AIRCRAFT DRY BAY FIRE PROTECTION:
A REVIEW OF AVAILABLE OPTIONS

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BACKGROUND

Several years ago, when the F/A-18 EIF and V-22 aircraft contracts were finalized, the USN (following DoD requirements) required that the production versions of the F/A-18 EIF and V-22 aircraft utilize non-halon technologies for fire protection in both engine nacelles and "Dry Bays." "Dry Bays" are the compartments immediately adjacent to fuel tanks or other flammable fluids. They frequently contain fluid lines, control lines, electrical equipment, etc. (Figure 1). Ballistic damage to some of these bays, from hostile fire, can allow fuel to enter the bay causing fire and loss of the aircraft (Figure 2). To protect the critical Dry Bays, Solid Propellant inert Gas Generators (SPGG) were selected as the fire protection technology for both the V-22 and the FIA-18 E/F.

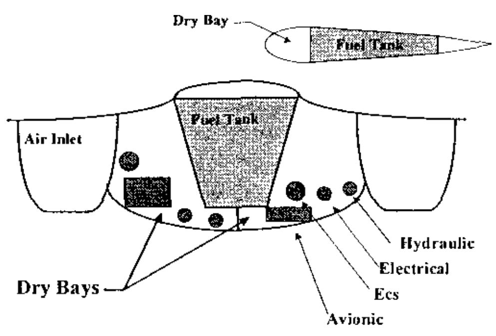

Figure 1. Representative Dry Bays.

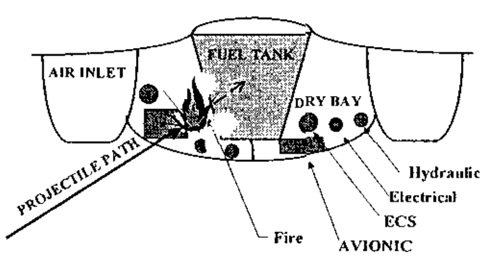

Figure 2. Fire hazard for Dry Bay

Recent advances in Gas Generator design, better understanding of the capabilities of gaseous agent technologies, and a renewed emphasis on life cycle cost now provide an incentive to revisit this technology selection. Boeing has just completed a generic trade and sizing study of the various near-term Dry Bay fire protection technologies for a representative advanced Fighter / Attack aircraft design. The sizing methodology, results, and conclusions of that study, which emphasizes weight and cost, will be presented in this paper.

HISTORY

Protecting combat aircraft from fuel related fires and explosion has been an issue for decades. During World War II (WW 11), later versions of most American mainline combat aircraft, both fighters and bombers, were equipped with self-sealing fuel tanks, small areas of armor, and occasionally other vulnerability reduction concepts, including balsa wood in some locations for passive Dry Bay protection. The B-17 (Flying Fortress), P-38 (Lightning), P-47 (Thunderbolt), P-51 (Mustang), F6F (Hellcat), and F4U (Corsair) **all** used some form of vulnerability reduction design. At least one of the Soviet aircraft, the IL-2 (Sturmovik), was equipped with exhaust gas inerted fuel tanks. The IL-2 exhaust gas was so corrosive that the tanks were expected to fail about 90 days after first being pressurized with the exhaust gas. This was not considered a real liability since the anticipated combat lifetime for these aircraft was less than **30** days (Figure 3).

During the Vietnam conflict, thousands of combat aircraft were lost, with more than 50% of those losses attributed to fuel system leaks, fires and / or explosions (Figure 4). This experience resulted in renewed emphasis on vulnerability reduction. As the Vietnam War progressed, US aircraft began to be equipped with improved self-sealing fuel tanks, self-sealing fuel lines, and reticulated explosion suppression foam (a passive sponge-like material) to protect the fuel tanks. Improved Dry Bay ballistic protection was provided by either passive (semi-rigid foam) or active (halon discharged by optical sensors) Dry Bay protection systems [1].

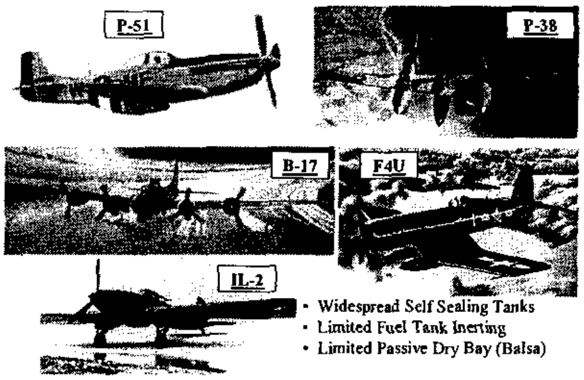

Figure 3. World War II protection.

