

AIRFRAME AND PROGRAM IMPEDIMENTS AND INCENTIVES FOR INCORPORATING NONHALON TECHNOLOGIES

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ABSTRACT

Although there are incentives for transition to nonhalon fire protection alternatives, the impediments for immediate transition to commercial and military aircraft are significant. This is especially true for retrofit programs. Both military and commercial aircraft have very stringent requirements for safety, certification, performance, weight, volume, and acquisition and operational costs. All the halon replacement technologies must compete on the basis of these as well as their firefighting figures of merit. This paper will compare several of the leading nonhalon technologies on these bases, provide an airframer's perspective on the impediments and incentives for transitioning the alternative technologies, and recommend approaches to future research of nonhalon alternatives.

APPLICATIONS

There are several aircraft applications for fire protection systems on all types of military and commercial aircraft. Commercial aircraft must protect the cargo bays, the passenger and crew compartments, the lavatories, APU bays, and the engine nacelles, while military aircraft may protect fuel tanks, dry bays adjacent to fuel tanks, crew compartments, APU bays, and engine nacelles. The crew, APU, and nacelle protection systems of military and commercial aircraft have much in common with the potential for dual use of the technologies developed in one segment having wide application in the other. While the area being protected may be similar, the customers and incentives driving the selection of the extinguishing agents can be very different.

The challenges of protecting the cargo bays of commercial aircraft and the dry bays of military aircraft are unique and little commonality is anticipated except for fire detection sensors developed for one may be applicable to the other. The following discussion will concentrate primarily on military aircraft applications.

Fuel Tank Protection: Some military aircraft protect fuel tanks from ballistic threats. One of the ballistic threat protection concepts used has been to inert the fuel tanks with halon before the aircraft enters the combat zone. Aircraft using this scheme include the Lockheed F-16. (Boeing products use other protection concepts, which are neither pilot activated nor halon based.) A simplified schematic of this approach is shown in Figure 1. When the pilot anticipates a threat, he activates the halon system and in a short period of time the fuel tank ullage space (the gas space in the tank above the fuel) becomes inert because of the concentration of halon. The pilot then has a modest period of time to perform any combat maneuvers with the tanks protected until the halon is depleted, then the tank ullage space will be replenished with air and shortly thereafter become non-inert. The inert period is dependent on several variables including fuel volume, and the degree and aggressiveness of vertical maneuvering. A contract has recently been awarded to study the use of CF_3I for this application. CF_3I is a reasonable choice based on a comparison with the other potential alternatives shown in Table 1.

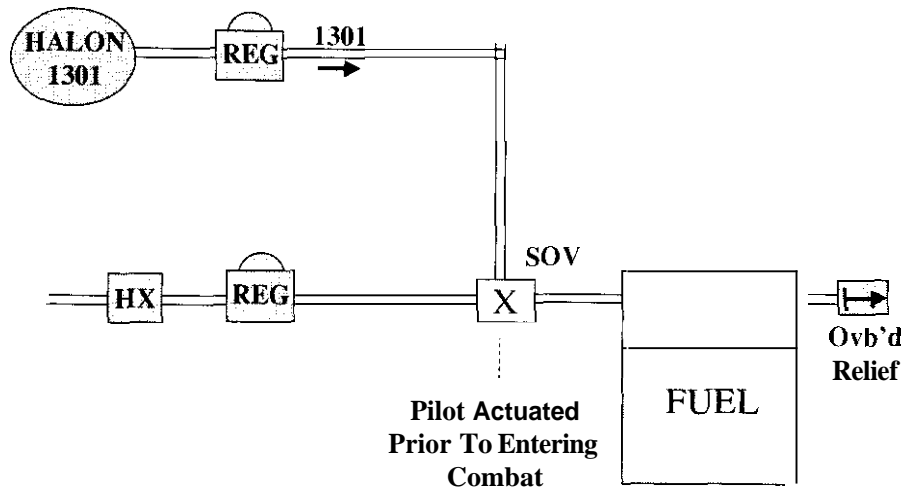


Figure 1. Simplified schematic of halon fuel tank protection system.

TABLE 1. ALTERNATE “AGENTS” FOR FUEL TANK PROTECTION (REPRESENTATIVE F/A).

“Agent”	Equipment’; Weight (lbs)	ODP (-)	GWP (-)	Atmospheric Lifetime (vrs)
Halon	26	16	5,400	65
HFC-125	54	0	2,800	33
CF ₃ I	31	< .01	< 1	< 0.005

* Equipment Weight = Agent Weight + Container & Valve Weight (total system weight would add lines, regulators, brackets, etc.)

