A Brief Status, Current Powerplant Halon Replacement Activity

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Presentation Purpose & Content

- **...a Brief Overview & Status on Local Powerplant Halon-Replacement Fire Testing[2a]**

- **Presentation contents...**
  - Brief Overview of the Test Process
  - Illustrations of the Local Test fixtures
  - Tabular Listing of Candidate Results to Date
  - Background Reference Presentations
  - Appendices

[2a] known in short-hand as "MPSHRe/rev04", the "Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments (MPSHRe rev04)"

A Brief Test Process Overview

- **Proposed certification criteria from 2 revisions**
  - directly relate to halon 1301[3a] performance
  - based on replicate, multi-condition testing
    - concentration measurements
    - fire-suppression observations
  - candidate's performance will equal or exceed CF3Br's
  - is a part of aircraft certification, although passing the MPSHRe does not guarantee certification

[3a] halon 1301 is CF3Br, bromotrifluoromethane; the 6%v/v halon 1301 concentration criterion from the FAA certification criteria is a significant contributor to the state of the art [SotA]; this CF3Br concentration criterion is analogous to a peak-inertion concentration, as derived from bench-scale testing & reported in literature.

A Brief Test Process Overview [continued]

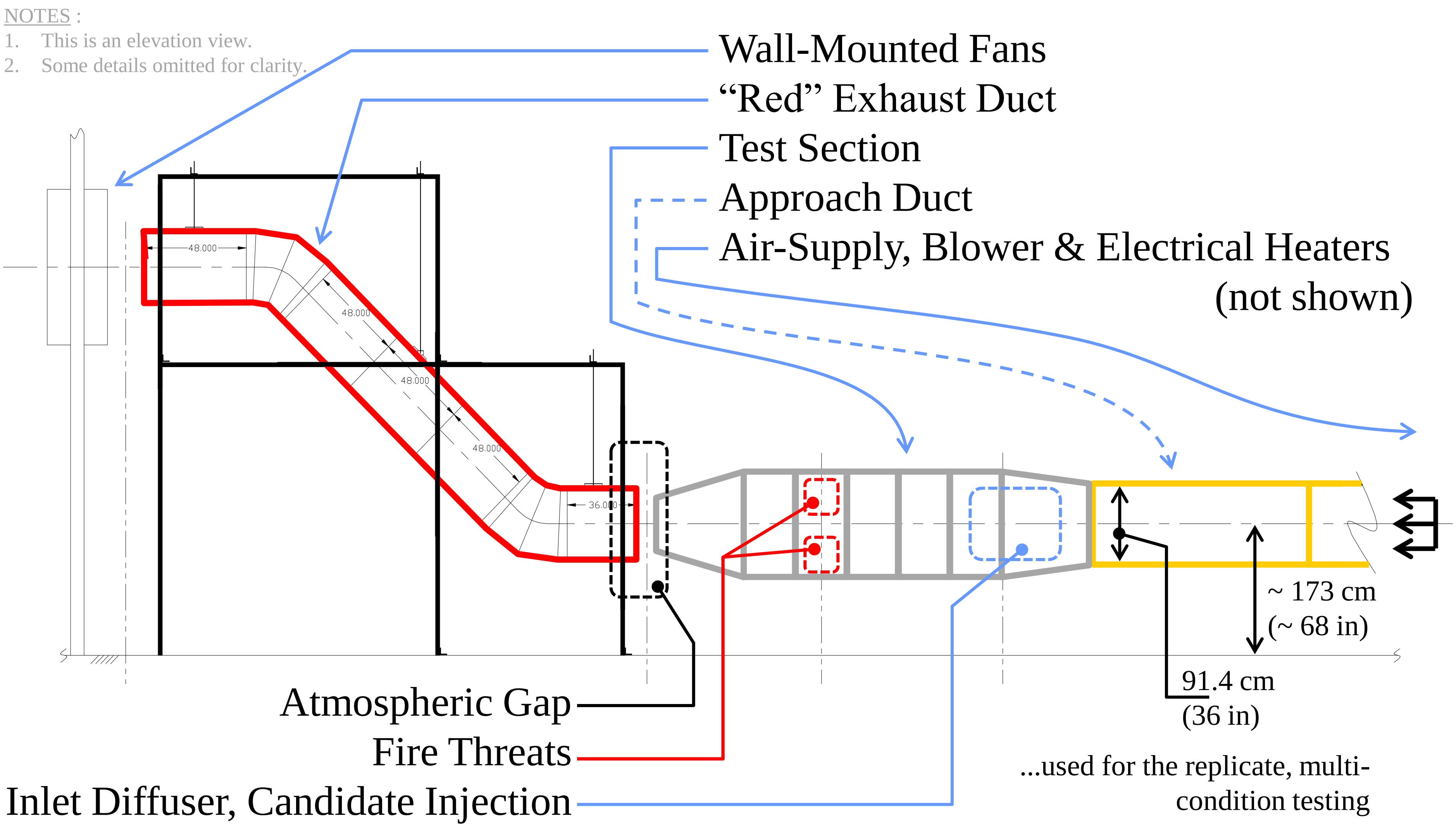
- **MPSHRe/rev03 : 2003-2008, implicit empiricism**
  - rev03 built around CF3Br
  - initially uninformed, tested to find parity, & then characterized it
  - candidate firex[4a] agents became less like state-of-the-art CF3Br; i.e. CF3I, 2-BTP, C6F12O, NaHCO3 aerosol
  - ...empiricism falters, rev03 retired

