Engine Nacelle, Halon Replacement

Overview & Update

Presented to : FAA International Aircraft Systems Fire Protection Working Group

By : Doug Ingerson
Federal Aviation Administration
WJ Hughes Technical Center/Fire Safety Branch
Atlantic City Int'l Airport, NJ USA
tel : 609-485-4945
email : Douglas.A.Ingerson@faa.gov

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Federal Aviation Administration

Presentation Overview

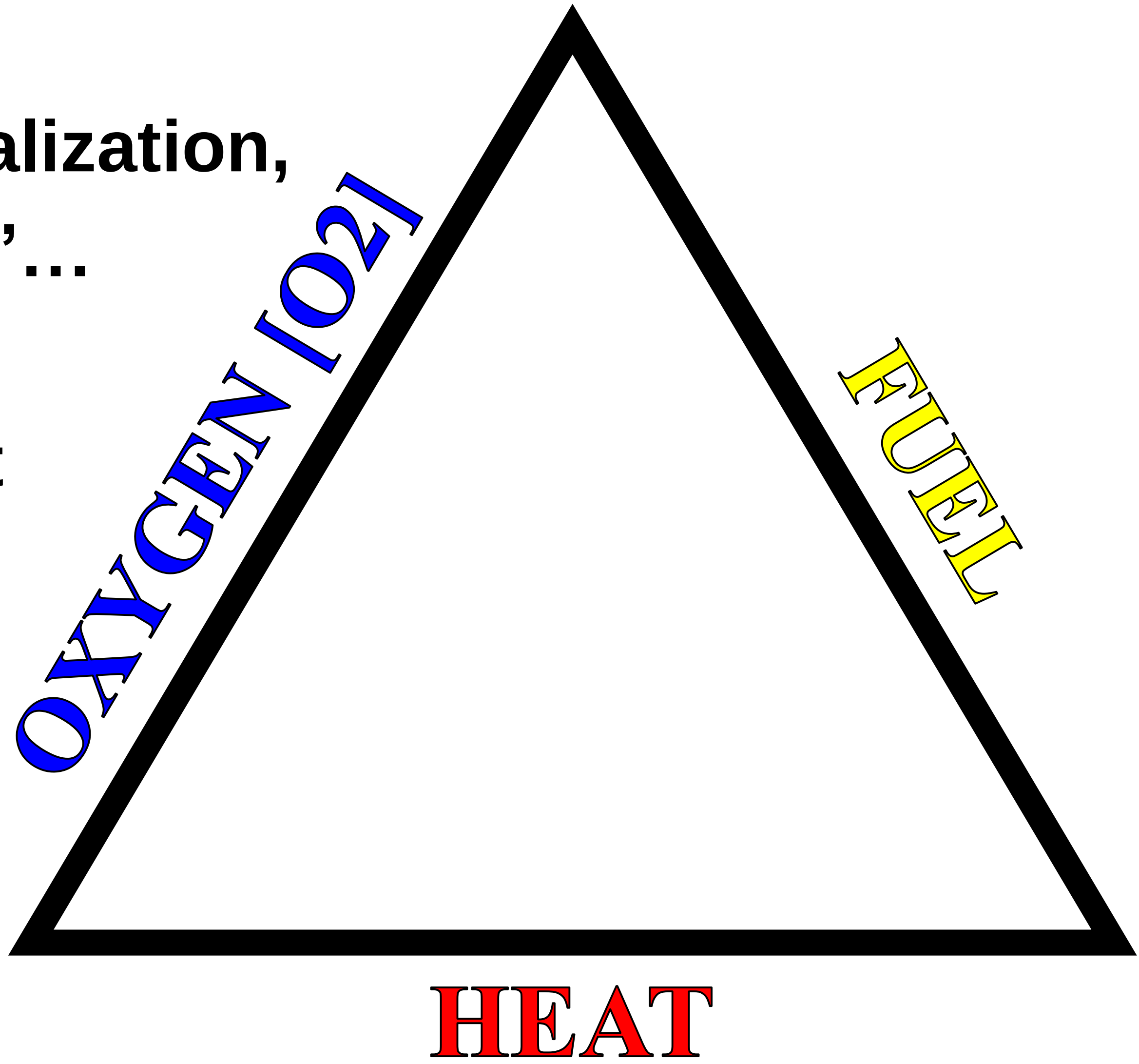
- **Overview of Undesired Fire & Its Defeat**

- **Provide a Focus On & Relate to :**
  – Aircraft powerplant/APU fire zones
  – Associated halon replacement activities

