Halon 1211 Stratification/ Localization in Aircraft

Louise Speitel

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

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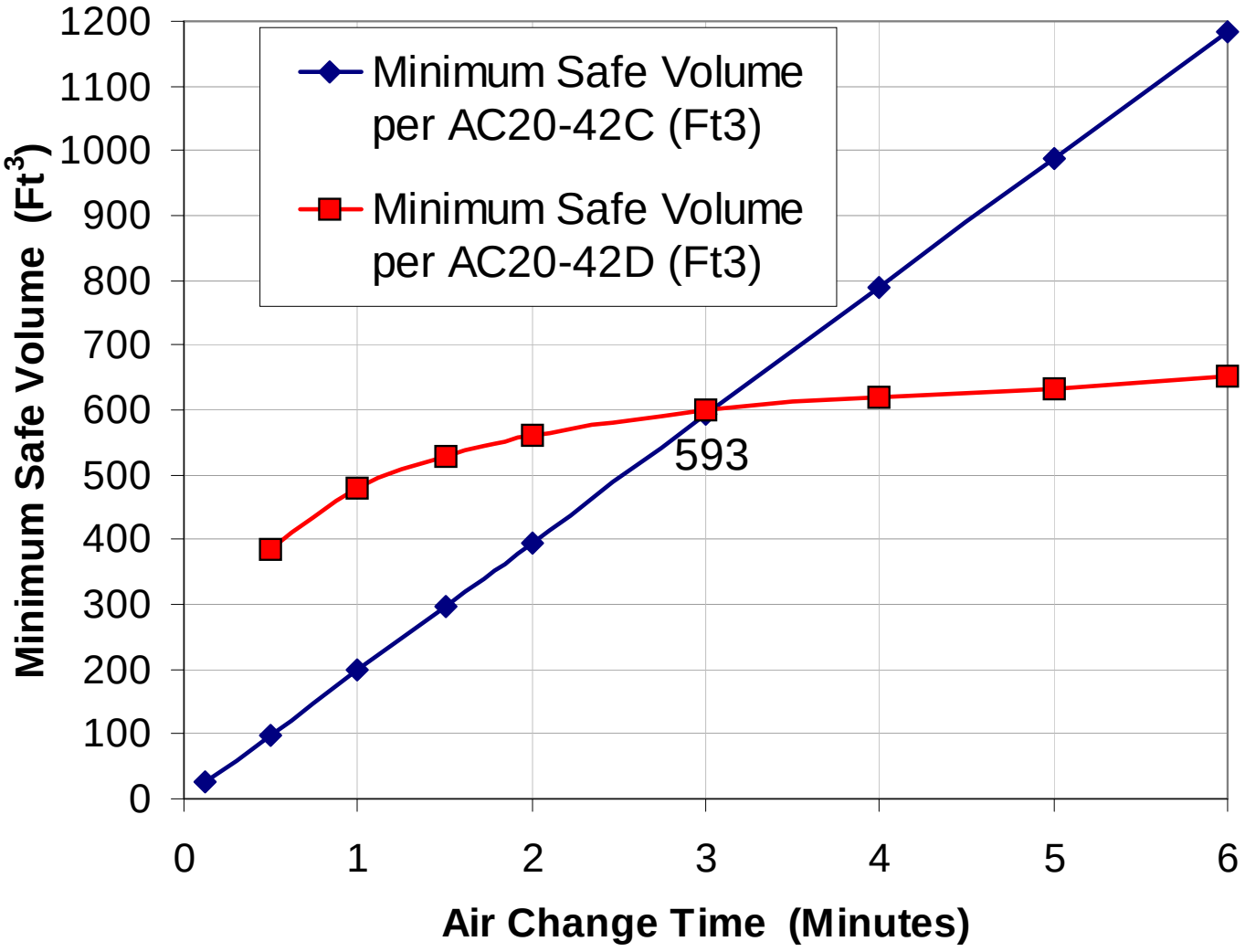
Background

Per AC20-42D - Halon 1211, Halotron 1, and BTP are unsafe for use in Boeing airplane 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.

Comparison of Minimum Safe Volumes for 2.5 lb Halon 1211



Minimum Safe Compartment Volume for One Extinguisher in Unventilated Compartments *(from AC 20-42D)*

Agent	Agent Weight[a] (lbs)	Minimum Safe Volume for One 5 B:C Extinguisher (ft^3)					
		Sea Level (info only)	Pressurized Aircraft 8,000 ft CPA	Non-Pressurized Aircraft			
				12,500 ft	14,000 ft	18,000 ft	25,000 ft
HCFC Blend B[b]	5.5	1102	1482	1768	1877	2209	2973
HFC-227ea[b]	5.75	104	141	167	177	209	280
HFC-236fa[b]	4.75	79.8	107	128	136	159	214
Halon 1211[c]	2.5	1116	1502	1790	1908	2232	3016
Halon 1211[d,e]	2.5	558	751	895	954	1116	1508
Halon 1301[b]	5.0	192	258	308	327	385	517

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 this AC.

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 ($MF_{Ventilated}$) for Ventilated Compartments *(from AC 20-42D)*

Agent	Air Change Time, τ (minutes)								
	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	>6[a]
HCFC Blend B	2.80	2.33	2.14	2.02	1.89	1.79	1.70	1.62	1
HFC-227ea	1.90	1.53	1.39	1.32	1.24	1.19	1.16	1.14	1
HFC-236fa	1.98	1.58	1.42	1.34	1.25	1.20	1.17	1.15	1
Halon 1211 [b]	**1.96**	**1.57**	**1.42**	**1.34**	**1.25**	**1.21**	**1.17**	**1.15**	**1**
Halon 1301	1.96	1.57	1.42	1.34	1.25	1.21	1.17	1.15	1

a No $MF_{Ventilated}$ is applied if air change time is greater than 6 minutes.

b More conservative $MF_{Ventilated}$ than actual. Based on Halon 1301 $MF_{Ventilated}$.

Goal

- Develop test- based multiplication factors to allow higher concentrations than AC 20-42D guidance provides :

  - Small aircraft
  - Flight decks
  - Large cabins

- Tests evaluate stratification/ localization of Halon 1211 discharged from one extinguisher.
- Determine multiplication factors based on equivalent safety for that test ventilation rate.

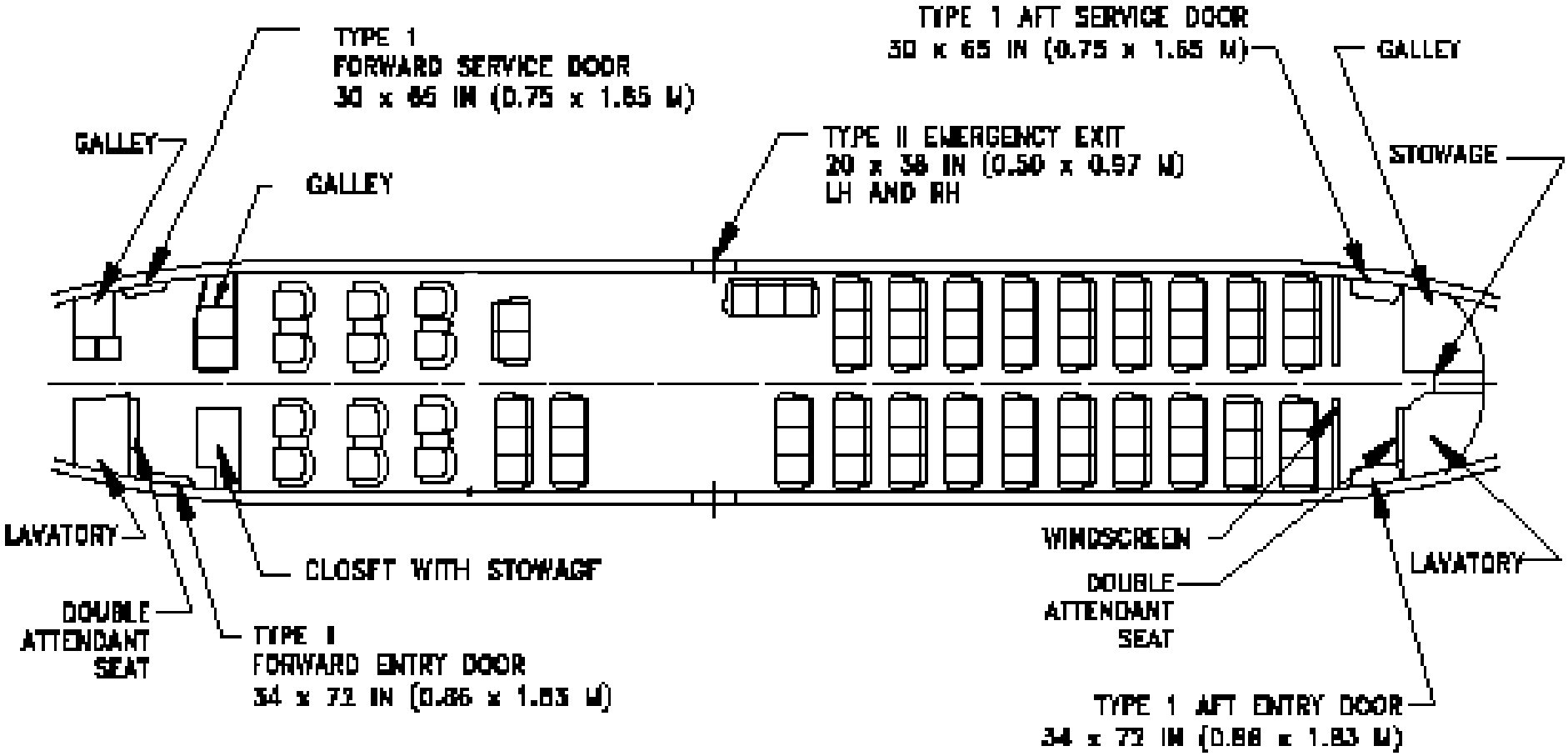
Method

- Small aircraft: Use concentration histories from existing reports.
- Flight decks: B 737 Tests
- Large cabins: B 737 Tests
- Multiplication factors (MF) will be based on maximum computed human arterial blood concentrations, B: Compare maximum B for perfect mixing (ventilated) to test (ventilated) maximum B.
- This MF will be a multiplier for the maximum agent W/V in AC 20-42D.

$$MF(Stratification\ \&\ Localization) = \frac{B_{Max}(Ventilated - PerfectMixing)}{B_{Max}(Ventilated - Stratification - Localization)}$$


B-737 Test Article

B 737 Test Article



B 737 Test Article

- The passenger cabin is 630” long x 137” wide (52.5 ft x 11.4ft)

- Total Cabin Volume = Front Galley + Passenger Seating Area + Rear Galley
  = 315 ft^3 + 3489 ft^3 + 323 ft3
  = 4127 ft^3

- The cabin volume includes the front and rear galleys and the passenger seating area.