[4a] firex = fire-extinguishing or fire extinguisher

A Brief Test Process Overview [continued]

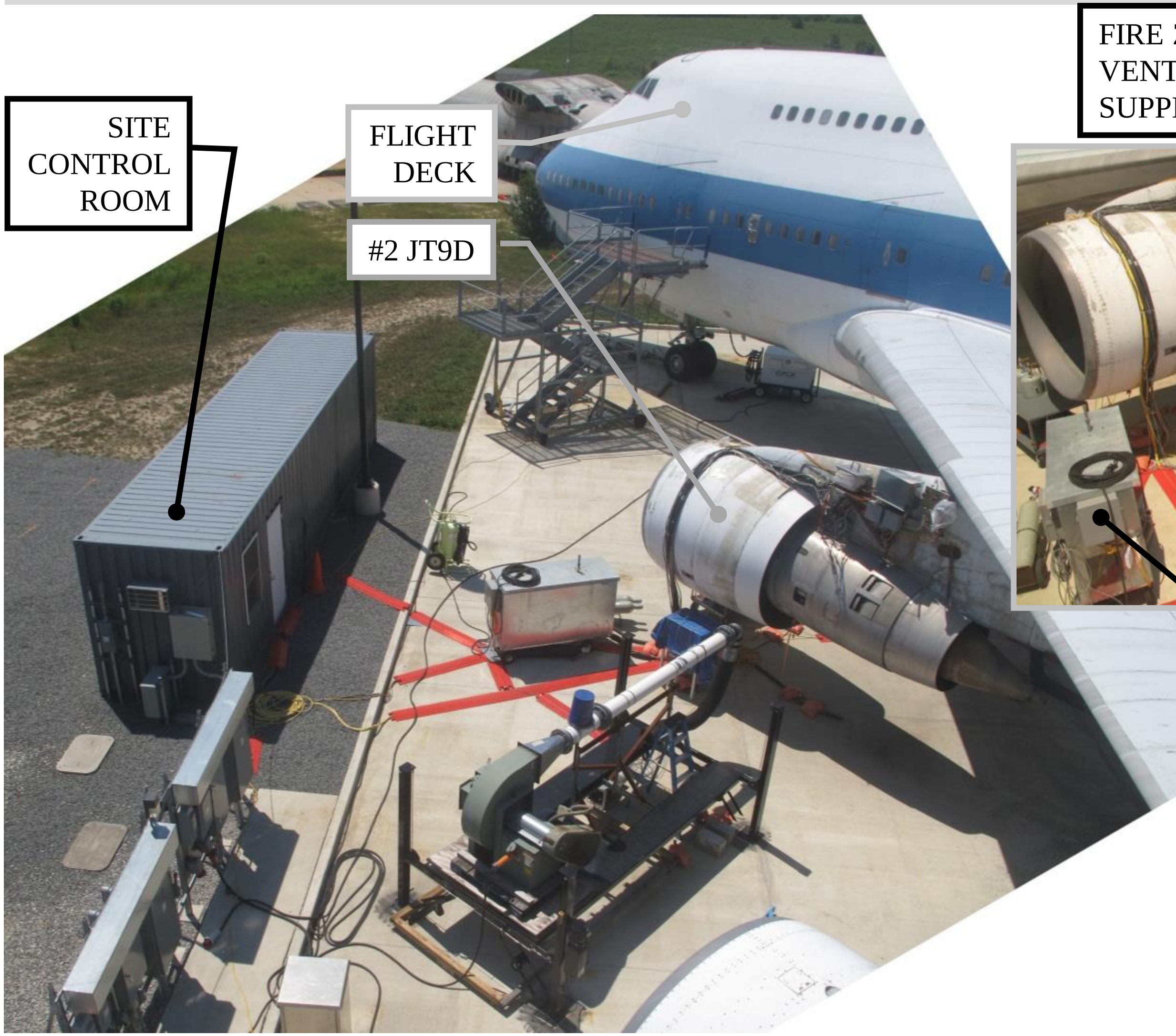
- **MPSHRe/rev04 : 2010-?, active, a proof-test**
  - must know candidate firex agent's bench-scale/flame-inhibition characteristics before commencing this testing
  - if initial criteria test faulty, need to review situation...
  - if candidate different than SotA :
    - real-scale/high-fidelity demonstration testing is required
    - based on dissimilarity between candidate circumstances & :
      - CF_3Br
      - legacy aircraft-based storage/delivery methods
      - legacy concentration measurement technique; Statham-derivative...