Since the tank is non-occupied, and agent discharge occurs while airborne, operational toxicity is not an issue. Post-flight servicing and in-tank maintenance may become concerns if the pilot lands while the tanks are still inert, although this is unlikely based on the mission and agent design quantity.

Engine Nacelle and APU Compartment Protection: The engine nacelles and APU compartments are protected by similar and sometimes shared systems with the engine nacelle usually being more challenging than the APU Bay because of its larger size and greater ventilation airflow. The following discussion will be restricted to engine nacelles, although the conclusions can be reasonably extended to APU compartments.

Most multi-engine aircraft are required to have fire protection of the engine nacelles, regardless of whether they are commercial, military, fixed wing, or rotary wing aircraft. This protection is provided to ensure that a fire associated with one engine can be extinguished and the engine secured, allowing the remaining engine(s) to supply the necessary power to return to base. Single engine aircraft are usually not protected since extinguishing a fire usually requires securing the only engine. The exceptions to this general rule are some of the single engine Fighter/ Attack

aircraft designed in the former Soviet Union; some of these have fire protection systems to allow the pilot some short period time to select a preferred bailout location.

The historic protection systems for engine nacelles have been halon based. These systems have sensors in the nacelle to detect a fire, which then activates an advisory in the cockpit. The pilot typically reduces throttle and closes the firewall shutoff valve to the affected engine denying fuel flow to that nacelle and, hopefully, the fire. If the sensor continues to indicate that fire is present, the pilot will discharge the bottle to extinguish the flames. The fire is usually extinguished, but may reignite if there are surfaces in contact with the leaking fuel which remain hot enough to cause reignition after the “agent” concentration falls below some critical limit (Figure 2). Some multi-engine commercial aircraft helicopters provide a second shot capability to cover this situation.

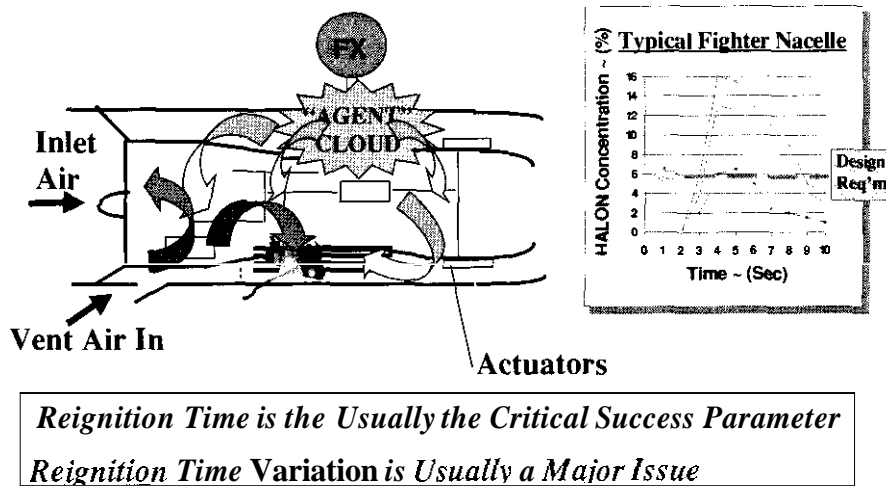


Figure 2. Engine nacelle protection.

Weight penalties have been calculated for several alternate technologies for representative Fighter/Attack aircraft engine nacelle Fire Protection Systems and are presented in Table 2.

TABLE 2. ALTERNATE “AGENTS” FOR ENGINE NACELLE PROTECTION (REPRESENTATIVE F/A).

“Agent”	Distribution	Equipment* Weight (lbs)	ODP (-)	GWP (-)	Atmospheric Lifetime (Years)
Halon	Baseline	12	16	5400	65
HFC-I25	Baseline	22	0	2800	33
	Improved	17	0	2800	33
CF ₃ I	Baseline	14	< .01	< 1	< .005
	Improved	11	< .01	< 1	< ,005

* Equipment weight = agent weight + container and valve weight (total system weight would add lines, regulators, brackets, etc.)

DESIGN CHALLENGES

There are several design challenges when incorporating any fire protection technology. Three of the more interesting challenges are discussed in the following paragraphs. They will be described in association with engine nacelle protection but the issues may have broad application.

