LESSONS LEARNED FROM IN-SERVICE D TO C CONVERSIONS

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Abstract

In-flight suppression testing of numerous narrow body cargo compartments has shown that the important factors in meeting detection and suppression requirements include good system design, control of leak rate, and consideration of baggage loading effects. Smoke testing results depends on a good smoke generator and air flow limitation within the compartment.

INTRODUCTION:

Pacific Scientific Company has been working in aircraft fire suppression for 35 years. The company made it into the big time in the mid 60s on the 747 and A300 with hermetic fire extinguishers which have not changed much since then. Pacific Scientific made an excellent choice of stainless steel (21-6-9) to use for pressure vessels then, and is using the same material today. We have added a variety of pressure switches and gauges and multiple outlets, but the basic design is the same. Fire extinguishers come in sizes from 10 cu in to 2500 cu in.

Pacific Scientific has become the leader in converting the narrow body fleet by the addition of suppression systems. The company is aligned with several integrators. I like to think the success is because we developed a technically advanced suppression system. It may just be a marketing serendipity that we do not have our own smoke detection group, so we have teamed with most of the detector manufacturers and integrators.

What the D to C industry is doing, because of an FAA rule change in the aftermath of the Valujet DC-9 cargo fire and crash, is adding a detection and suppression system to the narrow body fleet. The added equipment meets the requirements of a Class C cargo system. Class C cargo compartments have a suppression and detection system. The larger transport planes generally have Class C compartments, starting with the B 747, DC 10 and most of the Airbus fleet. Smaller (narrow body and commuter) planes and some DC 10s and L1011s and A320s have class D compartments. In a class D compartment, the relatively air tight sealing of the compartment was supposed to starve any fire. This has proved not to always work.

Quite a number of suppression and detection systems have been designed for 737, 727, MD80, and DC9 aircraft and other commuter airplanes and the few DC 10s and L1011s which do not have systems. There are five smoke detector manufacturer options and at least two fire suppression options. There are seven integrators that we know of, not counting the OEMs. This has equated to quite a number of STC programs at various FAA ACOs. Furthermore The Boeing Company has there own service bulletin for 727s and 737s. Douglas Boeing originally decided to come out with their own retrofit kit, but has not released anything yet.

The majority of the suppression installations have the Pacific Scientific system which is the same for all narrow body planes. The only variation is a two way valve or a three way valve based on whether the plane has two or three cargo bays. There is also some variation in nozzle configuration.

Detection Background

Detection has most always been with smoke in one form or another. The requirement is one minute detection of a small smoldering fire. In a stroke of standardization brilliance, the FAA released a tape of a small suitcase fire which became the industry standard. Today's aircraft use detectors which often look like home detectors but work a little differently. Aircraft detectors have a light source, typically an LED, and a light detector which looks for obscuration. The detector looks at the beam of light usually at a perpendicular orientation. It is looking for light scatter from the beam. If there is enough smoke to cause an obscuration of about 4%, the detector sees the beam and sends a signal.

The D to C fleet is using passive no-flow detectors. The smoke has to find its way inside the unit. Some of the wide body systems used a network of tubes and a fan to draw samples from various locations into a central detector. This system could be faster reacting, but it tends to draw in contaminants and moisture causing early failure. Also the moving parts of the fan could be a reliability problem. Therefore, the passive detectors are more popular today.

The trick for accomplishing 60 second detection has been to install more detectors. Typical compartments have from 4 to 6 and sometimes 8 detectors. Typical logic to mitigate false alarms, is to make two detectors signal a fire before the cockpit gets a fire warning. Other signal verifications such as temperature and dew point have been suggested to help screen out false alarms.

Lessons Learned No. 1

Quick detection depends of generating warm smoke and considering the air flow in the compartment. The standard smoke generators available at the start of this program generated a cold fog, being mostly water with some ethylene glycol. With this unit and others brought in for this testing, detection times were long until the smoke was heated as it exited the generator. This make the smoke rise because of added energy and tend to enter the smoke detectors recessed in the cargo liner ceiling.

But detection times were still long if smoke had to fight air movements in the compartment due to leakage. Some leaks were found in the mounting area of the smoke detectors which created an insulating blanket of fresh air, preventing smoke from reaching the detectors. Also, air drafts from the compartment pressure equalization valve to the door leak sometimes prevented smoke from reaching certain locations.

Solutions were to seal the compartments, especially around the detectors and the add more detectors to areas where drafts made certain areas smoke free.

Suppression Background

The suppression requirement is: 5% volumetric concentration initially to knock down the fire and 3% maintained for the remainder of the flight. The FAA has ruled that these values may be met as an average, not requiring 3% at every point in the compartment. European authorities seem to be demanding 3% at all points for the remainder of the flight. This raises some serious issues which will be discussed later.

The narrow body fleet has mainly settled on a 60 minute system, but some operators and asking for 90 or 120 minutes. The DC 10 and L1011 operators generally want 3 or 4 hours.

The system is pilot controlled. The detection system sends a signal to a cockpit panel which turns on a fire light and master caution and perhaps an aural warning. The pilot then selects the cargo compartment, or accepts the selection made by the alarm, and pushes a button to start the suppression.

We call it suppression rather than extinguishing since the fire may not be fully extinguished. Smoldering could continue and re-ignition occur when the Halon 1301 concentration decays below 3%. It has been noted in tests that embers may not be extinguished unless the exposure to 5% or more is quite long.

