IMPACT OF HALON REPLACEMENT ON AIRCRAFT ENGINE BAY FIRE PROTECTION SYSTEM DESIGN

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INTRODUCTION

Following the adoption of the Montreal Protocol. the United States Navy issued OPNAV Instruction 5090.2A, barring the inclusion of specifications or standards requiring Class I ozone-depleting substances (ODS), such as Halon 1301, from any contract awarded after I June 1993. **A** recent Navy fighter aircraft program was among the first programs affected by this instruction. In response, the Navy/Contractor (Boeing and Northrop Grumman) team considered a number of technologies, including inert gas generation, Halon 1301-like liquid agents, and dry powders to replace Halon 1301 in engine bay fire protection systems. Transferring the technology from the laboratory and small- to medium-scale testing to full-scale application has been difficult. During full-scale testing, trade studies, and efforts at design incorporation. a number of significant issues were encountered. The objective of this document is not to endorse any of these or other technologies, but rather. to give the reader an understanding of those design issues and their potential effects on the future incorporation of non-halon technologies into existing and developing military aircraft.

AGENT DESCRIPTIONS

Gas Generation

Inert gas generation is a technology that has sparked keen interest in all branches ofthe US military as a potential replacement for Halon 1301. This technology involves the controlled burning of a solid propellant to produce a large quantity of inert gases. including nitrogen, carbon dioxide. and water vapor. As the development of gas generators continued, active fire extinguishing chemicals were added to the propellant mixture. The formulation of these solid propellants varies from supplier to supplier.

Liquid Agents

Since the discovery of the effects of ozone-depleting substances, the scientific community **has** been hard at work trying to find an agent that can be used as a "one-lor-one" replacement for Halon 1301, that can both interfere with the chemistry of the fire and cool surfaces in the area of the fire to prevent reignition. Compounds such as HFC-125 have been very promising.

Dry Powder

Dry powder-based agents have been used for years in handheld fire extinguishers as well as larger, in-situ systems. Generally speaking, they are based on the same baking soda compound that one would use to put out a grease fire in a kitchen. Additives are mixed in to improve the flow characteristics and prevent caking in damp conditions.

AIRCRAFT OPERATING ENVIRONMENT

Before proceeding to specific design issues involved with replacing Halon 1301 in military aircraft engine bays, the surrounding environment must be understood. The engine bays of modem military aircraft, especially small fighter aircraft, are very tightly packed. The addition of even a small component, or the movement or enlargement of an existing one could make maintenance activities such as engine removal impossible or so difficult as to violate maintainability requirements. Even if the component is added early in the developmental stages of the aircraft, it may he moved to a location that does not allow for optimum performance or next to another component that may interfere with its operation. Location can be critical in the case of fire extinguishing components.

The thermal environment of the engine bay, depending on the aircraft and engine design, can be severe. Surface temperatures during normal operations can exceed 400 "F, and non-operating temperatures can reach –65 "F. Additionally, in most aircraft specifications. critical systems, such as the fire extinguishing system, are required to operate following a 5 min exposure to a 2000 °F fire in the fire zone (i.e., the engine bay). Engine bay ventilation/cooling airflow can make fire extinguishing more difficult unless it can be minimized or stopped altogether prior to discharging the agent. This is impossible with most aircraft, meaning that in such aircraft, the fire may be sustained by airflow rates of several pounds per second, depending on the flight condition. This ventilation/cooling airflow can sweep the fire extinguishing agent out of the affected engine bay before hot surfaces have cooled, potentially allowing the fire to reignite.

Vibration and shock loads are one of the most difficult environmental conditions to account for in the design of any component. With potential accelerations of more than 25 G resulting from aircraft vibration and 15 G or more resulting from shock requirements, few parts are able to pass these required tests on the first attempt.

Even the outside environment can he a challenge. The ambient temperatures, altitude, humidity, salt, fog, etc., work together to cause parts to fail. This is especially true of naval aircraft lashed to the deck of an aircraft carrier in bad weather.

Every component in the aircraft must demonstrate that it can not only withstand these environmental conditions but consistently perform to specification requirements during and after exposure.

IMPACTS ON SUBSYSTEM **DESIGN**

The impacts of Halon 1301 replacement will vary from aircraft to aircraft depending on such factors as aircraft configuration, desired mission, etc. The information presented herein is based largely on lessons learned while attempting to incorporate some of these emerging technologies into an existing aircraft design. It would be impractical to attempt to discuss all of the possible design impacts here; therefore, this discussion will limit its focus to general concerns of component qualification, system installation, maintenance, system safety, weight, and cost.

