

**FAA Engine Compartment Halon Replacement Project**  
**Background, Overview, and Current Status**

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## ABSTRACT

The Federal Aviation Administration (FAA) is involved in a program which will result in guidance through interim and permanent recommendations to replace all aircraft-based fire suppression chemicals belonging to the halon family. This presentation focuses on the portion of the program looking at the engine nacelle/auxiliary power unit (APU) compartments. The project is managed by participants from the Engine/APU subgroup within the International Halon Replacement Working Group. Through this subgroup, the *Minimum Performance Standard for Engine and Auxiliary Power Unit Compartments* has been written describing one possible method to replace halon fire suppressants in these areas. Currently, a simulator representing a generic high-bypass ratio turbofan is being fabricated at the FAA W. J. Hughes Technical Center to evaluate the methodology described in the aforementioned document. An overview of the project covering its methods, goals, and current status will be presented. Also, as a courtesy to the reader, a brief history for the development of Halon 1301 in the aircraft engine nacelle application is laid out.

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## HALON 1301 HISTORY

Fire suppression systems in aircraft engine compartments, like most suppression systems, consist of two components; detection and agent delivery. Dedicated aircraft engine fire protection has been evident since the mid 1900s (Hansberry, 1943; Tarbell and Keeler, 1950). Reports of this era suggest dedicated fire protection may be found earlier than the mid 1900s. Presently, the current level of safety for engine compartment fire protection is defined as an amount of Halon 1301 producing a 6 percent volumetric concentration throughout the protected zone for a duration of one-half second. The development of the current level of safety has been an evolutionary process spanning better than fifty years. This process has involved the evaluation of many chemicals and associated technologies. To further complicate issues, aircraft propulsion itself was changing during this period (Gunston, 1995; Gunston, 1998). The bias of this report is directed towards United States Government work primarily within the Federal Aviation Administration (FAA), which by no means is the sole entity involved in the process. This body of work should not be considered the only source of information regarding this issue.

The development of the current level of safety has been a historical process. The major steps leading to current standards span the time frame from the 1940s to the present. Halogenated suppressants stored under pressure in appropriate hardware appear very early in the literature. One of the early reports suggesting active fire suppression in an engine compartment was written by Mr. H. L. Hansberry and published in 1943. The report discusses general fire protection considerations and provides design information for two fire suppressants, carbon dioxide and Halon 1001 (methyl bromide). Distribution of these chemicals is achieved through multiple nozzles located on a ring of tube which surrounds the engine power section. One should note that both suppressants are compressible fluids. By using compressible fluids, the technology for fire suppression is conceptually fixed. This fact has remained unchanged for the duration. Further, the propulsion mode for this period was the radial piston engine. Hansberry indicated 3,000 fire tests involving the Douglas DC-3, the Curtiss-Wright CW-20, and the Waco YKS-37 had been performed during this period (Hansberry, 1943, p. 1).

One of the first aircraft given propulsion fire protection consideration during its design stage was the Lockheed Constitution (Navy XR60-1) (Tarbell, 1953, p. 3). This aircraft possessed a radial piston power plant. Chemicals evaluated during this work involved carbon dioxide and Halons 1001 and 1011 (bromochloromethane). Further, during the evaluation of the Lockheed Constitution, different methods of engine nacelle fire suppression were considered (Tarbell, 1953, pp. 1-2, 20-28). Going one step further, over the entire span of this history, other methods of nacelle suppression have been suggested and evaluated.

Regarding the work on the Lockheed Constitution, the primary emphasis involved finding a simpler, yet more effective, way to deliver gaseous agents. The perforated tube, a relatively complex distribution system, was the standard approach until this effort. This concept was repetitiously cited as an element to possibly improve system performance. One approach evaluated involved storing the agent in small capsules located between cylinder heads within the nacelle. The agent was released by exploding the capsules. The capsule approach was determined to require more work, but was not well received. Another method of gaseous

delivery was evaluated; generically referred to as a high rate discharge (HRD). The HRD method eliminated the complex distribution tubing but maintained the agent storage hardware. This method, or variations thereof, has come to be the primary method to distribute gaseous agents within the nacelle. Yet another method suggested for evaluation during this program involved the introduction of conditioned exhaust gases into the nacelle to inert the protected volume. The lack of work evident in later reports has shown the exhaust gas concept drew no widespread interest from the aviation community.

In this same vein of different approaches to nacelle fire suppression, three other suppressive methods have been attempted; the modification of a bottle to accept pressurization from a gas generator device, the use of dry chemical fire suppressants, and the restriction of air flow into the nacelle. The gas generator pressurized bottles were considered during a significant turbofan evaluation in the 1960s (Klueg and Demaree, 1969, pp. 86-91). Limited comparisons between squib and gas generator released pressurized bottles indicated the gas generator fired bottles performed much better in distributing the agent. However, 3 of the 41 tests were failures as the releasing system failed. No further pursuit of this concept was noted in later work until the advent of the solid propellant gas generator. At a minimum, dry chemicals have been evaluated on two separate occasions (Altman, date unknown; Bennett, et al., 1997a). Comments from the most recent work indicated no further interest in this method because the agent cleanup from a discharge would be too burdensome for operational considerations. The restriction of nacelle airflow in conjunction with agent discharge has also been suggested (Johnson, 1988, pp. 47, 56). This method was perceived to augment suppression system performance by eliminating air flow to the nacelle. Upon evaluation, the test fires were extinguished, however a re-ignition phenomena persisted. This effort had no later widespread interest.

