
  - Aerosol Production
    - Rate of aerosol production
    - Total quantity of aerosol production
    - Repeatability of aerosol production
  - Smoke transport
    - Volumetric flow rate (vertical)
    - Horizontal smoke transport
  - Quantifying the effects of the ambient environment
  - Verifying which artificial smoke generators produce an aerosol with similar particle characteristics to smoke

Particle Size and Light Scattering

Smoke generators used by major airline manufacturers are capable of producing an aerosol that is comparable to particles from some smoke sources

Smoke generator

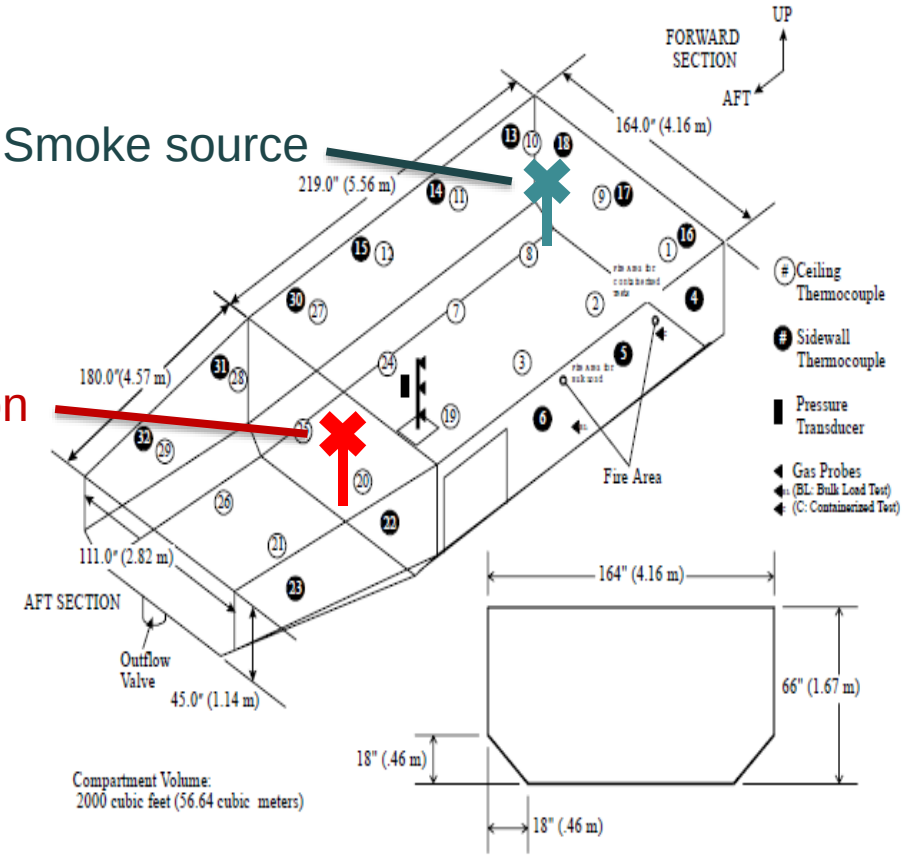
Smoke Source	Average Particle Size (SMPS), nm	Average Percentage of Blue Signal (BIRD)
MFR 1	240	56
MFR 2	192	34
MFR 3	167	29
MFR 4	293	40
Average	223	40
Standard Deviation	56	12

Smoke sources

Smoke Source	Average Particle Size (SMPS), nm	Average Percentage of Blue Signal (BIRD)
Lithium-Ion Battery	209	62
Smoldering Foam	130	39
Smoldering Wood	182	51
Average	174	51
Standard Deviation	40	12

Identifying important smoke generator parameters for cargo smoke detection

- 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.

