COST ANALYSIS OF FIRE SUPPRESSION SYSTEMS

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ABSTRACT

The objective of this effort was to perform a comparative cost analysis for Halon 1301 and HFC-125 fire protection systems.

This effort developed a methodology to determine total system costs, cost savings incurred, and net cost of an aviation fire protection system. This methodology was developed for systems with equivalent and varied performance of Halon 1301 to optimize benefit per system weight and cost. The methodology has been developed for engine nacelle applications for representative cargo, fighter, and rotary wing aircraft. The methodology is being developed for dry bay applications for representative fighter and rotary wing aircraft and engine nacelle applications for representative unmanned aircraft.

Based on the studies performed to date, it appears that the benefit of having either fire protection system substantially outweighs its cost, and the difference in total cost of the two systems is modest compared to the total cost of owning and operating the aircraft.

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 (NGP)

The goal of the Next Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate 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. 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 FIRES

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 Department of Defense. 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), and dry bays (which can include wing leading/trailing edges, landing gear, avionics, and weapons bays). These systems are fixed in configuration and activated remotely to totally flood the compartment in question with fire extinguishant. Auxiliary power units (APUs), 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 bays 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, bleed air ducts, and electrical cables and may contain avionics, flight 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 flight, 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 (i.e., bird strike), or burning stored munition propellants, can also be responsible in rare instances. [2]

METHODOLOGY

A methodology was developed to determine the net cost of the fire suppression system. This methodology incorporates the cost of the system, which is a function of system size/weight, and the cost savings provided by the system, which are a function of extinguishant effectiveness and the resultant aircraft saved. The net cost is the cost of the system minus the cost savings.

System characterization was necessary to fully understand and appreciate the system cost information. This was accomplished for both a Halon 1301 and HFC-125 system. Information which assisted in characterizing these systems included technical manuals, HFC-125 Design Guide, and assistance from the program managers. Additional system characterization data included the number of bottles, bottles size, activation, number of shots, and information on the distribution system. Space limitation, bottle/plumbing accessibility, and modification potential data were compiled.

System cost information was developed utilizing the data contained in logistics databases that contains part numbers, suppliers, and other logistical information specifically for the Service of interest, and various traditional costing factors that are used by government and industry. Additional data came from the program managers. Fire suppression system and chemical manufacturers were contacted for cost information. Maintenance costs were based on the maintenance manhour per flight hour. Military personnel costs were based on authorizations.

The following figure shows a standard process used to determine fire suppression system costs.