During the 1940-50 time frame, a new propulsion method appears; the turbojet. An effort was planned to perform a fire protection analysis of the Ryan Fireball (Navy FR-4). Turbojet technology was changing rapidly and the FR-4 powerplant was deemed obsolete before any work had begun (Middlesworth, 1952, p. ii). The fire protection effort then changed to an evaluation of fire suppression agents available at the time. The effort included work with carbon dioxide and several halogenated agents which included three new ones not considered before; Halons 104, 1003, and 1202. From this effort, the distribution system is again identified as the main element impacting performance. Additionally, halogenated suppressants are recommended for further investigation (Middlesworth, 1952, p. 19). From this point, more work occurs with various halogenated agents and the distribution system evolved into a simple tube-based arrangement where the use of nozzles was minimized (Hughes, 1953; Hughes and Middlesworth, 1954; Hansberry, 1956). As can be seen in Table 1, Halon 1301 appeared in early 1956. Halon is briefly mentioned in the work on the Northrop F-89 Scorpion as reported by Mr. A. V. Young (1958, p. 19). Regarding this effort, nothing significant resulted from the work as the test fixture had degraded to a questionable integrity due to previous fire testing by the time the agent was used.

Another significant change occurred near this time; a change in the propulsive method once again. During the 1960s, the civil sector comes into the age of the turbofan engine. To uncover unknown complexities, a two-year effort evaluated the fire protection aspects of the Pratt and Whitney JT3D-1. From this work, the ranking of agent effectiveness was given in order of the

most effective first, as Halon 1301, 1202, 1211, then 1011 (Klug and Demaree, 1969, p. 117). From this time forward, Halon 1202 and 1301 underwent continual evaluation (Chamberlain, 1970; Sommers, 1970; Chamberlain and Boris, 1987; Johnson, 1988). Ten or so years later two additional efforts compared Halon 1301 and 1202. The result of these efforts indicated Halon 1301 performed better than Halon 1202 (Chamberlain and Boris, 1987, pp. 55-59; Johnson, 1988, pp. 41, 60).

Table 1. Fire Suppressants Evaluated in FAA Reports, 1943-1988

Report Number	Date	Fire Suppressant (chemical or Halon name)								
		C	1	1	1	1	2	1	1	1
31	Sep, 1943	x		x						
107	Apr, 1950	x								
184	Oct, 1952	x	x	x	x	x	x			
198	Apr, 1953	x		x	x			x		
205	Jun, 1953	x		x	x			x		
206*	Jun, 1953	x		x	x					
240	Jun, 1954				x			x		
260	Feb, 1956			x	x			x		x
365	Oct, 1958				x			x		x
403*	Sep, 1959	x		x	x			x		x
NA-69-26	Apr, 1969				x			x	x	x
FAA-DS-70-3*	Mar, 1970							x		x
FAA-RD-70-57	Nov, 1970									x
AFWAL-TR-87-2066	Nov, 1987							x		x
AFWAL-TR-88-2022	Jun, 1988							x		x

\*Signifies work involved in developing gas concentration analysis equipment

All during this effort, in addition to finding a desirable fire extinguishant, one realizes the agent must be quantified in some way so its effectiveness can be measured. Early work in the span of time discussed here had been based on destructive testing. Results were quantified by agent weight and compared against fire extinguishment performance. When considering the ability of a gaseous suppressant to put out a fire in an unknown dynamic environment, the most effective way to quantify it is to measure its concentration in the region of interest. During the middle 1950s, the U.S. Air Force (USAF) funded an effort to develop a gas analyzer capable of recording a discharge event in an engine nacelle (New and Middlesworth, 1953, p. 1). The device produced by Statham Laboratories measured a pressure drop of a binary gas mixture flowing across a porous plug at known temperature. Given one part of the binary mix being air, the unknown concentration of the second component can be calculated based on a known calibration curve. The first generation analyzer was known as the GA-1 and possessed 18 data gathering channels. The Statham Laboratories analyzer was later modified to the GA-2A having

12 data gathering channels (Demaree and Dierdorf, 1959, p. 3). This device is commonly known as the Statham analyzer. Today, the familiar variant is the Halonyzer II, as produced by Pacific Scientific HTL/Kin-Tech Division. Currently, Walter Kidde Aerospace, Pacific Scientific HTL/Kin-Tech, the Boeing Company, the French airworthiness authorities, and the FAA possess derivatives of the Statham analyzer.