Overview/Undesired Fire & Its Defeat

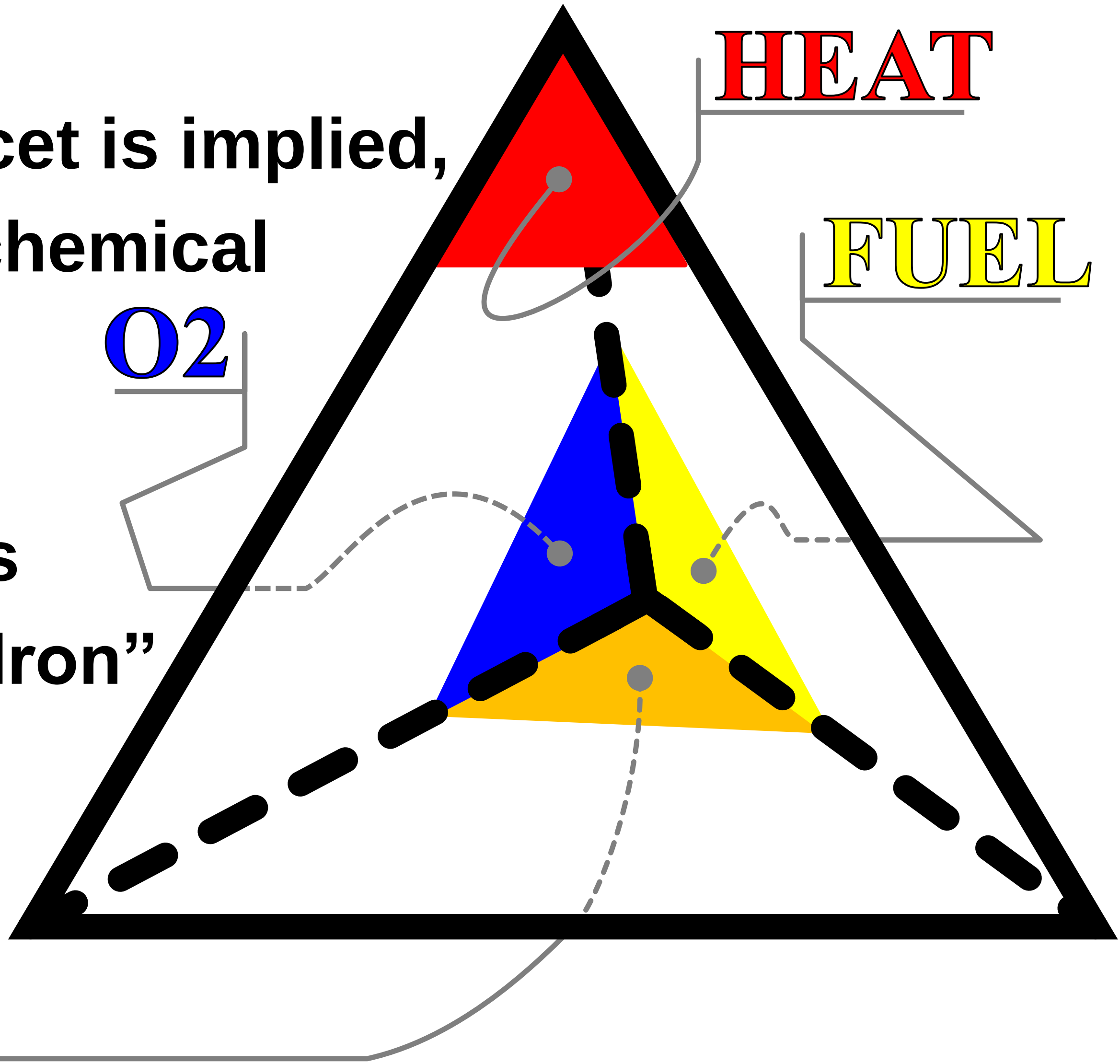
- **Classic conceptualization, the "Fire Triangle"…**

- **Three facets must agreeably coexist for fire to exist :**
  - Oxidizer [oxygen]
  - Fuel
  - Heat



Overview/Undesired Fire & Its Defeat

- **However, a 4TH facet is implied, but missing; the chemical reaction itself**
- **Conceptualized as the "Fire Tetrahedron"**



Overview/Undesired Fire & Its Defeat

❑ About the oxidizer :

A. Frequently considered as atmospheric O_2
   1. O_2 density changes with height
   2. Fire can occur at “high” aircraft altitudes

B. Not always atmospheric O_2, although esoteric
   1. Other oxidizers, alone or cooperating with O_2, create hazard
   2. OEA = oxygen enriched atmospheres
   3. These forms of fire are unfamiliar & “very” threatening
   4. Some examples of loss due to OEA
      - NASA Apollo 1
      - Accidents involving pressurized-O_2 aircrew breathing-air systems
      - Medical surgical settings

Overview/Undesired Fire & Its Defeat

❑ About the fuel :

A. Initial phase is solid, liquid or gas

B. Gaseous fuel participates in the fire
   1. Liquid fuels must vaporize [boil, evaporate]
   2. Solid fuels must [a] sublime or [b] melt then vaporize

C. Fire is classifiable; per NFPA in the US…

1.	Natural substances, cellulosic :	“class A”
2.	Flammable gases & liquids :	“class B”
3.	Electrically-energized equipment :	“class C”
4.	Metals :	“class D”
5.	Commercial-kitchen equipment :	“class K”

NFPA = National Fire Protection Association

Overview/Undesired Fire & Its Defeat

❑ About fire extinction…

A. Remove 1 facet from the tetrahedron & the fire's done

B. Basically, something must be added or removed to inhibit, or possibly prevent, the fire

1. Remove O2 : bury with pot lid, resilient clothing or sand, etc.
2. Remove heat : flame/spark arrestors
3. Remove fuel & disturb chemical reaction : flame-straining

   …Blowing out a candle
4. Introduce a fire extinguishing [firex] agent :
   - Water : heat removal, O2 removal
   - Excess air : fuel removal
   - Excess N2 : O2 removal
   - Halon 1301 : disturb chemical reaction

Overview/Undesired Fire & Its Defeat

❑ About fire extinction…

C. If opting for a firex agent, the circumstances encompassing its use drive its selection

1. What is the expected fire threat?
2. How will the threat be eliminated?
   - Adequately storing the firex agent
   - Identifying the means to deliver the firex agent
   - Determining how much firex agent is needed
3. What other circumstances are important that affect selection?
   - Proximity to & effect on life during use
   - Environmental acceptability
   - Stability; shelf-life, wetted-materials compatibilities
   - Availability

Overview/Undesired Fire & Its Defeat

❑ Quantifying a firex agent for flame extinction

A. Preference is for “bench”-scale characterization

B. 2 common assessment methods cited

   1. Cup-burner :
      - An air/agent mixture defeats a “small” laminar diffusion flame
      - Representative specifications maintained by NFPA 2001
   2. Peak-inertion [a variation of determining fuel/air flammable limits] :
      - A fuel/air/agent system prevents a reaction in a closed vessel
      - Representative specifications maintained by ASTM

C. These methods are quite different

   1. Each’s different circumstances produce different outcomes.
   2. Peak-inertion values are larger; **approximately** 1.8 * cup-burner.