Important parameters for smoke detection

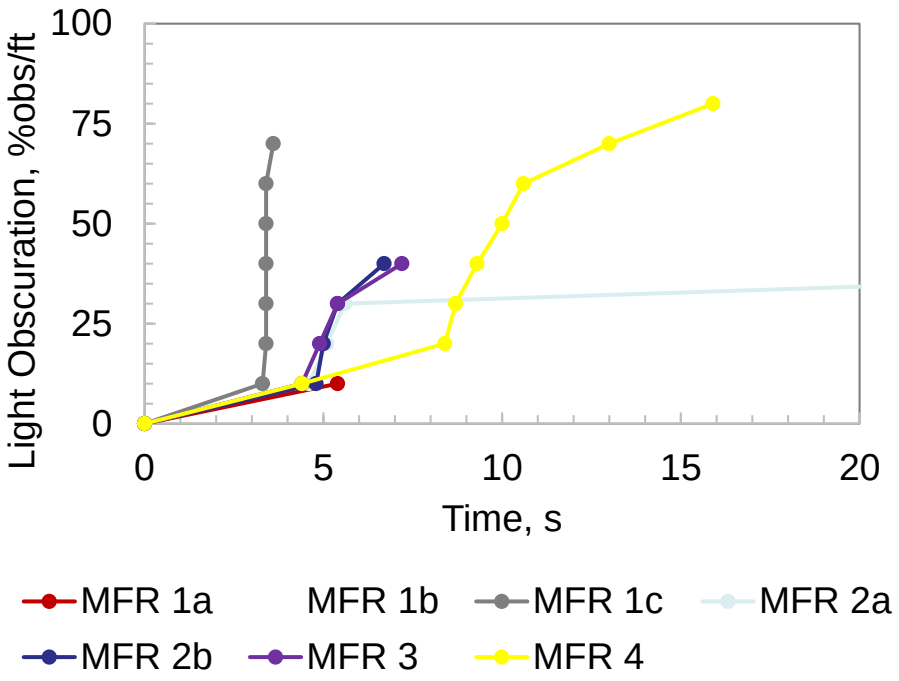
- Detection time depends on:
  - **Thermal buoyancy**
    - Heater wattage
  - **Aerosol production**
    - Gas input pressure

Gas input pressure and heater wattage	Time to Detection
15psi 160W Heater	105
15psi 640W Heater	63
30psi 160W Heater	81
30psi 640W Heater	62
50psi 160W Heater	71
50psi 640W Heater	46
Cardboard Fire	23
Cardboard Smolder	57

Testing conducted with Aviator UL
Average of two tests

Rate of Aerosol Production

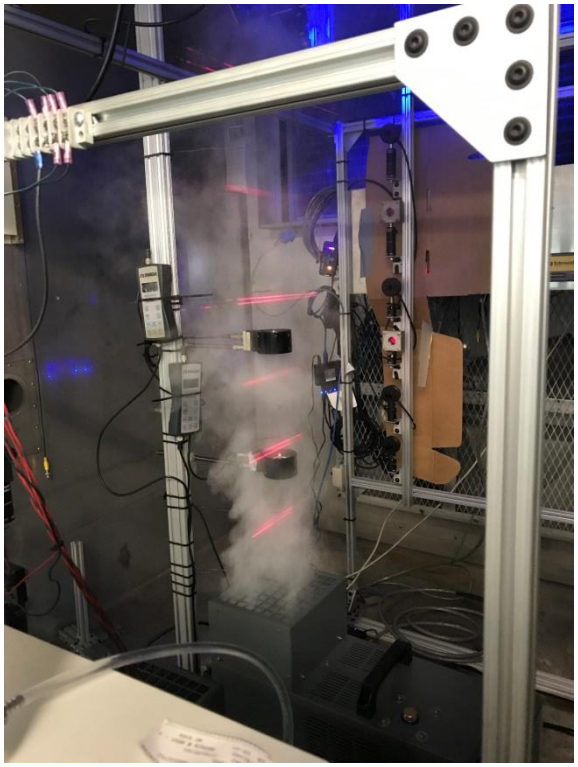
- **Quantified the importance of having continuous aerosol production rather than pulsed**
- The data points represent the time required to reach the respective light obscuration (y-axis)
- The slope of the curve represents the smoke production rate
- There is a range of smoke production rates used for smoke detection certification testing