Agent quantification begins transformation when the ability to capture the gas concentration appears. Agent evaluation changes from weight-based measure to concentration-versus-time profiles illustrating distribution in the protected zone. Three major reports dealing with concentration measuring equipment begin providing concentration and duration data for a given agent (New and Middlesworth, 1953; Demaree and Dierdorf, 1959; Chamberlain, 1970). The duration of one-half second of specified concentration is noted in work from Mr. J. E. Demaree and Mr. P. R. Dierdorf (1959, p. 13). The agents quantified are carbon dioxide and Halons 1011, 1001, 1202, and 1301. The quantification was based on "...numerous fire extinguishing tests conducted on full-scale powerplant installations at the Technical Development Center" (Demaree and Dierdorf, 1959, p. 13). Later on, issues such as operating the Statham analyzer, agent distribution, and system development are discussed in greater detail by Mr. G. Chamberlain (1970). Halon 1301 was identified as the most prominent agent, while Halon 1202 was next in importance with carbon dioxide remaining in service as well (Chamberlain, 1970, p. 1). Of particular interest in this report is further discussion of the current level of safety. Chamberlain introduces a flammability curve of n-heptane, air, and Halon 1301. The peak of the flammability region is approximately 6 percent volumetric Halon 1301 (Chamberlain, 1970, pp. 33-35). Soon after Chamberlain's report, Advisory Circular (AC) 20-100 is published in 1977. The information in AC 20-100 is reflective of Demaree's, Dierdorf's, and Chamberlain's work.

As seen by this history, the development of the current level of safety has been quite involved. Through the span of time just described, the FAA was involved in the development of engine nacelle fire protection covering 51 individual aircraft models (Chamberlain, 1970, p. 54). In this era, we are now in the midst of the next generation of work pertaining to the concept of the equivalent level of safety. In essence, the problem is the same, but the approach is slightly different.

## HALON REPLACEMENT

Within this decade, halogenated fire suppressants, members of the Ozone Depleting Substances (ODSs) governed by the Montreal Protocol and its amendments, have been eliminated from production and existing quantities are being recycled for future use. There will be an end point at some time in the future. Regarding aviation, the potential elimination of halon is not imminent; however, efforts are being made to move in a direction to replace halon.

This replacement effort is global in scale, spanning governments and their respective agencies. The FAA has been involved in the process through its International Halon Replacement Working Group (IHRWG). The four facets of interest pertinent to replacing Halon within civil aviation are the lavatory trash receptacles, cargo holds, hand-held extinguishers, and the engine and auxiliary power unit (APU) compartments. This discussion focuses on engine and APU halon replacement efforts.

The IHRWG has been pursuing halon replacement since October 1993. One component of the IHRWG is interested in the engine/APU compartment. This subgroup initially focussed on a large-scale, multiphase program being run by the USAF (Bennett, et al., 1997a; Bennett, et al., 1997b). The partnership for the project consisted of the representatives from the U.S. Army, Navy (USN), and Air Force (USAF), the FAA, and the aviation industry. This program, titled "Halon Replacement For Aviation" occurred in a three-phase process. The process was a broad brush stroke to evaluate many chemicals and eventually select one to act as the intermediate halon replacement agent until a better replacement, more like halon, could be found.

Phase one of the USAF program involved determining the most significant factors which would impact the quantity of an agent required to suppress a nacelle fire. Parallel to phase one, the USAF sponsored an effort which evaluated 600 potential halon replacements for possible application in the nacelle. The resultant list contained 12 chemicals. The National Institute of Standards and Technology (NIST) was then employed to reduce the list of 12 down to 3. The results of the parallel efforts was a selection of 3 of the 600 potential chemicals and 7 of 15 fire-related parameters most impacting system design which would pass into phase two work. The three chemicals selected were CF<sub>3</sub>I, HFC-125, and HFC-227ea. Phase two was implemented to select one of the three potential replacements for phase three. Work from phase two resulted in the selection of HFC-125 as the recommended replacement for Halon 1301 in the aircraft engine nacelle. The third phase incorporated further work with HFC-125 which would eventually yield equations intended for designers to use in protecting nacelles.

This USAF process focussed strictly on compressed fluid technology. During this same period, work occurred with other technologies offering different suppression options. The significant one noted here is the solid propellant gas generator (SPGG). SPGG is a pyrotechnically based suppression technology. There are three classes of SPGG; the inert gas generator (IGG), the active gas generator, and the hybrid gas generator. The USN has been the primary instrument in the evolution of this technology (Budd, 1995). NIST and the USAF have also been involved in this effort (NIST, 1995; Gillespie, 1997).

IGG is a controlled combustion process where inert gases of nitrogen, carbon dioxide, and water vapor are liberated from the combustion of a propellant. The resulting effluent is the fire suppression agent. The release is harnessed within a casing and the effluent is distributed through a manifold to desired points within the protected volume. Another variant of the SPGG is the active gas generator. The active gas generator is intended to actively suppress a fire by including special chemicals in addition to or in place of the inert effluent. The final SPGG variant is the hybrid system which uses the effluent of an IGG to pressurize and release another suppressant, similar to the gas generator-fired bottle previously discussed. SPGG is relatively new to aircraft fire suppression. Two USN airframes, the F-18 and V-22, have been evaluated for protection with the gas generator technology. The V-22 has installed protection with IGG. One aircraft has suffered an event in which the gas generator system functioned as designed in response to a mid-wing fire (Hennigan, spring 98, pp. 10-11).

The IHRWG engine subgroup has also formulated a plan. This effort incorporates results from the USAF efforts but is more focussed on transport category aircraft. The process is described in

a document titled "The Minimum Performance Standard for Engines and Auxiliary Power Unit Compartments" (MPSE) and is untried as of November 1998. The plan describes the geometry of a nacelle simulator and a process that could be used to demonstrate the equivalence of a replacement agent to that of Halon 1301. The backbone of the plan is the maintenance of the current level of safety, as defined previously.