- The seats, overhead storage and other enclosed areas were subtracted out.

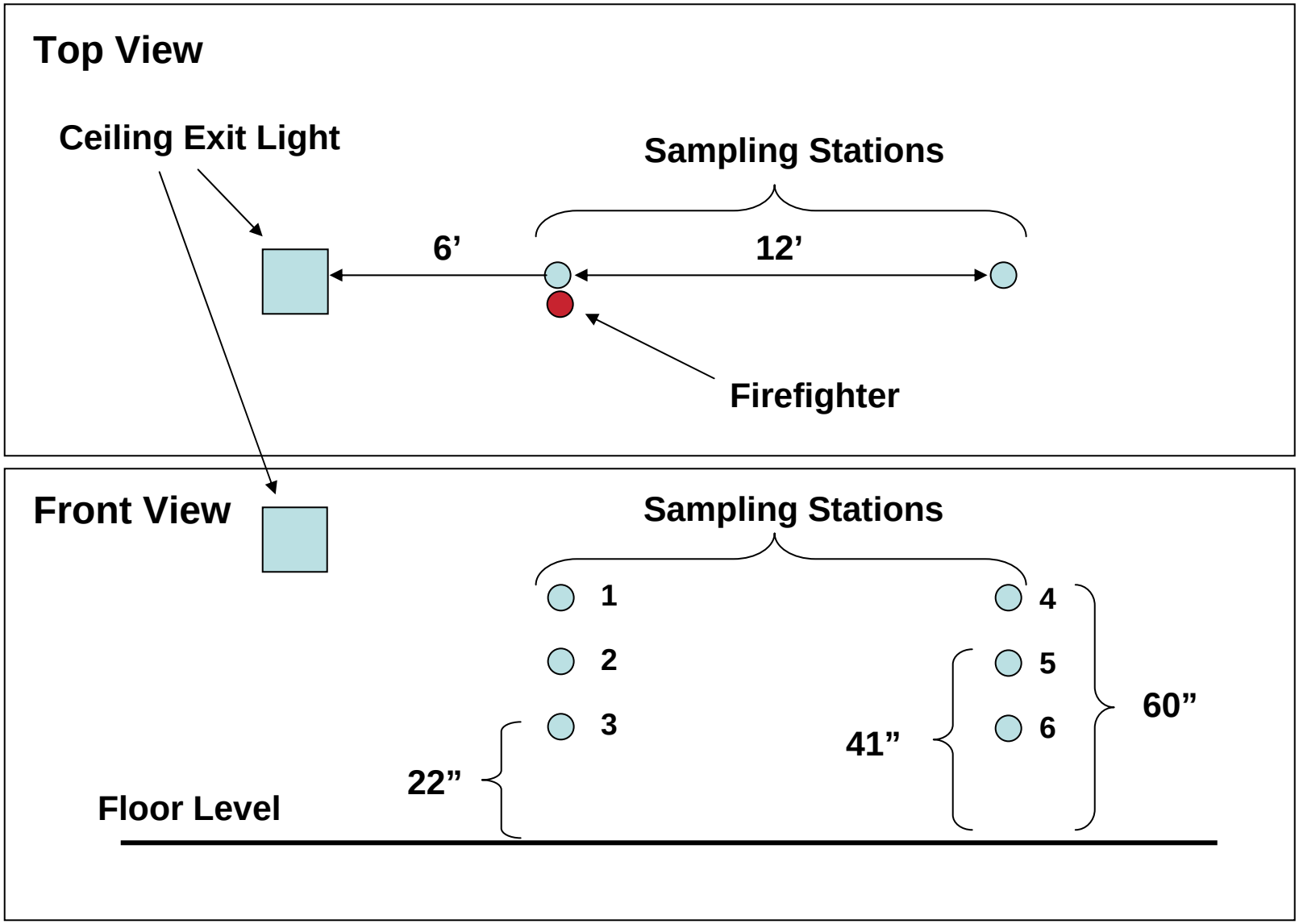
- The flight deck volume is 129 ft^3

- The firefighter volume is 5.7 **ft^3**

Cabin Test Plan:

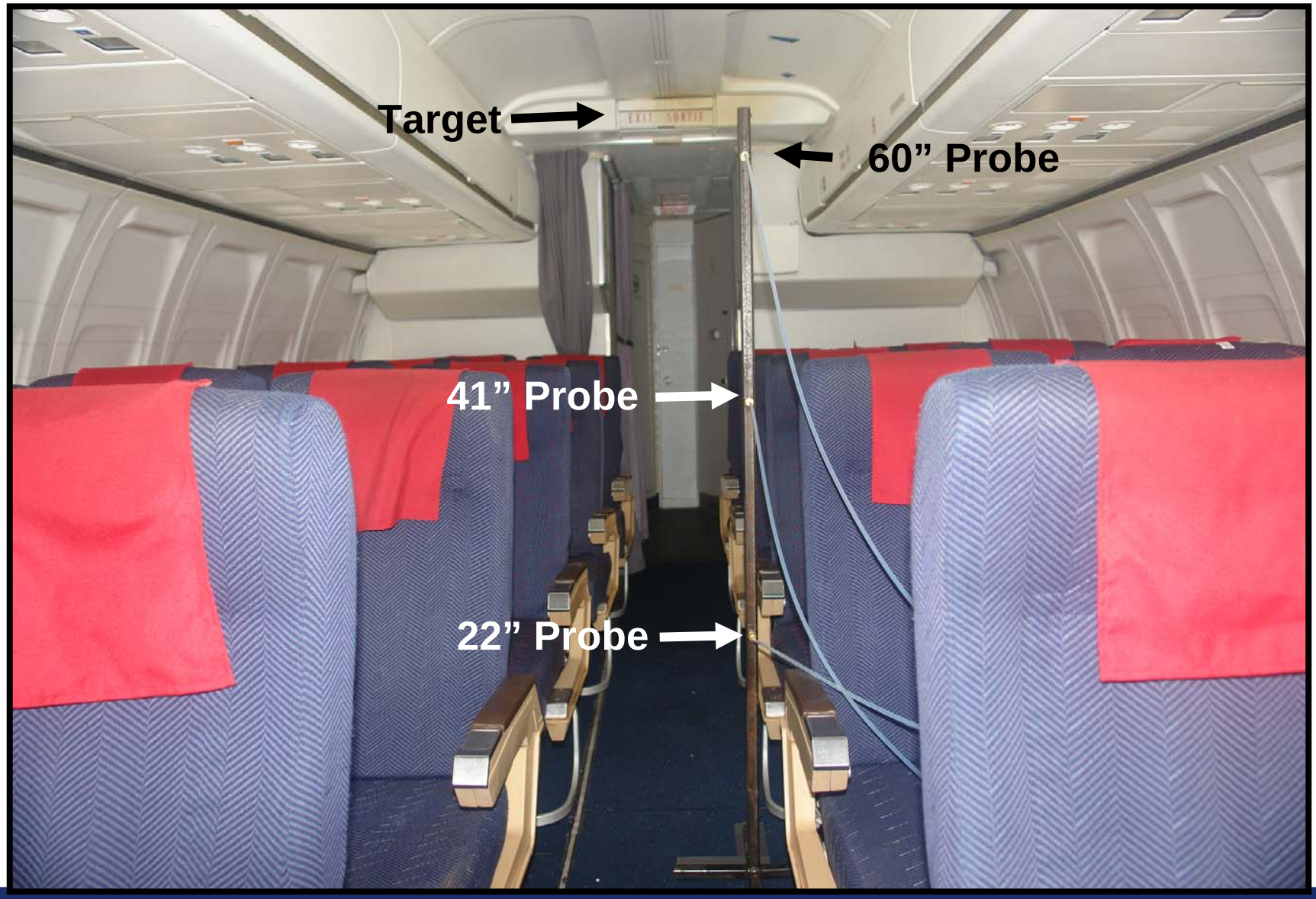
- Discharge one 5 B:C Halon 1211 extinguisher in rear of passenger compartment. Aim at exit light leading to rear galley.
- Sampling stations: 1 Sampling station per discharge test.
  - 6’ horizontally from the target (at firefighter’s position)
  - 18’ Horizontally from the target
  - 3 Heights: 60”, 41” and 22’ (Standing, seated and resting nose height). Extinguisher nozzle is held 6” forward of the sample tree
- Predict maximum arterial concentrations (B_{Max}) for each Halon 1211 discharge test.
- Compare to the maximum arterial concentration that would be obtained if perfect mixing (same compartment, same ventilation).
- Determine multiplication factors for each position