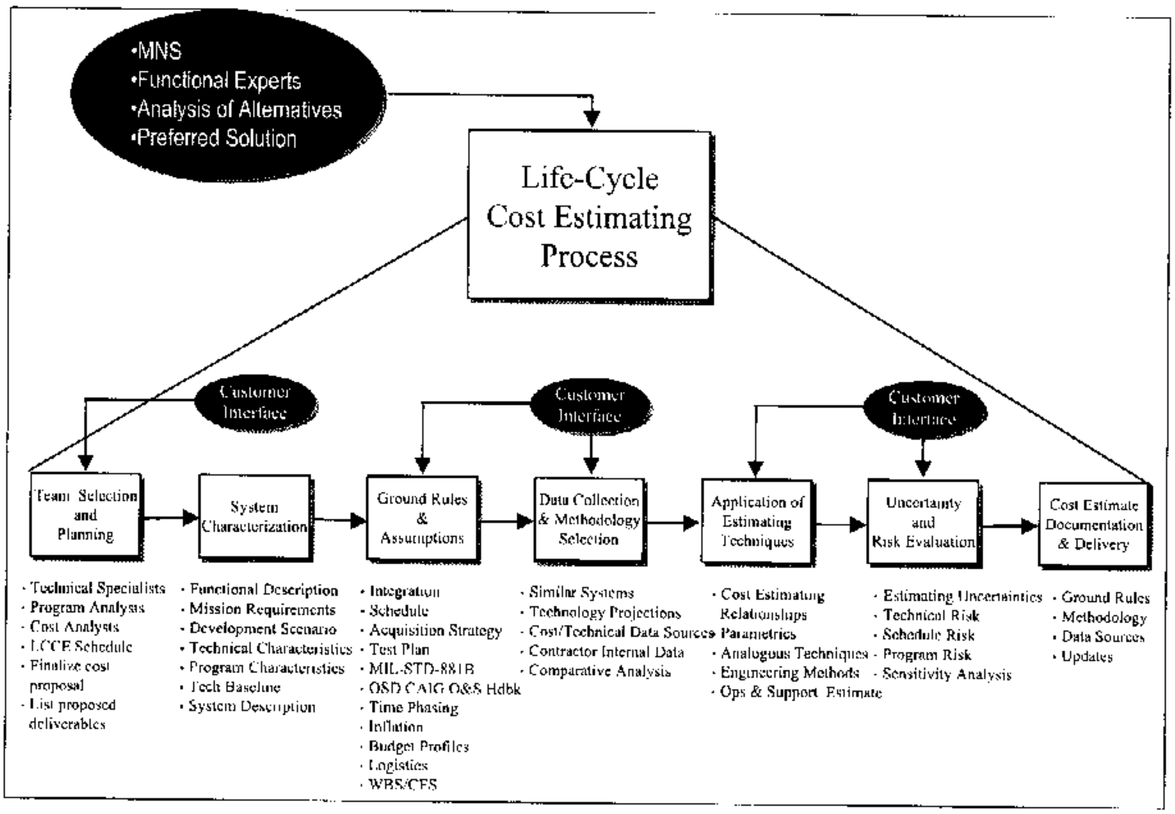

Figure 1. Standard Life Cycle Cost Estimating Process.

The cost savings for the life cycle period of interest in this study were estimated by using the traditional success rate for existing engine halon systems, the estimated fire costs per flight hour, and the number of flight hours for the aircraft of interest. Field experience of existing engine halon systems on current aircraft, depending on the platform, shows that the systems have a 60 to

80 percent success rate. The *Annual Fire Protection Cost Model* (described previously in this paper) postulated that future aircraft losses due to fire incidents were a function of the total number of flight hours (FH) for this period. An historical relationship between fire costs and flight hours was established. The resulting average fire costs per flight hour (in FY 2000 dollars) was $62.85 per flight hour.

COST ANALYSIS

The life-cycle cost of a system includes the acquisition, operation, and maintenance over the life of the system. The HFC-125 system is reusable/rechargeable. The pressure vessels must be 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. Costs associated with actual system utilization are generally low 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 potential for increased weight that may result from incorporation of a nonozone-depleting fire extinguishing system. [3]

Costs estimated in this effort would be incurred in the research, development, test and evaluation (RDT&E), procurement, and operations and maintenance (O&M) phases of an acquisition. RDT&E costs deal with all costs required to develop the fire suppression technology into a deployable system. Procurement (also called initial or nonrecurring) costs include those associated with the purchase of the fire suppression system (and associated hardware) and suppressant. O&M costs are broad and far-reaching. Included in this category are those costs associated with program management support and life-cycle sustainment management.

COST ELEMENT STRUCTURE DATA DEVELOPMENT

This fire suppression system's detailed cost element structure (CES) is based on the DoD 5000.4-M and MIL-HDBK-881 CES. It was customized for this particular system and approach. The resulting CES used in this methodology is given in Table 1.

Table 1. Detailed Cost Element Structure.