Component Qualification

All components installed on an aircraft must he certified to meet the detailed specification requirements for both performance and safety in all foreseeable operational and noli-operational conditions.

In **a** general sense, for ***a*** component (in this case the agent tank) the qualification requirements for hoth liquid agents and dry chemical agents are similar to thosc for cxisting Halon 1301 containers. It is likely that these agents will he placed in a pressurized vessel and installed in an area adjacent to the enginc bays. Aside from possible agent chemical compatibility issues with other aircraft components or structure, qualification of the pressure vessel will probably he identical, whether the agent is **a** dry powder. ***a*** liquid agent such as HFC-125, CF_3I, or Halon 1301. In each of these cases. the system will probably he actuated using **a** commercially available explosive cartridge to open a burst disk in the agent tank, allowing the agent to flow through a series of distribution tubes to strategic locations in the fire zonc. **All** of these potential extinguishers must also demonstrate compliance with Department of Transportation (DOT) shipping requirements.

Gas generators, both active and inert, must fulfill significantly different qualification requirements due to the method used to produce the extinguishing agent. Due to the presence of the propellant, large gas generators are considered cartridge-actuated devices. To qualify a cartridge-actuated device for aircraft use, requirements such ***as*** those of MIL-D-21625G, "Design and Evaluation of Cartridges for Cartridge-Actuated Devices." [1] must be satisfied. In **US** Navy programs, qualification requirements are broken up into three separate test programs: Design Verification Tests (DVT). Service Release Tests (SRT), and, for devices containing more than 1 lb of propellant (or other explosive mixtures), Insensitive Munitions (IM) Tests. These test programs are extensive and require a large number of test extinguisher units.

DVT verifies that the part meets the requirement of the specification in a fashion similar to that required of the liquid or dry powder agents. MIL-D-21625G requires that up to 174 extinguisher units he dedicated to both functional (i.e., destructive) and non-destructive tests including 40-foot drop tests and a combined **temperature-altitude-liumidity** endurance tests. Passing this test program freezes the design configuration.

Subsequent to the successful completion of DVT and design freeze, SRT is conducted. The SRT procedure repeats many of the tests conducted in DVT. The difference between the two test programs is that SRT is conducted on the "production" configuration subsequent to "design freeze." The intent of SRT, therefore. ***is*** to demonstrate that the final design of the part ***is*** safe for use in the field. Up to 192 extinguisher units are required for this test program.

The final test program required is insensitive munitions. The purpose of this test series is **to** demonstrate that the part will not react in any way that would he hazardous when subjected to environmental extremes or battle damage. Fourteen extinguisher units are required for this series. To verify that the gas generator (regardless of whether its product gases are inert or active) is an insensitive munition. the following five tests must be conducted: bullet impact. fragment impact, sympathetic detonation. fast cook off. and slow cook off. In order **to** pass, the gas generator reaction to each of these tests must he no more severe than this: "the energetic material ignites and burns, non-propulsively. The case may open, melt or weaken sufficiently to rupture nonviolently, allowing mild release of combustion gases. Debris stays mainly within the area of fire. This debris is not expected to cause fatal wounds to personnel or be a hazardous beyond 15 m (49 ft)" [2]. The interpretation of the test results in relation to the requirements is done by the Government's Insensitive Munitions Board. If the gas generator does not fully meet these criteria, a redesign of the gas generator may be required.

System Installation

Before discussing the topic of system installation in any depth, some simple facts regarding the engineering task of systems installation should be noted. Modern military aircraft, especially fighter aircraft, are very compact; there is little unallocated space. When trying to locate system hardware, it becomes clear very quickly that the fire extinguishing system is not considered the most important system aboard. If a hard interference or riding condition involving a fire extinguishing system component and another part or structural component occurs, something must move. Depending on the impact of relocating the other component, it may be the fire extinguishing system part that will move. The issue does not have to be a hard interference. If a part of the fire extinguishing system is within the engine removal envelope, for example, it must be moved. The engine will not be made smaller nor will the removal envelope be altered to accommodate the fire extinguishing system. Design requirements have been established to avoid these problems. They include requirements to route the distribution system tubing such that it will clear all structural elements and other components by 1/8 in and avoid both the engine and the engine removal/installation path by at least 1 in. These and other issues, such as designing for maintainability (discussed in a later section herein) make the installation of the system one of the most challenging tasks of the design process. The issue is even more pronounced if the system is being put aboard an existing aircraft as a retrofit.

