Halon 1211 Stratification/Localization in Small 4-Seater Aircraft

Louise Speitel

Fire Safety Branch
FAA Wm. J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

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Background

- Per AC20-42D - Halon 1211, Halotron, and BTP are unsafe for use in flight decks and other small volumes.

- AC 20-42D, Chapter 4.4b(3), (4) states that concentrations may be adjusted to account for agent localization/stratification...a report will be published at the FAA Technical Center with method to adjust safe-use concentrations.

- B-737 flight deck stratification/localization data for discharges of 2.5 lb Halon 1211 extinguishers was presented at the May 2012 Systems Meeting along with multiplication factors.

- These test-based multiplication factors ($MF_{\text{Stratification-Localization}}$) can be applied to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization: B-737 flight decks and cabin.
Comparison of Minimum Safe Volumes for 2.5 lb Halon 1211

- Minimum Safe Volume per AC20-42C (Ft³)
- Minimum Safe Volume per AC20-42D (Ft³)

Halon 1211 Stratification in Small Aircraft
Minimum Safe Compartment Volume for One Extinguisher in Unventilated Compartments *(from AC 20-42D)*

<table>
<thead>
<tr>
<th>Agent</th>
<th>Agent Weight(^a) (lbs)</th>
<th>Minimum Safe Volume for One 5 B:C Extinguisher ((ft^3))</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Sea Level (info only)</strong></td>
<td><strong>Pressurized Aircraft 8,000 ft CPA</strong></td>
<td><strong>Non-Pressurized Aircraft</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12,500 ft</td>
<td>14,000 ft</td>
<td>18,000 ft</td>
<td>25,000 ft</td>
</tr>
<tr>
<td>HCFC Blend B(^b)</td>
<td>5.5</td>
<td>1102</td>
<td>1482</td>
<td>1768</td>
<td>1877</td>
<td>2209</td>
</tr>
<tr>
<td>HFC-227ea(^b)</td>
<td>5.75</td>
<td>104</td>
<td>141</td>
<td>167</td>
<td>177</td>
<td>209</td>
</tr>
<tr>
<td>HFC-236fa(^b)</td>
<td>4.75</td>
<td>79.8</td>
<td>107</td>
<td>128</td>
<td>136</td>
<td>159</td>
</tr>
<tr>
<td>Halon 1211(^c)</td>
<td>2.5</td>
<td>1116</td>
<td>1502</td>
<td>1790</td>
<td>1908</td>
<td>2232</td>
</tr>
<tr>
<td><strong>Halon 1211(^d,e)</strong></td>
<td><strong>2.5</strong></td>
<td><strong>558</strong></td>
<td><strong>751</strong></td>
<td><strong>895</strong></td>
<td><strong>954</strong></td>
<td><strong>1116</strong></td>
</tr>
<tr>
<td>Halon 1301(^b)</td>
<td>5.0</td>
<td>192</td>
<td>258</td>
<td>308</td>
<td>327</td>
<td>385</td>
</tr>
</tbody>
</table>

\(^a\) Agent weight for a 5B:C extinguisher is extinguisher dependent. Nozzle design, pressurization differences and other factors can result in different agent weights for extinguishers using the same agent. The tabulated minimum safe volumes should be corrected for the actual agent weight if different from the agent weight in this figure.

\(^b\) Values based on the safe human concentration. See reference report appendix 3, paragraph 7.m. of AC20-42D

\(^c\) Values are based on the Halon 1211 NOAEL concentration of 0.5% \((v/v)\)

\(^d\) Values are based on the Halon 1211 LOAEL concentration of 1.0% \((v/v)\).

\(^e\) Safe human concentrations are not available for Halon 1211 using the same criteria as for other agents. However, the Halon 1211 LOAEL concentration of 1% \((v/v)\) has been shown to be safe for humans. See report mentioned in note \(^b\) above. Also, the safety factor is smaller than that set for other agents.
## Multiplication Factors (MF\textsubscript{Ventilated}) for Ventilated Compartments \textit{(from AC 20-42D)}