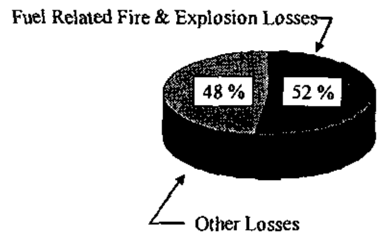

Figure 4. Causes of combat losses in Southeast Asia.

INTRODUCTION TO DRY BAY PROTECTION

The tops and bottoms of wing fuel tanks are generally bounded by the aircraft mold line; therefore, any fuel leak at these boundaries is immediately transported overboard, thus avoiding an interior fire hazard. Portions of some fuselage tanks may also he bounded by the aircraft mold lines, providing similar protection. When fuel tank boundaries do not reach the mold line, the “Dry Bay” cavity between the fuel tank boundary and the mold line can become an interior fire hazard, especially with ballistic damage from high-energy incendiary rounds. In some bays, the potential for fire damage to hydraulic lines, electrical wire bundles, avionic boxes, and/or control cables, etc., increases the probability of aircraft loss.

Modem combat aircraft frequently utilize state-of-the-art active systems to protect critical Dry Bays from ballistic induced fire damage as shown in Figure 5. Several current and/or evolving aircraft programs are also considering Dry Bay protection systems for critical areas of the vehicle. In these active systems, a high response optical sensor detects the “Flash” of the incendiary round and/or the initiation of a hydrocarbon fire from the leaking fuel tank, then immediately discharges an extinguishing “agent,” which extinguishes the flame. For the current inert gas SPGG technology systems in the V-22 and F/A-18 E/F aircraft, the “Agent” is generated by burning a solid propellant charge and using the exhaust gas to extinguish the flame. The exhaust gas usually contains a mixture of inert N, and CO, gas with a small quantity of water vapor and residual “Dust.” Alternate technologies for actively extinguishing the flame in the protected Dry Bay area are the subject of this paper. Figure 6 illustrates the more commonly recognized vehicles using or considering Dry Bay protection. (Passive systems based on installing semirigid “foam” or [in WW II] balsa wood blocks, in the dry hay to deny the void cavity to the leaking fuel, were abandoned some time ago in favor of active systems due to the risk of undetected corrosion and other maintenance issues associated with use of these passive systems.)

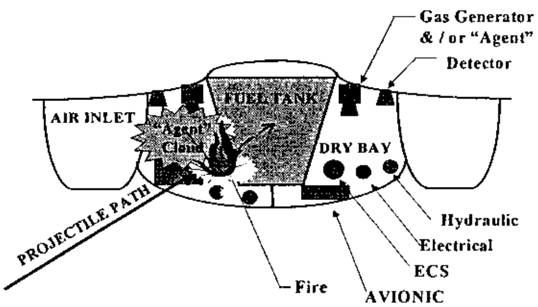

Figure 5. Active Dry Bay protection against ballistic threats.

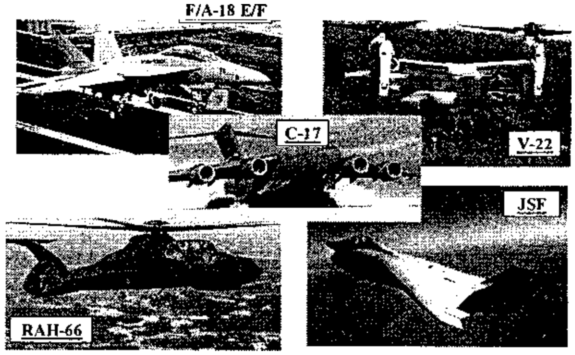

Figure *6*. Aircraft using or considering protection.

ALTERNATE NONHALON DRY BAY PROTECTION TECHNOLOGIES

Several potential alternate technologies were considered. Only four were considered mature enough for near-term applications.

(1) Solid Propellant Gas Generator	Discharges inert gases
(2) HFC-125	Discharges inert gas
(3) CF_3I (CF_3I)	Discharges "active" gas
(4) "Active" Solid Propellant Gas Generator	Discharges inert & "active" gases

Although there are limited data on CF_3I and "Active" SPGG, it is believed that they can be matured enough to meet near-term needs if given the necessary priority and funding.