The USAF and IHRWG efforts are different in particular aspects; however, the overall goal is to offer halon replacement information. The USAF process incorporated simulations spanning the current propulsion spectrum from the fighter-based, low-bypass ratio turbofan to that of the high-bypass ratio turbofan found in certain military transport aircraft. The MPSE is primarily focussed on the large transport category aircraft powerplant, the high-bypass ratio turbofan currently found in the civil fleet. Other differences between the USAF and IHRWG methods lie in the agents evaluated and the method of data presentation.

The USAF effort concluded with equations a designer would use to protect an engine compartment if using HFC-125. The commercial interests in the IHRWG expressed a desire for information on all materials in the USAF phase two work (Mehta, et al., 1996). The IHRWG effort requires presentation of final data for gaseous suppressants in the form of the familiar concentration-versus-time duration. The final data presentation for the MPSE was a result of two synergistic effects. Primarily, from an operational standpoint, the civil certification process has come to rely on the presentation of test data in concentration-versus-time format. The FAA is not involved in the process to develop a specified distribution within the nacelle; that is the domain of the applicant. Simply, the applicant, by use of certified gas analysis equipment, must demonstrate the agent adequately diffuses within the nacelle in accordance with FAA requirements. Secondly, the effort to generate equations for HFC-125 was substantial. Generating comparable information for the remaining two agents was deemed too cumbersome for the IHRWG effort.

#### Minimum Performance Standard for Engine and Auxiliary Power Unit Compartments

The IHRWG formulated a plan to address the issue of finding replacements for Halon 1301 in the engine and APU compartments. The approach conceived is based on the principle of maintaining the current level of safety. The document describes the two facets needed to effect such an evaluation; a simulator and a procedure. The group crafting the document has been involved in this effort since October 1993. The current version was accepted by the group during the July 1996 IHRWG meeting held at the FAA W. J. Hughes Technical Center.

The first step of the MPSE requires fabricating a simulator of specified geometry. The simulator must be supplied with an airflow, a spray fire scenario, a residual pool fire scenario, a system to deliver Halon 1301 representative of the current level of safety, and an ability to deliver a potential replacement to challenge the chosen fire scenario. Particulars of each simulation element are based on reasoning pertinent to the fire or agent delivery as found in an engine compartment application. The process is designed to challenge the existing level of safety while providing an ability to determine the equivalent of an alternate agent/technology to that same level of safety.

The MPSE no longer reflects requirements to demonstrate equivalence for an alternate in the APU compartment. The discontinuation of the APU effort within the IHRWG was based on results uncovered during the USAF program. The nacelle criteria was found to far exceed what was actually needed to adequately protect APU compartments as they currently exist. For this reason, protection in this compartment is based on the criteria defined for the nacelle.

The second part of the MPSE is the process of demonstrating the equivalence of an alternate to the current level of safety, as defined by Halon 1301. This process is dependent upon issues relevant to conditions of airflow, agent, and the fire seen in the test section. The primary step is the development of a system capable of delivering Halon 1301 to the test section of the simulator meeting the intent of current certification criteria. Upon completing this step, the next process involves repeating fire tests until an 80-90 percent suppression rate is achieved. Various fire parameters can be altered to generate a fire which allows suppression at this statistical rate.

Upon achieving the 80-90 percent fire suppression rate with halon, halon-based testing stops. At this point, the alternate is put in place and the fire parameters are left alone. The fire testing begins again. The quantity of the alternate is iterated until an amount can repeat the statistical suppression rate of halon. If the alternate is gaseous, the gas analysis equipment is pulled out and the alternate then quantified.

The MPSE has been written broadly to allow different technologies potential evaluation in this challenge. Realizing the input from the transport category interests however, the main technology considered will be compressed fluid suppressants.

### Nacelle Simulator

Beginning in 1995, work began on a simulator located at the FAA W. J. Hughes Technical Center. The simulator is a flow pathway having a front end to condition and supply air, a test section, and an exit to eject effluent from the entire device. The entire simulator is roughly 90 feet (27 m) long. The front end to the test section accounts for 50 feet (15 m), the test section approximately 20 feet (6.1 m), and the exit completes the balance of the length. The front end is composed of a supplying centrifugal fan, a 484-tube heat exchanger, a stream straightener, and 32 feet (9.8 m) of 36-inch (91-cm) diameter duct. The test section consists of two concentric cylinders, having 24-inch (61-cm) and 48-inch (122-cm) diameters respectively. The annular volume of the compartment is approximately 100 cubic feet (2.8 m<sup>3</sup>). The test section also houses obstructions for clutter, equipment to support spray and residual fire scenarios, and hardware to deliver gaseous fire suppressants. The exit of the simulator consists of ducting to pass the effluent from the test section exit up and out of the building.

The front end of the test section contains hardware to provide air flow as prescribed in the MPSE. The air flow is provided by a centrifugal fan. After the fan, the flow then passes through a transition section and enters a tube bank heat exchanger. At this point, the flow departs the exchanger, passes through a grill structure, and finally enters a 36-inch (91-cm) diameter duct.