1.0. RDT&E (3600)	**2.0. PROCUREMENT (3010)**	**3.0. OPERATIONS AND MAINTENANCE (3400)**
1.1. Concept Exploration	2.1. Prime Mission Product	3.1. Program Administration
1.2. Prototype EMD Cost Sharing	2.1.1. Subsystems	3.1.1. Program Management Support
1.2.1. Subsystem	2.1.1.1. Group A Kit	3.1.1.1. Miscellaneous Contract Services
1.2.1.1. Group A Kit	2.1.1.2. Group B Kit	3.1.1.2. Government Technical Support
1.2.1.2. Group B Kit	2.1.2 Non-Recurring Engineering	3.1.1.3. Travel
1.2.2. COTS/GOTS Software	2.1.3. Software Integration	3.1.2. Life-Cycle Sustainment Management
1.2.3. Development Software	2.1.4. Integration, Assembly, Test and Checkout	3.2. Program Operational Support
1.2.4. Integration, Assembly, Test and Checkout	2.2. System/Platform Integration and Assembly	3.2.1. Recurring Training
1.3. System/Platform Integration	2.3. Systems Engineering/Program Management	3.2.2. Technical Data Revision
1.4. System Engineering/Program Management	2.3.1. Systems Engineering	3.2.3. Software Maintenance
1.4.1. Systems Engineering	2.3.2. Program Management	3.2.4. Hardware Maintenance
1.4.2. Program Management	2.3.3. Logistics Management	3.2.4.1. Organic Support
1.4.3. Travel	2.4. System Test and Evaluation	3.2.4.2. Contractor Maintenance
1.5. System Test and Evaluation	2.4.1. Operational Test and Evaluation	3.2.5. Replenishment Spares
1.5.1. Developmental Test and Evaluation	2.5. Engineering Change Orders	3.2.6. Repair Parts and Materials
1.5.2. Operational Test and Evaluation	2.6. Initial Cadre Training	3.2.7. Transportation, Packaging, and Handling
1.6. Data	2.7. Data	3.2.8. Storage
1.7. Training	2.8. Operational Fielding/Site Activation	3.2.9. Disposal
1.8. Evolutionary Technology Insertions (ETI)	2.9. Depot Setup	3.2.10. Facility Projects/Upgrades/Leases
1.8.1. Program Management	2.10. Support Equipment	3.2.11. Operational O&M Impacts of ETIs
1.8.2. Prototype and Test Bed	2.10.1. Common Support Equipment	3.2.12. Program Operations
1.8.3. Market Surveys	2.10.2. Peculiar Support Equipment	3.2.13. Unit Level Support
1.9. Support Equipment	2.11. Initial Spares and Repair Parts	3.2.13.1. Recurring Training (Unit Travel/TDY Costs)
1.9.1. Common Support Equipment	2.12. Warranty	3.2.13.2. Operating Consumables
1.9.2. Peculiar Support Equipment	2.13. Evolutionary Technology Insertions	3.2.13.3. Unit Level O&M Impacts of ETIs
	2.14. Interim Contractor Support	3.2.14. Depot Level Support
	2.15. Flexible Sustainment Support	3.2.15. Contractor Logistics Support
		4.0. MILITARY PERSONNEL (3500)
		5.0. MILITARY CONSTRUCTION – N/A

COST SAVINGS

Aircraft fires are a significant cost to the Department of Defense. 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.

In a previous study (*Annual Fire Protection Cost Model*), the historical and projected costs due to fire were determined. By combining the components which comprise the costs 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 ($95), based primarily on Southeast Asia experience was incurred; for the costs of utilizing aircraft fire protection, approximately $315.651 million ($95) was experienced. Thus, the total historical costs of fire to the U.S. Air Force over the 1966 to 1995 time period was estimated to be $15.465 billion ($95). The total projected costs of fire to the U.S. Air Force over the 1996 to 2025 time period was estimated to be $15.990 billion ($96). A net present value of over $119 million was projected to be the net benefit of fire suppression systems over the next 30 years. [4]

COSTS OF CURRENT/PROPOSED SYSTEMS FOR VARIOUS AIRCRAFT TYPES

This effort developed a methodology to determine total system costs, cost savings incurred, and net cost of an aviation fire protection system. This methodology was developed for systems with equivalent and varied performance of Halon 1301 to optimize benefit per system weight and cost. The methodology has been developed for engine nacelle applications for representative cargo, fighter, and rotary wing aircraft. The methodology is being developed for dry bay applications for representative fighter and rotary wing aircraft and engine nacelle applications for representative unmanned aircraft. The results of these efforts are given below.

CARGO AIRCRAFT

For cargo aircraft, the cost of ownership for the legacy Halon 1301 system is $25M and for a legacy HFC-125 system ranges from $35 to $41M. The estimated fire cost is $204M. The estimated cost savings are between $122M and $163M. The estimated net cost for the Halon 1301 system ranges from $ 97M to $–138M. The estimated net cost for the HFC-125 system ranges from $–81M to $–129M.