ASSESSMENT METHODOLOGY

Several existing and advanced combat aircraft designs were reviewed to determine the size, dimensions, criticality, etc., of representative Dry Bays in combat aircraft. A representative Fighter/Attack vehicle configuration was developed based on this review with representative Dry Bay sizing. This information was given to several suppliers who agreed to provide their recommendations for Dry Bay protection. Figure 7 summarizes the representative configuration utilized; Figure 8 shows the operation of the Dry Bay protection system

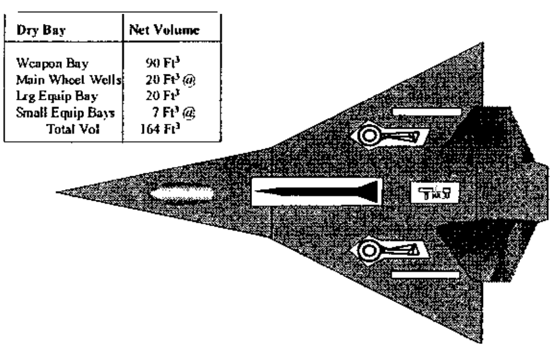

Figure 7. "Representative" advanced fighter/ attack Dry Bay configuration.

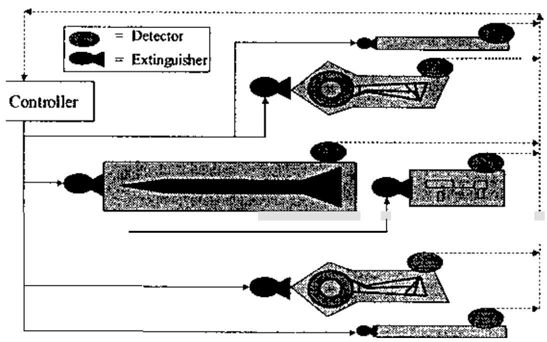

Figure 8. "Simplified" dry bay detect/ discharge arrangement.

Each supplier responded with the approximate weight and cost estimates for protecting the Dry Bays based on several technologies. Boeing then compared their recommendations with our prior experience and future projections, and synthesized a weight and cost estimate for each technology using data from multiple suppliers. The adjusted component data for each technology were evaluated first on an aircraft level and then on a fleet-wide basis, assuming a 400-aircraft fleet with a 20-year / 4000-flight life expectancy, and a 5-year pyrotechnic element replacement interval. This evaluation generated approximate values for Take-Off Gross Weight (TOGW), fuel used, Operational and Support (O&S) Costs, Life Cycle Cost (LCC), etc. The weight data are presented in Figure 9 and the cost data in Figure 10. A larger aircraft fleet and/or longer service life would impact the absolute dollar value of cost assessments, but would not affect the relative value of the technologies evaluated.

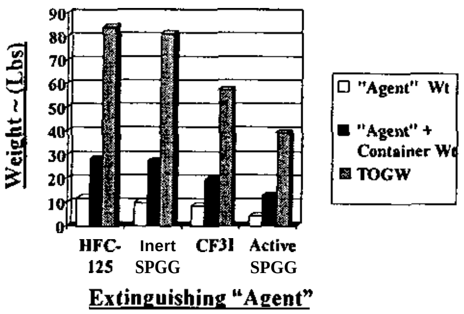

Figure 9. Weight comparison.

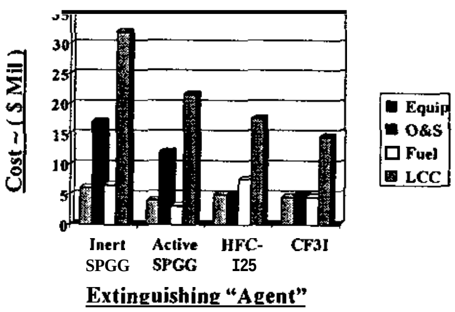

Figure 10. Cost comparison.

This assessment was based on an advanced design "rubber" aircraft model in which any weight and/or volume growth in the equipment requires a resizing of the vehicle to accommodate that additional volume, resizing the engine to provide the same performance for the larger vehicle, and additional fuel for the larger engine to meet the same range, speed, and acceleration requirements. This re-sizing approach is repeated until the vehicle design converges and all performance requirements are satisfied. This methodology is illustrated in Figure 11.

LIKELY IMPLICATIONS

The data developed in this study give no clear absolute preference for any technology; however, the results do present preferred technologies depending on the critical program performance metric in use at the time a technology must be selected (Figure 12).

Weight Critical Programs

On some applications, such as a vertical take off and/or landing vehicle, weight can be an overriding factor forcing the selection of the lowest weight system. The weight assessments from this study yield a preference for "Active" Solid Propellant Gas Generators (SPGG), with CF_3I a reasonably close second.