<table>
<thead>
<tr>
<th>Agent</th>
<th>Air Change Time, $\tau$ (minutes)</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>3.0</th>
<th>4.0</th>
<th>5.0</th>
<th>6.0</th>
<th>$&gt;6^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCFC Blend B</td>
<td></td>
<td>2.80</td>
<td>2.33</td>
<td>2.14</td>
<td>2.02</td>
<td>1.89</td>
<td>1.79</td>
<td>1.70</td>
<td>1.62</td>
<td>1</td>
</tr>
<tr>
<td>Halon 1211 $^b$</td>
<td></td>
<td>1.96</td>
<td>1.57</td>
<td>1.42</td>
<td>1.34</td>
<td>1.25</td>
<td>1.21</td>
<td>1.17</td>
<td>1.15</td>
<td>1</td>
</tr>
<tr>
<td>HFC-227ea $^c$</td>
<td></td>
<td>1.90</td>
<td>1.53</td>
<td>1.39</td>
<td>1.32</td>
<td>1.24</td>
<td>1.19</td>
<td>1.16</td>
<td>1.14</td>
<td>1</td>
</tr>
<tr>
<td>HFC-236fa $^c$</td>
<td></td>
<td>1.98</td>
<td>1.58</td>
<td>1.42</td>
<td>1.34</td>
<td>1.25</td>
<td>1.20</td>
<td>1.17</td>
<td>1.15</td>
<td>1</td>
</tr>
<tr>
<td>Halon 1301 $^c$</td>
<td></td>
<td>1.96</td>
<td>1.57</td>
<td>1.42</td>
<td>1.34</td>
<td>1.25</td>
<td>1.21</td>
<td>1.17</td>
<td>1.15</td>
<td>1</td>
</tr>
</tbody>
</table>

- $^a$ No MF\textsubscript{Ventilated} is applied if air change time is greater than 6 minutes.
- $^b$ Lower MF\textsubscript{Ventilated} than actual. Based on Halon 1301 MF\textsubscript{Ventilated}.
- $^c$ Multiplication factors are similar for all non-chlorinated halocarbons.

**Cessna 210C ventilation with overhead vents open:** $\tau = 1.16$ min
Objective

- Retrospective study of 1984 FAA stratification/localization data for Halon 1211 hand extinguishers discharged in a small 4-seater Cessna Model 210C aircraft in a wind tunnel with an airspeed of 120 mph.

- Develop test-based multiplication factors ($MF_{Stratification-Localization}$) for that particular small aircraft to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization.

- These $MF_{Stratification\ & \ Localization}$ will be a multiplier for the maximum agent $W/V$ in AC 20-42D, after $MF_{Ventilation}$ is applied.
Method

• Use concentration histories from existing report:

• Compute arterial concentration histories using FAA’s Simplified Kinetic Model and Halon 1301 kinetics.

• Stratification/localization Multiplication factors (MF) will be based on maximum computed human arterial blood concentrations, $B_{\text{Max}}$.
  Compare $B_{\text{Max}}$ for theoretical perfect mixing (ventilated) to test (ventilated) $B_{\text{Max}}$.

\[
\text{MF}_{\text{Stratification & Localization}} = \frac{B_{\text{Max}} \left(\text{Ventilated} - \text{Perfect Mixing}\right)}{B_{\text{Max}} \left(\text{Ventilated} - \text{Stratification} - \text{Localization}\right)}
\]

• This MF will be a multiplier for the maximum agent W/V in AC 20-42D, after MF Ventilation is applied.
Simplified Kinetic Model

Simulates human arterial blood concentration histories from inhaled constant or dissipating halocarbon concentrations
Arterial Blood Concentration, B(t)

General equation for changing Halocarbon Concentrations:

\[
B(t) = k_1 \int_0^t A(x)e^{-k_{23}(t-x)} \, dx + \]

\[
k_3 k_4 P_{BA} \int_0^t \left( \int_0^t A(x)e^{-k_4(t-x)} \, dx \right) e^{-k_{23}(t-y)} \, dy
\]

From:


1st Order Kinetic Modeling of Halon 1301 in Ventilated Compartments

Ratio of the Arterial Blood Concentration of Halon 1301 to the Target Value $B_{\text{safe}}$ for Simulated Human Exposures to $A_{\text{safe}}$ in a Ventilated Cabin at the Indicated Air Exchange Times
Tests

• 2 Discharge locations: Under instrument panel & at copilot’s seat

• Discharge 1 circa 2.5 lb Halon 1211 hand extinguisher at selected targets in each compartment.

