NGP LIFE-CYCLE COST ANALYSIS OF AIRCRAFT FIRE SUPPRESSION SYSTEMS

J. Michael Bennett, Ph.D
Bennettech, LLC
1020 Kellyn Lane
Hendersonville, TN 37075
Tel: (937) 367-5675; e-mail: mikebennett@bennettechllc.com

BACKGROUND

TECHNICAL CHALLENGE

Fire is either the primary cause or a contributing factor in a large portion of mishaps that result in a material loss of aircraft assets; in many instances, injuries to personnel and loss of mission capability accompany a fire event. Aircraft fires impose a significant cost impact to the military. Methods and technologies to mitigate them or "design them out" are typically desirable, not only to save aircraft, but also to save lives and prevent property damage.

To determine the preferred fire extinguishing medium, system or method for any application, typically the most holistic manner of approach is to compare alternatives based upon on an overall cost of ownership, or "life cycle cost" over its useful life, or some fixed period of use. This approach can incorporate various facets of the costs associated with procuring, installing and maintaining such equipment, including non-hardware costs such as development and certification, as well as maintenance, repair and replacement. Fire protection equipment that functions successfully will prevent damage to property and other assets (including personnel), resulting in an offsetting cost savings, based upon the success rate and speed of suppression (thereby minimizing physical damage), and the cost of the protected assets themselves. The net "cost" or savings of each alternative can then be compared to determine the best choice, in this case as a replacement for the Halon fire extinguishing chemicals. This process can then be used to also determine whether any fire extinguishing system provides any net cost savings, where the cost savings in terms of assets preserved exceeds the "life cycle cost" of the technology itself, thereby justifying the use of any fire protection system at all for an application of interest. It may also be used to determine an optimal firefighting capacity of a system, wherein the cost savings due to the degree of effectiveness of the system (which may not be the highest level of effectiveness possible) exceeds the cost of providing such a system at a size that provides that level of effectiveness, to the maximum extent possible over a range of effectiveness levels and associated size capacities considered.

There is a need to quantify any new fire protection technology by its cost in order to determine if it is sufficiently superior to the state-of-the-art to warrant further pursuit; to provide a groundwork for a future, more comprehensive model to be used by weapon system program managers for determining, via life cycle costs, the most appropriate alternative to use to replace Halon 1301 in their systems; and to use the developed methodology to identify the aspects of fire protection technologies which offer the highest potential payoff.

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]

OBJECTIVES AND APPROACH

TASK OBJECTIVES

In accordance with these principles, in support of the NGP program this initiative conducted a life-cycle cost analysis of aircraft fire extinguishing systems, in the following manner to achieve the following objectives:

(1) A life cycle cost baseline was established for typical Halon 1301 fire extinguishing systems that are used on aircraft today, by considering several varied aircraft platform type representatives (both legacy (existing) and future platform types), to establish a life-cycle cost equivalence goal for any Halon replacement derived from and considered by the NGP program.

(2) A similar cost analysis was performed for the same platforms using the “first generation” Halon replacement HFC-125 selected and placed into service prior to the NGP program (sized to the same level of performance as the existing Halon systems), to establish “threshold” cost-of-ownership levels that any Halon replacement considered by the NGP must exceed to be of preference over the pre-existing HFC-125 and thus maintain further interest for research and implementation, while still targeting the life cycle cost “goal” of Halon equivalence for the program.

(3) Cost of ownership studies were also performed by varying the performance levels of such systems, by adjusting the size capacities (with resultant weight and size impacts on life cycle cost), to determine an “optimal” performance level in terms life cycle cost by balancing firefighting effectiveness with the size capacity cost implications.

(4) The cost studies also evaluated the merits of Halon 1301, HFC-125 or any other fire protection systems, in terms of their ability to “pay for themselves” by determining if the cost savings in terms of assets saved historically actually exceed the life cycle costs of developing, installing and supporting such systems in the field, to confirm if the systems actually provide a tangible monetary benefit to their aircraft customers, to determine which aircraft configurations (if not all, or none) provide such benefits, and to quantify any perceived benefits.