ASTM = American Society of Testing & Materials

Overview/Undesired Fire & Its Defeat

❑ Quantifying a firex agent for flame extinction

D. Cup-burner overview

1. “Low”-speed, pre-mixed, air/firex agent mixture moves upward in vertical/circular chimney
2. Air/firex agent mixture passes an included cup
3. A test flame sits atop & attached to the cup
4. The cup holds either liquid- or gaseous-fuel
5. One alters the composition of the air/firex agent mixture to find the minimum one that extinguishes the flame

Overview/Undesired Fire & Its Defeat

SECTION 4. FLAME SUPPRESSION EFFECTIVENESS 381

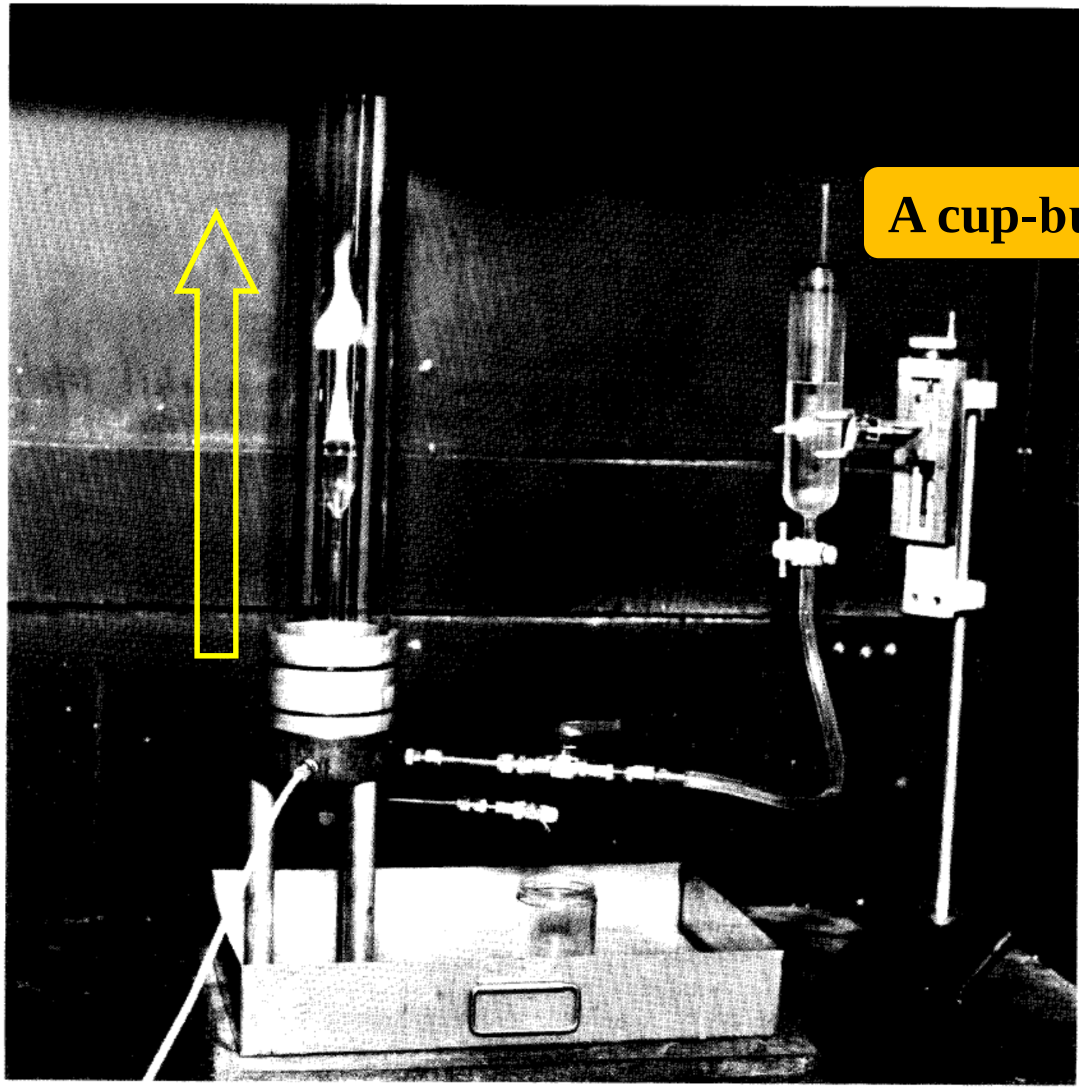


Figure 24. Photograph of cup burner and liquid fuel supply.

A cup-burner…

NIST SP861, "Evaluation of Alternative In-Flight Fire Suppressants for Full-Scale Testing in Simulated Aircraft Engine Nacelles and Dry Bays", Section 4, "Flame Suppression Effectiveness," A. Hamins, et al, April 1994

378 SECTION 4. FLAME SUPPRESSION EFFECTIVENESS

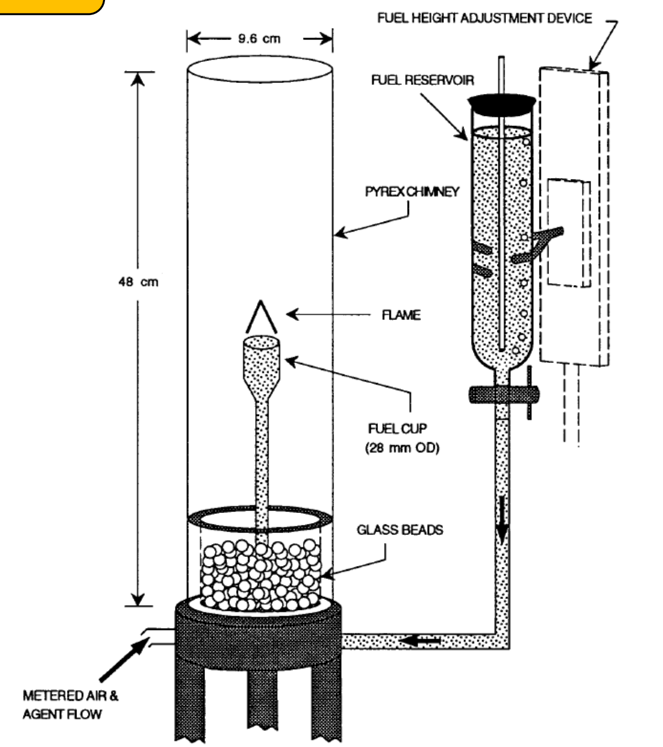


Figure 22. Schematic drawing of the cup burner.