Cabin Test using Luft NDIR Gas Analyzers



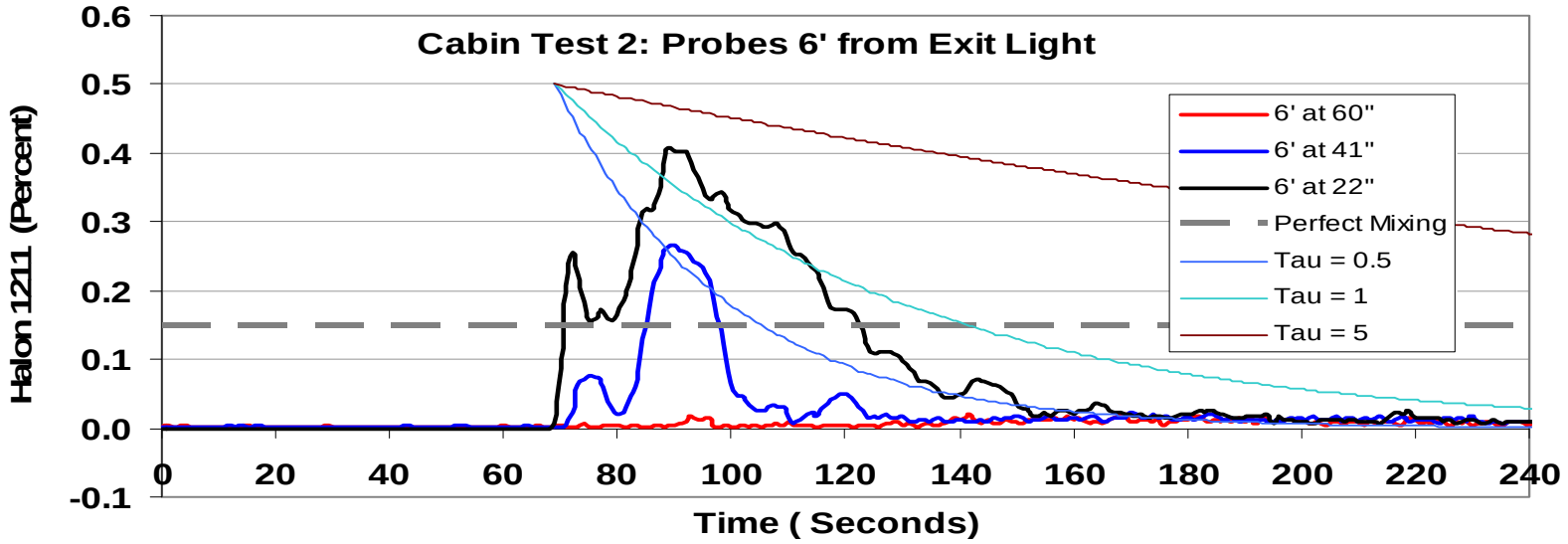
Cabin Test: Target

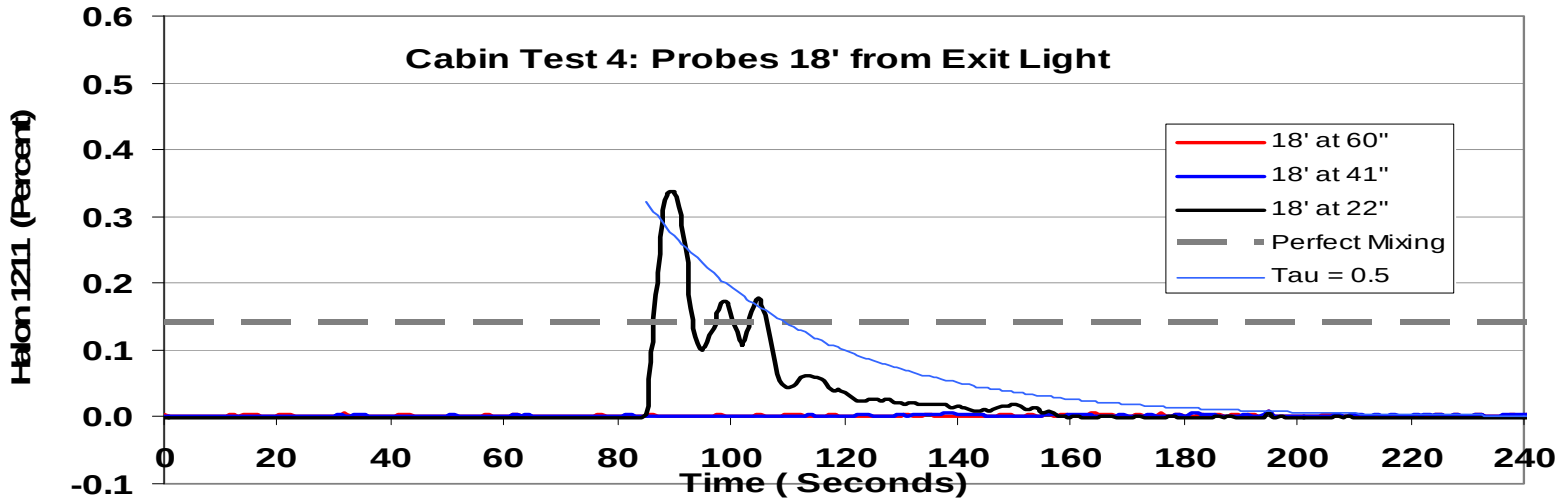
Cabin Test



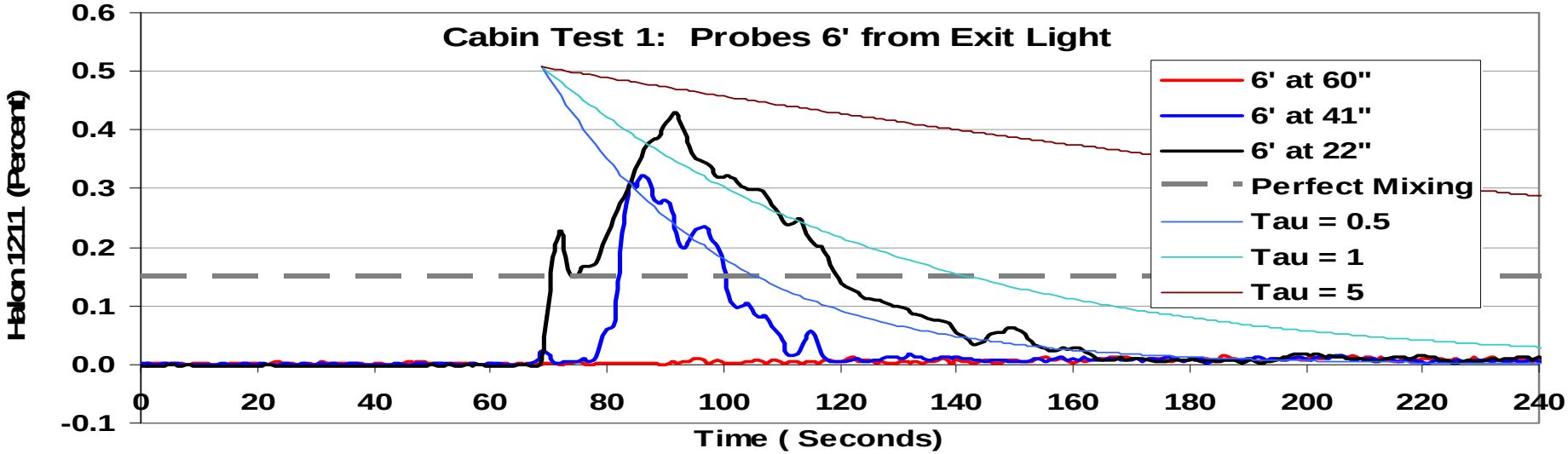
Cabin Test

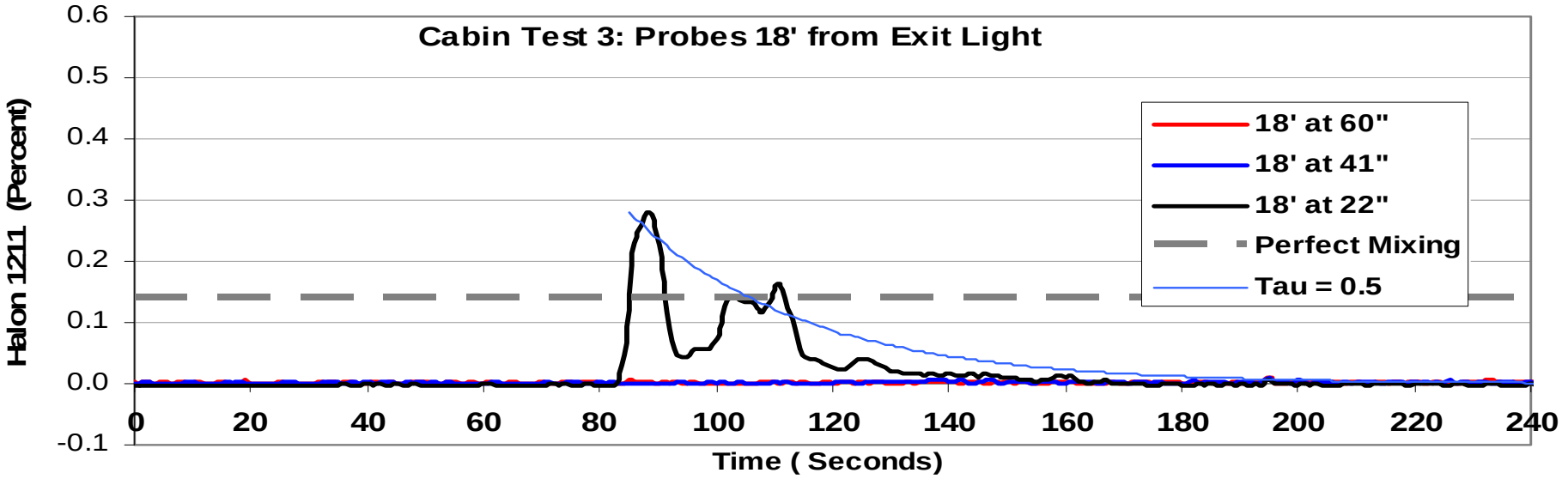
Cabin Test


Cabin Test 2: Probes 6' from Exit Light
Halon 1211 (Percent)
Time (Seconds)
6' at 60"
6' at 41"
6' at 22"
Perfect Mixing
Tau = 0.5
Tau = 1
Tau = 5
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
20
40
60
80
100
120
140
160
180
200
220
240


Cabin Test 4: Probes 18' from Exit Light
Halon 1211 (Percent)
Time (Seconds)
18' at 60"
18' at 41"
18' at 22"
Perfect Mixing
Tau = 0.5
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
20
40
60
80
100
120
140
160
180
200
220
240

Cabin Test


Cabin Test 1: Probes 6' from Exit Light
Halon 1211 (Percent)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (Seconds)
6' at 60"
6' at 41"
6' at 22"
Perfect Mixing
Tau = 0.5
Tau = 1
Tau = 5


Cabin Test 3: Probes 18' from Exit Light
Halon 1211 (Percent)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
20
40
60
80
100
120
140
160
180
200
220
240
Time (Seconds)
18' at 60"
18' at 41"
18' at 22"
Perfect Mixing
Tau = 0.5

B 737 Flight Deck

Flight Deck: Plan:

- Discharge one 5 B:C Halon 1211 extinguisher with side to side sweeping motion.