Time vs light obscuration
Used to determine transient light obscuration

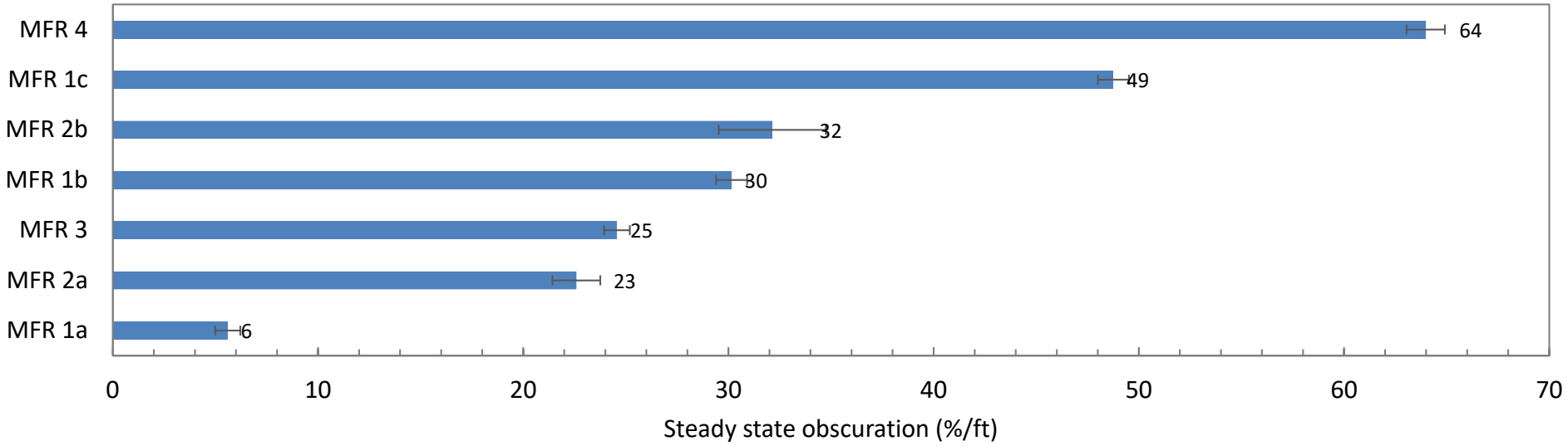
Aerosol Production

- The test chamber shall be a square-cornered box with inside dimensions of 93±1in (236±2.5cm) tall x 72±1in (183±2.5cm) wide x 71±1in (180±2.5cm) deep and a volume of 275ft^3±1% (7.77m^3 ±1%)
- The light monitoring system shall mount 60±1in (152±2.5cm) (65±2% of test chamber height) from the bottom horizontal surface of the test chamber.
- Well mixed with convection from smoke generator chimney heaters



Test Apparatus

Aerosol production results and proposed requirements



Time vs Light Obscuration for Steady-State Light Obscuration

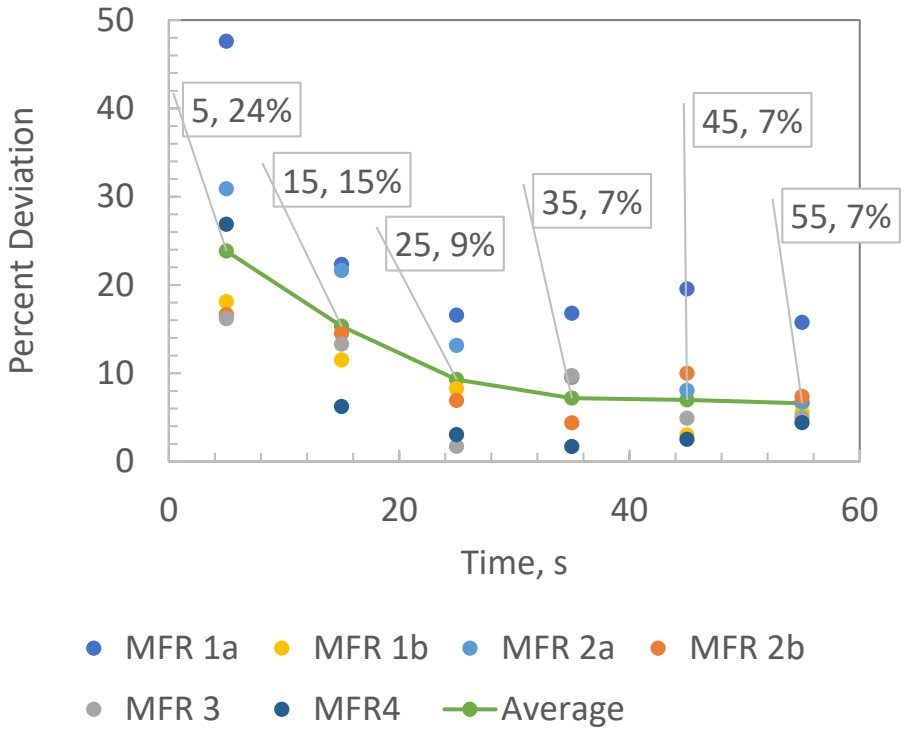
The overall average steady-state light obscuration of the tested aerosols was 32%/ft with a standard deviation of the means of 17%/ft.