Historically there are several types of systems being used in cargo compartments:

1) Single discharge of high rate bottle into a well sealed compartment.
   This is a simple, light weight system, generally designed to provide well over 5% concentration. It is being used for up to one hour systems. It may not provide extended protection as the compartment ages and leakage increases. It has been argued that high concentrations achieved actually extinguish the fire so maintaining 3% may not be important.
2) Multiple discharges of high rate bottles.
   This is still a simple system. It is used for short and long time systems. Two bottle, discharged over an hour apart are being used for three hour systems. It is usually a heavy weight option since it does not use Halon efficiently, using excessive concentration to extend the time until concentration decays to 3%. The two bottle systems still may have significant times when concentration drops below 3% during certain flight scenarios. For instance the following chart is a computer model of a typical two bottle system for a one hour system. The computer model plots average

concentration for a compartment with a leak rate of 2000 cubic feet per hour (CFH).

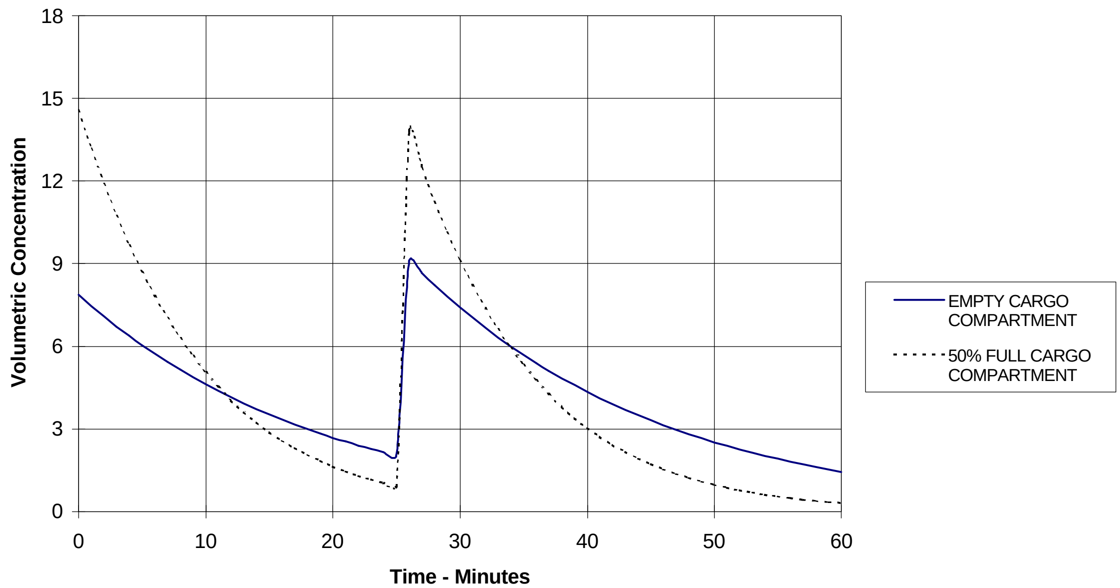

FIGURE 1. Concentration vs Time
600 cu ft, 2000 CFH leakage, Two high rate 20 lb bottles

Even if agent amounts are increased to stretch the system to several hours, the dips below 3% will occur.

At only 1000 CFH, the same system performs a lot better. Figure 2 models a 1000 CFH leak rate compartment.

If you can guarantee leakage less than 500 CFH, practically any system will maintain concentration. Of course it should be noted, that this is a computer model of the average concentration. Certain areas of the compartment, generally near the ceiling, will drop below 3%. This is acceptable under FAA rules, but may not be acceptable under CAA and JAA rules.

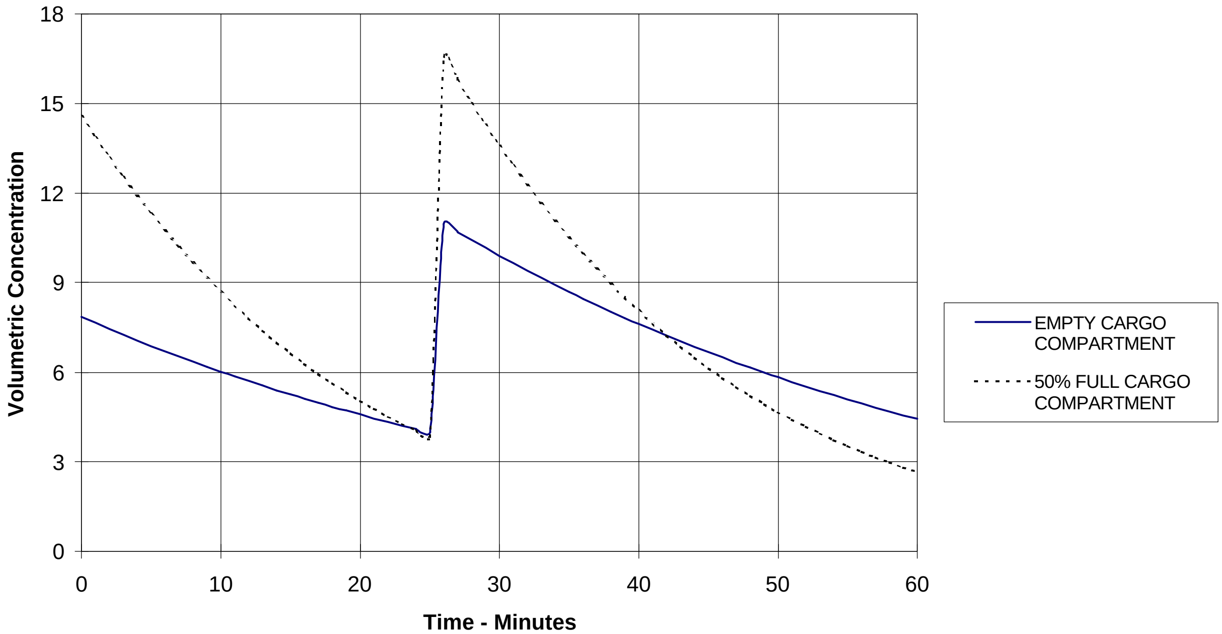

FIGURE 2. Concentration vs Time
600 cu ft, 1000 CFH leakage, Two high rate 20 lb bottles

3) Metered systems using orifices built into secondary bottles.