Local Test Fixtures ~ generic nacelle fire simulator



...used for the replicate, multi-condition testing

Local Test Fixtures ~ FAA-owned 747SP's #2 JT9D



...used for demonstration testing
...imagery from 2011-2012, but
is similar to more recent

Tabular Candidate Overview

Candidate [chemical, ASHRAE, & example product names]	**Year[s] Any Testing Occurred In**	**MPSHRe Revision & Associated LEC[8a]**	**Comment[s]**
pentafluoroethane, C2HF5 HFC-125 Chemours FE-15	2003-2004	3, 17.6 %v/v 47.4 %m/m	➢ LEC > CPIC[8b]
iodotrifluoromethane, CF3I FIC-13I1 Ajay-SQM Group Triodide	2003-2004, 2006, 2019, 2021-2022	3 & 4, 7.1 %v/v 33.8 %m/m	➢ LEC ≈ CPIC ➢ atypical flame attachment ➢ defeated “version-2 cold” testing[8c]
2-bromotrifluoropropene, C3H2BrF3 Halotron BrX	2004	3, none	➢ withdrawn before completion ➢ enhanced combustion, generated audible cues...
dodecafluoro-2-methylpentan-3-one, C6F12O FK-5-1-12 3M Novec 1230	2006, 2011	3, 6.1 %v/v 42.8 %m/m	➢ LEC < CPIC; **ABNORMAL**; future action will spawn review ➢ atypical flame attachment ➢ failed “version-1 cold” testing[8c]
sodium bicarbonate aerosol, NaHCO3 Collins Aerospace/Kidde Aerospace KSA	2007-2008, 2010-2012, 2018-?	3 & 4, ? g/m^3 ? %m/m	➢ work continues...
equal-mass blend, CO2 & C6F12O Parker-Meggitt Blend A	2014-2015	4, 30.6 %v/v 54.2 %m/m	➢ blended composition requires added situational attention in the end-use...

[8a] LEC = *Largest Equivalent Concentration* from the MPSHRe testing. See Appendices A1 & A2 for mass concentration calculations included in this column.
[8b] CPIC = *Candidate’s Peak-Inertion Concentration*. Recall, 6%v/v CF3Br is comparable to its peak-inertion concentration.
[8c] See Appendix B for high-level detail differentiating the 2 “cold” testing projects.

Additional Background References

A. “Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments (MPSHRe rev04)”.

>>> FAA Fire Safety Website’s International Aircraft Systems Fire Protection Forum webpages

https://www.fire.tc.faa.gov/pdf/systems/MPSErev04_MPSeRev04doc-02submtd.pdf

B. “Engine Nacelle Halon Replacement”, 26oct2006.

>>> International Aircraft Systems Fire Protection Working Group meeting

https://www.fire.tc.faa.gov/pdf/systems/Oct06Meeting/Ingerson-1006-HalonReplacement.pdf