Proposed requirements

- The average steady-state light obscuration per unit length over the three tests shall be 32±10%/ft (72±29%/m). Continuous smoke production

Repeatability

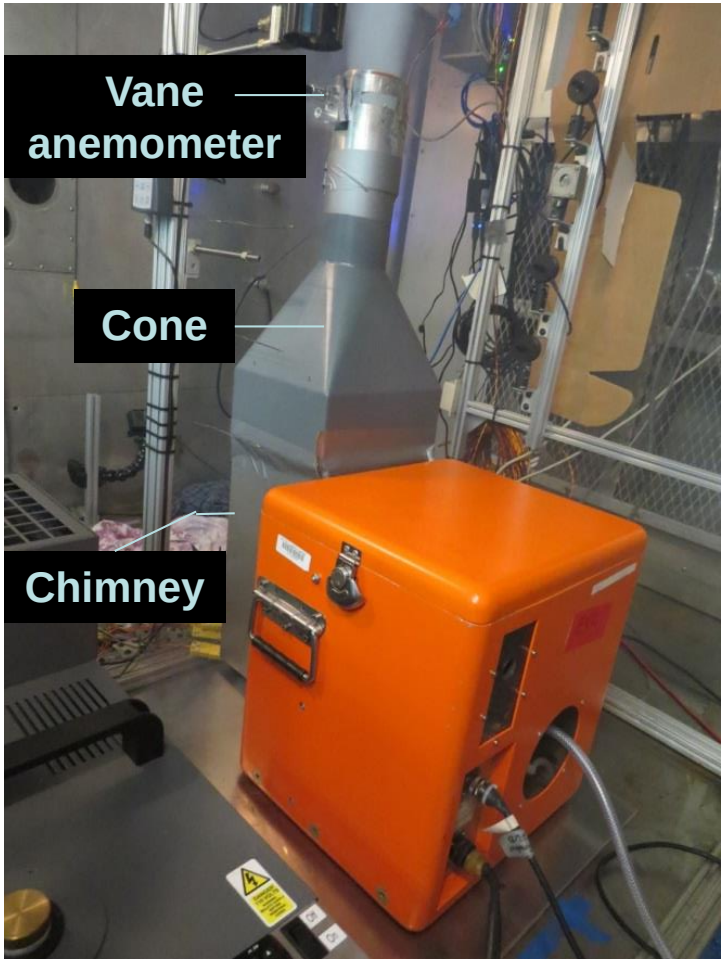
- The relative percent deviation helped determine the variability of each smoke generator's aerosol production throughout the 60-second test and overall repeatability
- The initial 10 seconds are the least repeatable and arguably the most significant portion of certification testing
- The first 10 seconds have an average of 24% deviation between tests from an individual smoke generator