There are several systems installed on planes which use one high rate bottle discharge followed by a simple metered system discharge which consists of a bottle with an orifice either inside the bottle or down stream of the bottle. The orifice meters the Halon flow, but has more flow when the bottle is hot (higher pressure), less flow when cold (lower pressure). This is opposite of what the physics would demand for protecting a compartment. When a compartment is cold, it requires more flow to maintain 3% concentration than when it is hot. The following figure shows two types of metered bottle, a stand alone bottle with an interior orifice, and a dual bottle. The dual bottle has a high rate part, the outer bottle, and a metered inner bottle

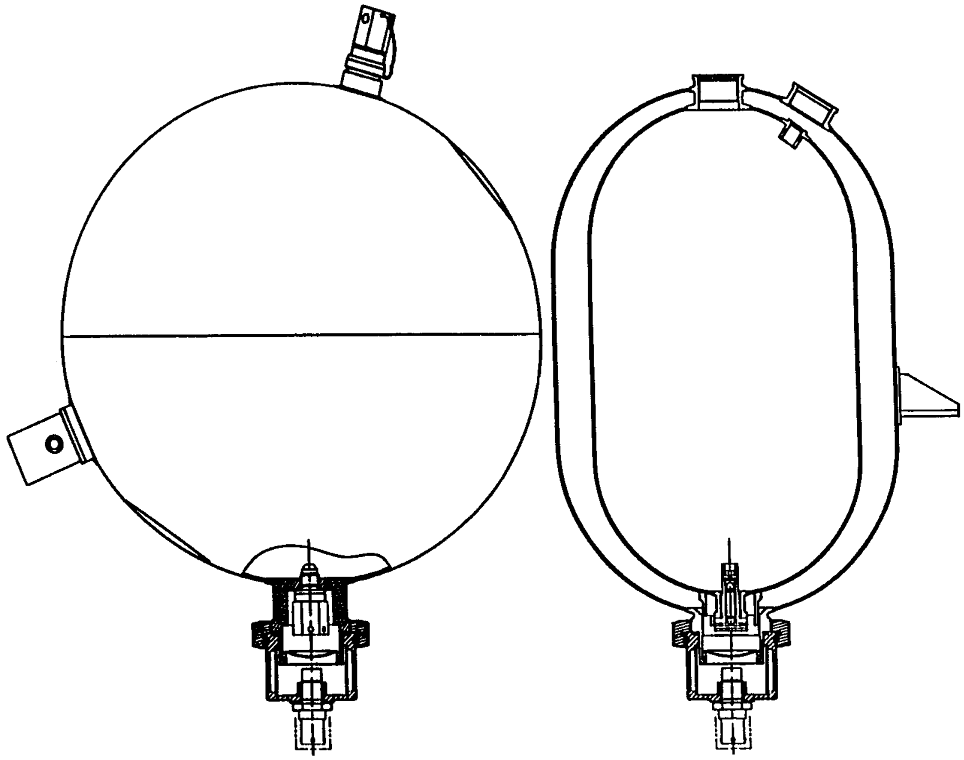

FIGURE 3. METERED BOTTLES

4) Metered systems using regulator and orifice systems.

There have been many planes supplied with simple pressure regulators and an orifice or series of orifices to regulate flow. These systems are good and use Halon efficiently. Most Airbus planes, and Boeing Seattle planes from the B767 on use this system.

There is still one problem. Halon does not flow well through orifices even if a pressure regulator can supply it with constant pressure. When Halon is cold, it is denser than when it is warm.. Therefore cold Halon flows through an orifice at a faster mass rate than warm Halon at a fixed pressure. This change in density can be visualized as follows: A typical Halon bottle may be half full of Halon at 70 °F. As it gets to 130 °F, it becomes completely liquid full. Clearly the density must be less for the 130 °F Halon.

5) Metered systems using temperature compensated regulators and orifice.

This system offers the best performance over a reasonable temperature range. The Pacific Scientific metering valve for the D to C program uses a temperature compensating regulator. It senses the Halon temperature and changes the regulated pressure slightly to even out the mass flow. The assumption is that the Halon bottle and the cargo compartment are at about the same temperature. The valve actually lets the mass flow increase slightly when the Halon is colder because a colder compartment needs more Halon to maintain 3%. Figure 4 shows the complete system