C. “Halon Replacement in the Civil Transport Aircraft Engine Nacelle (2013)”, 5dec2013.

>>> Fifth Triennial International Fire & Cabin Safety Research Conference

https://www.fire.tc.faa.gov/2013Conference/files/Halon_Replacement_I/IngersonEngineHalonReplacement/IngersonHalonreplacementenginePres.pdf

D. “Engine Nacelle, Halon Replacement Overview & Update”, 31oct2018.

>>> International Aircraft Systems Fire Protection Forum meeting

https://www.fire.tc.faa.gov/pdf/systems/Oct18Meeting/Ingerson-1018-PwrplantHalRepOvrview.pdf

E. “Investigating Powerplant Halon Replacement in a Generic Nacelle Fire Simulator”, 18oct2022.

>>> The Tenth Triennial International Fire & Cabin Safety Research Conference

https://www.fire.tc.faa.gov/2022Conference/files/Powerplant_Propulsion_Fire_Protection_I/IngersonGenericNacelle/Ingerson_GenericNacelle_Pres.pdf

The End,

Thank You, &

Good day.

Appendices

- ❑ Appendix A1 ~ mass concentrations, pure gaseous
- ❑ Appendix A2 ~ mass concentrations, blended gaseous
- ❑ Appendix B ~ versions of “cold” testing...

Appendix A1 ~ mass concentrations, pure gaseous

...variables...

Y = volume fraction [volume concentration/100]
V = volume
T = temperature of the system
P = total pressure of the system
R = ideal gas constant
D = density
m = mass
X = mass fraction

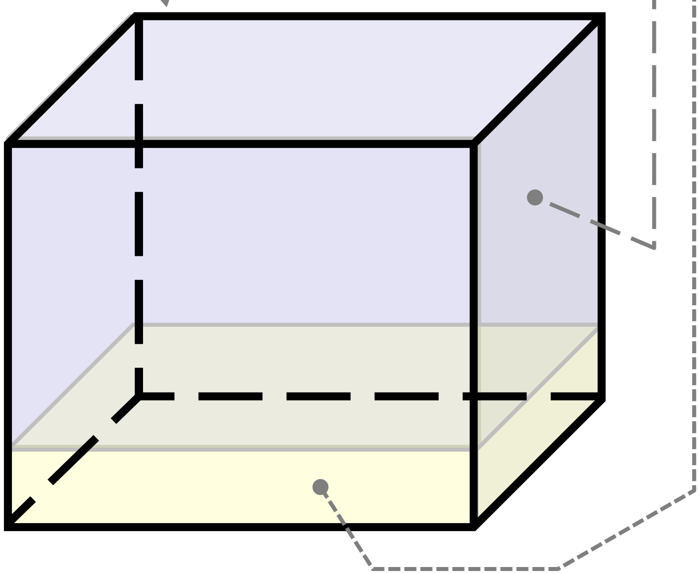
...subscripts...

T = total
A = air
FA = fire-extinguishing agent
FAv = fire-extinguishing agent vapor

System of V_T at T & P with Y_{FA} & balance is air...
...utilizing partial volumes

P = 1 atm, 101.3 kPa
T = 77°C, 25°C, 298.15 K

$$V_T = V_A + V_{FA} = \{ [1 - Y_{FA}] * V_T \} + \{ Y_{FA} * V_T \}$$



Given a system of V_T at T & P with Y_{FA}, & balance is air...

$$m_A = P * \{ V_T * [1 - Y_{FA}] \} / [R_A * T]$$
$$m_{FA} = V_T * Y_{FA} * D_{FAv}$$
$$X_{FA} = m_{FA} / [m_{FA} + m_A]$$

$$D_{FAv}\ [kg/m^3] = 1 / [a + b * T[°C]]$$

firex agent : a, b
CF3Br[12a] : 0.14781, 0.000567
C2HF5[12b] : 0.1826, 0.0007
CF3I[12b] : 0.1138, 0.0005
C6F12O[12b] : 0.0664, 0.0002741

Given : P=101.3 kPa, T=298.15 K, V=1 m^3, R_A= 0.287 kJ / [kg K]

frx agent	volume concentration	Y_{FA}	D_{FAv} [kg/m^3]	m_{FA} [kg]	m_A [kg]	mass concentration
CF3Br	6.0	0.060	6.17	0.370	1.11	25.0
C2HF5	17.6	0.176	5.00	0.880	0.976	47.4
CF3I	7.1	0.071	7.92	0.562	1.10	33.8
C6F12O	6.1	0.061	13.6	0.830	1.11	42.8

[12a] National Fire Protection Association, 1989, “NFPA 12A Standard on Halon 1301 Fire Extinguishing Systems 1989 Edition“, Quincy, MA; table 2-5.2, pg. 12A-18.
[12b] National Fire Protection Association, 2008, “NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems 2008 Edition”, Quincy, MA; Appendix A, tables A.5.5.1.

