

ASSESSING THE COST IMPACT OF HALON ALTERNATIVES ON AVIATION

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ABSTRACT

The *ongoing* conversion to halon substitutes for fire protection systems is beginning to have a notable impact on the cost of protection. These costs **are** particularly sensitive in the aviation industry, where increases in weight of only a few pounds **or** size increases in small amounts **can** translate into millions of dollars of increased cost per **airframe** over its life. New approved design and sizing methodologies for the current approved halon substitutes for aviation suggest that these systems will be several times heavier and bigger than their halon counterparts. The costs of using such systems will be enormous, in terms of retrofit cost, increased fuel capacity required, and other cost drivers over the **life** of the aircraft. Some alternatives offer the potential of more efficient sizing, but suffer from other cost penalties such **as** increased maintenance or precautions due to toxicity. The development costs of such new approaches (which may be very different in approach from conventional clean agent systems), and the associated certification techniques are also significant cost contributors.

This suggests that hard questions must be asked regarding the expected benefits of using such systems versus the overall costs incurred in providing such protection. With the increased cost expected with the new systems, a detailed and comprehensive assessment of the benefits that such systems will be expected to deliver for different aircraft applications and platforms versus the costs experienced throughout the **life** of the aircraft is needed. Armed with such knowledge, the merits of various potential future technologies and concepts can be evaluated and compared holistically to determine the most cost effective solutions and maximize payoff, as well **as** justify the merits of using any protection techniques on the platform. In addition, the cost drivers of a given concept can be identified early in the development process, and R&D resources can be concentrated in such areas to deliver maximum cost payoff. The investment costs of such research can be verified against the expected payoff in eventual fielded systems.

Such a program is now underway and sponsored by the U.S. Air Force. The comprehensive cost due to the “fire problem” to the Air Force, both historically and anticipated for the future, is being established, which will bound the resources invested in this ~~area~~ and dictate the global cost boundaries of protection schemes to provide payoff. The entire cycle of development and use, including research, advanced development, certification, procurement and installation, maintenance and support, and disposal ~~are~~ being incorporated. Costs of lire events will include aircraft and personnel lost, *cargo* and munitions lost, other property lost, and other factors. Both peacetime and wartime events and scenarios are being included. This will be evolved into a methodology that will allow a forecast of the expected life cycle cost of new concepts (particularly halon substitutes) proposed or in development. It is anticipated that industry will also have access to such a methodology to guide their own internal development, and in preparing proposals to the Air Force to encourage relevant products and coordinated progress. The ultimate goal of these tasks is to optimize the cost effectiveness of aircraft lire protection.

INTRODUCTION

This paper presents the results of a study whose objectives were to quantify the historical costs to the U.S. Air Force of fire and fire protection systems and develop a projection of these costs. This paper focuses on historical cost development for the 30-year time period from **1966 - 1995** and projected costs for **1996 - 2025**.

All fire related costs were assigned to one of three broad categories:

- I Costs of Peacetime Aircraft Losses Due to Fire,
- II Costs of Combat Aircraft Losses Due to Fire, and
- III Costs of Aircraft Fire Protection.

Each of these categories is in turn composed of very many components, and resource constraints precluded investigating all of them. However, data were obtained on many and these have formed the basis of the analysis. Unfortunately, much of the data are of a highly sensitive nature, allowing only summary results to be presented.

COST OF PEACETIME AIRCRAFT LOSSES DUE TO FIRE

Data were requested from the Air Force Safety Center at Kirtland AFB. This **office maintains** peacetime incident data. Data provided included both in-flight and ground fire incidents aboard aircraft, airframe type, costs to the Air Force, and injury classification, if applicable, for the time period 1971 - 1996. Based on these **data**, the cost of peacetime aircraft lost to fire was estimated to be \$2.265 billion over this 26-year timeframe, measured in then-year dollars (the dollar value in the year of the incident). Adjusting for inflation and extrapolating backwards for the 5-year period 1966 - 1970, total costs in 1995 dollars **are** estimated to be \$4.335 billion for the time period 1966 - 1995.