For cargo aircraft, the cost of ownership for the future Halon 1301 system is $36M and for a future HFC-125 system ranges from $35 to $44M. The estimated fire cost is $226M. The estimated cost savings are between $136 and $181M. The estimated net cost for the Halon 1301 system ranges from $--99 to $ 144M. The estimated net cost for the HFC-125 system ranges from $–91M to $–146M.

The results of this effort are detailed in SURVIAC TR-00-006, "Cost Analysis of Fire Suppression Systems For Cargo Aircraft", M.L. Kolleck, M.V. Bennett, and K.L. Mercer, Technical Report, Booz Allen Hamilton, Dayton, Ohio, January 2002. [5]

FIGHTER AIRCRAFT

For fighter aircraft, the cost of ownership for the legacy Halon 1301 system is $11.2M and for a legacy HFC-125 system ranges from $15.7 to $17.8M. The estimated fire cost is $258M. The estimated cost savings are between $154.8 and $206.3M. The estimated net cost for the Halon 1301 system ranges from $–143.5M to $–195.1M. The estimated net cost for the HFC-125 system ranges from $–136.9M to $–190.6M.

Using the fighter aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Even if the fighter aircraft fire suppression system only saved seven percent of the aircraft assets it was designed to protect, the benefit (assets saved) would still be greater than the cost of the fire suppression system.
- Using a conservative value of 60 percent fire suppression system effectiveness, a system cost of up to $282K per aircraft could be justified. Note that the current as well as forecast fire suppression system costs per aircraft are an order of magnitude less than this value. This value is a breakpoint between system cost and benefit.

For fighter aircraft, the cost of ownership for the future Halon 1301 system is $14.4M and for a future HFC-125 system ranges from $15.8 to $18.0M. The estimated fire cost is $260.8M. The estimated cost savings are between $156.5 and $208.7M. The estimated net cost for the Halon 1301 system ranges from $–142.1 to $ 194.2M. The estimated net cost for the HFC-125 system ranges from $–138.5M to $–192.9M.

Using the fighter aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Even if the fighter aircraft fire suppression system only saved seven percent of the aircraft assets it was designed to protect, the benefit (assets saved) would still be greater than the cost of the fire suppression system.
- Using a conservative value of 60 percent fire suppression system effectiveness, a system cost of up to $285K per aircraft could be justified. Note that the current as well as forecast fire suppression system costs per aircraft are an order of magnitude less than this value. This value is a breakpoint between system cost and benefit.

The results of this effort are detailed in SURVIAC TR-01-005, "Cost Analysis of Fire Suppression Systems For Fighter Aircraft", M.L. Kolleck, M.V. Bennett, and K.L. Mercer, Technical Report, Booz Allen Hamilton, Dayton, Ohio, January 2002. [6]

ROTARY-WING AIRCRAFT

For rotary-wing aircraft, the cost of ownership for the legacy Halon 1301 system is $33.4M and is $45.3M for a legacy HFC-125 system. The estimated fire cost is $620.2M. The estimated cost savings are between $372.1 and $462.7M. The estimated net cost for the Halon 1301 system ranges from $–338.7M to $–462.7M. The estimated net cost for the HFC-125 system ranges from $–326.8M to $–450.9M.

Using the rotary-wing aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Even if the rotary-wing aircraft fire suppression system only saved eight percent of the aircraft assets it was designed to protect, the benefit (assets saved) would still be greater than the cost of the fire suppression system.
- Using a conservative value of 60 percent fire suppression system effectiveness, a system cost of up to $307K per aircraft could be justified. Note that the current as well as forecast fire suppression system costs per aircraft are an order of magnitude less than this value. This value is a breakpoint between system cost and benefit.

For rotary-wing aircraft, the cost of ownership for the future Halon 1301 system is $40.1M and is $42.2M for a legacy HFC-125 system. The estimated fire cost is $631.2M. The estimated cost savings are between $378.7 and $505.0M. The estimated net cost for the Halon 1301 system ranges from $–338.6M to $–464.8M. The estimated net cost for the HFC-125 system ranges from $–336.5M to $–462.7M.