The heart of the simulator is the test section. This section contains hardware to provide a spray or residual fire scenario and receives the fire suppressant. The fire scenarios are located approximately 130 inches (330 cm) from the inlet of the test section. The spray scenario is

located in the upper part of the annular cross section. A fuel delivery nozzle, a 2-inch (5.0-cm) tall baffle, electrodes to ignite the spraying fuel, and a local hot surface work integrally to provide the fire. In the lowest portion of the annular cross section lies a residual fire scenario. A pan with an ability to maintain constant fill level during a fire event, a 2-inch (5.0-cm) tall baffle, electrodes to ignite the pan contents, and a local hot surface combine to provide the residual fire threat. The last component in the test section to complete the simulation is the fire suppression system. The bottle storing the gaseous agent straddles the test section inlet diffuser. It is a unit on loan from the USAF, courtesy of Wright Laboratories. The unit is a right circular cylinder capable of varying volume and temperature control. The unit is plumbed into the test section roughly 36 inches (91 cm) from the inlet to test section. Currently, the agent is delivered into the test section through four 0.500-inch ( 1.3-cm) outside diameter tubes near the section wall penetrations. The agent is introduced in counter flow fashion within the test section.

### Current Status

The simulator has been under construction since 1996 and is nearly complete. Of all the components, the hot plates and a capable supply fan are the only items still required.

The first of two hot plates is currently being finished. Each plate is supplied with a 200-ampere circuit. An individual plate is composed of two blocks of steel and a piece of plate. The entire assembly will weigh approximately 480 pounds (2.1 kN) when completed. The target surface temperature of the hot plate is 1300°F (705°C).

The existing supply fan is a 3-horsepower (2.2-kW) unit. Upon placement of the heat exchanger responsible for heating the air, the best possible flow downstream was determined to be five times less than what was specified in the MPSE. Current efforts are under way to acquire a larger fan capable of the airflow required to meet the intent of the MPSE.

### Where to Next

Upon determining that the use of a tube bank to heat the test section airflow was too restrictive for the existing air flow, the tube bank was removed. The current plan is to characterize the distribution of the fire suppression system without the tube bank in place. In addition, work is planned to generate further data in support of the use of HFC-125 to simulate Halon 1301 distribution testing. The lack of the conditioned air and hot surfaces should not significantly impact the preliminary work being the work is performed at or above ambient conditions. Parallel to this effort, the first hot plate will be completed, burned in, and placed in the simulator. The supply fan is currently being evaluated for purchase. Some front end sheet metal duct and electrical feed work will be required upon acquiring the fan. When the plate and fan items are completed, fire testing efforts in accordance with the MPSE will begin.

### HFC-125 AS A HALON 1301 SIMULANT.

Halon replacement is the goal of this project. However, information has not been provided to accomplish such within the FAA, nor has an applicant approached the FAA with such intention. However, during the interim period, any action to minimize the discharge of halon for events

other than fire suppression is perceived to be a step in the correct direction. Other entities have moved in such a direction already, on both the business and the regulatory sides. Efforts by the USN, NIST, Walter Kidde Aerospace, the Boeing Company, and Shorts Brothers PLC have provided information to support such a concept for the engine nacelle. Outside the engine group, but within the IHRWG, the cargo replacement effort is also moving in this direction.

Through 1994 and 1995, the USN contracted NIST to determine an acceptable chemical which would be capable of imitating Halon 1301 during an aircraft engine nacelle discharge (Womeldorf and Grosshandler, 1995). NIST recommended HFC-125. Additionally, the USN contracted Kidde Technologies to further evaluate HFC-125 (Mitchell, 1994; Mitchell, 1995). During this same time frame, Shorts Brothers PLC of Ireland (Riordan, 1995) and the Boeing Company (Kaufmann et al., 1995) also pursued the use of HFC-125 as an acceptable simulant for Halon 1301 during an engine nacelle discharge test. Simply stating the collective results for this application, HFC-125, when stored and delivered in a certain fashion, has the ability to travel plumbing, vaporize, and disperse in a manner very similar to Halon 1301. The quantity of HFC-125 needed to simulate the Halon 1301 distribution is found by multiplying the desired weight of Halon 1301 by a factor of 0.77. The HFC-125 must then be stored in the bottle as the Halon 1301 would be (Womeldorf and Grosshandler, 1995, p. 605).

During April 1998, while performing gas concentration support for the USN, the Boeing Company, and Northrop Grumman, two tests were run in the same ventilated compartment to capture further data. The results are presented as Figures 1-4. The analyzer used was a Pacific Scientific Halonyzer II, s/n 001. The analyzer was calibrated that morning for HFC-125 and Halon 1301 and each test was captured with the respective calibration curve in memory. The agent distribution and storage systems were identical. Pertinent statistics for the simulator used in this test pair are listed in Table 2.