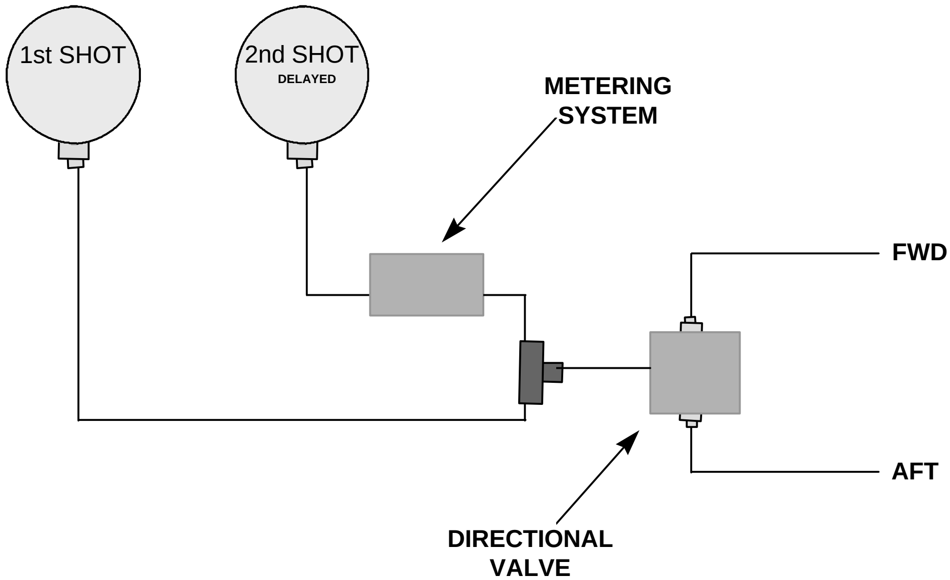

FIGURE 4. System Schematic

Figure 4a is a computer model of how the metered system would perform using the same compartment shown in Figure 1.

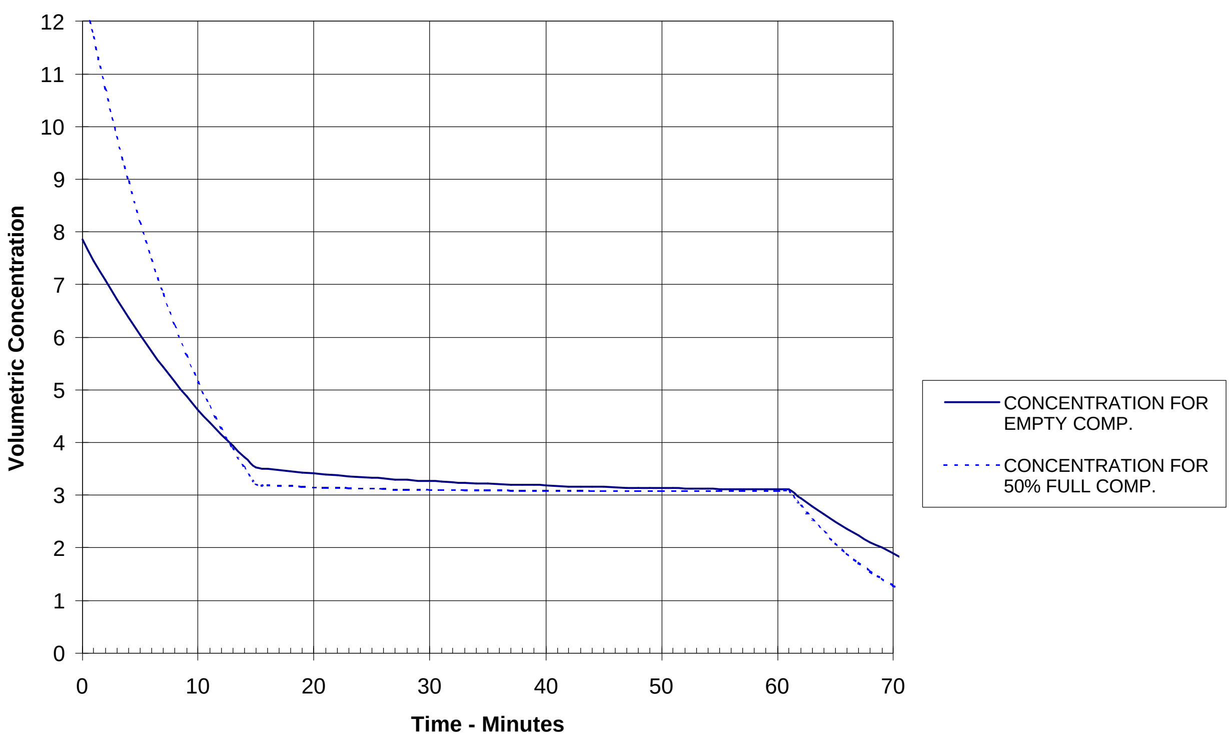

FIGURE 4a. Concentration vs Time Model for 600 Compartment
2000 CFH leakage, 20 pound bottle high rate, 20 lb bottle metered at .42 lbs/minute

It should be noted that Halon flow loves to freeze up in restricted flow. Contaminant moisture tends to plate out at an orifice where the Halon can chill well below the ice formation temperature. The process takes place because water is slightly soluble in Halon at room temperature. When Halon gets colder while flowing thru an orifice, the solubility of water goes much lower and it comes our of solution. Since it is often below the freezing point, it comes out of solution as ice. There are about two ways to prevent this from happening:

1. Use a filter dryer in line with the metering system.
2. Use methanol in the Halon.

Pacific Scientific has opted for the methanol. We are using 0.5% methanol by weight. Methanol works by allowing water to remain in solution at lower temperatures and lowers the freezing point of the water if it does come out of solution.

The industry is still using Halon 1301. When the mandate to add suppression systems to another 6000 airplanes, the industry was polled to see if there was enough Halon. We agreed that there was. Currently Pacific Scientific treats Halon as a commodity. We buy 100,000 pounds per year for our fire extinguishers. Some of this is imported. The US can import Halon if the exporter gets a permit from the EPA.

Lessons Learned Number 2.

Control of a fire (or from our stand point, maintaining sufficient concentration) is easy if the compartment leak rate is small. This effect was shown in earlier charts. But let’s look at it again and look at the data we have gathered. When Pacific Scientific started the first program, the leak rate to be experienced was unknown.

Analytically we knew that leak rate would be the important variable. The following curve is a model of average concentration decay of a typical size compartment with several leak rates.