Life Cycle Cost Critical Programs

In today's political and business environment, cost is becoming a much more important decision metric, many times the dominant metric. From this study, the preferred technology, on a Life Cycle Cost (LCC) basis, is CF_3I with HFC-125 a reasonably close second.

Acquisition Cost Critical Programs

If the short-term acquisition costs are of primary concern, this study indicates that an "Active" SPGG may be the preferred technology because its smaller size, lower weight, and potentially fewer units make it potentially the lowest acquisition cost option, providing cost and weight growth are controlled during maturation.

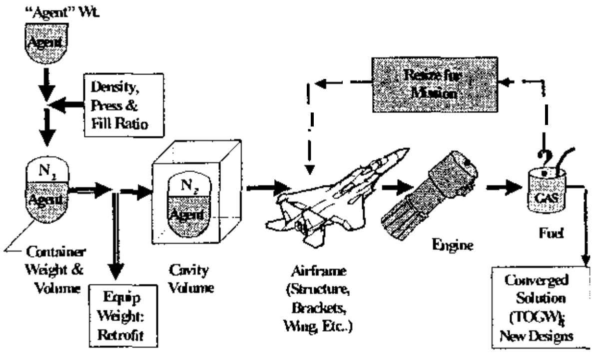

Figure 11. Aircraft sizing illustration.

<u>Weight Critical Program:</u>
(TOGW ~ Lbs)
1. "Active" SPGG 31 #
2. CF3I 57 #
3. Inert SPGG 81 #
4. HFC-125 84 #

<u>Cost Critical Program:</u>
(LCC ~ $ Mil)
1. CF3I $ 12.5
2. HFC-125 $ 16.5
3. "Active" SPGG $21.5
4. Inert SPGG $ 32

<u>Equip Cost Critical Program:</u>
(Acquisition Cost ~ $ Mil)
1. "Active" SPGG $ 4
2. CF3I $ 4.5
3. HFC-125 $ 5
4. Inert SPGG $ 6

<u>Risk Critical Program:</u>
(Rank)
1. Inert SPGG
2. HFC-125
3. CF3I
4. "Active" SPGG

Figure 12. Ranking dependent on metric

Risk Adverse Programs

Should the Program Management consider commonality and/or risk reduction to be the overriding issues, then "Inert" SPGG and/or HFC-125 are the technologies likely to be pursued. The relative immaturity of "Active" SPGG development, the limited amount of CF_3I fire test and low temperature data, and the lingering perception of potential health concerns associated with CF_3I, could result in these technologies being excluded if risk avoidance is the dominate decision criteria.

Balanced Assessment Programs

The program metric perceived as most critical at the time the technology decision is required will likely determine which technology is selected. The "Active" SPGG and CF_3I both rate well on most of the metrics and would likely be given preference in most balanced assessment programs. The relative lower cost and lighter weights associated with these technologies may well overcome other concerns, resulting in further development of both of these technologies. In addition, these are the only technologies having the intangible benefit of halon like "Active" suppression. This may provide the tiebreaker in any close evaluation. (Note: The "Active" SPGG data are likely to be the least accurate because it is perceived to be the least mature candidate technology. In fact, this could be considered several technologies since there are several candidate chemicals still being considered for the "Active" component of these devices.)

RECOMMENDATIONS

(1) Continue R&D with CF_3I unless administratively prohibited; additional work is recommended to address:
   a. Low temperature performance concerns.
   b. Hazard analysis to address potential health concerns.
   c. Low cost, light, reliable mitigation concepts for each of the above concerns.

(2) Continue R&D with "Active" Solid Propellant Gas Generators with particular emphasis on:
   a. Containing non-recurring cost.
   b. Containing O&S cost by extending service life, reducing fielded unit replacement cost, modular replacement, etc.
   c. Selection and utilization of the "active" ingredient to avoid additional problems (corrosion, health, handling, etc.).

(3) Control the cost and weight growth in these technologies as these programs mature. Excessive growth, in either cost or weight associated with resolving issues that arise as these technologies mature, could make them unattractive leading to their abandonment.

(4) Continued research into additional alternatives not considered in this study is still needed, since after all the years of study no alternative has yet been found to be equivalent in all aspects to halon, and all the alternatives to date have unattractive features.

REFERENCE

1. **Ball, Robert,** *The **Fundamentals of Aircraft Survivability Analysis and Design,*** **American Institute** of **Aeronautics and Astronautics, Inc, New York, NY, pp. 11-22, 1985.**

SOURCE OF PICTURES:

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Historical Aviation Art, the Boeing Company (Web Site) F4U

Various Web Sites - P-51, P-38, B-17, IL-2