Table 2. Nacelle Statistics for April 1998 Simulant Test Pair

Parameter	general	Halon 1301	HFC-125
ambient temperature	64°F (18°C)		
barometric pressure	30.2" Hg (767 mm Hg)		
relative humidity	42%		
nacelle airflow rate	2.1 lb/s (0.95 kg/s)		
nacelle inlet airflow temperature	107°F (42°C)		
nacelle compartment air change rate	2-3/min		
agent charge weight		5.50 lb (2.50 kg)	4.25 lb (1.93 kg)
bottle pressure		600 psig (41.3 Bar)	600 psig (41.3 Bar)
bottle temperature		ambient	ambient

The graphs illustrating the comparison between agents are compared by clusters of three analyzer channels. The clusters for each agent on each graph are offset for clarity. As seen in the comparisons of the analyzer data, the results are qualitatively striking. Quantitatively, Table 3 illustrates the results. For comparison purposes, each concentration trace has been reviewed to

determine the time elapsed to achieve each of the 4, 6, 8, and peak percent volumetric concentrations. Additionally, the duration the concentration was at or above 6 percent volumetric concentration has also been determined. Halon 1301 is treated as the standard for all error estimates. The error in the duration to achieve the specific concentrations ranged from -28.6 to +15.4 percent. The range of error in the peak concentrations were -0.8 to 5.9 percent. The error associated with the time each trace was at or above 6 percent volumetric concentration was 0 to 13.8 percent.

Those error values listed in Table 3 having negative values indicate the HFC-125 trace was actually larger in magnitude in either duration or concentration; a positive value indicates the opposite. For this pair of tests, the largest noted discrepancies during the increase in agent concentration reflect differences of 300 milliseconds and 0.7 percent volumetric concentration between the agents. The largest differences in the peak value concentrations was 0.5 percent volumetric concentration. The largest difference between the durations the traces were at or above 6 percent volumetric concentration was 400 milliseconds. Based on these results and observations when considering the common over-design of Halon 1301 systems, an interim opportunity to reduce halon emissions for other than fire suppression purposes is offered by using HFC-125 as a simulant for Halon 1301 in this application.

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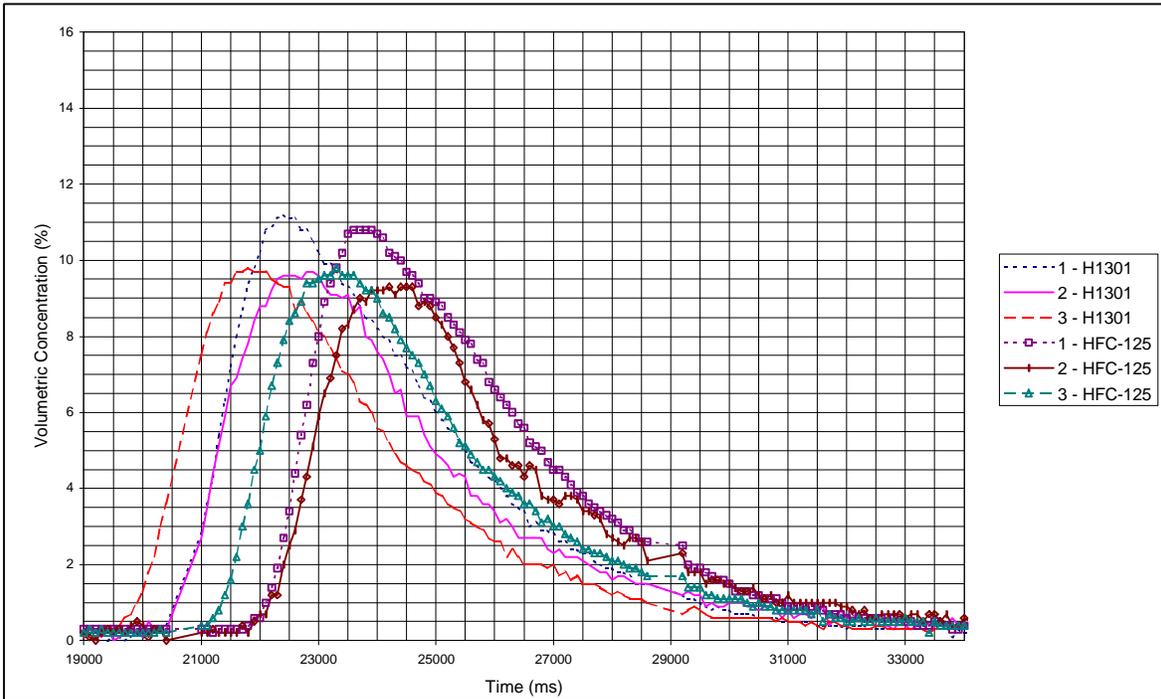