A somewhat similar process was **used** to project peacetime fire costs for the 1996 - 2025 time period. For this analysis, it was 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. Flight hour data for current fleet aircraft only were available from 1971 - 1995. The AF Safety Center costs of \$2.265 billion reflected costs associated with aircraft no longer in the inventory (e.g., F-4s, A-7s, etc.). Therefore, those costs associated with the out-of-inventory aircraft were removed from the total costs, leaving \$1.323 billion attributable to current fleet aircraft. This number was adjusted to 1995 dollars. Based on these data, the average cost per flight hour (FH) was \$61.25, measured in 1995 dollars.

In order to project future costs, not only must the cost per FH be determined, but the projected number of FH as well. Using a baseline of 2.253 **million** flight hours for FY95, **annual** flight hours were estimated for the 1996 - 2025 time period. When combined with the average cost per FH, a total projected cost of \$3.084 billion (\$96) was determined.

In addition to the value of the aircraft lost to fire, there are ground related costs **as** well, such **as** the various fire departments. Data compiled by the Air Force Civil Engineering Support Agency, Tyndall AFB, FL, show the operating cost for the Air Force-wide fire departments to be \$300 million for FY94. These costs included military and civilian payroll, training, and fire fighting vehicle operating and maintenance costs.

Fire fighting and crash rescue vehicles **are** used in this cost model because, regardless of whether a given Air Force base has an assigned flying mission, an aircraft fire fighting and crash rescue capability must be maintained on station to support any transient aircraft traffic at that base. Fire fighting manpower at each Air Force base is based on the number of aircraft supported, either stationed **or** anticipated **as** transient air traffic. Additionally, the manning strategy assumes there will be no cross-manning of equipment for other fire fighting purposes, i.e., structural fire fighting. This means that fire fighting personnel are used on either aircraft crash and rescue tasks, or they are assigned to a structural fire fighting vehicle, depending on the emergency. If a fire crew is responding to a structural fire assignment, and an in-flight emergency is declared, the crew will immediately respond to the in-flight emergency, with the personnel immediately transferring to the aircraft fire fighting or crash rescue vehicle. Discussions with Air Force Base Civil Engineers, who are also the *de facto* Base Fire Marshalls, established that structural fire fighting vehicles normally respond to aircraft fire incidents, because the crash and rescue vehicles typically carry Aqueous Film-Forming Foam (AFFF) for aircraft fire suppression, and in case of large fires, often need additional water supplies. Also, often times a fire from an aircraft incident spreads to surrounding airfield areas such as grass infields and surrounding pavements and/or structures (mainly due to the spread of burning fuel) and therefore, requires additional water-carrying fire fighting vehicles. Estimated costs of ground-related equipment and personnel is **\$4.935** billion in **1995** dollars for **1966-1995**. Projected costs of ground-related equipment and personnel is **\$9.474** billion (**\$96**) for **1996-2025**.

Other costs are also relevant to this analysis. These include medical costs, liability costs, repair costs, and the cost of cargo in cargo aircraft. However, none of these was included in this analysis. Medical costs were not included because these costs were not reported in a consistent manner in the incident reports. They were sometimes reported and other times not, even when the incident mentioned that a fatality had occurred. Therefore, in order to avoid the possibility of double counting, medical costs were omitted. Similar types of comments apply to liability costs and repair costs, i.e., they were not consistently reported in the incident reports and therefore not included in this analysis.

The cost of **cargo** involved in a cargo aircraft incident is very difficult to determine. An itemized list of the **cargo on** a destroyed cargo aircraft would be required in order to get an accurate representation of these costs. Such information was not available in the incident reports. However, these costs could be significant, especially if the aircraft is carrying troops.

By combining the components which comprise the Cost of Peacetime Aircraft Losses Due to Fire, a resulting historical cost of approximately \$9.271 billion was obtained, measured in 1995 dollars. Projected fire-related costs totalled \$12.558 billion (\$96) for 1996- 2025.