• 3 ventilation conditions at 120 mph air speed
  - Overhead vents open, Air change time, $\tau = 1.16$ minutes
  - All vents open
  - All vents closed

• Gases measured at pilot’s nose level and at target position
Determination of Stratification Multiplication Factors: Arterial Blood Concentrations

Perform following steps based on Halon 1301 kinetics and 2.50 lb. Halon 1211 extinguisher charge weight.

• Correct Halon 1211 concentration histories to a 2.5 lb. Halon 1211 discharge basis weight. (2.55 to 3.15 lb. actual)

• Calculate arterial concentration histories for the theoretical and actual discharge assuming Halon 1301 kinetics (& 2.5 lb. basis weight).

• The ratio of the theoretical peak arterial concentration to the peak experimental concentration is the multiplication factor.

• Multiplication factor can be applied to the AC 20-42D ventilation-corrected minimum safe volumes or safe-use W/V concentrations.
Wind Tunnel Profile with Cessna 210

- The aircraft volume is 139.9 ft³
- At 120 mph, the air change time, $\tau = 69.6$ seconds
Target: Under Instrument Panel, Copilot’s Side
Overhead Vents Open, $\tau = 1.16 \text{ min.}$

$\text{MF Stratification & Localization} = 0.81, 2.2$ (Target and Pilot’s Nose Height)

*Data from 1984 Report, Fig 6, Test 4*

*Based on Halon 1301 Kinetics*
Target: Under Instrument Panel, Copilot’s Side
All Vents Open

**Data from 1984 Report, Fig 7, Test 7**

**Based on Halon 1301 Kinetics**

Halon 1211 Stratification in Small Aircraft
Target: Under Instrument Panel, Copilot’s Side
All Vents Closed

Data from 1984 Report, Fig 8, Test 6

Based on Halon 1301 Kinetics
Target: Copilot’s Seat

Overhead Vents Open $\tau = 1.16$ minutes

$\text{MF} \quad \text{Stratification & Localization} = 0.81, 2.1$ (Target and Pilot’s Nose Height)

Data from 1984 Report, Fig 17, Test 17

Based on Halon 1301 Kinetics

Halon 1211 Stratification in Small Aircraft
Target: Copilot’s Seat, All Vents Open

Data from 1984 Report, Fig 19, Test 20

Based on Halon 1301 Kinetics

Halon 1211 Stratification in Small Aircraft
Target: Copilot’s Seat, All Vents Closed

Data from 1984 Report, Fig 20, Test 19

Based on Halon 1301 Kinetics

Halon 1211 Stratification in Small Aircraft
Target: Under Instrument Panel, Copilot’s Side
Comparison of Ventilation Methods
Halon 1211 at Nose Height

Data from 1984 Report, Fig 6, 7, and 8
Based on Halon 1301 Kinetics
Target: Copilot’s Seat
Comparison of Ventilation Methods
Halon 1211 at Nose Height

Data from 1984 Report, Fig 17, 19, and 20

Based on Halon 1301 Kinetics

Halon 1211 Stratification in Small Aircraft
Target: Under Instrument Panel, Copilot’s Side
Comparison of Ventilation Methods:
Peak Arterial Concentrations

21.3 mg/L = Safe-Use Halon 1211 Arterial Concentration

Based on data from 1984 report, Fig 6, 7, and 8
Target: Copilot’s Seat
Comparison of Ventilation Methods
Peak Arterial Concentrations

21.3 mg/L = Safe-Use Halon 1211 Arterial Concentration

![Bar graph showing peak arterial concentrations for Halon 1211 in different ventilation conditions.]

Based on data from 1984 report, Fig 17, 19, and 20
Cabin Tests: Stratification/ Localization MFs
Pilots Nose Level, Overhead Vents Open, , $\tau = 1.16$ min.
*Based on Halon 1301 Kinetics*

![Graph showing stratification/localization MFs](image-url)
Conclusions

- Stratification is significant for the Cessna 210C, resulting in lower than theoretical perfect mixing Halon 1211 concentrations at the pilot’s nose level:

- Stratification & Localization MFs greater than one were attained at the pilot’s nose level for discharges under the copilot’s instrument panel and the copilot’s seat: 2.2 and 2.1 respectively.

- Multiplication factors for stratification/ localization were determined by test to allow safe use of higher charge weights of extinguishant. Calculations were based on Halon 1301 kinetics.