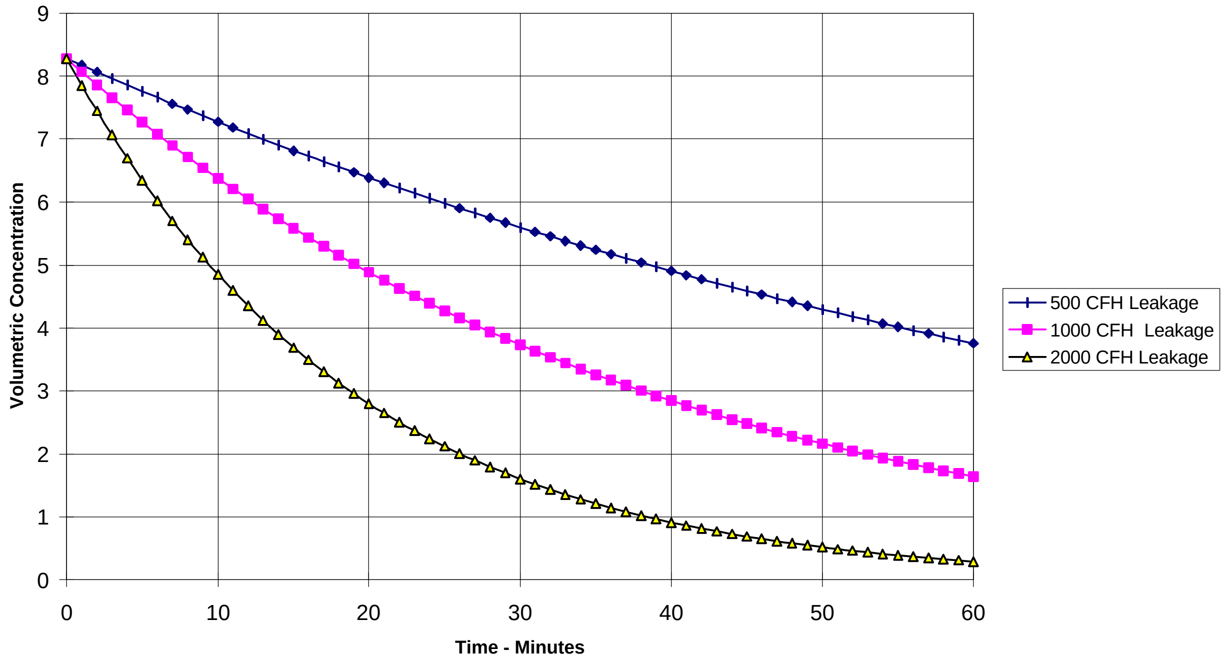

Figure 5. Computer model of various leak rates
600 cu ft compartment volume, 20 lb Halon discharge

We could easily size the first shot fire extinguisher to be adequate for the compartment size range, but for the metered shot, we had to select a maximum leak rate which would allow a compromise of weight savings and fleet maintenance practices.

The largest compartment in the narrow body and commuter fleet was about 800 cu ft. Twenty pounds was adequate for this volume to achieve an initial 5% concentration.

We selected a leak rate of 2000 cubic feet per hour (CFH) as our maximum. Polling the OEMs gained little definitive help. So we did some leak testing by, firing a bottle into compartments in flight and measuring decay rate and back calculated the leak rate. We were lucky to have willing partners in an airline and integrator. We had a plane available for quite a series of tests.

The integration team undertook a classic series of smoke and suppression tests. They compared ground smoke tests with flight smoke tests. (Ground testing was not much use). We did flight compartment leak tests by firing bottles of Halon into the compartment and measuring decay. We did metered system tests with the compartment empty and then full.

Table 1 is a listing of tests we have conducted from those early days until now, showing the calculated leak rates.

	AIRCRAFT	SYSTEM TYPE	TEST TYPE	LEAK RATE (cu ft/hour)
1	DC9-30 AFT	High rate (leak test)	Engineering Test flight	700
2	DC9-30 FWD	High rate (leak test)	Engineering Test flight	2000
3	DC9-30 FWD	Metered	Engineering Test flight	1400
4	DC9-30 AFT	Metered	Engineering Test flight	780
5	DC9-30 FWD (FULL)	Metered	Engineering Test flight	1000
6	DC9-30 FWD	Metered	Certification flight	1000
7	DC9-30 AFT	Metered	Certification flight	660
8	737-300 AFT	High rate (leak test)	Engineering Test flight	2000
9	737-300 AFT	Metered	Engineering Test flight	Not measured
10	737-300 AFT	High rate (leak test)	Engineering Test flight	1000
11	737-300 AFT	Metered	Engineering Test flight	960
12	MD82 MID	Metered	Engineering Test and Certification	280
13	737-300 FWD	Metered	Engineering flight	1500
14	737-300 AFT	Metered	Engineering flight	840
15	727-200 FWD	Metered	Engineering flight	6000
16	727-200 AFT	Metered	Engineering flight	6000
17	737-300 FWD	Metered	Certification flight	1620
18	737-300 AFT	Metered	Certification flight	1200
19	727-200 AFT	High rate (leak test)	Engineering, Ground Test	900
20	727-200 FWD	High rate (leak test)	Engineering, Ground Test	690
21	727-200 FWD	High rate (leak test)	Engineering, Flight	500
22	727-200 AFT	High rate (leak test)	Engineering, Flight	1000
23	727-200 FWD	Metered	Certification flight	1500
24	727-200 AFT	Metered	Certification flight	1200
25	MD82 FWD	Metered	Certification flight	600
26	MD82 MID	Metered	Certification flight	720
27	MD 82 AFT	Metered	Certification flight	540
28	FALCON 20	Metered	Certification flight	1600
29	727-200 AFT	Metered	Certification flight	1400
30	727-200 FWD	Metered	Certification flight	1300

* Note: The leak rate for high rate discharges was calculated using a computer model which matched the decay rate of the average concentration.