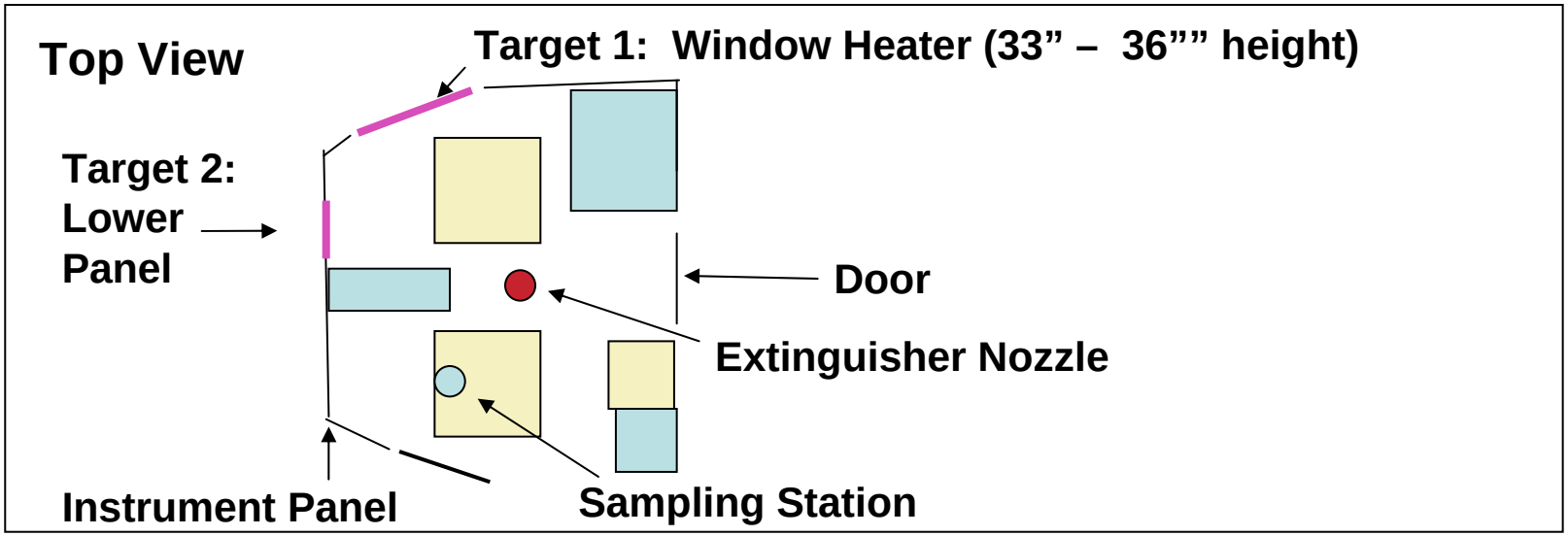
- Firefighter seated in aft port seat behind pilot. Nozzle height= 36”,
  - Scenerio 1: Target: copilot’s window heater.
    Target: 33” to 36” height, width of target=17”. Target is 38” from nozzle.
  - Scenerio 2: Target: copilot’s instrument panel. 17” to 25” off floor, 10” width, Target distance from centerline: 9” to 19”. Target is 42” from nozzle.

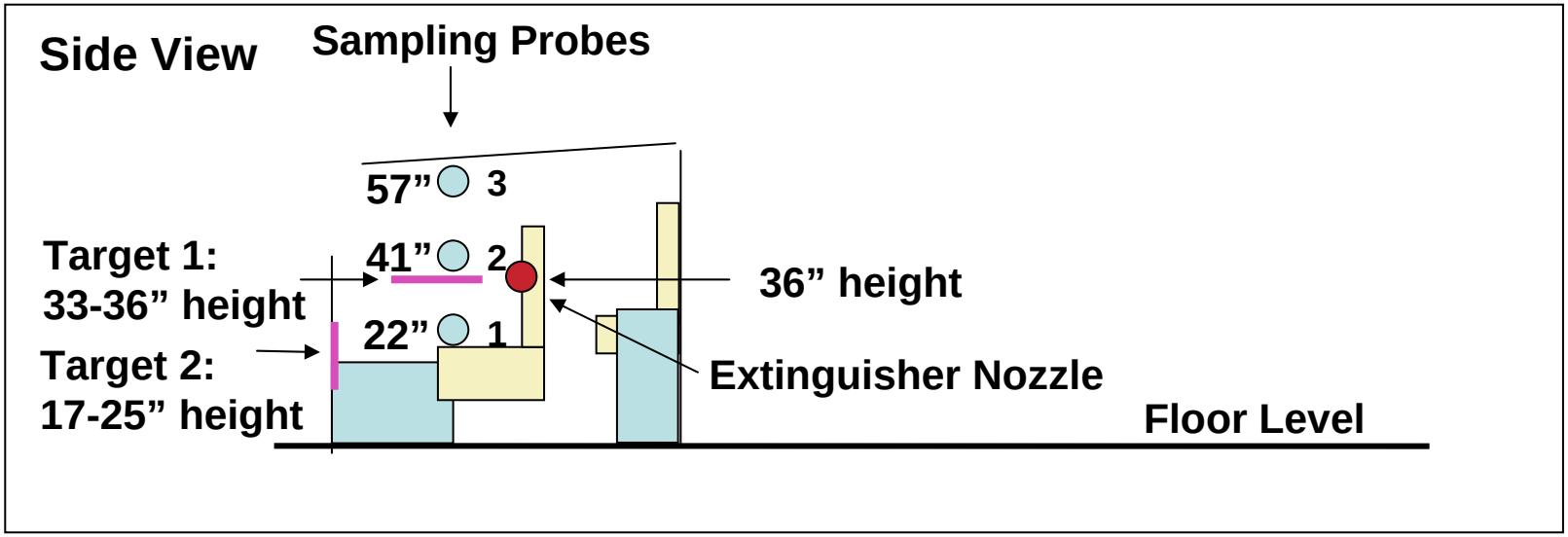
- Sample position: Pilots nose position
  - 3 Heights:
    - 57” Standing
    - 41” Seated
    - 22’ Resting nose height

- Predict maximum arterial concentrations (B_{Max}) for each Halon 1211 discharge test.

$$MF(Stratification\&Localization) = \frac{B_{Max}(Ventilated-PerfectMixing)}{B_{Max}(Ventilated-Stratification-Localization)}$$