(5) The methodologies developed, modified and demonstrated in this initiative, applied in this case to Halon 1301 and HFC-125, were fashioned to serve as a stand-alone product

of the NGP (having already been used on some developmental aircraft since their formulation), and provide the framework to build modified models using new Halon replacements considered by the NGP or other future research, to compare versus the off-the-shelf goal and threshold baselines established in this study, and serve as an analysis tool to suggest key indicators of ideal Halon replacement properties to consider in later research of new technologies, as expressed in system and aircraft-level cost impacts.

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 man hours incurred per flight hour. Military personnel costs were based on the number of personnel authorizations per airframe.

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

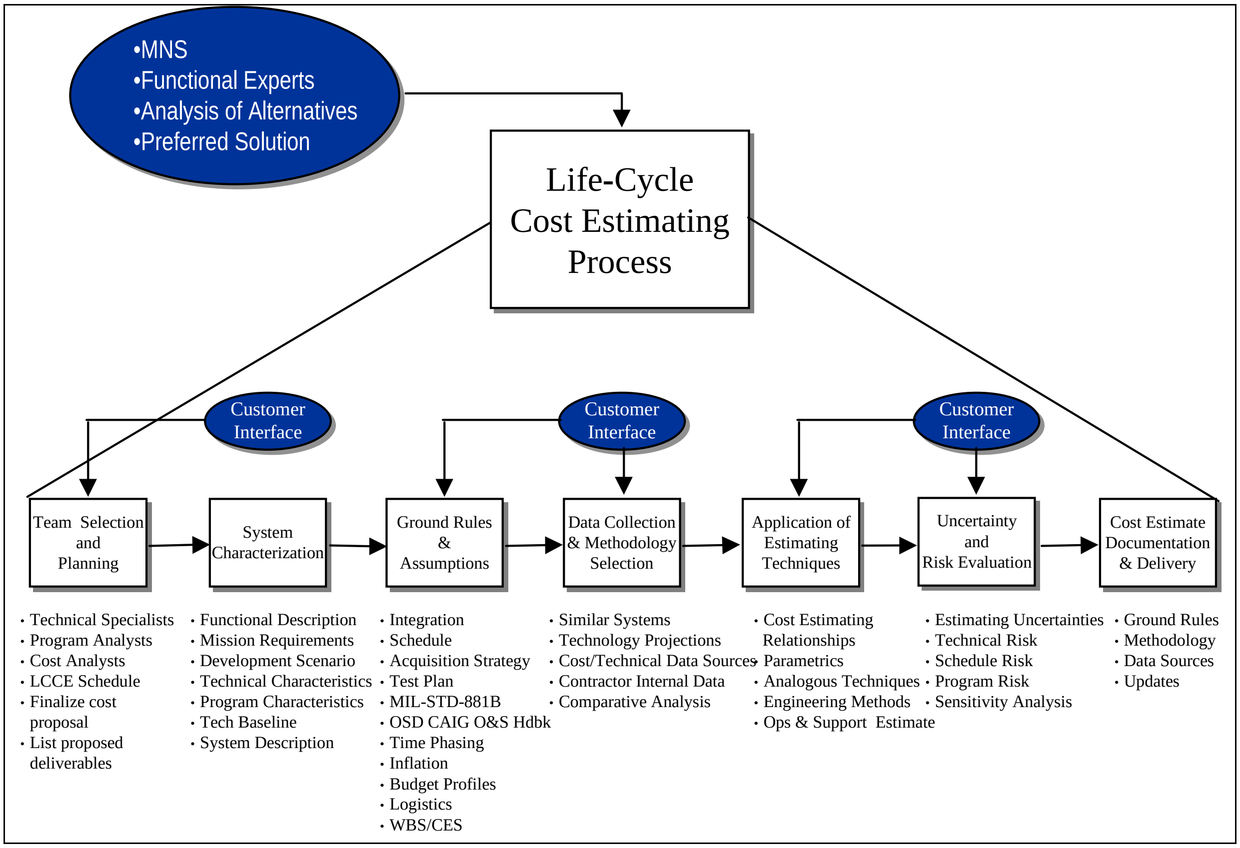

Figure 1. Standard Life Cycle Cost Estimating Process.