The impact of temperature change on bottle discharge pressure and the subsequent effect of changing pressure on “agent” performance can be significant. Bottles are typically filled with “agent” to approximately 50% capacity (50% fill ratio) then charged with nitrogen to approximately 600 psi at ambient temperature. As the bottle cools, pressure decreases and as the bottle is heated pressure increases. In addition to the effects of the “agent’s” vapor pressure (the dominant variable at high temperature) and gas expansion and contraction, the nitrogen gas dissolves into the “agent” and evolves from the “agent” with temperature and pressure changes. Aircraft setting on the ramp overnight, at high latitudes, in winter months can “cold soak” to very low temperatures. Temperatures of -20 °F are not uncommon and -40 to -60 °F are not unheard of. Some commercial airliners mount the bottles in the wing leading edge or in the pylons, which guarantee temperatures in the -60 °F range at altitude. Some Fighter/Attack aircraft mount the bottles in the keel between the engines. During some flight conditions, these bottles, even with insulation and ventilation, can approach +250 °F. This broad range of potential operating temperatures, the resulting pressure changes associated with these changes, and the reliance on fixed geometry discharge/distribution systems can result in significant variation in performance at various temperatures.

The variation of bottle pressure with temperature for HFC-125 at 50% ambient fill ratio is presented in Figure 3. The fire protection performance variation with pressure resulting from temperature variations is presented in Figure 4 for a representative test series. “Fire-Out Time” is used as the performance figure merit. Testing at high and low temperatures complicates the certification effort, increases cost, extends schedules and increases uncertainty, especially with the fixed geometry systems usually deployed. Several approaches could be considered to address this pressure/temperature variation issue including the following:

- Variable geometry systems (increased weight & cost)
- Heaters (increased cost & power)
- Increased ventilation flow (increased drag)
- Hybrid pressurization (added variation of pyrotechnic combustion pressure with temperature)

Establishing the required temperature limits is both aircraft and mission dependent, requiring significant effort for each vehicle.

The concern about low temperature performance of CF₃I is directly related to the preceding topic. Since CF₃I boils at approximately -9 °F and halon 1301 boils at approximately -73 °F, there is concern that the halon equivalent performance of CF₃I observed at ambient conditions may fall off dramatically at very low temperatures. Figure 5 presents concentration data for various temperatures for CF₃I discharged into a small room with no ventilation. Although the data do not fully simulate an engine nacelle, they do indicate that performance can be degraded at low

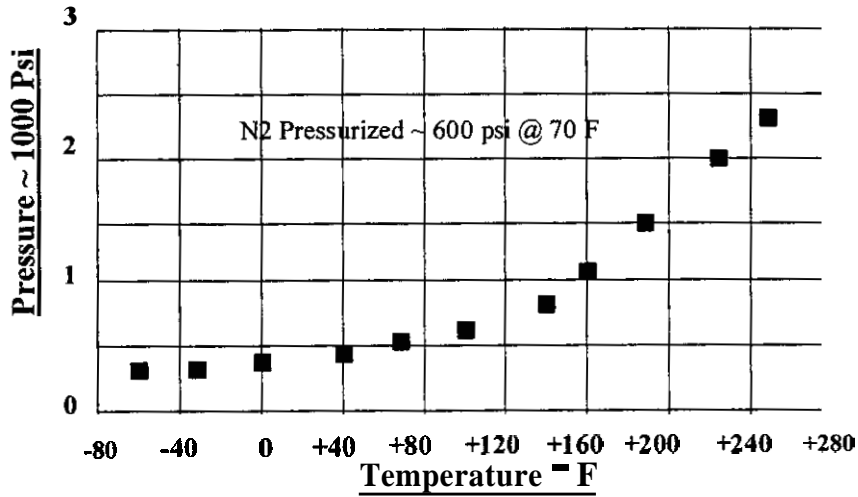


Figure 3. HFC-125 bottle pressure variation with temperature.