Flight Deck Tests using NDIR Gas Analyzers



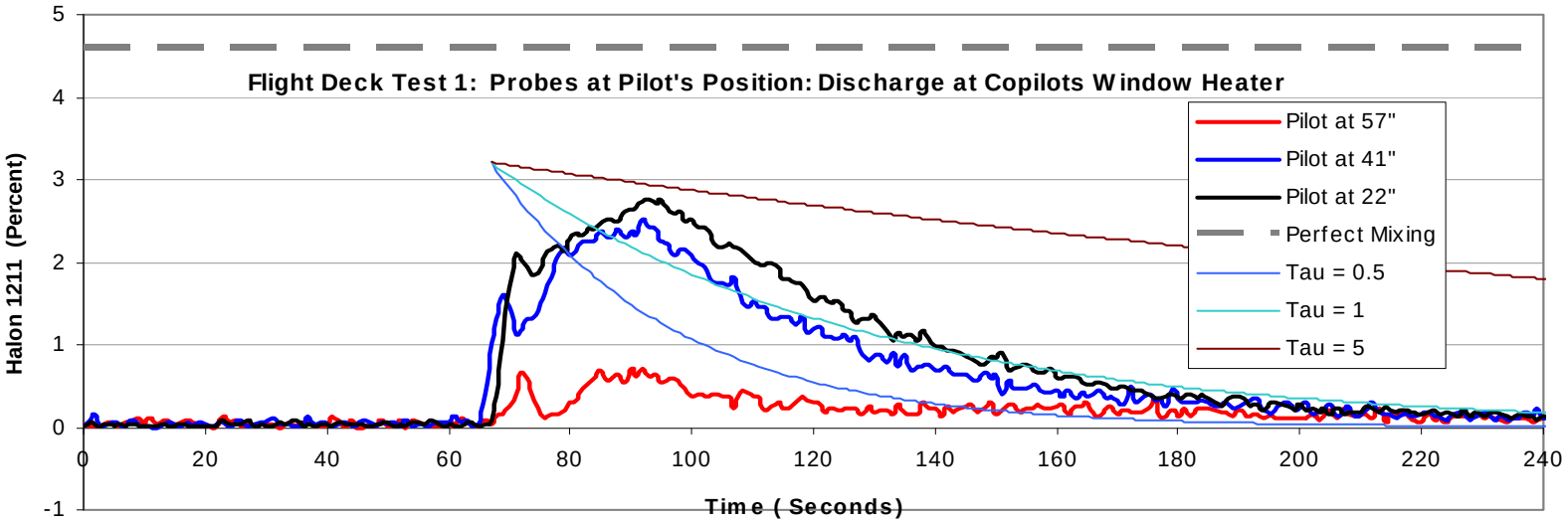


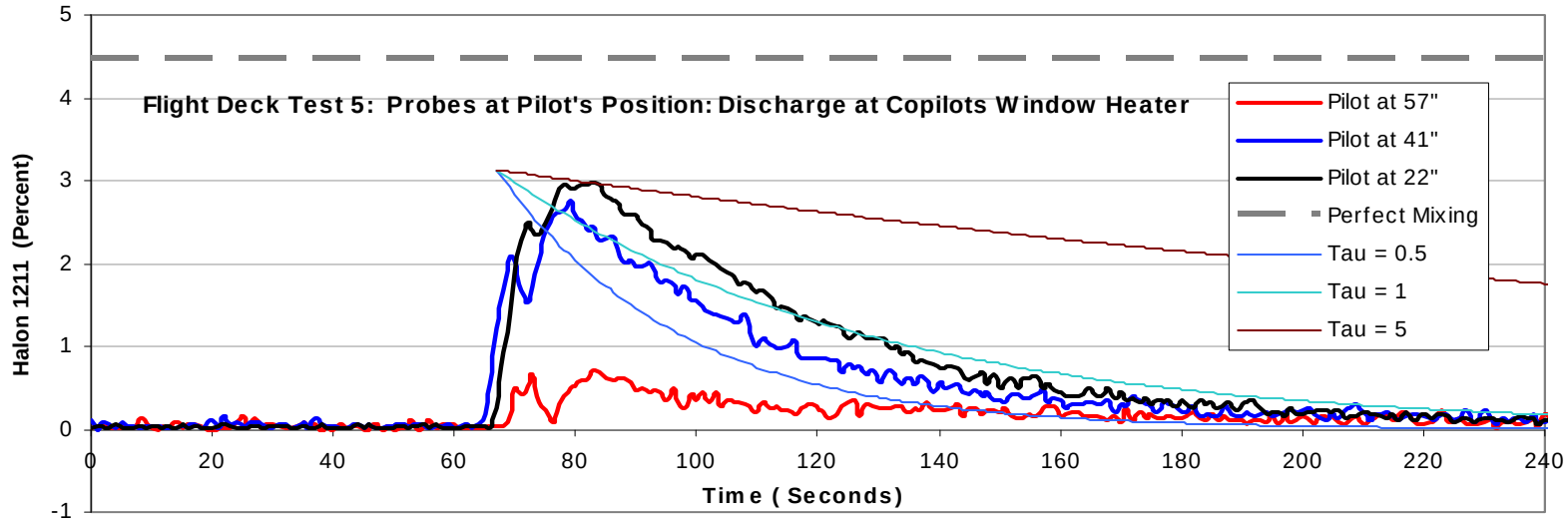
Flight Deck Targets

Flight Deck Sampling Position : Above Pilot's Seat

Flight Deck Tests: Target: Copilot's Window Heater

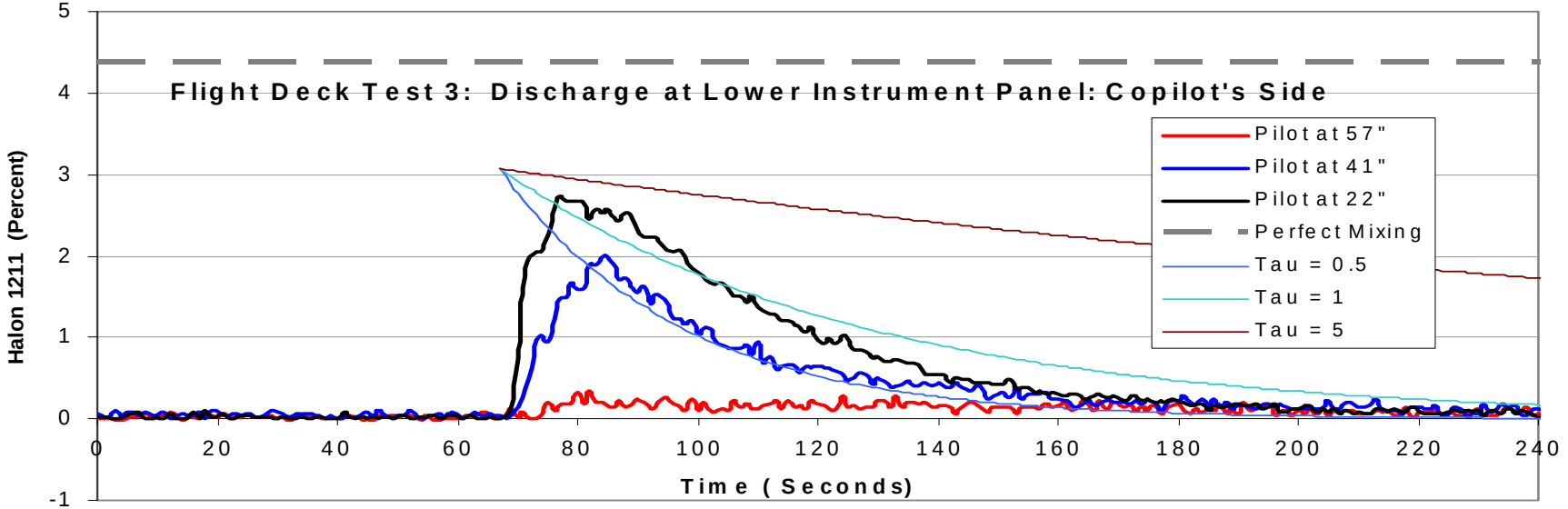
Flight Deck Tests: Target: Copilot's Window Heater