Overview/Undesired Fire & Its Defeat

❑ Quantifying a firex agent for flame extinction

E. Peak-inertion overview

1. A static, typically gaseous*, equilibrated, homogenous fuel/air/firex agent mixture exists within a vessel
   - Glass tube; a.k.a. explosion buret, explosion tube, detonation tube
   - Metal sphere; a.k.a. combustion sphere
2. An ignition source is activated in each vessel's interior
3. Vessel interior is monitored to assess if a reaction occurred; reaction occurred if :
   - Flame propagated through the mixture in the glass tube
   - A pressure pulse of certain size occurred in the sphere
4. One varies composition of the fuel/air/firex agent mixture to find a maximum [peak] firex agent concentration that prevents reaction

a.k.a. = also known as
* = mixture's phase depends upon its constituents; consider an aerosol…

Overview/Undesired Fire & Its Defeat

Inertion, Tube

Bulletin 503, “Limits of Flammability of Gases and Vapors," H. Coward & G. Jones, 1952.

10 LIMITS OF FLAMMABILITY OF GASES AND VAPORS

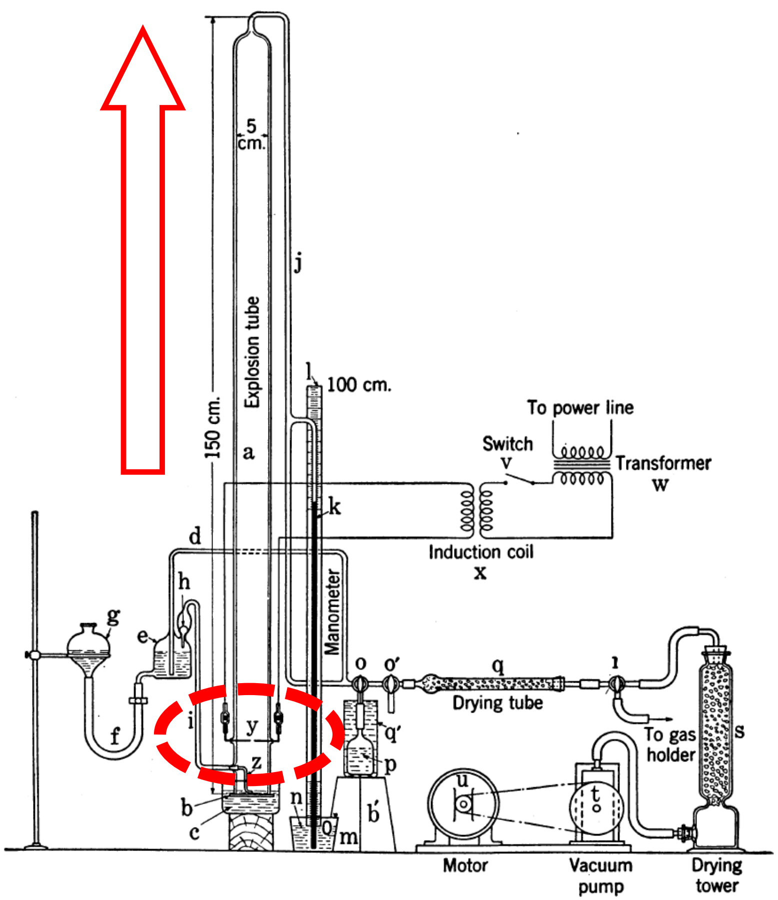


FIGURE 3.—Apparatus for Determining Limits of Flammability of Gases and Vapors.

Inertion, Sphere

DOT/FAA/TC-15/59, "Lithium Battery Thermal Runaway Vent Gas Analysis," T. Maloney, November 2016

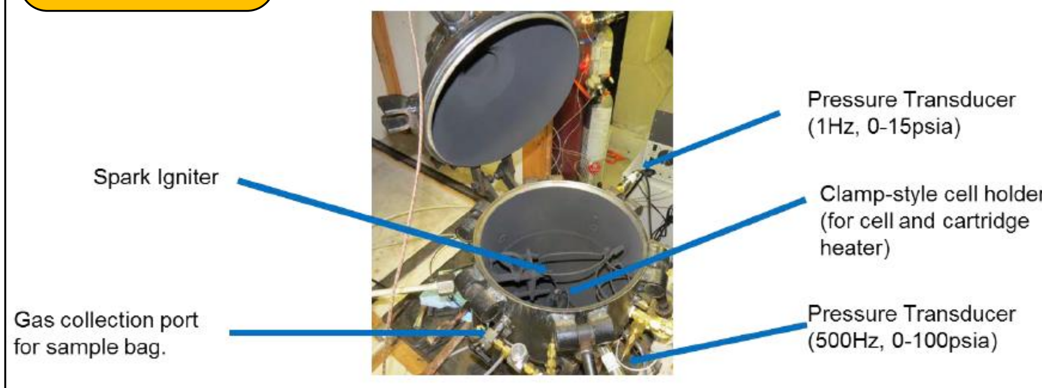


Figure 4. A 21.7 L test chamber for small-scale tests

DOT/FAA/TC-TT16/55, "Flammability Limits of Lithium-Ion Battery Thermal Runaway Vent Gas in Air and the Inerting Effects of Halon 1301," M. Karp, September 2017

