RELATIVE BENEFIT ASSESSMENT OF FIRE PROTECTION SYSTEM CHANGES

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ABSTKACT

The program discussed below will perform a cost of ownership assessment (and cost savings due aircraft assets preserved) for the existing Halon 1301 system and off-the-shelf-alternative (HFC-125) to define operational cost baseline and goals **for** Next-Generation Fire Suppression Technology Program technologies. The assessment will be perfonned for two platforms —ne with critical space limitations and associated significant modification costs impact and one with a lesser impact. The program will be developed for a system with equivalent performance of Halon 1301 and for a system with varied performance. Business solutions with technical expertise in evaluating halon replacement systems will be applied. Financial and technical variables are being taken into consideration. Fixed and variable costs associated with converting to fire suppression alternatives from conventional Halon 1301 systems are considerable. Quantification/qualification of costs and benefits will enable the decision-maker to obtain the optimum solution.

BACKGROUND

All three services and their respective platforms have special problems in regard to fires. Each carries munitions, which can be initiated by a **fire.** In addition, each also contains large quantities of fuel distributed in fuel tanks throughout the platform with fuel lines running between these tanks and the engine(s).

NEXT-GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM

The goal of the Next-Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate (by 2005) retrofitable, economically feasible, environmentally-acceptable, and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by Halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities. The results will be specifically applicable to fielded weapon systems, and will provide dual-use fire suppression technologies for preserving both life and operational assets [1].

AIRCRAFT

In most cases, fire is either the primary cause or a contributing factor of loss of aircraft assets. In many instances, injuries to personnel and loss of mission capability accompany a fire event. Aircraft fires are a significant cost to the Air Force. Methods and technologies to mitigate them or "design them out" are imperative, not only to save aircraft, but also to save lives and prevent property damage.

Fire extinguishing systems are used on military and commercial aircraft to protect engine nacelles (the region surrounding the exterior of the jet engine case and shrouded by an outer cover, and typically ventilated), dry bays (which can include wing leading/trailing edges, landing gear, avionics, and weapons bays), and fuel tanks (as an inertant in the fuel tank ullage). These systems are fixed in configuration and activated remotely to totally flood the compartment in question with fire extinguishant. Auxiliary power units (APU), which provide ground, supplementary or emergency power, are also frequently protected using such systems, either as stand-alone units or in conjunction with the engine nacelle fire extinguishing system.

Engine nacelle fire protection systems are designed to protect against events such as ruptured or leaking fuel, hydraulic fluid, or oil lines within the nacelle. In these circumstances, flammable fluid can leak onto the hot engine case or accessory components and ignite. These systems also protect against catastrophic events such as thrown turbine blades that instantaneously rupture fuel sources or overheating components that can initiate fuel fire scenarios. The two most common types of fire hazard in the engine nacelle are a direct consequence of the means of fuel delivery, i.e., either a spray fire or a pool fire. An additional fire hazard associated with the aircraft engine nacelle is that even after extinguishment is achieved, a strong potential exists for reignition of the fire from hot surfaces. Hot surface reignition remains a threat as long as fuel vapor and air can come in contact with sufficiently hot surfaces. Suppression of the hot surface reignition fire hazard in the engine nacelle requires an additional amount of agent over that required for flame extinguishment in order to maintain extinguishment until the hot surfaces cool.

Dry hays are defined as void volumes within the mold line of the aircraft, excluding air inlets, engine compartments, and exhaust nozzles. Examples include wing leading edge bays, landing gear wheel wells. avionics equipment bays, and weapons bays. Dry bays frequently contain fluid lines (fuel, hydraulic, coolant), bleed air ducts. and electrical cables and may contain avionics, ilight control actuators, hydraulic accumulators and liquid oxygen dewars. A fire in a dry bay typically requires a rupture of the flammable fluid components and the generation of an ignition source. For this reason, it is assumed that this scenario is created when a ballistic projectile impacts a dry bay in tlight, rupturing fuel system components and generating tremendous ignition energy. Although this is the assumed primary initiation means, other initiation sources, such as overheated, shorting electrical circuits in avionics bays, some other form of impact (e.g., bird strike). or burning stored munition propellants. can also be responsible in rare instances.

Ullage (the void space above the fuel level in a fuel tank) in aircraft fuel tanks can have a potentially explosive fuel-air mixture. If initiated by a combat threat, an explosion can result. Halon 1301 is used to inert these fuel tanks and prevent this phenomenon from occurring. Currently, two aircraft systems use halon for fuel tank inerting: F-16 and F-l 17. Fuel tank explosions are a result of ullage deflagrations or detonations where the combustion overpressure generated exceeds the structural strength of the tank. With large ignition sources, combustion will occur and overpressures will vary according to the threat level, tank volume, and oxygen concentration. If the combustion wave propagates throughout the ullage with near stoichiometric fuel/air mixture, a pressure increase of over 790 kPa (100 psig) (eight times atmospheric pressure) is theoretically possible. The inerting system must provide protection from in-tank arcing due to lightning, electrostatic discharge, and combat threats [2].