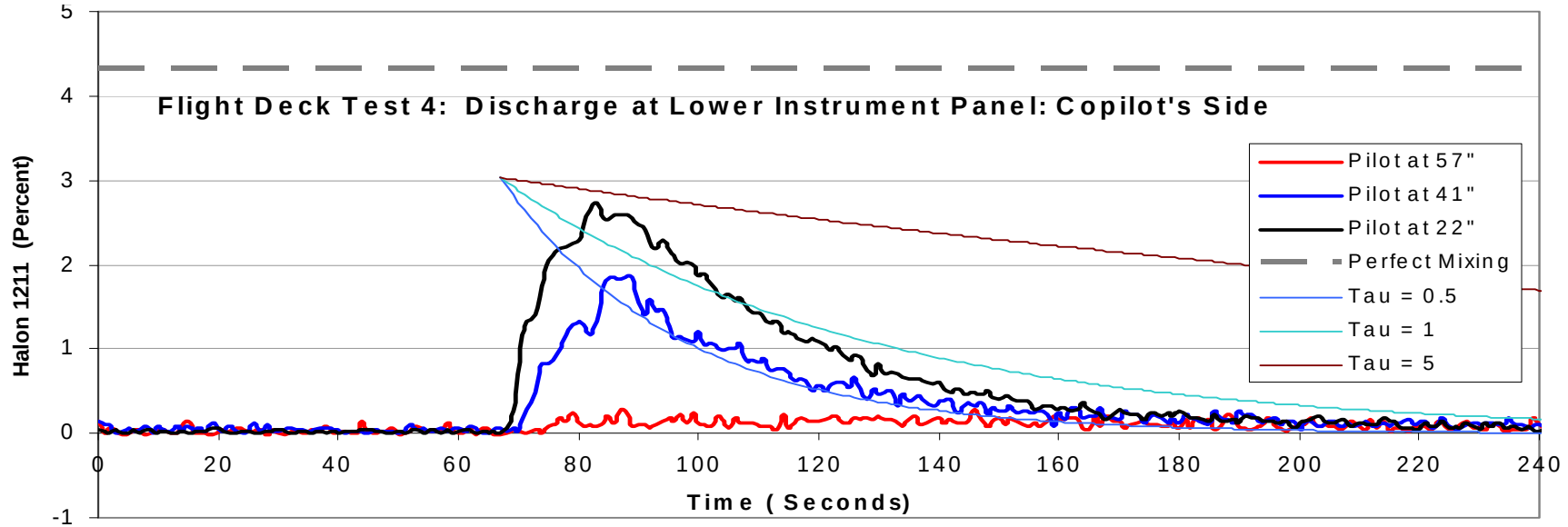




Flight Deck Tests: Target: Copilot's Instrument Panel

Flight Deck Tests: Instrument Panel: Copilot's Side





Flight Deck: Ventilation Rate Measurement

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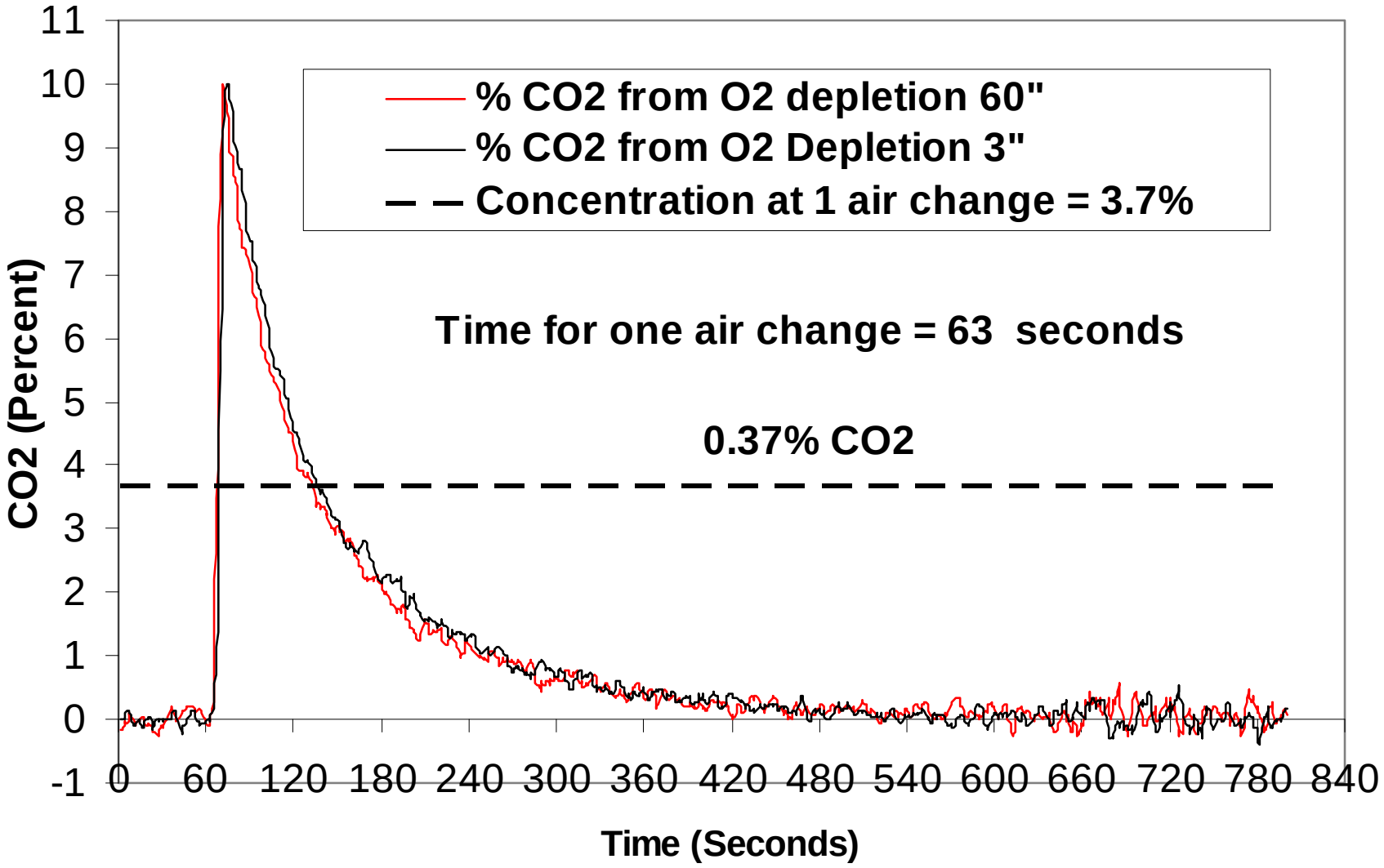
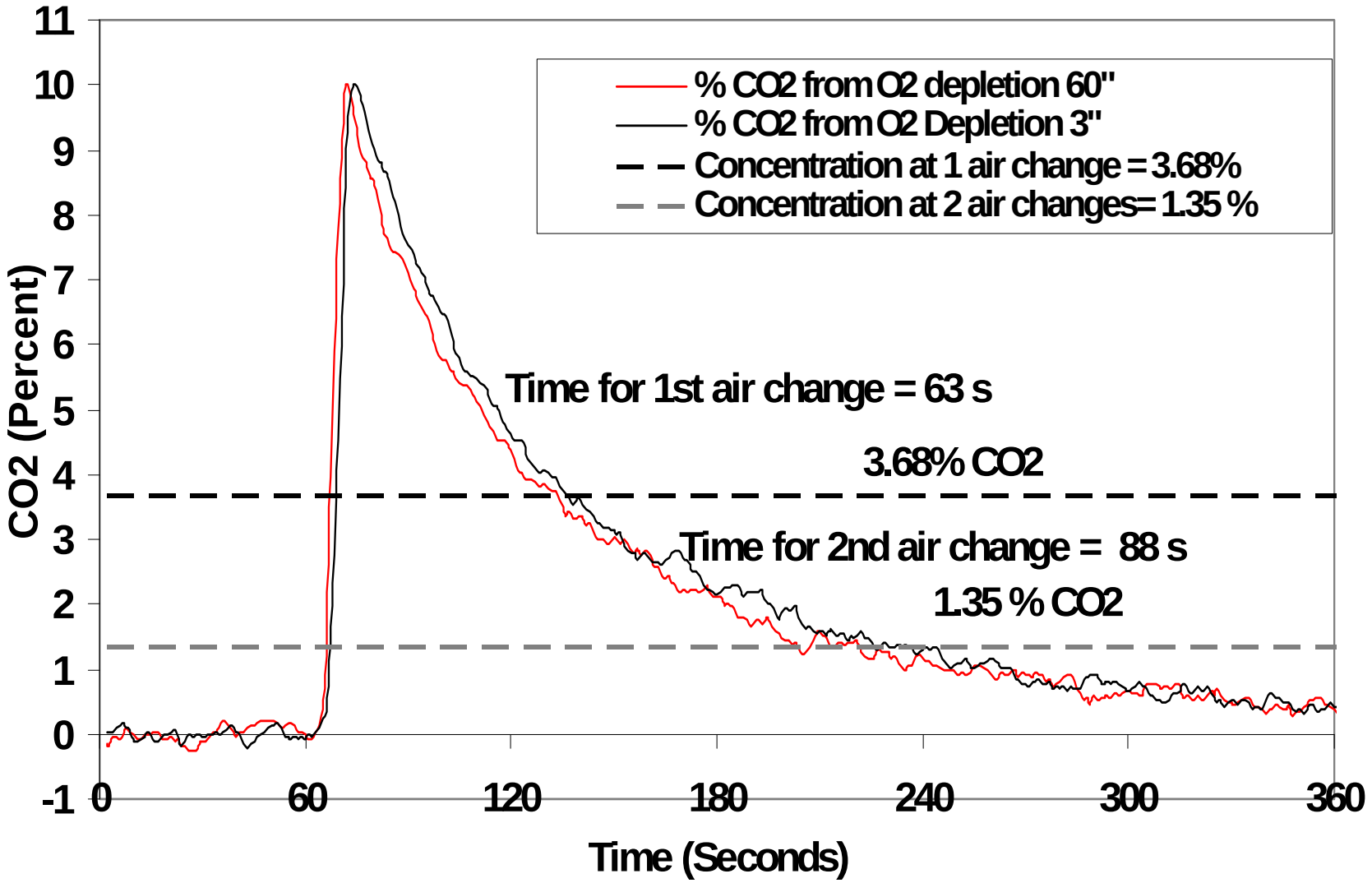
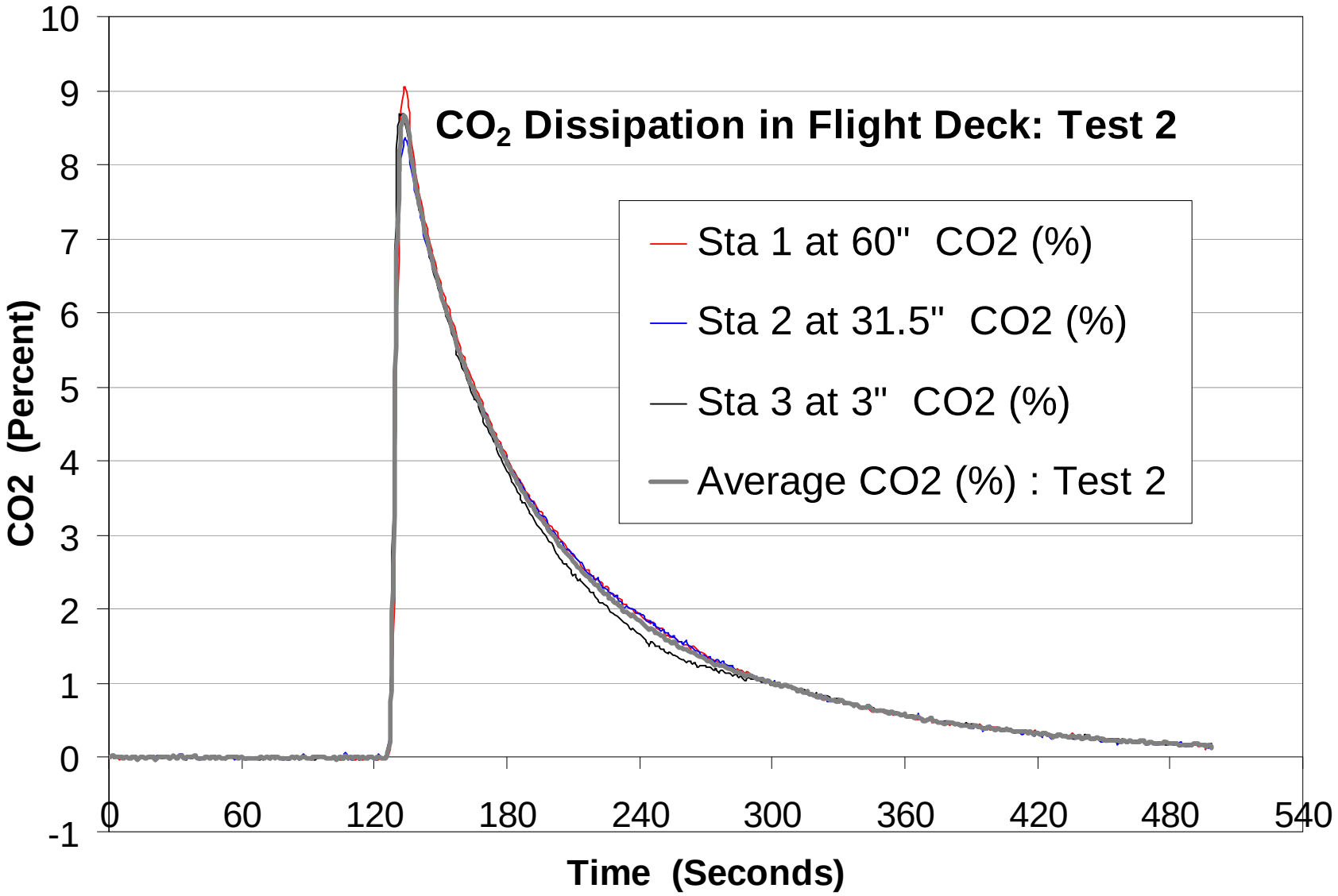


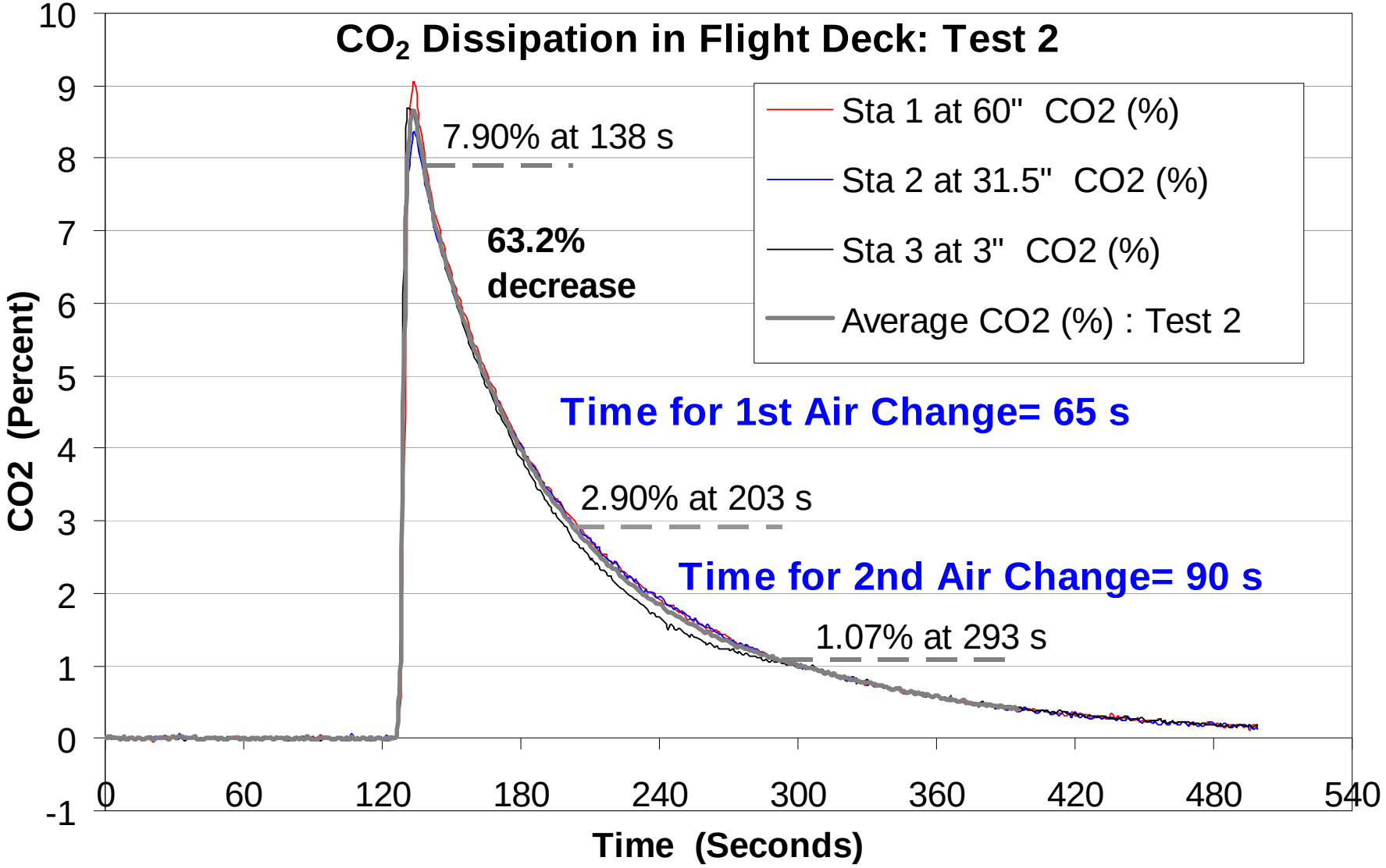
Flight Deck: Ventilation Rate Measurement