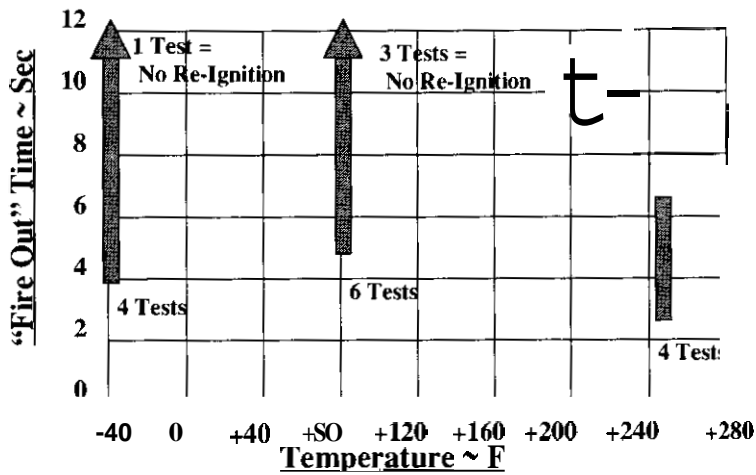


Figure 4. Variation of fire protection performance with temperature - HFC-125 testing.

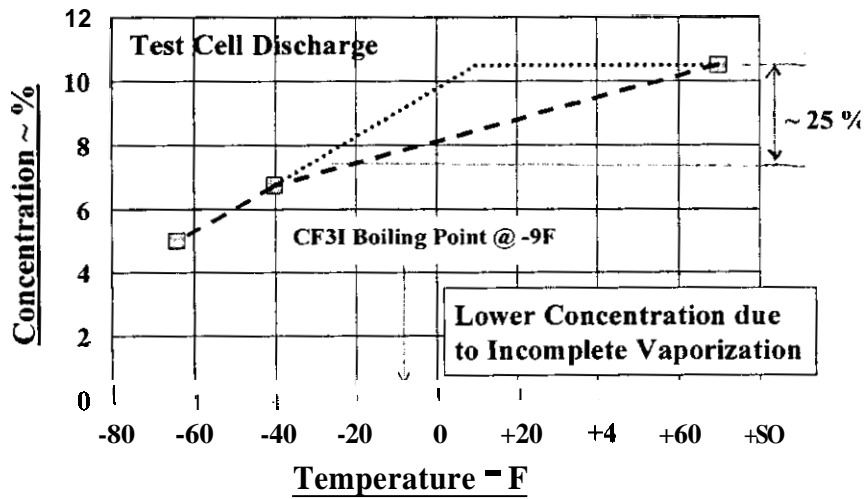


Figure 5. Reduced CF₃I concentration @ lower temperatures.

temperatures. Three approaches have been suggested to address the low temperature performance issue:

- Increase the quantity of CF₃I to compensate for reduced effectiveness at lower temperatures (approximately 25% increase for -20 °F performance).
- Add a heater to the bottle.
- Hybrid pressurization (Discharge a small Gas Generator for pressurization) which should also provide heat to warm the “agent.”

A system weight comparison of these approaches is presented in Table 3.

TABLE 3. LOW TEMPERATURE COMPENSATION CONCEPTS — ENGINE NACELLES.

“Agent”	Low Temperature Concept	Equipment’ Weight (lbs)	Halon Equivalent Volume
CF ₃ I	Baseline	14	1
	Extra Qty	16	1.25
	Heater	15	1.1
	Hvhrd	13	0.7

* Equipment weight = agent weight + container and valve weight (total system weight would add lines, regulators, brackets, etc.)

Analytical modeling tools, which allow cost effective simulation of engine nacelle geometry, ventilation, “agent” discharge/distribution, and concentration predictions, are needed to improve the design process and to reduce the time and money required for certification testing. Boeing is evaluating a commercially available CFD program whose results look promising, but much more work is needed to validate the program with test data, to determine the maximum grid size that still yields meaningful results, and to reduce the turn-around time to test multiple configurations. Continued improvement in computer capability and enhancement of the CFD code may make cost-effective simulation available for the next major program. If this can be done for engine nacelles, it may be applicable to cargo bays, passenger compartments, etc.

The simplified modeling, described above for program use in designing a fire protection system for a specific vehicle, may be too crude to understand fully the science of fire suppression, extinguishing, and re-light prevention. Both industry and the research community may need more detailed, complex, and resource intensive tools to understand and develop viable, cost effective halon replacements and to establish design/certification guidelines for their use.

IMPLEMENTATION PROCESS

To develop and implement a new nonhalon fire protection technology is a complex and time consuming process. The major elements of this process include the following:

- Research to develop and evaluate a nonhalon concept
- Recommendations to a program for implementing the concept
- Study authorization from program management/customer and/or regulator.