Figure 1. HFC-125 and Halon 1301 Channel Comparisons, Channels 1-3

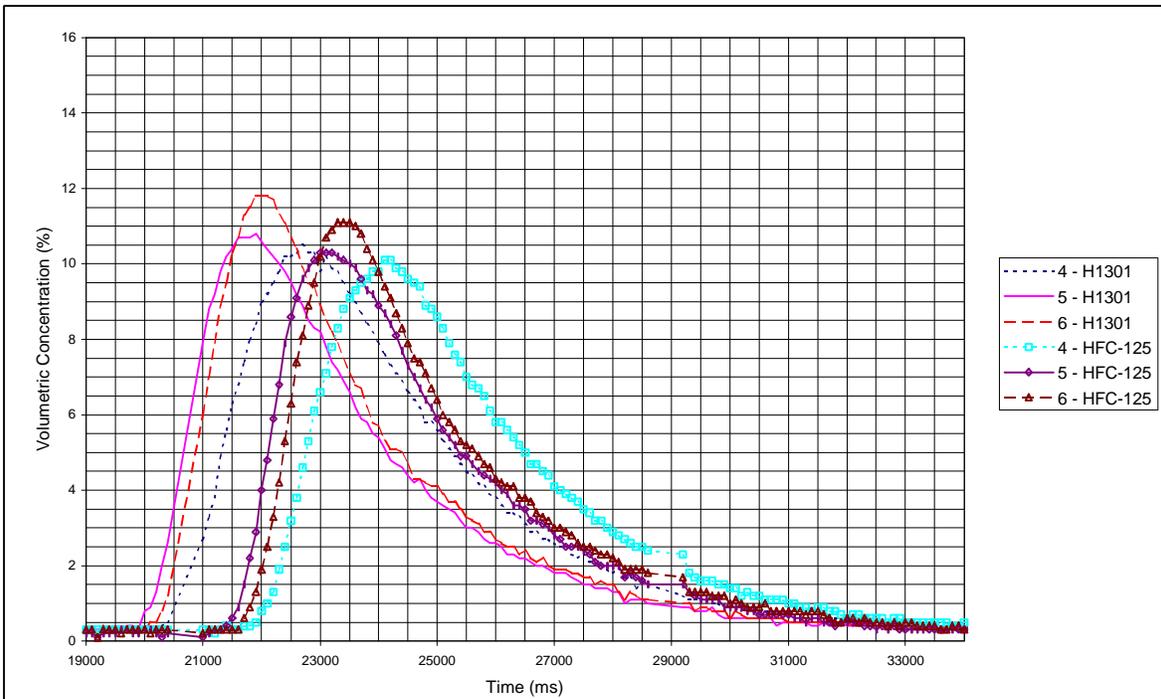


Figure 2. HFC-125 and Halon 1301 Channel Comparisons, Channels 4-6

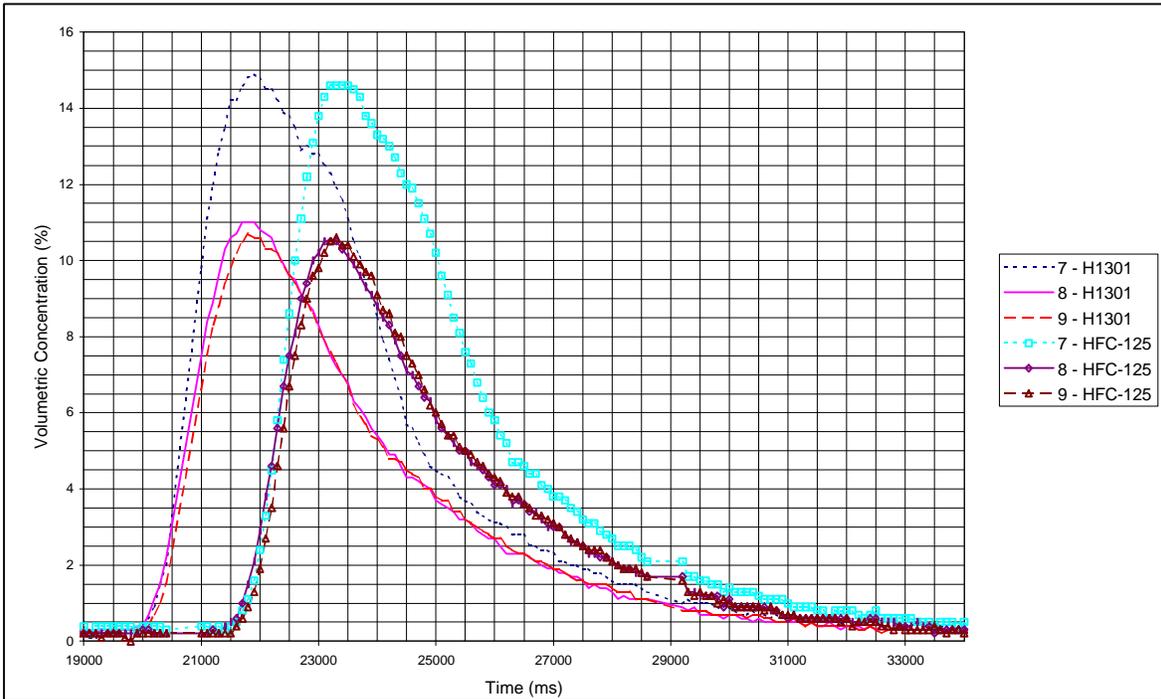


Figure 3. HFC-125 and Halon 1301 Channel Comparisons, Channels 7-9

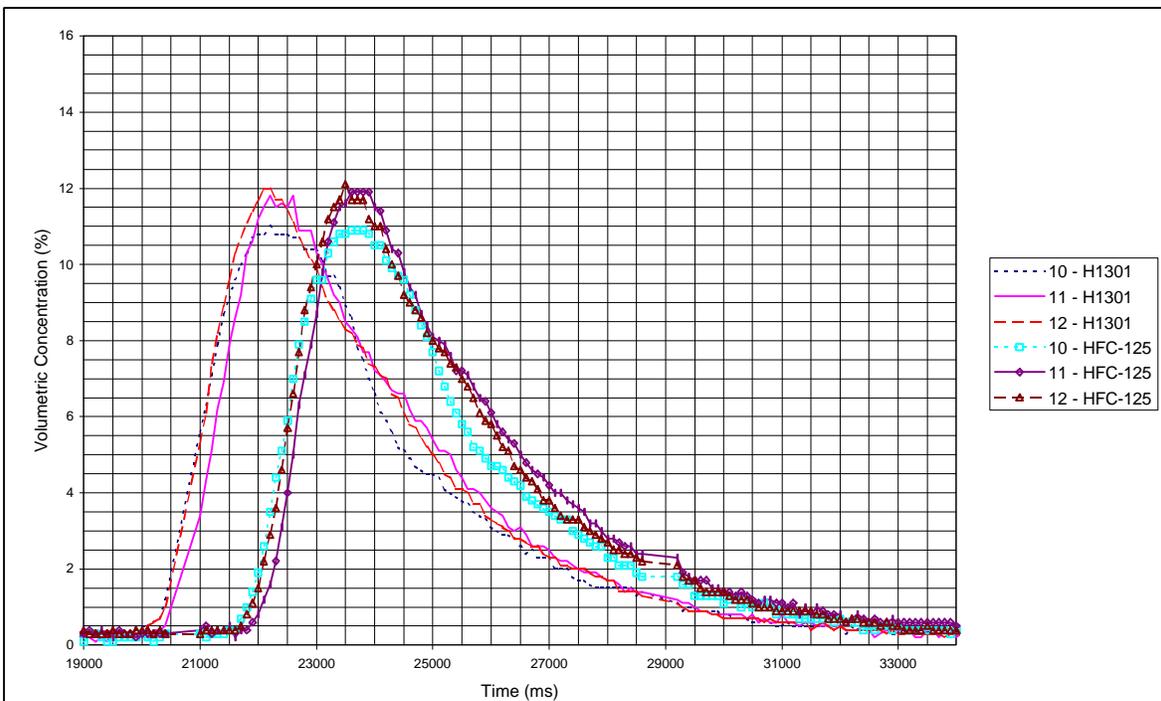


Figure 4. HFC-125 and Halon 1301 Channel Comparisons, Channels 10-12

Table 3. Volumetric Concentration Characteristics, April 1998 Simulant Tests.

Elapsed time to achieve volumetric concentration (ms)	Analyzer channel number											
	1	2	3	4	5	6	7	8	9	10	11	12
4% Halon 1301	900	<b>800</b>	<b>1000</b>	1200	<b>700</b>	<b>800</b>	<b>600</b>	<b>800</b>	<b>700</b>	<b>900</b>	800	<b>800</b>
4% HFC-125	900	900	1000	1400	700	700	700	900	800	900	700	800
6% Halon 1301	1100	<b>1100</b>	<b>1300</b>	1400	<b>900</b>	1000	<b>700</b>	<b>1000</b>	<b>900</b>	1200	1000	1100
6% HFC-125	1100	1200	1300	1600	1000	900	900	1100	1000	1200	900	1000
8% Halon 1301	1300	<b>1500</b>	1600	1700	1200	1300	900	1300	1200	1500	1300	1300
8% HFC-125	1300	1500	1600	2000	1200	1100	1000	1300	1200	1400	1200	1200
peak Halon 1301	2100	<b>2400</b>	2300	2600	2000	1900	1900	1900	1800	2300	1900	2100