Location, Location, Location

Based on some recent fire extinguishing testing completed on a fighter-type aircraft engine bay simulator [3], the effectiveness of Halon 1301 was demonstrated to be significantly less sensitive to discharge location and orientation than HFC-125, dry chemical, or gas generator-based agent. Factors such as agent discharge location, direction, and airflow strength and direction can drive the design of a successful system. As in real estate, aircraft fire extinguishing is all about location, location, location.

The size of the fire extinguisher, the space available, and environment in the aircraft engine bay will determine if the extinguisher unit is placed in situ in the engine bay, or remotely located with the agent flow plumbed in. If the fire extinguisher is installed in the engine bay, a fire-resistant electrical harness must be routed to the unit to provide power, actuation signals, and receive status data. The presence of the electrical harness will generally preclude the installation of the fire extinguisher in the optimal location, at the bottom of the bay, on the engine bay access door. The concern here is that the harness will be susceptible to damage when the door is cycled open and closed, resulting in reduced system reliability. Locating the fire extinguisher along the sides of the engine bay may result in interference with the engine removal envelope. The top of the bay, above the engine and between any protruding structural members may be the most likely location within the engine bay. Unfortunately, available space and access are very limited, so the fire extinguisher would have to be minuscule.

If the fire extinguisher is too large to fit in the engine hay, it can bc remotely located and the agent plumbed in. With this option as well, extinguisher size must still he limited depending on the space available in bays adjacent to the engine hay. If more space is available in a corner far away from the engine hay, a study is conducted to determine whether the increase in available volume will offset the discharge pressure losses and the additional discharge tubing weight that the system design must absorb to deliver the agent thc longer distance. Space available for the fire extinguisher unit is not the only issue that must hc addressed when rcmotely locating thc system.

Space must also bc available for routing tubes that will transport the agent to its discharge locations as well as for brackets to support the tubes. Thc tlow rate at which thc fire extinguishing agent will he delivered to the fire may be limited by the largest tube diameter that can be routed through the aircraft from the extinguisher to the engine hay. If the tlow rate is insufficient to defeat the anticipated fire. the extinguisher location must he reconsidered.

Materials

Typically, the material used for Halon 1301 distribution system agent transport tubes is aluminum, titanium, or corrosion resistant steel. The material choice is based on weight. cost, and the ability of the system to function after being exposed to an engine bay fire for 5 min [4]. Halon 1301 is nonreactive with most metals, *so* material compatibility has heretofore not been an issue in the design of the system. With the new agents. this may no longer he the case. Whatever the agent chosen for a design. it must be demonstrated not to he chemically reactive with the hardware with which it will come in contact. This is not just applicable to the extinguishing system hardware. hut to the hardware (including seals. paints. etc.) in the engine hay as well. In the event of an inadvertent discharge of the agent, a subsequent change-out or inspection requirement of engine hay equipment is unacccptahle.

Material compatibility is not just based on chemical reactivity. Thermal issues must also bc addressed. If the agent is vcry cold when discharged, as with the liquid agents, any detrimental effects of cooling the distribution system and other engine hay equipment must hc assessed. If the agent is very hot when discharged, as with the gas generators, the effect of the heat must also he assessed. **If** the discharge of the agent heats or cools the discharge tubes, the material from which those lines are made must be able to maintain sufficient strength and elasticity **as** not to fail. The installation must also take into account any potential expansion or contraction of the lines during hcating or cooling.

Brackets and Supporting Hardware

Distribution lincs are not the only components that must be designed for elevated or decreased agent temperatures. Depending on the extcnt of the temperature change, slip fits through bulkheads must he used, rather than standard bulkhead fittings. The brackets supporting these tubes must also he designed to accommodate these changes **as** well. Failure of ***a*** bracket may subsequently cause the failure of the system to extinguish the fire by either contributing to a tube failure or by misdirection of the discharging agent.

Care must also he taken when designing the brackets holding the fire-extinguisher unit. In addition to encountering the greatest of any possible temperature effects, these brackets must also overcome the thrust loads of the extinguisher, whether it is discharging a liquid agent, dry chemical, or hot gases.