COST OF COMBAT AIRCRAFT LOSSES DUE TO FIRE

The Survivability and Vulnerability Information Analysis Center (SURVIAC) was queried for information on combat aircraft losses in Southeast Asia (SEA) and Desert Storm. The SURVIAC search of combat losses employed the database ACFTDB. The search criteria used were: fire was the threat effect, the disposition of the airplane (repaired in theater, loss to theater, loss to inventory, repaired, **unknown**), the aircraft type, the service (USAF, USN, USMC), the date of the incident, the crew skill (pilot, copilot, navigator), and the disposition of the crew member (rescued, presumed dead, body recovered). Aircraft replacement cost data **are** contained in Technical Order (TO) 00-25-30 and were used when an aircraft was destroyed in combat. Using these data along with the number of aircraft lost in SEA and Desert Storm, the costs attributable **to** aircraft **fire** were \$4.205 billion and \$108 million, respectively, in 1995 dollars.

The cost of human life and medical care to the Air Force is a significant one. The costs under consideration in this study were those incurred as a result of a death or of an injury caused by aircraft fire. These costs consist of training and acquisition costs associated with replacement personnel, and costs associated with **various** outcomes, i.e., fatality, permanent total disability, permanent partial disability, lost workday, or hospitalized day. Costs associated with medical expenses were obtained primarily from Air Force Instructions (AFI 91-204--Standard Injury, Illness, and Fatality Costs for Officers, Enlisted, and Civilians). Training costs for replacement personnel were found in AFI 65-503. The total for SEA is estimated to be \$1.5627 billion in

1995 dollars. For Desert Storm, based upon the incident reports which had fire as the threat effect, no casualties were reported as a result of the fire.

The SURVIAC database did not provide aircraft battle *damage* repair (ABDR) cost information. However, man-hours were provided. For the aircraft which were repaired in theater, or which were loss to theater, the man-hours necessary to repair the aircraft and the necessary replacement parts, if given, were used to determine the costs attributable to fire. The labor rate assumed was that of an E-4 (\$19.37/hour). Southeast Asia ABDR costs are \$2.452 million in 1995 dollars.

Projected wartime attrition and repair costs were estimated based on assumed sortie rates and attrition factors. Historically, 50% of combat losses are a result of a fire or explosion. Provided that this estimate of combat loss due to fire remains the same in future conflicts, sortie rates and attrition factors can be used to estimate the expected number of aircraft lost in a future conflict. Sortie rates and attrition factors are classified and vary between threats, aircraft, and mission type. For the purposes of this study, allocating 50% of the USAF inventory to a combat theater for 90 days could generate an estimated \$5.71 billion in lost aircraft. If 50% of combat losses are related to fires, the cost of fire in a future conflict could be \$2.855 billion.

Attrition factors only account for lost aircraft, and do not include mishaps or battle damaged aircraft. To address the issue of battle damage costs, two assumptions must be made:

- 1) 50% of attrited aircraft are lost due to fire, and
- 2) Aircraft fire protection is less than 100% effective.

Given these two assumptions, the number of aircraft which sustained battle damage that included an on-board fire and recovered at a friendly base can be represented by the fraction

$$\frac{(\text{No of aircraft lost due to fire})}{(1 - \text{successful fire protection rate})}$$

This is the number of aircraft recovering from battle *damage* with an on-board fire. If the assumption is made that 100 aircraft are lost in battle in a particular campaign, then 50 of the lost aircraft were assumed to have involved fire damage. Using the fraction above, $(100 - 50) / (1 - 0.6) = 125$ aircraft have fire related battle damage and return with typical battle damage costs

representative of a Class C mishap. However in future conflicts (with more expensive aircraft, such as the B-2), **this** number could go up. Estimated fire related battle damage costs in a **future** conflict are \$12.5 million in 1996 dollars.

By combining the components which comprise the Cost of Combat Aircraft Losses Due to Fire, a resulting historical cost of approximately \$5.878 billion was obtained, based primarily on SEA experience. Projected costs were \$2.868 billion in 1996 dollars, based on the scenario and the assumptions defined above.