TABLE 1. LIST OF DISCHARGE TESTS

For the metered system, 20 pounds of Halon is adequate if we delay the bottle firing for 15 minutes. The concentration from the first bottle will decay to about 3% in 15 minutes in the worst case. Adding Halon at a rate of 0.4 pounds per minute will maintain the compartment at 3% if the leak rate is 2000 CFH. 0.4 pounds per minute will provide about 50 minutes of flow from a 20 pound bottle.

When we test an unfamiliar airplane, often one of the first tests done is this decay test: firing a bottle into the compartment and measuring decay. The primary leak source is the door seals. Also, the MD80s have 1/8 inch drain holes in the door frame. Figure 6A is a typical decay test. In this test, concentration was measured with the Pacific Scientific Halonyzer II, an instrument approved by the FAA to measure concentration. 12 probes were mounted in the compartment to draw samples into the Halonyzer.

Figures 7 and 8 are typical tests with the metering system actuated. Notice certain probes begin to drop early. These are probes which are 4 inches from the ceiling. The forward probes drops first since it is higher than the rest due to angle of attack of the airplane.

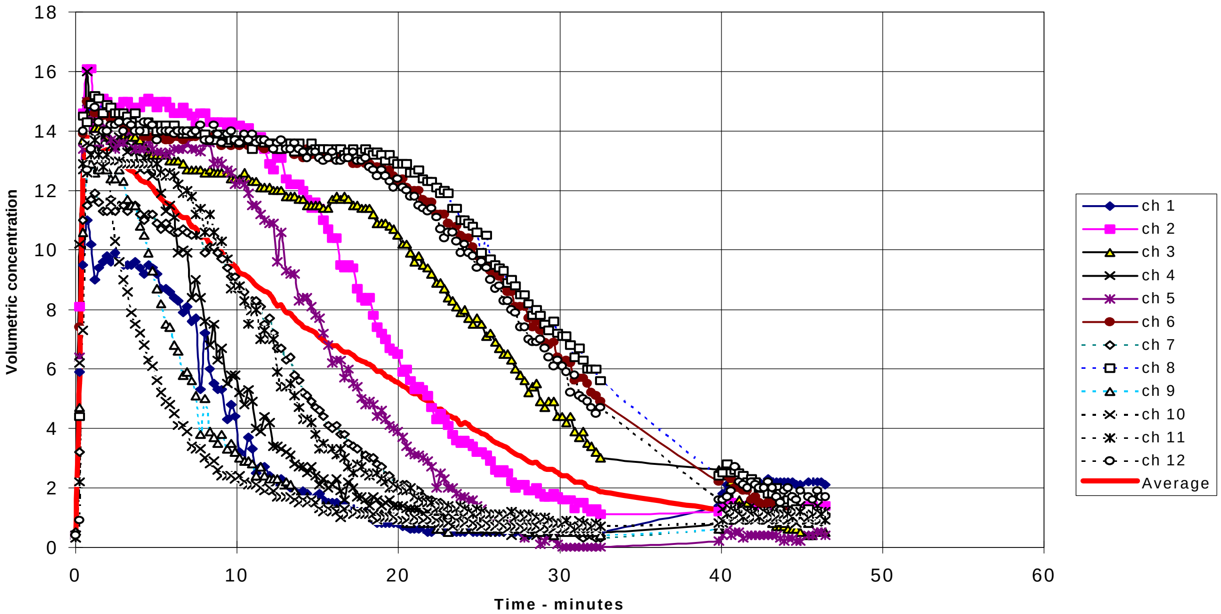

FIGURE 6A. 737-300 flight test, High rate bottle, 33 pounds for leak test
600 cu ft compartment, 8000 ft altitude

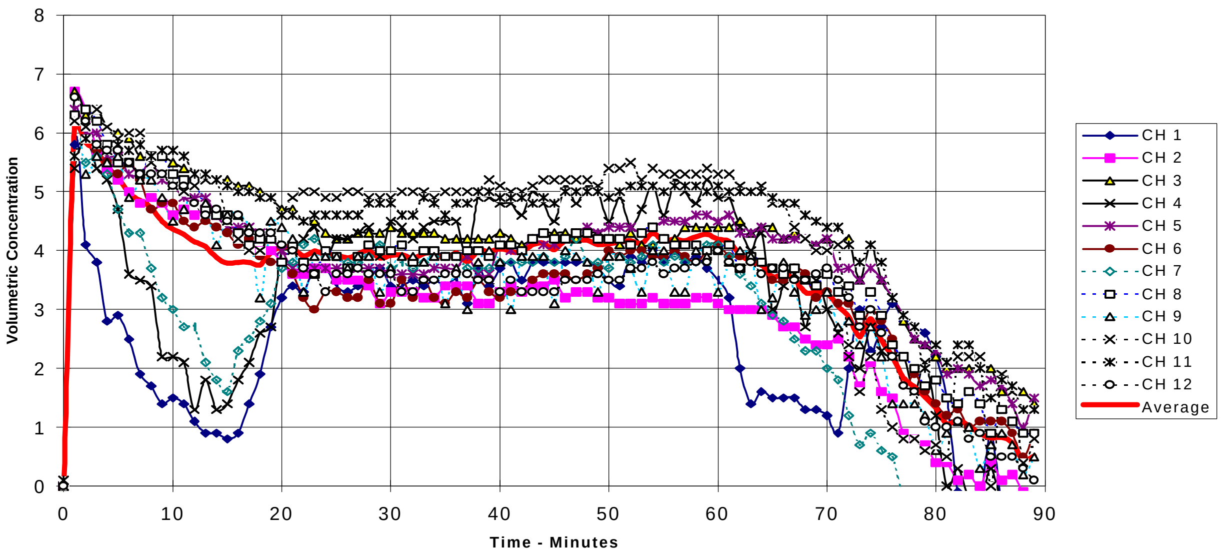

FIGURE 7. Concenrtration Certification Test, Aft Compartment 727-200, 1500 Ft Altitude