Other Installation Considerations

Depending on the type of system selected, liquid, dry chemical, or gas generator, other design considerations must be addressed. In the case of liquid agents, low points in the tube routing (traps) must be eliminated and measures must be taken to account for the possibility of dual-phase flow especially during cold environment operation.

In the case of dry chemical usage, and to a lesser degree, gas generators producing a high degree of solid particulate, steps must be taken to avoid the possibility of the agent clogging the lines after a discharge. In the life of an airframe, the fire extinguishing system may be discharged more than once, whether due to inadvertent actuation or against an actual engine bay fire. Because the discharge lines may be ‘‘buried’’ in closed-out areas of the structure of the aircraft, it may be impossible to replace these lines without a major overhaul. Consequently, the possibility of agent clogging a tube is unacceptable.

SAFETY

A light, low-cost, non-toxic, effective fire extinguishing agent with benign effects on the environment is desired by all. In reality, compromises will likely be required. The selection of an extinguishing agent is driven by several factors. Performance, cost, and safety are three of the critical factors in selecting a fire-extinguishing agent. Additional critical factors are the system weight and agent volume and complexity of the supporting system. The prime requirement of any tire extinguishing agent is the ability to extinguish a specified fire, in an operational scenario. Safety for the people that manufacture, transport, store, use, and dispose of agents is also a key requirement. This does not mean an acceptable agent will be free of all potential hazards to personnel or the environment.

Fire Protection in Engine Nacelles

Aircraft engine nacelles are an excellent example of the application of safe design features to the fire protection system, which significantly reduce the risk to maintenance personnel. Inadvertent release of a fire extinguishing agent during maintenance activity is the most likely way to expose personnel. The fire protection control systems controlling discharge of fire extinguishing agent into the engine nacelles of modem aircraft have been designed with effective safety interlocks minimizing the possibility of inadvertent release of extinguishing agent in the presence of maint-enance personnel. Additional measures may be taken to protect maintenance personnel from the effects of direct contact with the agent, such as installing mechanisms to divert the agent plume issuing from the discharge nozzles when personnel are in the engine bay. With these modern control systems and other measures, a less benign agent could, with minimal additional risk, be considered as a substitute for the current halon-filled tanks.

Safety at the System Level

Hazardous and toxic chemicals are in constant use throughout industry and the military. Applying the principles and analytical processes of system safety. safety communities coordinate with R&D organizations rind industry in two important ways: the selection of agents that are acceptably safe for specific applications. and secondly, assisting systcm design engineers in developing agent deployment systems compensating for residual hazards of the fire cxtinguishing agents to personnel or the environment. In the process, fire-extinguishing agents arc evaluated for effectiveness in fire extinguishing, inherent hazards to people. and threats to the environment. This analysis, evaluation. and design process is even more necessary today with the mandated elimination of halon in new US military aircraft. In specific applications. an evaluation of potential agents should also consider whether compensatory safety features can he designed into a fire-extinguishing discharge system to reduce the inherent hazards of extinguishing agents to people and the cnvironment.

Determination of Hazard Severity and Probability

The System Safety community uses analytical processes such as those outlined in MIL-STD-882 " System Safety Program Requirements" [5] to assess the severity of hazards and the probabilities of occurrence for components, subsystems and systems in design. After conducting a safety assessment of each hazard. its severity, and the probability of occurrence are entered into a table, which can be tailored to specific program requirements. The table provides a combined expression of severity and probability, known as the Hazard Risk Index (HRI). Using Table I. the HRI can be stated in a numeric fonn. As an example, a worst case hazard identified by severity and probability would be HRI=1, and the least hazardous condition would be HRI = 20. Once safety engineering has determined that the hazard has been adequately reduced, this number then identifies the level of approval required for acceptance of any remaining risk.

The order of precedence for satisfying safety requirements and resolving identified hazards is listed in descending order.

a. Design for minimum risk, if the hazards cannot be eliminated, then take steps to reduce the associated risks to an acceptable level.
b. Control risk by incorporating safety devices. or other design features to reduce the risk to an acceptable level.
c. Provide warning devices to provide an adequate warning signal to alert personnel of the hazard.
d. Develop procedures and training to reduce risk: procedures may include the use of protective equipment.

MAINTAINABILITY

Aircraft maintainability is a significant driver in aircraft subsystem design. Reducing the turnaround time between missions and decreasing down time for repairs make the aircraft more available, and thus more valuable. Along with the usual challenges. such as making the fire extinguishing agent tank accessible for removal and replacement without removing other equipment, the engine bay fire extinguishing system can, depending on the type of agent used. add some unique challenges for implementing a maintenance-friendly design philosophy.