Figure 3.1: Testing Pressure Vessel

Overview/Undesired Fire & Its Defeat

❑ Delivering a firex agent for flame extinction

A. 2 delivery concepts
   1. Direct/localized application
      - Fire location is known/observed
      - Firex agent is typically delivered as a stream directly onto the fire
   2. Indirect/flooding application
      - Fire location is NOT known/observed
      - Firex agent typically delivered to flood a compartment

B. Delivery is dependent upon the :
   1. Firex agent ‘s properties
   2. Environmental conditions in the end-use

Overview/Undesired Fire & Its Defeat

❑ Delivering a firex agent for flame extinction

C. Firex agent residence

1. Firex agent must adequately reside @ the fire to extinguish it
2. Considering 2 durations
   - “Transport” time : adequate time in a macroscopic flow field to permeate obstructions & physically contact the fire
   - “Chemical” time : upon contact with the fire, subsequent microscopic interactions have adequate time to initiate & complete
3. Again, a situationally-dependent proposition

Overview/Undesired Fire & Its Defeat

- **Why the previous slides ?**

…to facilitate opening up thought regarding how to approach fire mitigation…

…given there is so much information available to consider.

Focus/Relate, Powerplant Fire Zone

❖ **Circumstances about the powerplant fire zone :**

1. Spatial volume of complex structure with forced ventilation
2. Flowing flammable liquids normally contained in plumbing
3. Resident ignition sources; electrical arc, "hot" surfaces
4. Wide range of local conditions during operations
5. Failure can create conditions concluding in undesired fire
6. These compartments are typically not occupied
   - Ground personnel might have something to say here…

Focus/Relate, Powerplant Fire Zone

❖ **Mitigating the undesired fire threat :**

1. Employ passive & active fire prevention strategies
2. Focus on active prevention here : the firex system…

❖ **FAA regulatory basis :**

1. The broad foundation : 14 CFR §25.1181 – §25.1207
2. The specific interest...
   A. 14 CFR §25.1195 Fire Extinguishing Systems
   B. Demonstrating acceptability for fire extinguishing systems
      - FAA Advisory Circular (AC) 20-100
      - Acceptable performance at “worst”-case condition(s)

Focus/Relate, Powerplant Fire Zone

❖ **Challenges for the firex system :**

1. The aircraft's operational envelope
2. Location of the fire within the fire zone is unknown
3. Firex agent must inject into the fire zone & totally flood it
   - Prevents zonal fire migration so the agent's presence isn't outlived

❖ **Challenge reduces to a 2-part problem about :**

1. Quantity : how much agent needed to defeat a given fire
2. Distribution : adequately moving this quantity to defeat fire

Focus/Relate, Powerplant Fire Zone

- **The "state-of-the-art" is roughly a 30-year evolution, where it's typically…**
  1. Based on halon 1301 :
     - A. Stored in a pressure vessel :
       - Mixed with nitrogen (N2)
       - Mounted in the engine pylon, wing or fuselage
       - Connected to the fire zone with plumbing
       - Manually discharged from the flight deck
     - B. Discharging through open-ended tubes and drilled holes
  2. Shown acceptable :
     - A. With a Statham-derivative gas analyzer
     - B. By assessing the injected firex agent's concentration field [*no fire*]
     - C. Satisfies design criteria for "worst" case conditions

Focus/Relate, Powerplant Fire Zone

- **Why halon 1301?**
  1. Efficient fire extinguishing agent; extinction & less weight
  2. Fire extinction quantity compatible w/life
  3. Chemically stable during “normal” storage
  4. When pure, compatible with typical aerospace materials
  5. Thermodynamic character compatible with the aircraft’s operational envelope
  6. Others ?

Focus/Relate, Powerplant Fire Zone

❖ Illustrating some halon 1301 history…

1. AC 20-100/1977 :
   - A. Simultaneously equal/exceed 6%v/v halon 1301 for 1/2 second at the requisite number of sample points in the fire zone
     - p.8-9, Section 9, “Interpretation of Data.”
   - B. Cites FAA report no. DS-70-3, “Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Concentration Recorder” as a reference.

Focus/Relate, Powerplant Fire Zone

2. REFERENCE.

a. Report No. FAA-DS-70-3, "Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Concentration Recorder," is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151, under Accession No. AD 712 191.

reference

FAA, AC 20-100, "General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments," September 1977.

9. INTERPRETATION OF DATA.

a. The percentage of relative concentration, based on the ratio of oscillograph galvanometer displacements, does not indicate the concentration percentage on a volumetric or weight basis. To convert to a volumetric percentage or weight percentage, the curves shown in Figures 7 through 11 may be used. Referring to Figure 7, the concentration percentage corresponding 52.9 percent would be approximately 49 percent by volume and 60 percent by weight.

b. In order to determine by means of the recorder whether the extinguishing agent is to be effective, concentrations sufficient to extinguish fire must exist simultaneously at all sampling points long enough to provide initial extinguishment and assure protection while flammable vapors dissipate and hot surfaces cool. The minimum time that the minimum concentration should exist is one-half second.