- Program performs preliminary design/cost/ implementation study
- Customer/Regulator re-considers change and approves ECP submittal
- Program formally proposes ECP/design change/cost/effectively/schedule
- Customer/Regulator formally approves program, funding, effectively, retrofit, etc.
- Detailed system designed, procured, and certified
- System fabricated, installed, and tested in production and/or retrofit aircraft

This serial process will typically take 5 to 10 years from concept formulation to incorporation into the first aircraft and involves a wide variety of disciplines and organizations.

CERTIFICATION

Several production programs have certified HFC-125 engine nacelle fire protection systems on the basis of measured HFC-125 concentration without extinguishing fires in simulated engine nacelles (e.g., V-22 and OH-XX). These aircraft programs demonstrated conservative HFC-125 concentrations (approximately 15 to 18%) by test methods similar to the historic halon certification methods. This approach may impose significant weight penalties on the aircraft by requiring more HFC-125 than is required by actual **fire** testing. The F/A-18E/F program has successfully certified an HFC-125 system at approximately 120% of the halon weight by actual live fire testing.

Some retrofit programs are considering modification of their “Two-Shot” halon systems to make “One-Shot” HFC-125 systems based on a review of the field fire safety data that indicated that the “Two-Shot” system is seldom effective in extinguishing a fire on the second shot when the first shot had been unsuccessful. This approach will result in an HFC-125 quantity of approximately two times the minimum halon required to provide the same level of protection.

In the near term, if **we** are committed to minimizing the weight, volume, and cost penalties associated with nonhalon alternatives, there is no viable choice but to accept continued actual fire testing to develop and to certify those technologies for service. The knowledge base is simply not adequate to abandon this approach in the near term. In the longer term, this approach is too expensive, too time consuming, facility restrictive, and cumbersome to continue. Moving to an approach similar to the certification of the traditional halon systems seems to be the consensus goal. The halon certification process offers several advantages: suppliers, the airframe industry, and the certification agencies accept the approach; there is a large experience base associated with it; and it is much less costly and much easier to accomplish than actual fire testing.

One of the major limitations to accepting the halon-like method is the current level of uncertainty associated with concentration measurement. HFC-125 data from recent engine nacelle testing using the Gas Analyzer type concentration measurement system (Figure 6) indicated that the fire was extinguished at concentrations well below the accepted cup burner levels, and that reignition occurred at concentrations twice those of the extinguishing concentration (Figure 7). These tests were conducted with 1/4-inch diameter sense tubes transporting engine nacelle air/agent samples to the *Gas* Analyzer. Calibration testing with the sensors exposed to normal air at 0% halon concentration, followed by a “square wave” exposure to 100% halon, demonstrate the slow response of the existing system. The results show near 0% concentration readings early in the exposure cycle and a delay of 2-3 sec to reach 100% concentration (Figure 8). This has been attributed to the diffusion of the air/ halon interface in the 1/4-inch line ~~as~~ it moves through the sampling line (Figure 9).

Uses change in pressure drop across a screen to infer concentration. Intended for use with constant pressure and flow.