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 non-ozone-depleting fire extinguishing system. [2]

Costs estimated in this effort would include those 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

AIRCRAFT FIRE-RELATED COSTS AND SAVINGS (HISTORICAL DATA)

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 forecast 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. [3]

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 a “legacy” (such as those fielded today) Halon 1301 system was determined to be $25M, and a legacy HFC-125 system ranged from $35 to $41M. The estimated fire loss-related cost was $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 (for newly designed and manufactured aircraft, without retrofit expenses) is $36M, and 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 documented in another publication. [4]

FIGHTER AIRCRAFT

For a fighter aircraft, the cost of ownership for the legacy Halon 1301 system is $11.2M, and 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 legacy fighter aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Even if the legacy 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 future fighter aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Like the legacy systems, even if the future 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.

This study is also documented in a separate report. [5]

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 legacy 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, with this value being a breakpoint between system cost and benefit.

The cost of ownership for a Halon 1301 system for future rotor-craft 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 future 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.

This study is documented in a separate report. [6]

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, which collected a small set of data that documented reduced extinguishment success percentages, as a function of pre-set reduced quantities of extinguishant tested. This data revealed, as a hypothetical example, that an agent capacity of 2 kg may be observed in test to extinguish fires under certain conditions 30% of the time, 3 kg 60% of the time, and 5 kg 90% of the time. The actual suppression system mass capacities and corresponding effectiveness data collected in this cited test series were correlated to the cargo and fighter aircraft platforms considered in this project.

For cargo aircraft, the net cost change per single percent change increase in extinguishing effectiveness (i.e., 91 percent successful vs. 90 percent field success) of the fire system was approximately $-2.0M (thus, the benefit (in terms of increased assets saved) of increasing the success rate of the extinguisher system by just one percent increases the overall benefit (or negative cost) by this amount, even including the overall cost of the larger system). 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 considerably in assets saved.

Due to the lack of extensive 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). This analysis is detailed in a separate report. [7]

CONCLUSIONS/SUMMARY

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.

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.

ACKNOWLEDGEMENTS

This research was part of the Department of Defense's Next Generation Fire Suppression Technology Program, funded by the DoD Strategic Environmental Research and Development Program under DSS-W contract number SP0700-96-D-4000. The COTR for this effort was Mr. Martin L. Lentz (U.S. Air Force 46th TW/OGM/OL-AC).

The author would like to acknowledge the following organizations and individuals for their assistance with this project.

- C-17 System Program Office – Lt. Josh Bohnart, Capt. Brian Godfrey, and Mr. Daniel Hamblin
- NAWCAD (F/A-18 E/F) – Mr. Greg Drohat
- NAVAIR (Lakehurst) – Mr. Bill Leach, Mr. Marco Tedeschi, Mr. Don Bein
- NAVAIR (China Lake) – Mr. Joe Manchor
- Comanche Program Manager's Office – Mr. Scott Silies, Mr. Todd Miller, Mr. Glenn Wolf
- Pacific Scientific – Mr. Bill Meserve

- Walter Kidde Aerospace – Mr. Terry Simpson
- DuPont – Mr. Daniel W. Moore
- AFMC LSO/SGISA – Ms. Shelia Huis
- WPAFB ASRF – Mr. Neil Blevins

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. "The Impact of Halon Replacement On Aircraft Engine Bay Fire Protection System Design", G. Roberts, G. Doria, and T. Breeden, Northrop Grumman Corporation, Presented at the HALON Options Technical Working Conference, Albuquerque, NM, April 27 - 29, 1999.
3. "Assessing The Cost Impact Of Fire To The U.S. Air Force", M.L. Kolleck and J.M. Bennett, Presented at the International Aircraft Fire and Cabin Safety Research Conference, Atlantic City, NJ, November 16-20, 1998.
4. 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. 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. 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. 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.