1/2 second residence

9/21/77 AC No. 20-100

Examples of minimum concentrations sufficient to extinguish fire and prevent its recurrence are as follows:

AGENT	CONCENTRATION BY WEIGHT	IN PERCENT BY VOLUME	RELATIVE CONCENTRATION PERCENT
CO_2	49	37	40
CH_3Br	30	11	15
CH_2BRCl	36	11	25
CF_2Br_2	26.5	5	1[illegible]
CF_3Br	22	6	[illegible]

CF3Br

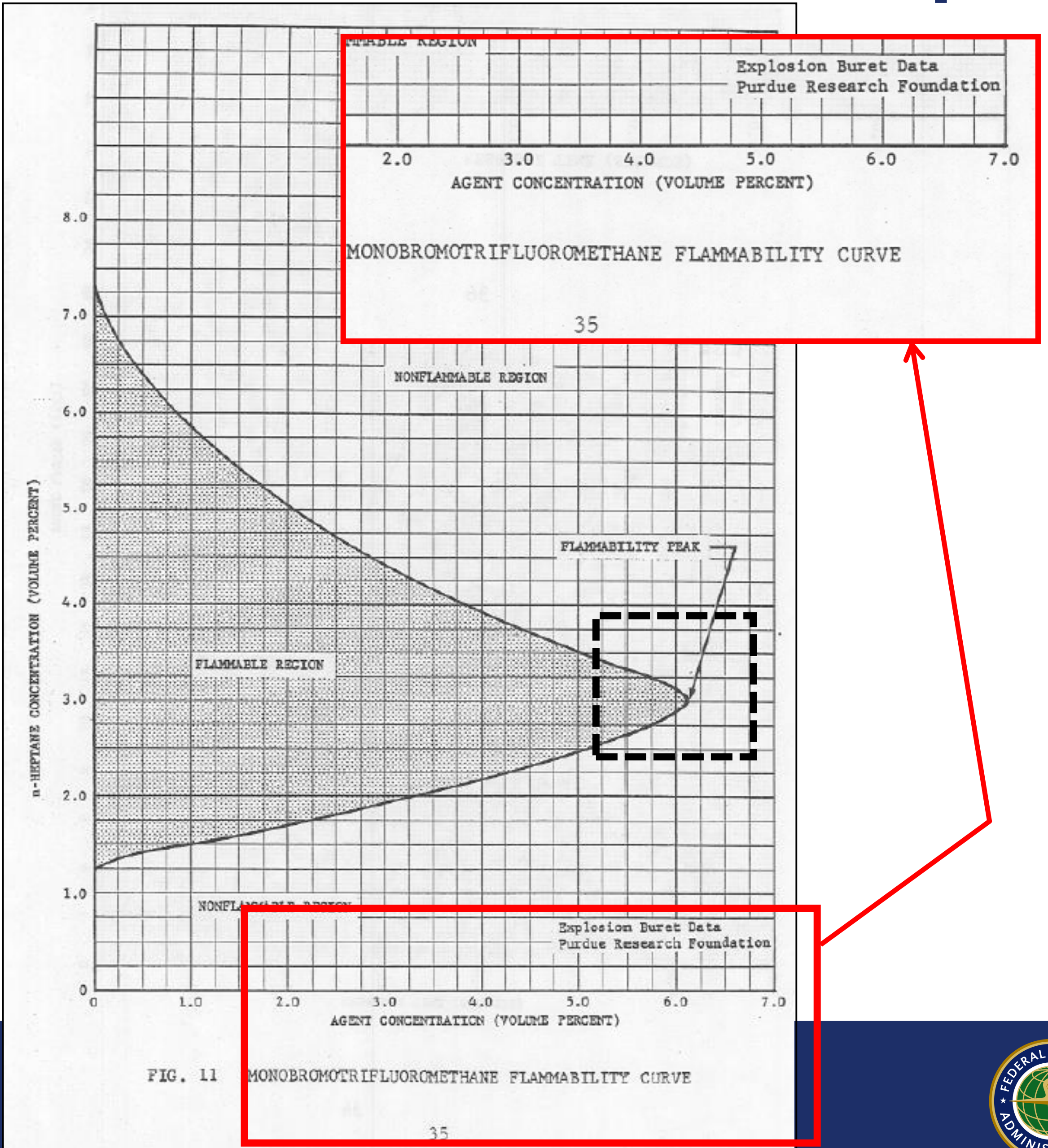
CF3Br

Focus/Relate, Powerplant Fire Zone

❖ …Illustrating some halon 1301 history…

2. Report No. DS-70-3
   - A. Brief discussion about fire's inability to exist if halon 1301 is resident at approximately 6%v/v or more, per figure 11.
     - p. 33-34, discussion
     - p. 35, fig 11
     - THIS IS A PEAK-INERTION CONCENTRATION…
   - B. Noting from figure 11 :
     - It's a flammability graph of an n-heptane/air/halon 1301 system
     - Moniker in lower right corner, "Explosion Buret Data Purdue Research Foundation"
   - C. Figure 11 is based on a report about work completed September 1947-June 1950 by the Purdue Department of Chemistry, via the Purdue Research Foundation

Focus/Relate, Powerplant Fire Zone



FAA-DS-70-3, "Criteria for Aircraft Installation and Utilization of an Extinguishing Agent Concentration Recorder," G. Chamberlain, March 1970

Report No. FAA-DS-70-3

CRITERIA FOR AIRCRAFT INSTALLATION AND UTILIZATION OF AN EXTINGUISHING AGENT CONCENTRATION RECORDER

George Chamberlain
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

MARCH 1970

FINAL REPORT

Availability is unlimited. Document may be released to the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151, for sale to the public.

Prepared for

FEDERAL AVIATION ADMINISTRATION
Aircraft Development Service
Washington D. C., 20590

Focus/Relate, Powerplant Fire Zone

❖ **…Illustrating some halon 1301 history.**

3. Purdue Department of Chemistry/Purdue Research Foundation
   - A. Much work done regarding halogenated firex agents & flammable systems in an inertion configuration; halon 1301 saw use in several investigations
   - B. Graph of n-heptane/air/halon 1301 flammability behavior
     - ≈ 6%v/v halon 1301 peak
     - Figure 3, p. 15
   - C. Table compares outcomes of many potential compounds
     - 6.1%v/v halon 1301 in an air/n-heptane flammable system listed as peak-inerting concentration
     - This mapping was established at “room” conditions
     - Table II, p. 17