COST OF AIRCRAFT FIRE PROTECTION

The costs of aircraft fire protection include research costs, maintenance costs associated with fire protection systems, and the cost of additional fuel required to fly the additional weight of the fire protection systems. Compiled information regarding costs of fire protection research was very difficult to obtain. The following sources were investigated:

- The Wright Laboratory Plans Office (WL/XPS) was contacted to investigate money spent on fire protection research.
- The AF Cost Analysis Agency was contacted, but did not have this type of information.
- The *Technology Development Plan for Alternatives to Ozone-Depleting Substances for Weapon Systems Use* (June 1996) provided significant cost information.
- Joint Technical Coordinating Group on Aircraft Survivability (JTTCG/AS). The JTTCG/AS Central Office was contacted to determine the amount of research dollars given to the Fuel Systems Committee in the past. Funding information was sent from the Central Office; however, they only retained funding information since 1990. The search criteria used by the JTTCG/AS point of contact were the terms fire, explosion, and fuel. JTTCG/AS also provided the FY97 Program Book, October 1996.
- A search of the Defense Technical Information Center (DTIC) for research funding dollars was beneficial.
- The Wright Laboratory Fourth Quarter FY96 Roadmap for research funding provided cost information.

- Manpower costs for the Survivability and Safety Branch of Wright Laboratory were included in the research costs.
- Costs for Live Fire Testing were also included in these research costs.

This information was quite difficult to obtain and it is believed that there **are** items which were omitted due to the lack of knowledge of their existence or location.

As stated previously, Wright Laboratory personnel were contacted to request data regarding the costs of performing Live Fire Tests of aircraft with fire suppression, detection, and inerting subsystems. LFT information was obtained relating to the C-17, F-22, B-1B, and Joint Live Fire (JLF) testing.

Using the data sources described above, fire protection R&D investment is estimated at \$260.771 million for 1966 through 1995. Projecting forward, in 1996 dollars, an estimated \$500.61 million will be expended on research between 1996 - 2025.

Historical maintenance costs associated with fire suppression systems were also estimated for 1966 - 1995. Trade studies conducted on current fleet aircraft have shown the operation and support costs associated with an HFC-125 fire suppression system. This number was used **as** the basis for estimating fire suppression system maintenance costs. The total number of aircraft in the inventory had to be estimated as well for this time period. Data on total aircraft inventory were available for 1977 - 1995. These data were used to estimate the aircraft inventory for 1966 - 1976 as well as 1996 - 2025. Total historical maintenance costs associated with fire suppression systems was calculated to be approximately \$51.097 million in 1995 dollars. Projected maintenance costs were \$60.138 million (\$96) for the period 1996 - 2025.

This study also estimated the cost of additional fuel consumption caused by the weight of the fire suppression system on an aircraft. In order to estimate this cost, three categories of aircraft were established - attack/fighter, bomber, and cargo/tanker. This categorization allowed the many different mission requirements of the various aircraft to be reflected in the analysis. With the assistance of appropriate aircraft crew members, typical aircraft configurations and mission profiles were defined for a representative aircraft from each group. The three aircraft selected were the F-15, B-1, and C-130. These aircraft were chosen because computer

descriptions of each reside in SURVIAC. These aircraft descriptions were run through their mission profiles using the BLUEMAX computer model. One of the outputs of this model is the additional pounds of fuel required per mission flight hour for the weight increment due to that aircraft's fire suppression system.

Flight hour data for aircraft in the three aircraft categories were found in various sources. Using these flight hours, the total weight increment, the BLUEMAX-generated additional fuel consumption per flight hour, and the cost per pound of fuel, the total cost of the additional fuel associated with the increased weight was calculated for each aircraft category. The cost of JP-8 fuel is currently \$0.115 per pound, based on information received from base supply at Wright Patterson ~~Air~~ Force Base. The cost of JP-4 was not available. The \$0.115 was adjusted for inflation over the relevant timeframe.

Historically, for the time period FY92 - FY95, these three aircraft groups accounted for approximately 65% of the total fleet. If this percentage is carried backwards, the total historical costs of the extra fuel for the entire fleet can be calculated as the sum of the costs for the three aircraft groups divided by 65%. This value is \$3.783 million 1995 dollars. Estimated cost of the extra fuel necessitated by the additional weight for the 1996- 2025 timeframe, using the projected number of flight hours determined previously, is \$2.994 million (\$96).

Other costs, such as those associated with halon banking and disposal/demilitarization, were also investigated. However, there are no data available on either. The DoD Ozone Depleting Substance (ODS) Reserve Bank at the Defense Supply Center in Richmond, VA, was queried to find the cost for banking Halon 1301. Their response was that it is virtually impossible to estimate that cost due to the magnitude of the number of individual contributors to that cost. **This** was the same response received from the Kelly AFB Halon 1301 bank.