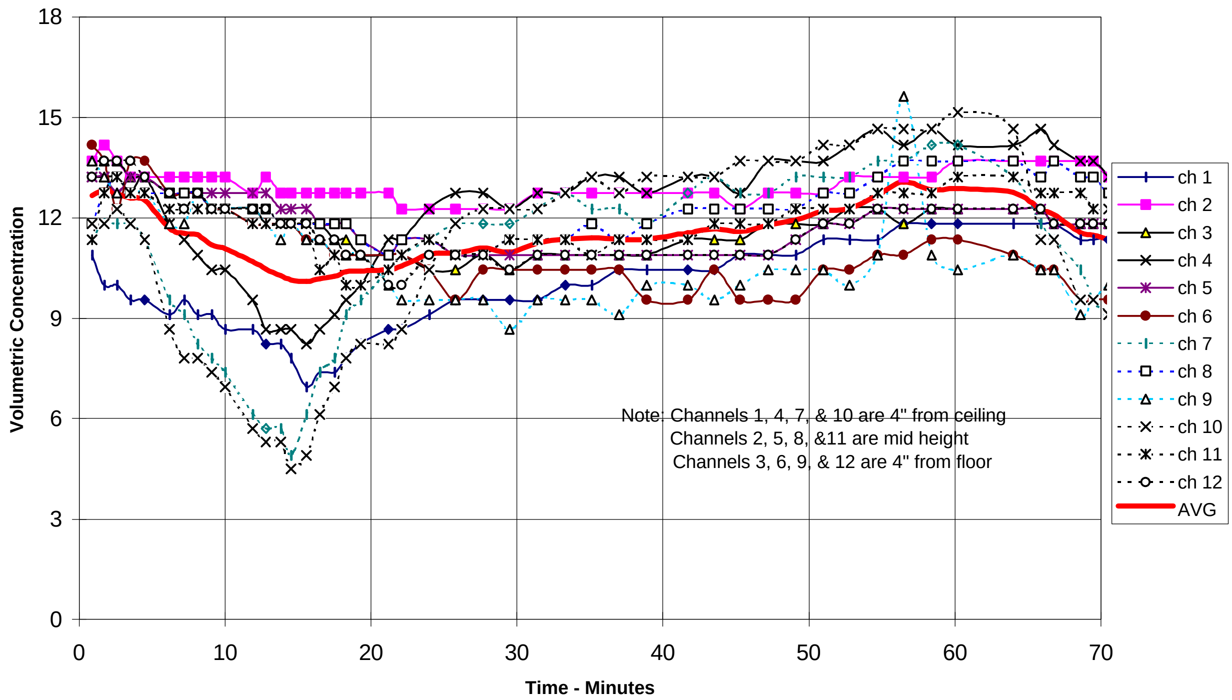

FIGURE 8. Metered System Test MD82 Forward Cargo

There is another way to assess leakage. Since the door is the prime source of leakage, pressurizing the plane on the ground to 7 or 8 psi and feeling around the door seals can be sufficient to know that a metering system will provide adequate concentration. With practice, this method can distinguish between an acceptable leak and an unacceptable leak.

We thought that unpressurized compartments would not have leakage since there is no pressure differential blowing air out a door seal leak. This turned out to be false in our first test of an unpressurized compartment. Apparently the shape of the fuselage at the door can create a low pressure which allows a poor door seal to leak. More on this as we gather more data.

Lesson number 3. Baggage loading condition makes a difference.

Analytically full compartments are a harder condition to protect than empty compartments. Once the high rate bottle has enough agent to cover the empty condition volume, forget about the empty condition. The full condition is the toughest. Baggage makes the compartment small and more difficult to protect because the number of air changes per hour increases. Imagine a large compartment with a small hole in the door seal. A certain leak may cause an air change within an hour. But now say that the size of the compartment is compressed with baggage. The same leak exists and the number of air changes can more than double. This causes a faster decay of concentration. It is true that you will build up higher concentrations initially, but this decays fast.

Figure 9 is a computer model of three baggage load conditions with a 20 pound high rate bottle discharge.

Figure 10 is test data from a DC-9 compartment which was stuffed with boxes and bags of packing material. It was 60% full.