COST OF OWNERSHIP

The solution to onboard aviation fire protection systems is not an obvious one. The best solution requires considering more than just laboratory data. Some additional factors, which affect this decision, include the following:

- Effect of clutter on the ability of the fire extinguishant to get to the fire
- Operation during temperature extremes (-65 to 300 °F)
- Transportation through long distribution plumbing lines
- Ability to flow and discharge in less than one second
- Compatibility of the extinguishant with the advanced aircraft materials

In the aviation design community, all of these diverse issues are typically compared on one common denominator—cost of ownership, which extends from research and development, acquisition, installation, and maintenance throughout its life.

The purpose of the NGP is to find technologies suitable for retrofit. The various technologies developed may be gaseous, particulates, mists, or combinations of these. All of these features can affect numerous issues related to the system design. Since eventually aircraft operators will have to implement one or more of these alternatives, they need information in terms of the optimal cost of ownership, which could lead to operators selecting different technologies as the most suitable. The program presented here will generate the data and analyses to assist those operators, and it will integrate all of the various types of data generated in the NGP and also assist the NGP in determination which technologies are most promising.

APPROACH

COST BENEFIT ANALYSIS

The process of a cost benefit analysis (CBA) was initially developed to evaluate the life cycle costs and benefits. It was believed that out of this CBA process, decision-makers would be able to evaluate fire suppression alternatives. The following items were performed and assisted in applying the cost benefit analysis process to the realm of fire suppression.

- Tailored the typical CBA process to this project.
- Developed a common set of ground rules and assumptions.
- Developed a comprehensive cost element structure to organize costs across alternatives.
- Developed a comprehensive benefit structure.
- Identified data sources for cost and benefit variables.
- Identified data collection techniques **for** cost and benefit variables.
- Determined estimating methodologies for evaluating various cost elements.
- Determined methodologies for evaluating benefits.

REDIRECTION OF EFFORT

In recent months, numerous changes and redirections have occurred both within this project and within the NGP. Originally, the focus of this effort included all the platforms (air vehicles, ground vehicles, and ships) being investigated by the NGP. However, the NGP has been descoped to focus on air platforms. The focus of this effort has shifted from multiple platforms to two platforms selected for their extremes — C-I7 and F/A-18 C/D. The C-17 may have a more forgiving space allowance, has long distribution lines, and has a much hotter engine nacelle temperature. The F/A-18 C/D is very space critical, has shorter distribution lines, and has a less hot engine. The original focus of this effort was a cost benefit analysis: however, it was decided to put everything in terms of cost. This decision did not nullify the results and analyses previously generated, but simply changed the focus to costs as opposed to benefits. It was also decided to focus on the old baseline of Halon 1301 and the new baseline of HFC-125. These provide bounds for the program with Halon 1301 being the upper bound (ultimate goal) and HFC-125 being the lower bound in that the extinguishant and its associated costs should be better.

METHODOLOGY DEVELOPMENT

A methodology is being developed that will help determine the net cost of the fire suppression system. This methodology incorporates the cost of the system (a function of system size/weight) and the cost savings provided by the system (a function of extinguishant effectiveness and result in aircraft saved). This methodology will he developed for the existing Halon 1301 system and an off-the-shelf-alternative (HFC-125) for one prototype platform (C-17), to define operational cost baseline and goals for NGP technologies and for one with critical space limitations and associated significant modification costs impact (F/A-18 fighter). It will he developed for a system with equivalent performance of Halon 1301 and for a system with varied performance.

The methodology will also he developed for one or two additional candidate fire suppression technologies developed and selected by the NGP TCC for the C-I 7 and F/A-18 C/D platforms for technologies with equivalent performance of Halon 1301 and with varied performance (if possible). Finally, provided that time and financial resources exist, the methodology will be developed for an additional platform for fire suppression technologies with equivalent performance of Halon 1301 and with varied performance (if possible).

COST OF THE SYSTEM

The costs utilized in this methodology development will focus on the research, development, test and evaluation (RDT&E), platform modification / integration, and operating and support (O&S) costs. RDT&E costs will deal with all RDT&E costs required to develop the fire suppression technology into a deployable system. These costs shall include, but not be limited to, the costs of associated hardware necessary to install and mount the fire suppression system as well as the fire suppression system hardware itself. Other RDT&E costs shall include test and evaluation costs, training costs, and the costs of associated support equipment, both common and peculiar.