Focus/Relate, Powerplant Fire Zone

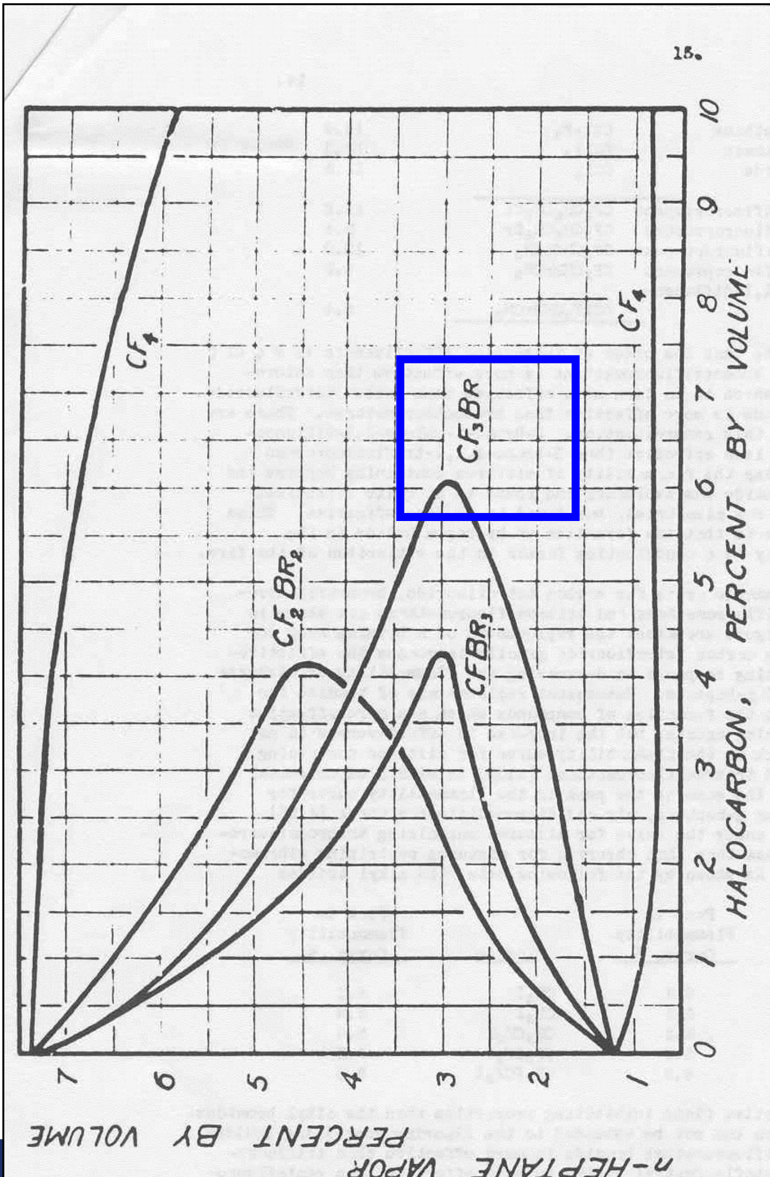


Figure 3 Effect on Flammability Curve of Replacement of Bromine for Fluorine Atom in CF_4

AD-654322 - "Final Report on Fire Extinguishing Agents for the period 1Sep1947 to 30June1950 covering research conducted by the Purdue Research Foundation and Department of Chemistry," Purdue University, under contract W44-009-eng-5057 w/Army Engineers Research and Development Laboratories, Fort Belvoir.

Final Report

on

FIRE EXTINGUISHING AGENTS

for the period

September 1, 1947 to June 30, 1950

covering research conducted by

Purdue Research Foundation and Department of Chemistry

Purdue University

17.

Table II

SUMMARY OF COMPOUNDS EVALUATED AS FIRE EXTINGUISHING AGENTS (Room Temperature)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, g.*	Order of Effectiveness Vol. basis	Order of Effectiveness Wt. basis
$CBrF_3$	Bromotrifluoromethane	6.1	40.57	12	8

Focus/Relate, Powerplant Fire Zone

- **Halogenated firex agents & the environment**
  1. Environmental researchers discover ozone-hole problem
  2. Linked to halogenated compounds used by many sectors
  3. Coordinated global effort to reduce halon usage occurs
  4. International Halon Replacement Working Group was born
     A. FAA working group forum; conceived 1993
     B. Parent of this working group
     C. Focused on aviation halon usage; powerplant is 1 of 4
  5. Climate change now a focus also; global warming…

Focus/Relate, Powerplant Fire Zone

- **Powerplant halon replacement**
  1. Task group forum coordinated by FAA Fire Safety
  2. Contains industry & governmental participants
  3. A test protocol exists & currently sits at rev04
     - A. Protocol directly links design criteria for candidate to halon 1301
     - B. Draws on much knowledge & experience
     - C. Has been used to investigate several potential candidates
     - D. Was intended to be “portable”
     - **E. Its successful completion does <u>NOT</u> guarantee certification**
       - Must assure safety of flight, plus compatibility with life & environment

Focus/Relate, Powerplant Fire Zone

❖ Brief test protocol history…

1. Rev01, 1993-1996; FAA not conducting "hands-on" testing
   A. US DoD, tri-service effort coordinated by USAF; 3 work phases
      - Started with broad-spectrum literature search for candidates
      - Culminated with an HFC-125 design model based on much testing [AFRL-VA-WP-TR-1999-3068, May 1997]
   B. Wealth of information generated; documented by US NIST
      - Special Publication [SP] 861, SP 890, & SP 1029; Collectively, around 3k+ pages of information…
      - Other information : DOT/FAA/TC-14/50, L. Speitel, "Options to the Use of Halons for Aircraft Fire Suppression Systems—2012 Update"
   C. Civil aviation manufacturers uncoupled & continued because :
      - Wanted other firex agent choices
      - Preferred the "…AC 20-100 way of doing business"

US DoD = United States Department of Defense
USAF = United States Air Force
NIST = National Institute of Standards & Technology