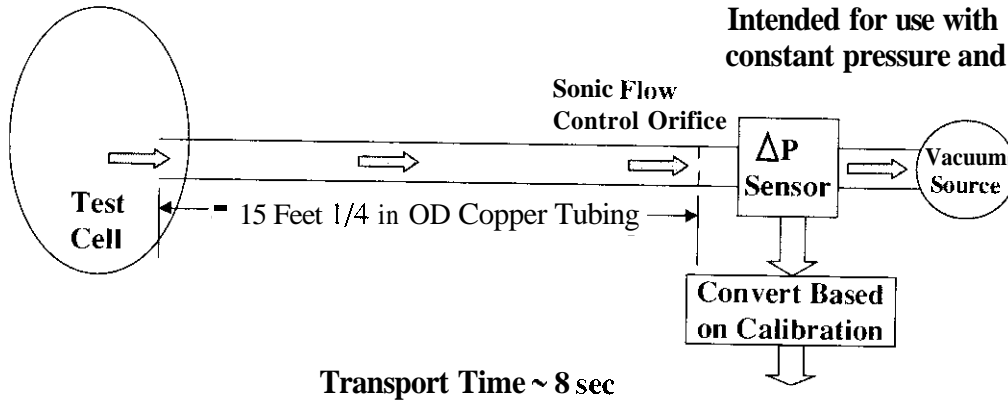


Figure 6. Gas analyzer concentration measurement

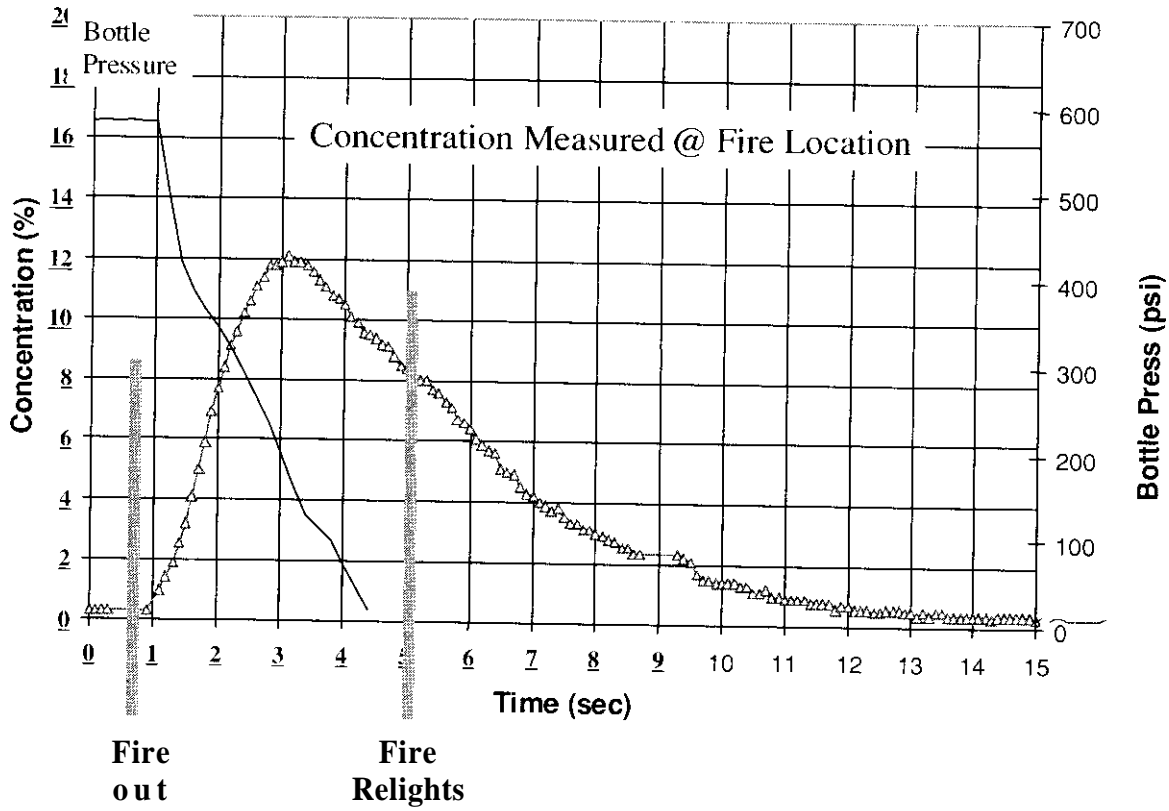
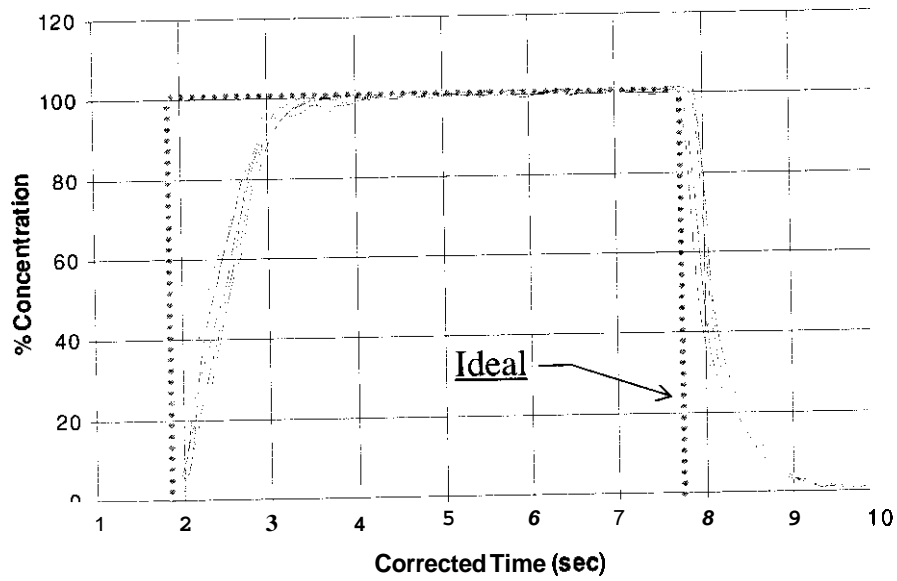


Figure 7. Comparison of measured concentration and fire extinction event.