Using the rotary-wing aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Even if the rotary-wing aircraft fire suppression system only saved seven percent of the aircraft assets it was designed to protect, the benefit (assets saved) would still be greater than the cost of the fire suppression system.
- Using a conservative value of 60 percent fire suppression system effectiveness, a system cost of up to $312K per aircraft could be justified. Note that the current as well as forecast fire suppression system costs per aircraft are an order of magnitude less than this value. This value is a breakpoint between system cost and benefit.

The results of this effort are detailed in SURVIAC TR-02-007, "Cost Analysis of Fire Suppression Systems For Rotary-Wing Aircraft", M.L. Kolleck, M.V. Bennett, and K.L. Mercer, Technical Report, Booz Allen Hamilton, Dayton, Ohio, April 2002. [7]

VARIED PERFORMANCE

Using the methodology previously developed, modifications were made to the performance of the cargo and fighter fire suppression systems by utilizing data from the Factor of Safety (FOS) study performed during Phase III of the Halon Replacement Program for Aviation. These suppression system weights and corresponding effectiveness were correlated to the cargo and fighter aircraft platforms.

For cargo aircraft, the net cost change per single percent change in extinguishing effectiveness (i.e., 91 percent successful vs. 90 percent field success) of the fire system was approximately $-2.0M. For fighter aircraft, the net cost change per single percent change in extinguishing effectiveness of the fire system was approximately $-2.5M. These estimates showed that additional investment in optimizing fire suppression system performance pays off in assets saved.

Due to the lack of FOS data, it is recommended that a test program be developed to provide better refinement of the existing FOS data and to reaffirm the hypothesis that the optimal effectiveness will provide the most dividends (cost savings).

The results of this effort are detailed in SURVIAC TR-01-006, "Cost Analysis of Fire Suppression Systems Methodology Using Altered Fire Suppression Performance", M.L. Kolleck, M.V. Bennett, and K.L. Mercer, Technical Report, Booz Allen Hamilton, Dayton, Ohio, January 2002. [8]

REMAINING PLATFORMS

Using the methodology previously developed, cost analyses are being developed for dry bay applications for representative fighter and rotary wing aircraft and engine nacelle applications for representative unmanned aircraft. These studies are currently underway and the results were not available at the time of this conference. System data are currently being collected to determine the sizing constraints of the system. Technical and cost information are being collected from the various representative platforms. Once these data arrive, the required mass for a Halon 1301 equivalent and varied performance system will be determined. The cost element structure will be populated which will determine the total system cost. The cost savings will be established. Once both the system costs and cost savings are determined, the net costs can be ascertained. Finally, the breakeven point between system effectiveness and cost will be determined.

CONCLUSIONS/SUMMARY

Fire is either the primary cause or a contributing factor in most cases 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.

The goal of the Next Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate 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.

There are a large number of contributing factors that must be considered when deciding which fire suppression system to select for a new platform or whether to retrofit the fire suppression system on a legacy platform. These include both objective cost factors and subjective value factors. Accordingly, the NGP has developed a methodology to quantify a fire suppression technology by its total, life cycle cost and to enable superimposing on this a subjective value system. The methodology determines the net cost of the fire suppression system: the cost of the system (which is a function of system size/weight) minus the cost savings provided by the system (which are a function of extinguishant effectiveness and result in aircraft saved).

The example used in developing the methodology is a comparison of an existing halon 1301 system and a system of equivalent and altered performance to halon 1301 using an off-the-shelf-alternative, HFC-125. This methodology was developed to be applicable to both legacy platforms (for decision makers who must consider retrofit costs for existing platforms) and future platforms (for decision makers currently designing new platforms).

This methodology has been used to examine the costs of Halon 1301 and HFC-125 for aircraft engine nacelle applications for example cargo, fighter, and rotary-wing aircraft. It is currently being adapted and used to examine the costs of Halon 1301 and HFC-125 for aircraft dry bay applications for example fighter and rotary-wing aircraft and engine nacelle applications for unmanned aircraft.

Based on the studies performed to date, it appears that the benefit of having either fire suppression system substantially outweighs its cost, and the difference in total cost of the two systems is modest compared to the total cost of owning and operating the aircraft.

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