TABLE 1. HAZARD RISK INDEX (HRI).

Hazard Category	Catastrophic	Critical	Marginal	Negligible
Frequency				
Frequent	1	3	7	13
Probable	2	5	9	16
Occasional	4	6	11	18
Remote	8	10	14	19
Improbable	12	15	17	20

Key:

Hazard Risk Index		Suggested Criteria
1-5	High Risk	Unacceptable
6 - 9	Medium Risk	Undesirable (Managing Authority [MA] approval required)
10 - 17	Low Risk	Acceptable with review by MA
18-20	Very Low Risk	Acceptable without review

While liquid agents such as HFC-125 have similar maintenance requirements to the existing Halon 1301 systems, dry chemical agents and gas generators bring up new issues. Dry chemical agents introduce the possibility of clogging the distribution tubes or outlet nozzles during initial discharge. Such blockages can degrade the advantages of a multidischarge system for aircraft with multiple engines. This may also require that the distribution tubes and outlet nozzles be cleared after each agent deployment. At a minimum, air must be blown through the system to clear any remaining agent. If this measure is insufficient, the distribution tubes must be removed and either cleaned and reinstalled or replaced. Because in many cases these tubes are within closed-out structural areas or behind other equipment. significant maintenance down time could be required, even if there were minimal or no fire damage.

The presence of the dry chemical agent in the engine bay is in itself a maintenance issue. After an agent discharge, regardless of whether a fire was present, the engine bay must be cleaned. The dry chemical agent particulate cannot be permitted to migrate to such places such as rotating sealing surfaces. If this occurs, the seal may be compromised resulting in an incipient leak. While gas generators do not put out nearly the amount of solid particulate dry powder agents do, they do expel enough to be a concern. The high temperature of the discharging gas presents an added maintenance concern when using gas generators. Not only is the gas plume an issue for the maintainer. as noted above, but the temperature of the discharge tubes can be a problem. Even with insulation around them. the surface temperature of the distribution tubes can reach very high temperatures. This not only creates a hazard for the maintainer, but makes the distribution tubes difficult to work with for hours after the discharge.

Weight

Weight has always been and always will to be a major concern for aircraft designers. The typical designer goes to great lengths to save as little as half a pound of aircraft weight and is subject *to* management scrutiny if the weight allocation is exceeded by any amount. Increased weight means decreased aircraft range and payload, and increased life cycle cost.

Accurately estimating the final weight at the beginning of the design process of any component resulting from an emerging technology is extremely difficult. In the case of nonhalon fire extinguishers. this is true regardless of the design approach chosen. Because the system components are being incorporated into an aircraft design for the first time, the final weight will typically increase as fixes are made for unanticipated design problcms. Rarely does the weight go down. The discharge tubing, if used. will add a significant amount to the system weight. A 0.5 in diameter (outer) aluminum (6061) tube with a wall thickness of0.026 in weighs 0.0464 lbs/ft. For a system that uses 10 ft oftubing, the weight penalty is 0.464 lbs. This weight will increase if a heavier material, such as Inconel, is required to withstand elevated temperatures. due either to the bay environment or the extinguisher discharge temperature. A comparison is shown in Table 2. Add to that the weight of fittings required to join the sections of tubing together. A typical 0.5-in CRES steel elbow fitting (AN 812-8) weighs 0.201 lbs. The aluminum version of this fitting weighs 0.065 lbs. If a system uses 10 ft of aluminum tube with 4 elbows, the total distribution system weight will he 1.27 lbs.

TABLE 2. TUBE MATERIAL WEIGHT COMPARISON.

Material	Weight, lbs/ft
Aluminum (6061)	0.0464
Titanium (CP)	0.757
Inconel 625	0.1417
Stainless Steel (CRES)	0.1330

Even minor design details will add to the total weight. If distribution tubes are used. brackets, clamps. and fasteners are required to support them as they make their way from the extinguisher unit to the engine bay. When the tube penetrates a bulkhead, a doubler must be added to maintain the structural. and in the case of firewalls, fire integrity. If the distribution tubes are likely to get hot during the discharge of the agent, insulation may required to prevent the tubes theinselves from becoming a reignition source. All of these measures will increase the system weight.