Calibration Run CF3I Discharge Test 12/96- Halonyzer Data



- All channels have been adjusted to common estimated start time
- All channels exposed to same level at the same time
- Similar results during simple testing on F/A-18E/F with HFC-125

Figure 8. Gas analyzer response to square wave input.

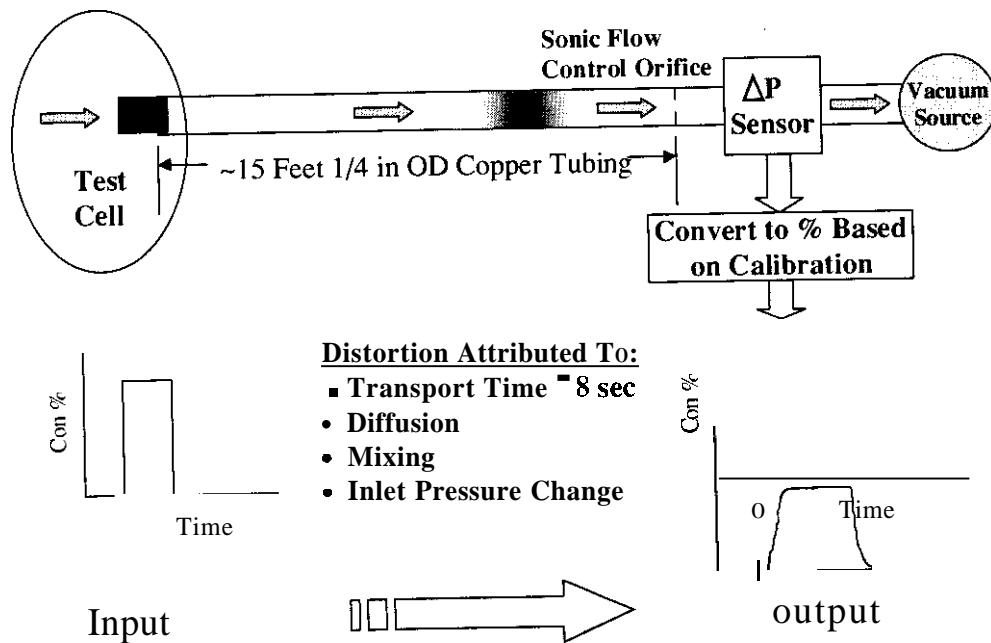


Figure 9. Diffusion of the air/halon interface in the gas analyzer.

Several approaches have been considered to address this issue, but none has yet completed the full live fire test cycle. Some reports indicate that changing the sense lines from 1/4-in diameter to 1/8-in diameter will improve the response time significantly; however, there will still be issues associated with the transport process. Boeing has developed an IR-based in-situ sensor to eliminate the transport issues and to provide high response, high accuracy data. There are plans to test this sensor in a live fire test rig (no fire discharge test) in **CY 2000** in parallel with a Gas Analyzer system for comparison.

One should note that the current system might be perfectly adequate for certifying halon systems. The slow response is conservative in predicting extinguishing concentrations, and halon chemically reacts with the fire which provides an unquantified extra degree of safety. The 0.5-sec inerting time and 6% concentration are both usually far exceeded in most of the nacelle. The problem is more severe with the nonhalon alternatives when trying to minimize the weight, volume, and cost impact associated with their use.

If we can obtain high quality concentration data on several nonhalon technologies on several test rigs that have parallel actual fire testing, we can begin to assemble the data needed to establish nonfire certification guidelines. This will require some additional effort on the next several actual fire test programs, but the savings on the first nonfire certified vehicle will more than pay for the additional effort. This is a case when programs need to fund "Another Science Test," because the potential downstream savings are so large. In fact, some programs have already begun moving toward nonfire certification, but they are doing so based on very conservative concentration values that may impose weight penalties too high for many programs to accept.

IMPEDIMENTS TO AND INCENTIVES FOR TRANSITION

The interest in developing nonhalon alternatives for potential future applications is a well-recognized need both in altruistic terms as responsible citizens making a good faith effort to develop effective alternatives, and in pragmatic terms to maintain the essential use of halon until cost effective replacement technologies are available. Transitioning the newly developed alternative technologies into actual service is more problematic.