peak HFC-125	1900	2300	2400	2800	1700	1700	1700	1800	1800	2200	1800	1900
percent error, duration to 4%	0.0	-12.5	0.0	-16.7	0.0	12.5	-16.7	-12.5	-14.3	0.0	12.5	0.0
percent error, duration to 6%	0.0	-9.1	0.0	-14.3	-11.1	10.0	-28.6	-10.0	-11.1	0.0	10.0	9.1
percent error, duration to 8%	0.0	0.0	0.0	-17.6	0.0	15.4	-11.1	0.0	0.0	6.7	7.7	7.7
percent error, duration to peak	9.5	4.2	-4.3	-7.7	15.0	10.5	10.5	5.3	0.0	4.3	5.3	9.5
Peak volumetric concentration												
Halon 1301	11.2	9.7	9.8	10.5	10.8	11.8	14.9	11.0	10.7	11.0	11.8	12.0
HFC-125	10.8	9.3	9.8	10.1	10.3	11.1	14.6	10.5	10.6	10.9	11.9	12.1
percent error	3.6	4.1	0.0	3.8	4.6	5.9	2.0	4.5	0.9	0.9	-0.8	-0.8
Duration of concentration at or above 6% volumetric concentration (ms)												
Halon 1301	3600	2900	3100	3200	2800	2800	3700	2900	2700	3000	3300	3400
HFC-125	3500	2600	2900	3000	2600	2600	3500	2500	2500	2800	3300	3200
percent error	2.8	10.3	6.5	6.3	7.1	7.1	5.4	13.8	7.4	6.7	0.0	5.9

Note 1: Italicized entries were linearly interpolated at one end point to calculate reported duration.

Note 2: All error calculations are made treating Halon 1301 measurements as the reference.

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