The weight and selected location for the extinguisher unit may also have an impact on aircraft weight. If the extinguisher unit is installed in a location that adversely affects the aircraft's center of gravity (CG), ballast may have to be added elsewhere. Depending on the severity of the CG problem, incorporation of ballast could double the total weight of the system.

COST

System cost is normally evaluated for the following three categories: development cost, unit cost, and life-cycle cost.

Development cost consists of those costs associated with system design, development, and qualification for use in an aircraft. Development costs for liquid and dry chemical systems are comparable to a halon system and are driven primarily by the cost of designing and qualifying an extinguisher pressure vessel (agent tank) for aircraft use and, to a lesser extent, the cost of designing the pressure vessel installation and agent distribution system. Additional distribution system nozzles are rcquired to optimize the concentration of the less effective non-ozone depleting agents. Further. to maximize the mass of agent that could be installed in the limited space available and reduce the weight of the agent tank, insulation and a ram air cooling system may be incorporated into the liquid agent system. This will minimize the agent tank maximum pressure, reducing the required wall thickness. Development costs of a gas generator system are significantly higher than liquid or dry chemical systems, largely driven by development and qualification test requirements associated with flight certification of a device that contains explosive material. The number of gas generator test units required for development and qualification can be as high as 380, an order of magnitude greater than the number required for the equivalent testing of a pressure vessel. The large number of test units required and the relatively high unit cost of an inert gas generator capable of extinguishing an engine bay fire could result in development costs of several million dollars.

Unit cost represents the cost per system, in this case, the cost of labor and materials for the fire extinguishing system on each aircraft. Minor cost increases associated with the extinguisher (agent tank) unit for the liquid system will result from increase:; size and higher agent price. The dry chemical agent tank is slightly more complex than the halon agent tank and the agent is more costly. Gas generators require fabrication using more exotic materials, such as Inconel, capable of withstanding the high temperatures associated with the burning propellant. The propellant and the complexity of the unit also add significantly to the cost. Installation costs for a cold gas (liquid) or dry chemical system are comparable to a halon system, with the exception of additional plumbing/nozzle requirements for both systems and the insulation and ram air cooling system that may be required for a liquid system. Installation costs for the gas generator are significantly higher, resulting from several factors. The high temperature effluent may require that high temperature materials (Inconel) be used for the distribution system tubing and fittings. Provisions to compensate for thermal growth (i.e., slip joints, etc.) must be incorporated into the design. Special high temperature tube clamps and steel interface mounts are required to minimize heat transfer into the aluminum structure. In some locations. tube insulation, heat shields, and plume deflectors may have to be added to the design. Compartment insulation and a ram air cooling system may be required to minimize thermal extremes and cycling of the propellant.

Life-cycle cost represents the cost of ownership for the system. This includes acquisition, operation, and maintenance over the life of the system. Life-cycle costs for the liquid agent and dry chemical agent systems are comparable, although slightly higher than a halon system. All these systems are reusable/rechargeable. The pressure vessels are hydrostatically tested periodically and the explosive initiators used in the design must be changed periodically due to the limited propellant life. Support equipment and facilities required to service these units add to the life-cycle cost. The relatively high acquisition and unit costs drive the life-cycle cost of the gas generator fire extinguishing system as well as the repetitive unit cost associated with the periodic replacement of the extinguisher due to limited propellant life. Gas generator units are typically not rechargeable. The replacement cost for a throw-away gas generator unit is partially offset because support equipment and facilities are not required to recharge/refurbish the units. Costs associated with actual system utilization are generally low for all systems because of the infrequent need to use the system, although the rate of inadvertent discharge in some older aircraft may be significant. The life-cycle cost of a system can be heavily impacted by the increased weight that results from incorporation of a nonozone-depleting fire extinguishing system. The addition of a single pound to a fighter aircraft could add a fleet-wide cost impact of several hundred thousand dollars.

SUMMARY

When transitioning from theoretical analysis and laboratory or intermediate-scale testing to integration into an aircraft design. the considerations for an aircraft engine bay fire extinguishing system design become very different. In this phase of development, agent and system functionality arc no longer the sole concern. Such issues as component qualification, system installation, system safety, weight, maintainability, and cost assume a high priority. To satisfy these additional concerns, compromises affecting system performance may he necessary, requiring the entire design team to work together to attain a balanced system that is effective as well as maintainable, safe to operate, light weight, and affordable.

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