Appendix A2 ~ mass concentrations, blended gaseous

...variables...

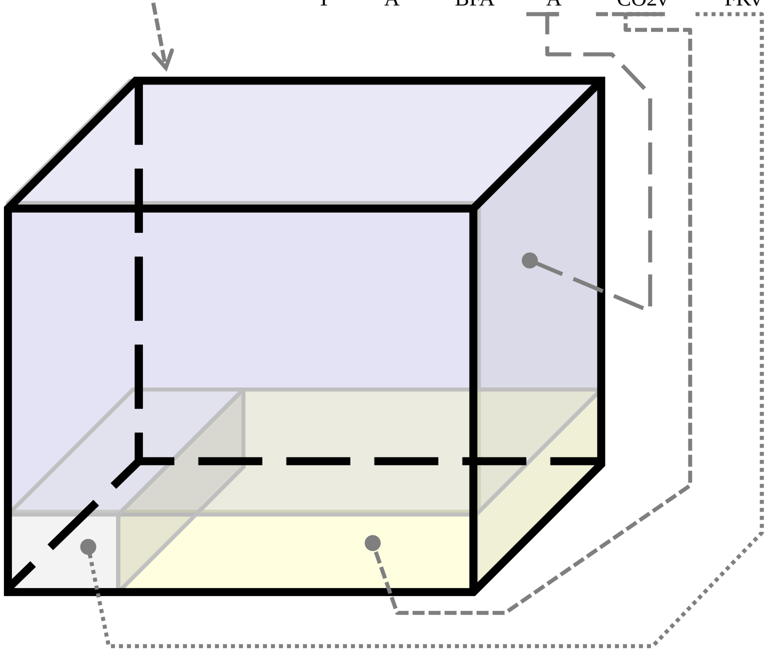
Y = volume fraction [volume concentration/100]
V = volume
T = temperature of the system
P = total pressure of the system
R = ideal gas constant
D = density
m = mass
X = mass fraction

...subscripts...

T = total
A = air
BFA = Blend-A fire-extinguishing agent
FK, FKv = C6H12O, C6H12O vapor
CO2, CO2v = carbon dioxide, CO2 vapor

System of V_T at T & P with Y_{BFA} & balance is air...
...utilizing partial volumes

P = 1 atm, 101.3 kPa
T = 77°C, 25°C, 298.15 K
$V_T = V_A + V_{BFA} = V_A + V_{CO2v} + V_{FKv}$



Given a system of V_T at T & P with Y_{BFA} & balance is air...

$m_A = P * \{ V_T * [1 - Y_{BFA}] \} / [R_A * T]$

for Blend A, $m_{CO2} = m_{FK}$ & all is vaporous

$V_{BFA} = V_T * Y_{BFA} = V_{CO2v} + V_{FKv} = V_{CO2} + V_{FK}$

... V * D = m

$= m_{CO2} / D_{CO2} + m_{FK} / D_{FK}$

... $m_{CO2} = m_{FK}$

$= m_{CO2} * [1 / D_{CO2} + 1 / D_{FK}]$

$m_{CO2} = m_{FK} = V_{BFA} / [1 / D_{CO2} + 1 / D_{FK}]$

$X_{BFA} = [m_{CO2} + m_{FK}] / [m_{CO2} + m_{FK} + m_A]$

D_{FKv} [kg/m^3] = 1 / [a + b * T[°C]]
firex agent [reference] : a, b
C6F12O[12b] : 0.0664, 0.0002741

D_{CO2v} [kg/m^3] $= m_{CO2} / V_{CO2} = P / [R_{CO2} * T]$
...via Ideal Gas Law, PV = mRT; m/V = P / [R * T]]
R_{CO2} = 0.18892 kJ / [kg K]