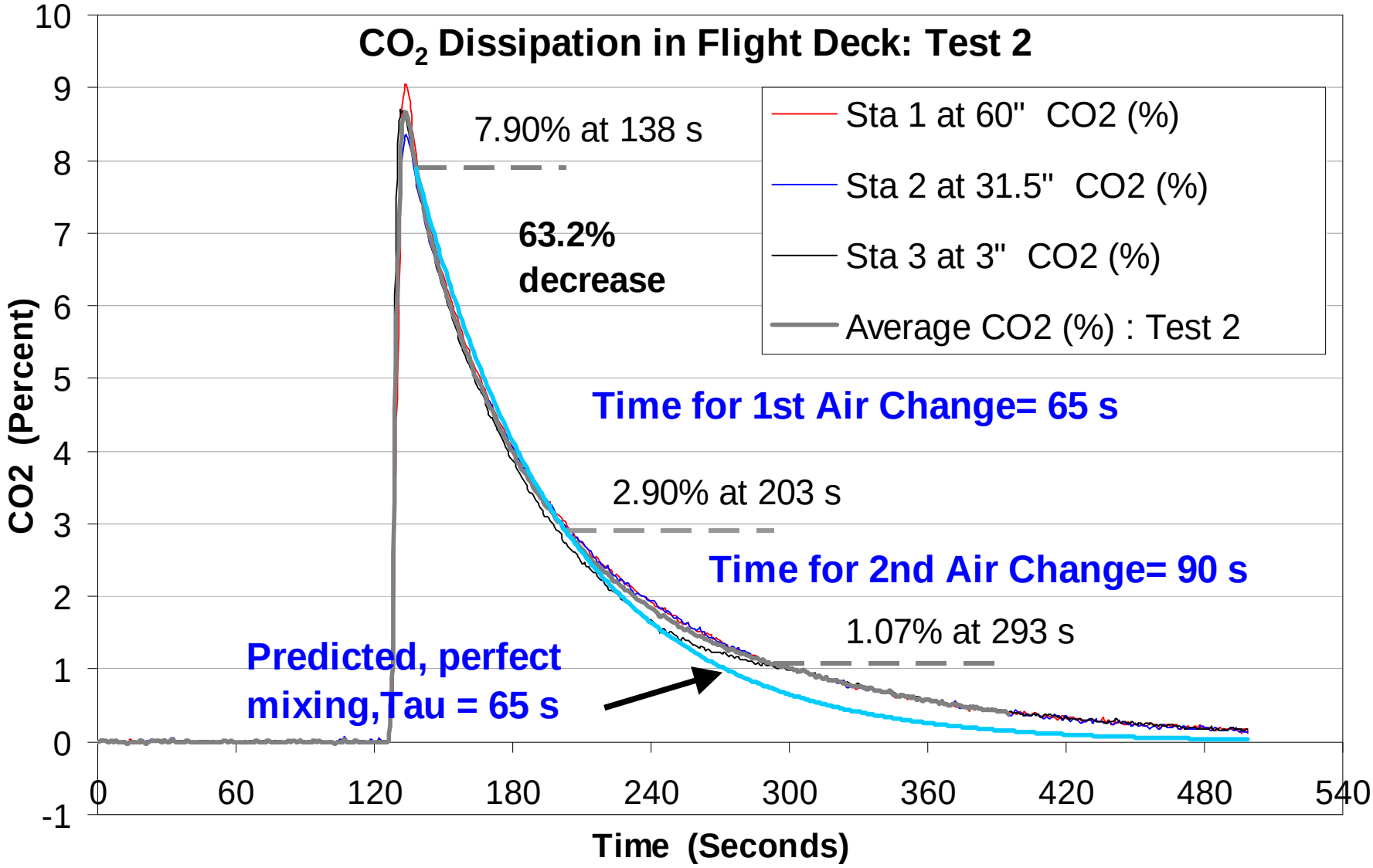
Flight Deck: Ventilation Rate Measurement



Flight Deck: Ventilation Rate Measurement



Flight Deck: Ventilation Rate Measurement



Summary

- Standing height : MF (Ventilation/Localization) will be very large
  - ➢ Flight Deck, **57”:** Maximum Halon 1211 Concentrations are 7 to 15 fold **lower** than initial perfect mixing concentrations
  - ➢ Cabin, **60”**: Maximum Halon 1211 concentrations are 10 to 20 fold **lower** than initial perfect mixing concentrations 6” from target. Agent barely detectable at 18’ from target
- Seated Height, **41”**
  - ➢ Flight Deck: Maximum Halon 1211 Concentrations are 1.6 to 2.4 fold **lower** than initial perfect mixing concentrations
  - ➢ Cabin: Maximum Halon 1211 concentrations are 1.9 to 2.1 fold **higher** than initial perfect mixing concentrations 6’ from the target. At 18’, the agent is barely detectable.
- **Resting Height, 22”**
  - ➢ Flight Deck: Maximum Halon 1211 Concentrations are 1.5 to 1.7 fold **lower** than initial perfect mixing concentrations.
  - ➢Cabin: Maximum Halon 1211 concentrations are 2.6 to 2.9 fold **higher** than initial perfect mixing concentrations 6’ from the target. At 18’ concentrations are 2.0 to 2.4 **higher** than initial perfect mixing concentrations.

Additional Work

- **Run CO2 discharge test for cabin to obtain cabin air change time.**
- **Calculate the maximum arterial concentrations for test and perfect mixing conditions with ventilation**
- **Calculate safety factors for each position in each test.**

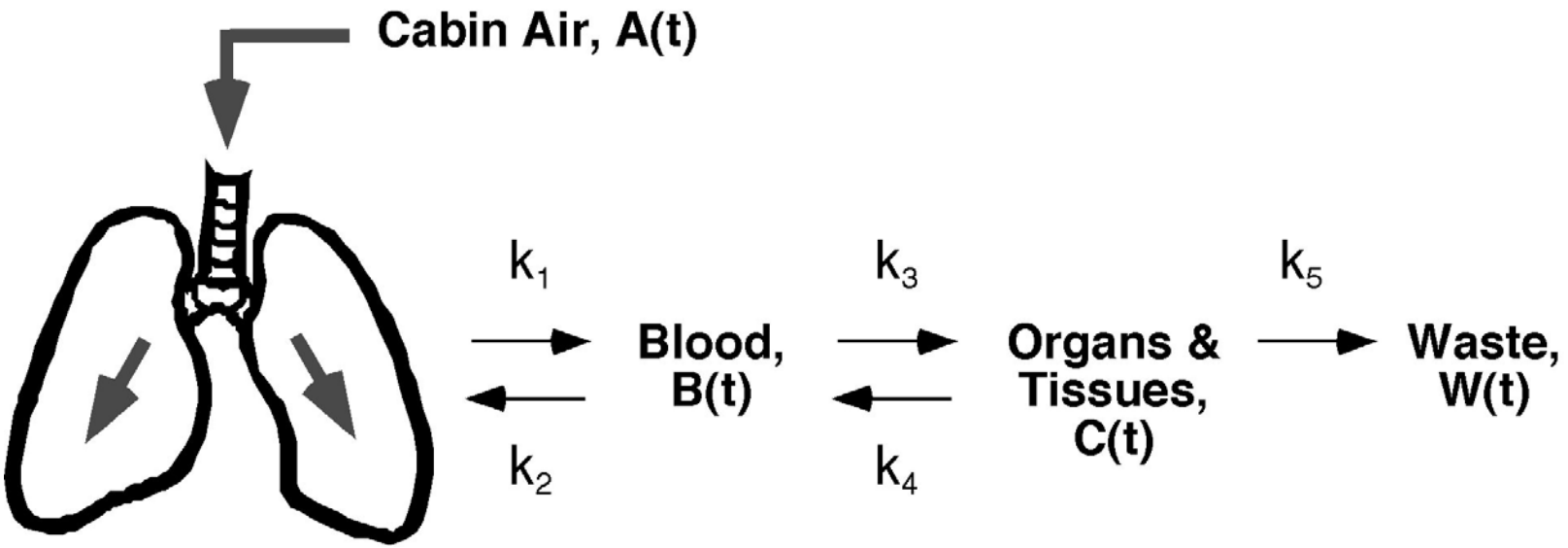
Considerations for Guidance Material

- Corrections need to be made for the maximum anticipated volume of the passengers and crew.
- Note: Test data is based on an non-inhabited cabin and flight deck (firefighter volume is subtracted out).