Platform modification / integration costs shall consist of those associated with airframe modifications required to utilized the various fire suppression technologies. These costs shall include, but not be limited to, (1) mounting hardware. (2) potential modifications to the bay in which the agent bottle resides to accommodate a larger bottle that could be necessary to achieve the same level of protection as provided by Halon 1301, and (3) potential modifications to the agent distribution system if required.

O&S costs are broad and far-reaching and include those costs associated with program management support and life cycle sustainment management. In addition, there will be costs associated with recurring training. possible technical data revision, spare parts, repair parts and materials, transportation, packaging, handling, and storage costs. Depending on the technology used, disposal costs could be incurred.

COST SAVINGS

Cost savings provided by the fire protection system are a function of extinguishant effectiveness and result in aircraft saved.

EXTINGUISHANT EFFECTIVENESS

The methodology will be developed for both a system with equivalent performance to Halon 1301 and a system with varied performance. The current specifications for Halon 1301 require a minimum of 6% concentration by volume in air be present simultaneously at all points in the engine nacelle for a minimum of 0.5 sec. Systems designed using HFC-125 will generally require additional quantities to varying degrees (per application) compared to their halon counterparts for an identical application [3].

To address the issue of a potential fire suppression system with vaned performance, data will be utilized from the Factor of Safety (FOS) study performed during Phase III of the Halon Replacement Program for Aviation. Phase III was conducted to develop design equations for using HFC-125 as a halon replacement. The development of the design equations is documented in two Wright Laboratory reports [3, 4]. As a final step in Phase III, the resulting design equations were "qualified" by performing FOS tests, which allowed an estimation of the fire protection effectiveness of the amount of HFC-125 predicted by the design equation. This estimate was expressed as the confidence of extinguishing a fire. Additional testing then estimated the fire protection effectiveness of agent amounts above and below the design equation amount. The extinguishant mass required as a result of this testing for both Halon 1301 and HFC-125 will be used to reverse engineer the bottle size and determine other implementation issues.

For this effort, several variances (higher and lower than currently designed effectiveness) will be selected to determine the optimal balance of cost savings and system cost. If flexible on a success rate, the optimal design to minimize cost of ownership can be determined.

AIRCRAFT SAVED

Aircraft fires are a significant cost to the Air Force. Methods and technologies to mitigate them or "design them out" are imperative, not only to save aircraft, but also to save lives and prevent property damage [5]. Field experience of existing engine halon systems on current aircraft, depending on the platform, shows that the systems have a 60 *to 80%* success rate [3]. The costs to the USAF of losses due to fire have been significant. By combining the cost components of peacetime aircraft losses due to fire, a resulting historical cost (over a 30-year period) of approximately $9.271 billion was obtained, measured in 1995 dollars; for the costs of combat aircraft losses due to fire, approximately $5.878 billion, based primarily on Southeast Asia experience; for the costs of utilizing aircraft fire protection, approximately $315.651 million, measured in 1995 dollars. Thus, the total historical costs of fire to the USAF over the 1966–1995 time period is estimated to be $15.465 billion (1995). The total projected costs of fire to the **USAF** over the 19962025 time period is estimated to be $15.990 billion (1996). A net present value of over $119 million is projected to be the benefit of fire suppression systems over the next 30 years [5].

If flexibility in the designed success rate is maintained for the system, the optimal design to minimize cost of ownership can be determined. However, this is a choice the aircraft manager must make.

CONCLUSION

The methodology currently being developed will result in a tool to assist decision-makers in obtaining the optimum solution for their particular platform.

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REFERENCES

1. *Next-Generation Fire Suppression Technology: Strategy for a National Program,* Department of Defense, Office of the Director, Defense Research and Engineering, July 1996.

2. "Fires Experienced and Halon 1301 Fire Suppression Systems in Current Weapon Systems," United States Air Force - Air Force Research Laboratory - Survivability and Safety Branch. Booz•Allen & Hamilton, Inc., United States Army - Army Research Laboratory. United States Navy - Naval Research Laboratory. and National Institute of Standards and Technology - Fire Science Division, July 1999.

3. Bennett. J.M.. *Aircraft Engine/APU Fire Extinguishing System Design Model (HFC-125),* WL-VA-WP-1999-3068, Wright Laboratories, Dayton. OH, May 1997.

4. Bennett. **J.M..** *Aircraft Engine/APU and Dry Buy Fire Extinguishing System Design Model (HFC-125),* WL-TR-97-3066, Wright Laboratories, Dayton, OH, May 1997.

5. Kolleck, M.L, Brightsen. G.M., Bennett, M.V., and Wheeler. J.A., *Annual Fire Protection Cost Model (1966–1995;1996–2025),* Technical Report, SURVIAC-97-033. Booz·Allen & Hamilton, Inc., Dayton, OH, 1997.