Focus/Relate, Powerplant Fire Zone

❖ …Brief test protocol history…

1. Revs02-04, 1996-2018
   A. Established test protocol & performed “hands-on” testing
      - Includes test process & a “real”-scale test fixture
      - Incorporates many facets of powerplant fires
   B. Includes experience from others
2. Rev02 [obsolete], 1996-2003
   A. Establish parity by extinguishing a “robust” fire 80% of the time.
      - Based on forced ventilation, spray fire, firex agent migration, & “hot” surface reignition
   B. “Robust” fire concept shown too statistically fickle
      - Too unstable/unreliable for comparing halon 1301 & its replacements

Focus/Relate, Powerplant Fire Zone

❖ …Brief test protocol history…

1. Rev03 [obsolete], 2003-2008
   1. Compare fire extinction durations between halon 1301 & possible replacement candidates
   2. Created durations in environment relating to powerplant fire zone
      - 2 forced ventilation flows
      - Testing independently against pool & spray fire
      - Persistent electrical arc & “hot” surface ignition sources
      - Firex agent injection & migration
      - Assessment based on agent distribution & fire suppression duration
   3. Discontinued because :
      - Empiricism, relating to halon 1301, implicit in assessment fails
      - Replacement candidates becoming more unlike halon 1301

        …CF3I, FK-5-1-12, solid aerosol

Focus/Relate, Powerplant Fire Zone

❖ …Brief test protocol history.

1. Rev04 [active], 2008-?
   - A. “Proof”-test rationale
   - B. Identify firex agent design criteria before testing; set it up in the test environment; ?%v/v for 1/2 second…
   - C. Must demonstrate parity between halon 1301 & its replacement candidate via fire suppression behaviors
   - D. If faulty, increase design criteria until demonstrating parity
   - E. If candidate circumstances are notably different than the “state of the art”, expect a “real”-world demonstration test
     - Performing an engine fire test, or something very close to it…
     - Consider differences in firex agent, its concentration analyzer, & its storage/injection
   - F. Working draft is available on FAA Fire Safety website

Focus/Relate, Powerplant Fire Zone

❖ **Who is driving the halon-replacement testing ?**

1. Recommendations from the working group
   - HFC-125 [scattered across 2002-2004]
   - CF3I [scattered across 2003-2006]
2. Aircraft certification projects
   - American Pacific 2-BTP [2004]
   - 3M FK-5-1-12 [2006]
   - Kidde KSA/solid aerosol [2007-2008, 2010-2012]
   - Meggitt Bend A [2014]

Focus/Relate, Powerplant Fire Zone

❖ Halon replacement candidate outcomes to date…

Candidate [boiling point, 1 atm]	What revision ?	Outcome from FAA Testing	Comment
HFC-125 [-48°C]	3	17.6	see note [1] on next slide
CF3I [-22°C]	3	7.1	did not complete required number of tests & test conditions; see note [2] on subsequent slide
2-BTP [+34°C]	3	n/a	withdrawn from consideration; see note [3] on subsequent slide
FK-5-1-12 [+49°C]	3	6.1	FAA result falls between cup-burner & peak-inertion [4.5 ,8.1-8.8%v/v]
KSA [n/a]	3, 4	n/a	undesirable performance during demonstration test
Blend A [n/a]	4	30.6	n/a
CO2 [n/a]	4	n/a	1 of 4 test configurations completed

Boiling point, 1 atm, halon 1301 = -58°C/-72°F
halon 1211 = -4°C/25°F

Focus/Relate, Powerplant Fire Zone

❖ **Halon replacement candidate outcomes to date…**

1. **HFC-125, additional details**
   A. 17.6%v/v HFC-125 is final outcome
   B. Compare to :
      - 14.5% - 26%v/v HFC-125 from US DoD HFC-125 design guide
      - 14.7%v/v HFC-125, peak-inertion in air/methane
      - 15.7%v/v HFC-125, peak-inertion in air/propane
        …NFPA 2001, Annex A.5.4.3, Table A.5.4.3, p.55
   C. No plans to retest…

Focus/Relate, Powerplant Fire Zone

❖ **Halon replacement candidate outcomes to date…**

2. CF3I, additional details

A. Incomplete test counts; did not complete 4 test conditions

B. Industry interest non-existent @ the time of assessment

C. Review of fire extinction literature yields reasonable justification to discontinue its testing

- MPSHRe rev04 outcome = 7.1%v/v CF3I
- peak-inertion = 6.5%v/v CF3I in air & propane
  …NFPA 2001, Annex A.5.4.3, Table A.5.4.3, p.55
- peak-inertion = 6.8%v/v CF3I in air & n-heptane
  …Purdue Department of Chemistry, Table II, p.18
  …this is the same work from Purdue that included halon 1301

Focus/Relate, Powerplant Fire Zone

❖ **Halon replacement candidate outcomes to date…**

3. 2-BTP, additional details

A. Did not complete testing; applicant withdrew it from further testing

B. Test observations suggested 2-BTP was contributing to combustion in certain circumstances

- Fires were extinguishing at the spray fire threat inside test fixture
- Anomalous phenomena occurred in remote part of the test fixture
- Witnessed fireballs escaping an atmospheric gap & occasionally heard audible cues

…both related to fire reignition

…halon 1301 does not behave similar, nor has anything else

Focus/Relate, Powerplant Fire Zone

❖ Other activities…

1. Still intending to complete CO_2 testing
2. US Army, preliminary investigation, potential low-GWP halon-replacement candidates, Aug 2018
   A. Considering firex agent for an aircraft powerplant fire zone
   B. Blended sodium bicarbonate & 2-BTP
   C. Concept based on a previous success
      - Blended sodium bicarbonate & HFC-227ea
      - Hand-held firex to replace legacy halon 1301 hand-helds …(Fielding is TBD)
   D. Review pending; forward progress unknown; funding issues...
   E. Point-of-contact : Mr. Tim Helton, US Army, Redstone Arsenal

Focus/Relate, Powerplant Fire Zone

Questions…