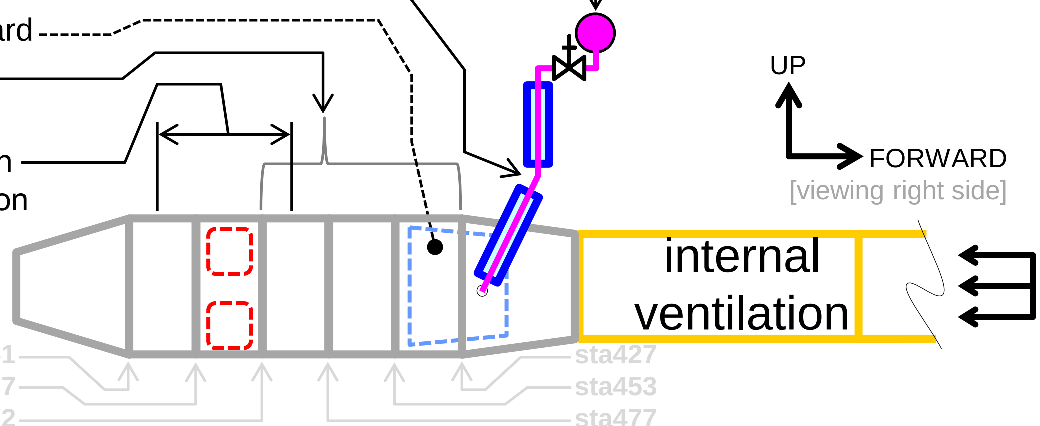
Given : P=101.3 kPa, T=298.15 K, V=1 m^3, R_A= 0.287 kJ / [kg K]

frx agent	volume concentration	Y_{FA}	D_{FAv} [kg/m^3]	m [kg]	m_A [kg]	mass concentration
Blend A	30.6	0.306	3.18	0.973	0.822	54.2
C6F12O	3.56	0.0356	13.6	0.486	0.822	27.1
CO2	27.0	0.270	1.80	0.486	0.822	27.1

[12b] National Fire Protection Association, 2008, “NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems 2008 Edition”, Quincy, MA; Appendix A, tables A.5.5.1.

Appendix B ~ versions of “cold” testing...

- fire extinguisher [firex] bottle & contents
- firex agent injection plumbing network
- firex agent injection, within cross-sectional plane or forward
- portion of the Generic Nacelle Fire Simulator’s [gNFS’s] exterior shell boundary chilled for the “cold” testing
- “protected” volume, the longitudinal annular volume within the gNFS sampled to define the firex agent’s concentration field during the “cold” testing



NOTES :
1. This is a schematic elevation view. Not drawn to scale.
2. Station (sta) numbers are incremented as inches.
3. Many details omitted for clarity.

“cold” test version	**“Protected” Volume Gas-Concentration Sampling Configuration**
1 C6F12O [march-april2011]	MPSHRe/rev04, 12 sample points, sta490 to sta514
2 CF3I [jun-aug & sep-oct2022]	analogous to FAA AC 20-100[14a], 12 sample points, sta502 to sta535

“cold” test version	**1** [march-april2011]	**2** [jun-aug & sep-oct2022]	**1** [march-april2011]	**2** [jun-aug & sep-oct2022]
test phase	conditions to establish the concentration field		conditions for the fire extinguishment test	
Various Aspects of the Test Environment	**Thermal States of Various Aspects of the Test Environment[14b]**			
internal ventilation	MPSHRe/rev04, “high-vent”	“mod-low” & “mod-high”, each at ambient	“mod-high” & ambient	“mod-low” & “mod-high”, each at ambient
firex bottle & contents	MPSHRe/rev04, ≈ +100°F/38°C	approximately -65°F/-54°C	approximately -65°F/-54°C	approximately -65°F/-54°C
firex injection plumbing network	ambient	ambient	ambient	“chilled” along parts of plumbing lengths
gNFS shell	ambient	ambient	“colder_cool”	“colder_cool”

[14a] FAA AC 20-100 : Advisory Circular 20-100, 1977, "General Guidelines for Measuring Fire-Extinguishing Agent Concentrations in Powerplant Compartments”, United States Department of Transportation, Federal Aviation Administration, Washington, D.C.
[14b] “colder_cool” indicates thermal gradient from 12:00/”colder” to 06:00/”cool”; “colder”≈ -94°F/-70°C, “cool”≈ +59°F/+15°C; measured “chilled” temperatures -80°C to +25°C