Regarding disposal/demilitarization costs, the Defense Reutilization and Marketing Service (DRMS) in Battle Creek, MI, was contacted for data concerning materiel which is disposed of when demilitarizing Halon 1301 fire suppression/inerting systems from aircraft. A DRMS Disposal Code was required to query the DRMS database and no code was assigned to

Halon 1301 systems. This was due to the fact that Halon 1301 is not disposed of, but banked. No code could be determined for the hardware (tubing, bottles, etc.).

By combining the various components which comprise the Cost of Aircraft Fire Protection - research costs, fire suppression systems maintenance costs, and the cost of additional fuel - an historical cost of approximately \$315.651 million was determined, measured in 1995 dollars. Projected costs are estimated to be \$563.742 million, measured in 1996 dollars, for the time period 1996 - 2025.

SUMMARY

The cost to the U.S. Air Force of losses due to fire have been significant. By combining the components which comprise the Cost of Peacetime Aircraft Losses Due to Fire, a resulting historical cost of approximately \$9.271 billion was obtained, measured in 1995 dollars; for the Cost of Combat Aircraft Losses Due to Fire, approximately \$5.878 billion, based primarily on SEA experience; for the Cost of Aircraft Fire Protection, approximately \$315.651 million, measured in 1995 dollars. The total historical costs of fire to the U.S. Air Force over the 1966 - 1995 time period is estimated to be \$15.465 billion (\$95). The total projected costs of fire to the U.S. Air Force over the 1996 - 2025 time period is estimated to be \$15.990 billion (\$96).

RECOMMENDATIONS

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. This paper has presented the methods and results from an extensive study to determine the costs attributable to aircraft fire. However, time did not permit an exhaustive investigation of all contributing costs. The following recommendations are made in order to provide a more comprehensive picture of the costs attributable to fire.

For technological advancements to be made in the mitigation and cessation of aircraft fire events, it is recommended that a structured fire investigation checklist be developed to provide better information about fires (how they are fought, and what methods, actions, and extinguishers are effective in fighting aircraft fires). The checklist provide information to enable improvements in the effectiveness of fire extinguishant/suppression systems.

Liability costs were included in some of the Air Force Safety Center data. Since there was no discrimination between the attributing costs, it was not possible to determine the impact of liability costs. Liability cost information should be requested from the Aviation Torts Section (providing the incident date, aircraft type, and location (on- or off-base)).

Transport and **cargo** costs for aircraft incidents within the past **30** years **are** difficult to estimate. The Safety Center incident reports did not report the amount of **cargo** and the **cargo** type. It is difficult to make an assumption of the cargo on-board. **An** itemization of cargo carried on the destroyed cargo planes, and determination of cargo at the time of the fire would need to be performed in order to give a more accurate representation of the costs attributable to **cargo** lost due to fire. However, for future projections typical **cargo** scenarios may be developed for cargo aircraft. A **cargo** aircraft could carry troops, munitions, tanks, helicopters, engines, etc. A typical fighter has up to **47** different configurations for their munitions and fuel tanks (T.O. 1F-16A-2-00GV-00-1). These options **are** necessary for different mission scenarios. It can be assumed that the same principle would apply to other aircraft, possibly to an even greater extent for cargo aircraft. It is recommended that a database of the possible configurations of munitions and cargo and their associated cost information be developed.

The cost of research was not all inclusive. Many items were not able to be considered. Such items include research regarding: facility design (fire extinguishers in **hangars**), support equipment design, fuel handling, equipment storage, survivability design, engine design, personnel safety gear (gloves, flight suits, maintenance crew apparel, ...), fuel volatility, etc. It is recommended that the research costs associated with these and similar ideas as well as their procurement, maintenance, and support costs be investigated.

No cost data were available for halon banking. It is recommended that follow-on studies be pursued to quantify these costs. For example, it is possible that Congressional appropriations for the DoD ODS Reserve **Bank** could be tracked and then analyzed for the DoD Halon 1301 portion.