Conclusions

- **Localization is significant in the aft of the cabin for the cabin tests.**
- **Stratification is significant for both the flight deck and cabin tests.**

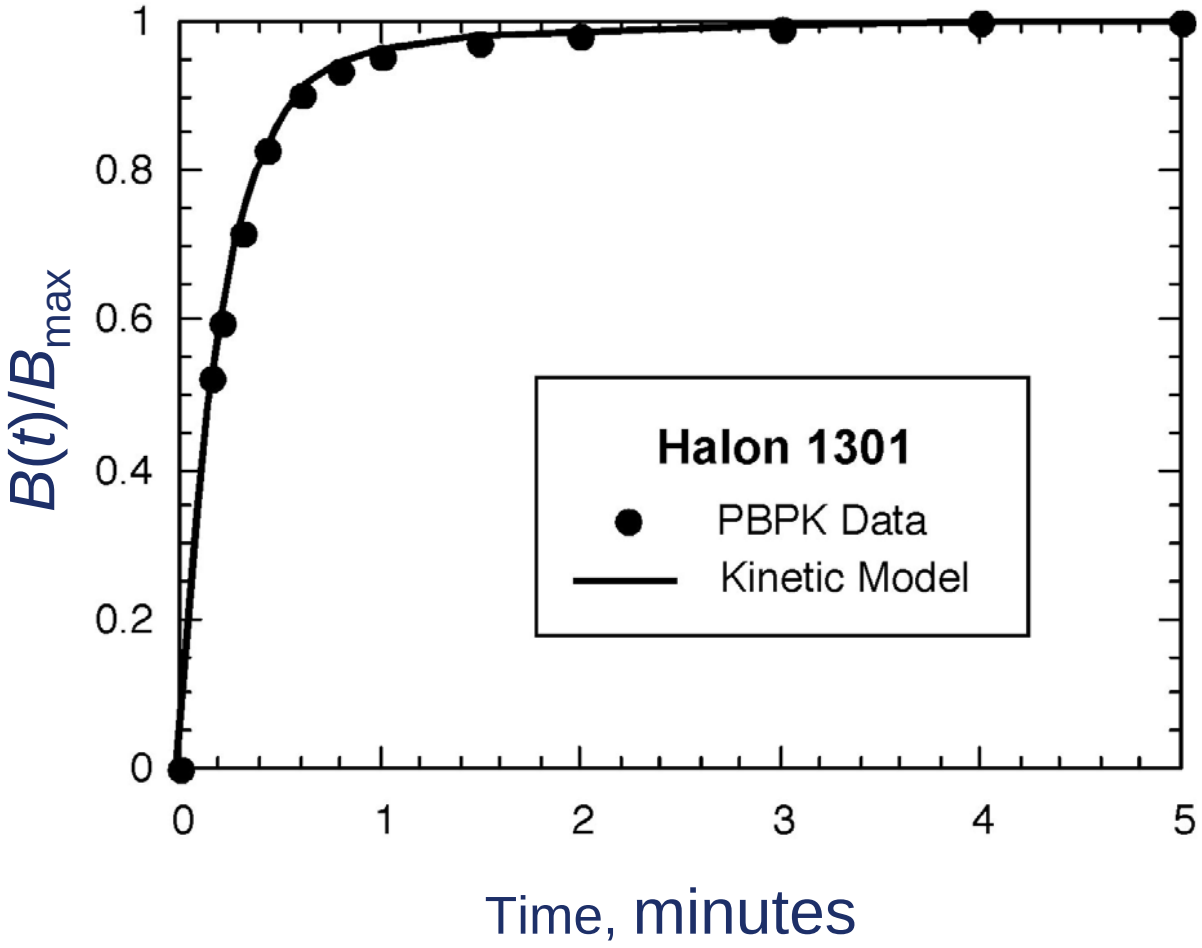
Simplified Kinetic Model



Simulates human arterial blood concentration histories from inhaled constant or dissipating halocarbon concentrations

Comparison of Kinetic Models for Halon 1301:

Unventilated Compartment ($\tau = \infty$)



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: Lyon, R.E. and Speitel, L.C., "A kinetic model for human blood concentrations of gaseous fire-extinguishing agents", *Inhalation Toxicology,* Volume 22, No. 14, December 2010, pp. 1151-1161.

Method

- Calculate B(t) for each sampling probe

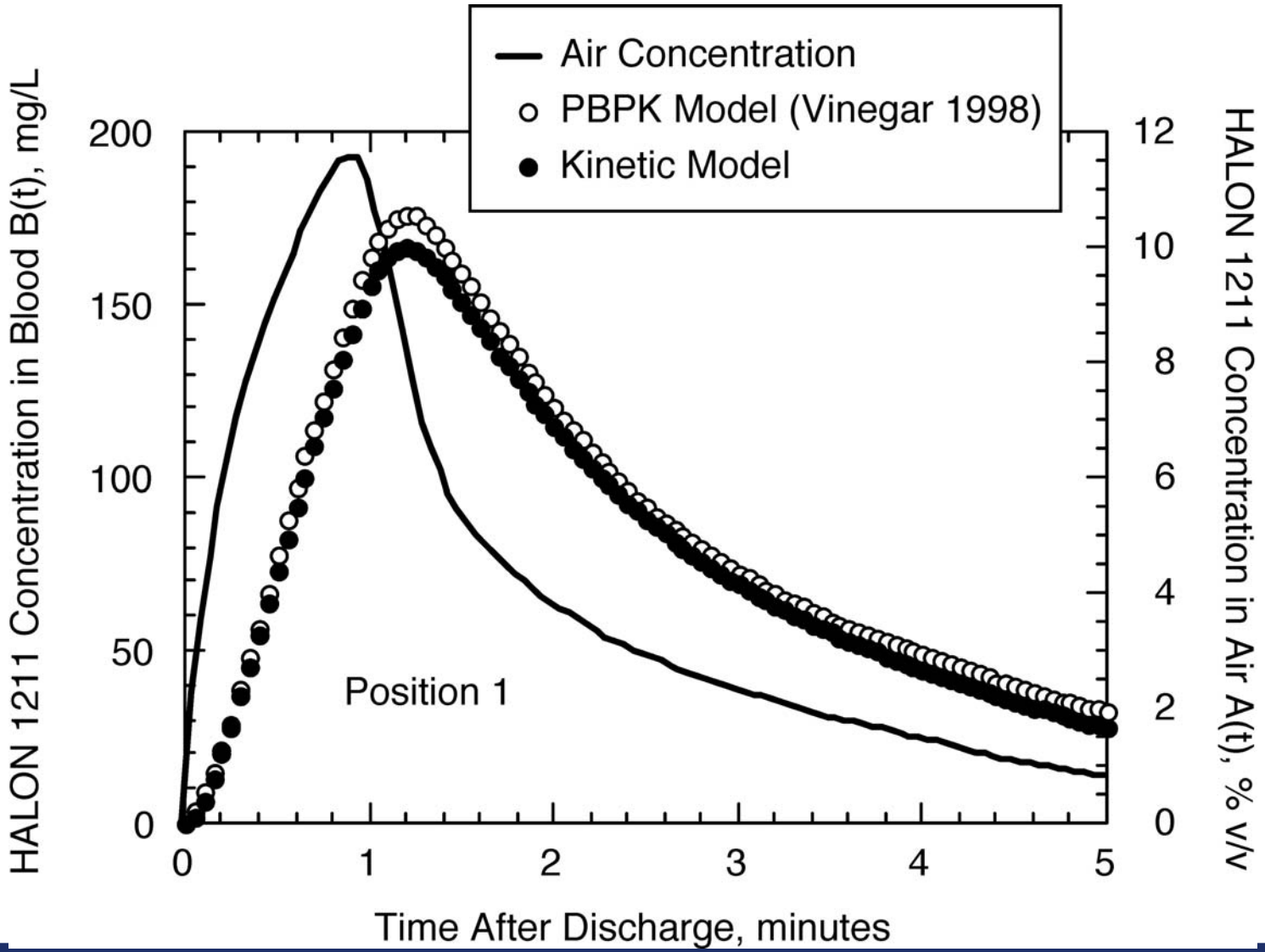
- Multiplication factors (MF) will be based on maximum computed human arterial blood concentrations, B

- Compare perfect mixing maximum B (ventilated) to test (ventilated) maximum B.

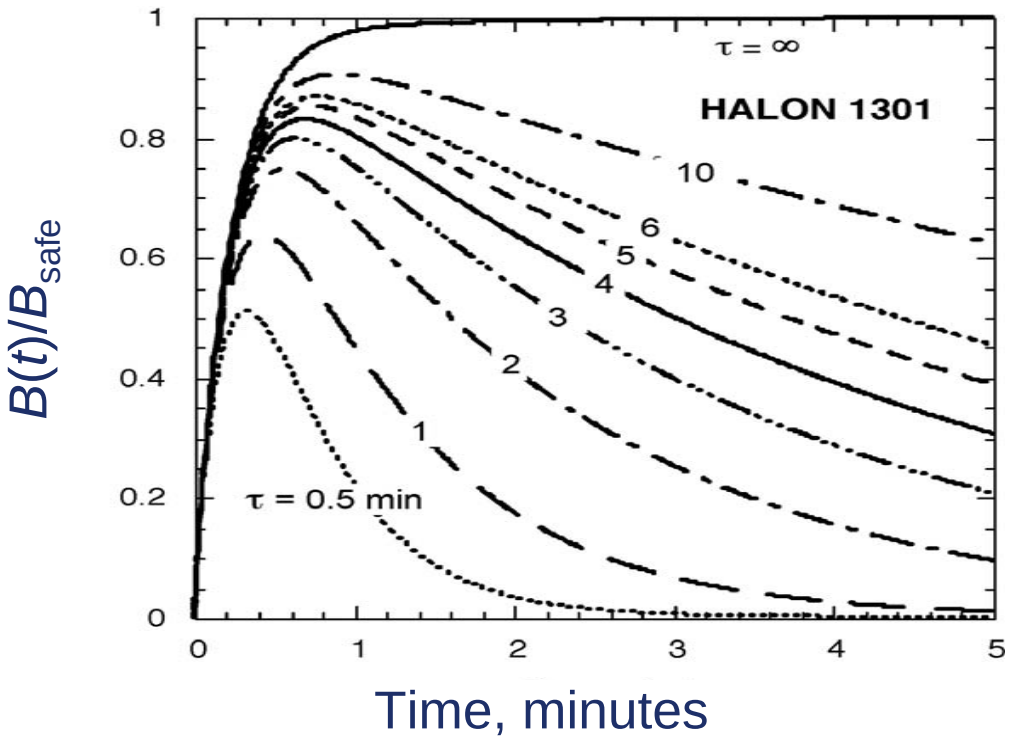
- This MF may be a multiplier for the maximum agent W/V in AC 20-42D.

$$MF(Stratification\ \&\ Localization) = \frac{B_{Max}(Ventilated - PerfectMixing)}{B_{Max}(Ventilated - Stratification - Localization)}$$

Kinetic Model



1st Order Kinetic Modeling of Halon 1301 in Ventilated Compartments



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