Unless the customer procurement policies or contracts require nonhalon systems or political developments, disasters, etc., cause concern about loss of access to the halon stockpile, program managers will need some incentive to overcome the natural inertia **and** transition from the current, legal, effective, safe, no additional cost halon-based technology. For new product designs, new technologies that are equal to halon in terms of cost, effectiveness, volume, etc., could easily be accepted provided the non-recurring costs associated with those technologies were nearly equal to those associated with halon systems. In the absence of these conditions, only technologies less expensive than halon will be attractive, because of the heavy current emphasis on affordability for both military and commercial aircraft. Retrofit is an even more complex issue.

Retrofit approaches can be grouped into two basic strategies:

- (1) Retrofit by attrition in which halon is replaced by nonhalon at the next scheduled halon service cycle, bottle activation, etc., by substituting nonhalon as the preferred spare and only procuring nonhalon for those spares. This is the most convenient, least disruptive, least expensive strategy preferred by most customers and program managers. The implications of

this exact strategy require that the nonhalon alternative be a “direct one for one drop-in” replacement. A somewhat more expensive variant of this strategy would be to make minor modifications to the vehicle during this replacement: however, even minor modifications of aircraft are relatively expensive.

- (2) Forced retrofit would require that all aircraft be forced to retrofit to a nonhalon system on a fixed schedule. This will likely be much more expensive, may force planes out of service, and may have significant impact on the customer. This approach is likely to be resisted, especially in light of the size of the current halon stockpile. Some commercial airliners are scheduled to be in service for 12 to 16 hours, carry hundreds of passengers, and generate up to a million dollars in revenue each day. The cost and inconvenience associated with placing an aircraft down for any extended period of time for retrofitting new nonhalon technologies are very high. Any retrofit concept that is too complex to fit within the routine servicing/inspection/repair cycle will likely be resisted. Military aircraft do not have the same financial impediments, but generals and admirals are evaluated in part on the sortie generation rate and aircraft availability. They will not want to accept complex retrofit activities that will adversely impact their record, opportunity for promotions, or a chance to “Beat Charlie’s” unit as a superior war-fighter.

The following implications are for nonhalon technologies based on this simplistic assessment:

- (1) The non-recurring costs associated with actual fire testing are too high to be continued as a long-term certification method. Less expensive methods, similar to the current halon certification methods are needed. Developing these methods will require a much better understanding of the science associated with the fire protection (suppression, extinguishing, preventing/delaying re-light, inerting, etc.). Much better methods for predicting fire protection system performance are also needed. In the near term, engine nacelles need much more accurate concentration measurement: in the longer term, more convenient and more accurate performance prediction tools need to be developed.
- (2) The retrofit systems for nonhalon alternatives need to be direct one for one drop-in systems (or nearly so) to avoid costly and time consuming retrofit. The lavatory trash container protection system, certified in cooperation with the FAA, is a good example of this approach.
- (3) Nonhalon technologies that are equivalent to halon in every respect may not be quickly transitioned unless there a cost advantage as compared to halon. Since this is unlikely, transition is likely to be slower than some would like.
- (4) The current successful transitions of HFC-125 to the production versions of the V-22, F-22, and F/A-18 E/F engine nacelles have been customer driven. This is likely to continue for all near term future transitions. (There are significant costs associated with abandoning the halon technologies.) In the longer term, other issues such as policies, regulations, public image, political climate, etc., may drive transition.

CONCLUSION AND RECOMMENDATIONS

The maturity of some of the nonhalon alternative technologies now allow deployment for several applications including engine nacelles, lavatory, and dry bays: however, the vehicle level impact of some transitions are still significant, especially for retrofit applications. The high cost of implementing new systems, particularly on existing aircraft, is a strong deterrent to incorporation of nonhalon systems. Additional work is needed to further define and reduce the negative

impacts of transition. Attention to the total "lust to dust" programmatic issues including less expensive, less complicated, higher confidence certification strategies, and retrofit impact will be required before program managers can justify making a change. These programmatic issues and the technical issues still need to be addressed including performance variation with temperature, operational temperature limits, improved analytical modeling techniques, and concentration measurement accuracy and response. Regardless of these difficulties, aggressive research needs to continue to mature cost effective alternatives and to maintain essential use of the existing halon stockpiles.