Time vs percent deviation
Used to determine repeatability

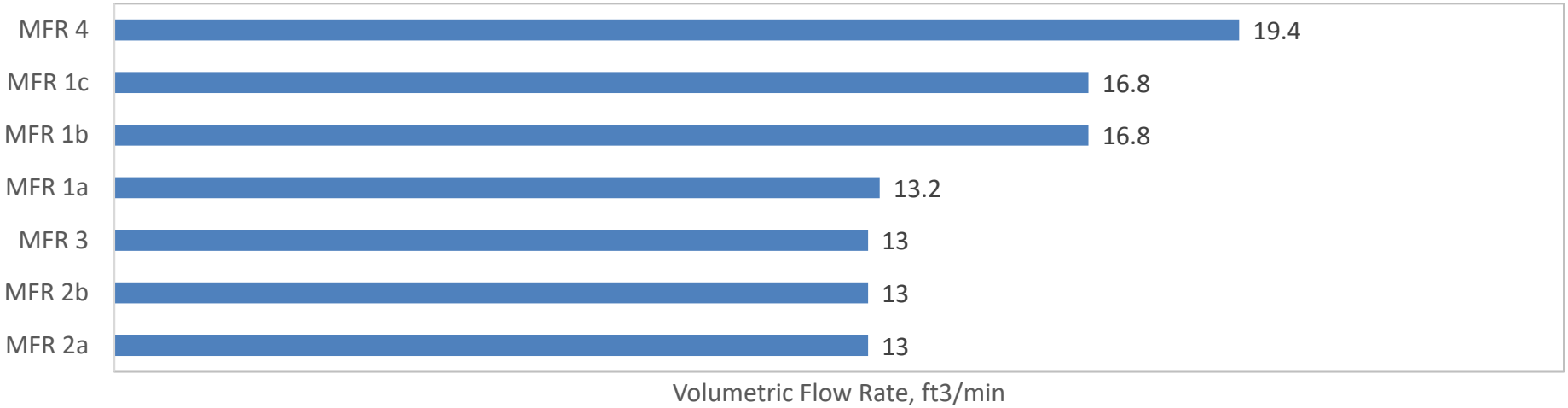
Smoke Transport

- 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

Smoke transport results and proposed requirements



Volumetric flow rate for airframe manufacturers' smoke generators

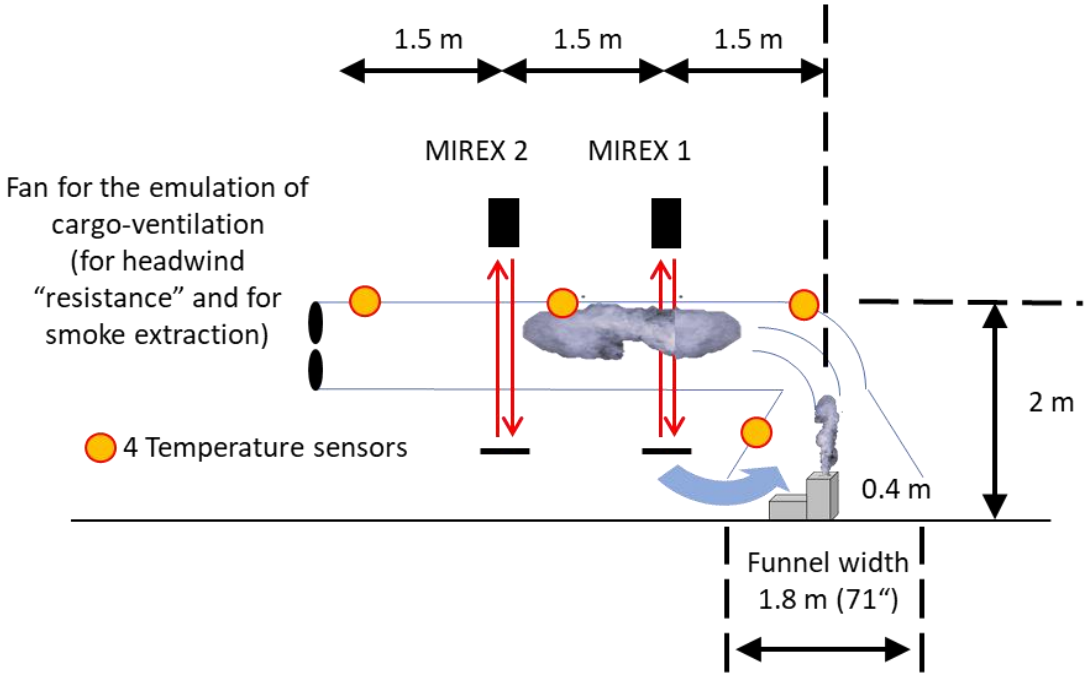
The volumetric flow rates ranged from 13.0 ft^3/min to 19.4 ft^3/min (Figure 10). The average volumetric flow rate was 15ft^3/min with a standard deviation of 2.6ft^3/min.

Proposed requirements

- For ceiling height less than or equal to 1 m, the volume metric flow rate shall be less than or equal to 13 ft^3/min. For ceiling height greater than or equal to 1.2 m, the volumetric flow rate shall be less than or equal to 16.8 ft^3/min.

Horizontal Smoke Transport Future Work

- Size representative of aircraft cargo compartment
- Two reference measurement devices for light obscuration
- Identify the speed at which the smoke spreads.
- Headwind fan simulates a ventilated compartment
- Evaluate for additional information



Horizontal velocity test apparatus

Conclusions

- Four major airframe manufacturers' smoke generators and settings were tested and compared.
  - Approved for certifying cargo smoke detection systems
  - But they varied significantly
- Relevant parameters for an internationally standardized smoke generator performance qualification have been identified
  - Steady state light obscuration (total aerosol production)
  - Volumetric flow rate (vertical smoke transport)
- Two possible additions for standardization requirements
  - Particle size
  - Horizontal smoke transport

Outlook

- Ongoing work within an international working group (Cargo Smoke Detection Task Group)
  - Major airframe manufacturers
  - Airworthiness Authorities
  - Systems manufacturers
- Goals
  - Create a handbook to outline a qualification procedure for artificial smoke generators
  - Define values and tolerances for the parameters that have been investigated in this study so that an international agreement on the performance of smoke generators for aircraft use is achieved
  - Create list of approved smoke generators and settings

Questions and Answers

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