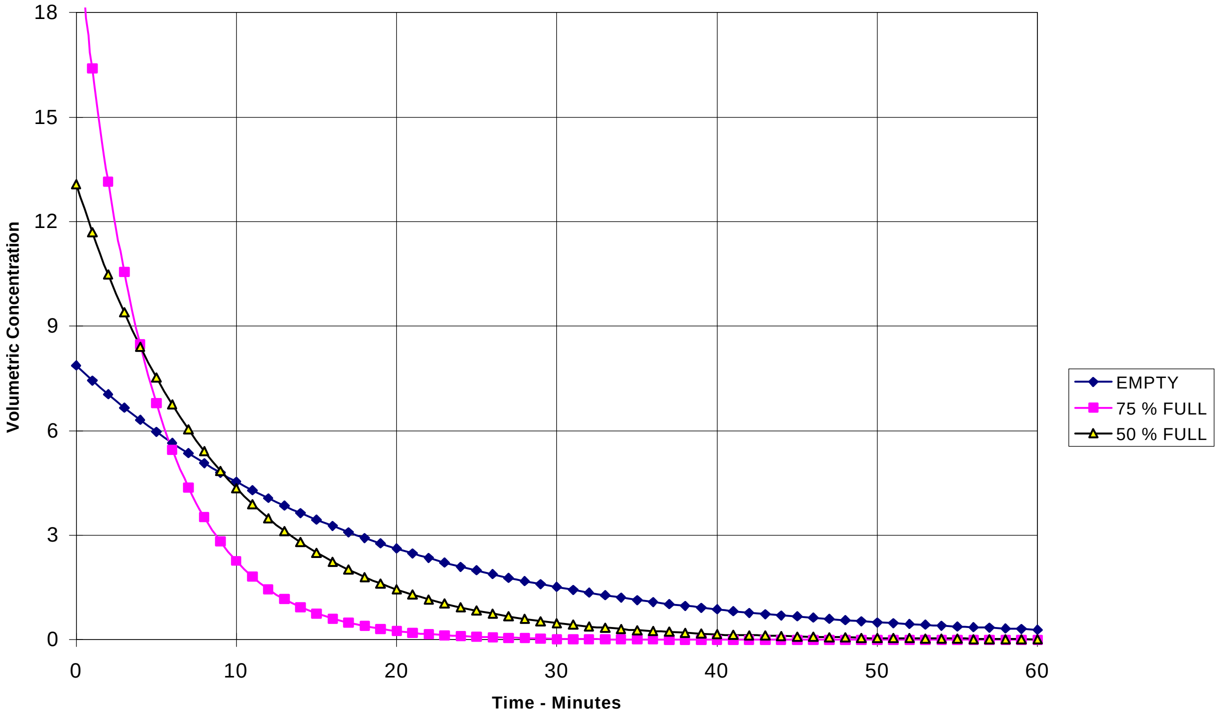

FIGURE 9. 20 POUND BOTTLE IN TO 600 CU FT COMPARTMENT WITH VARIOUS LEAK RATES

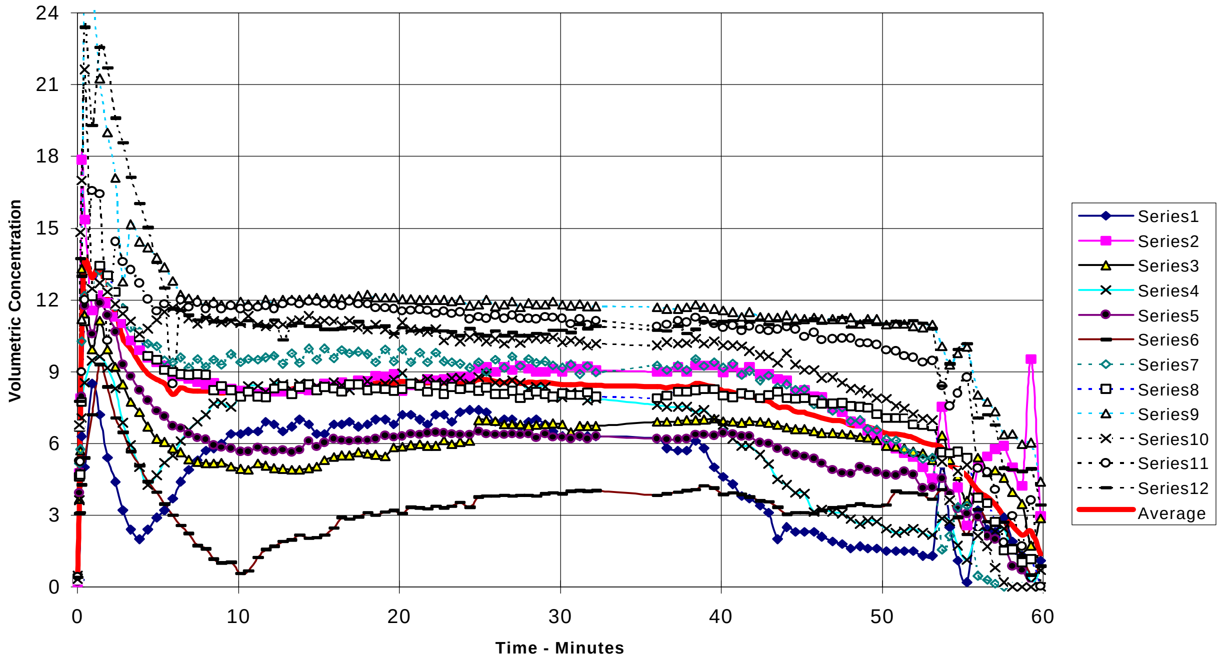

FIGURE 10. DC9-30 Forward Compartment, 60% full 20 lb high rate, 20 lb metered, 8000 ft altitude

The consideration of these lessons lead us directly to the best engineering solution for the cargo compartments. It wasn't the cheapest system, and it was different than what Boeing and Douglas were offering

This design keeps a good mix of Halon in the compartment, unlike the high rate systems which allow separation, low concentration on top. Look at how the concentration falls away from the ceiling in a typical test. We wait 15 minutes for first bottle, but if we had only one bottle or had to wait about 30 minutes for a second high rate bottle, more of the area would fall below 3%.

The metered system more important for small compartments or compartments which will receive high loading percentage.

Nozzle design is important. It is important to have sufficient nozzles to initially have good mixing of Halon with the air and have an even distribution. The same nozzles can be used for the metering system to keep the compartment evenly inerted.

Acknowledgments:

The author wishes to thank ValuJet, AAE, and Barfield for giving Pacific Scientific the opportunity to test the original suppression system and the foresight to test beyond the FAA requirements.