FUEL INERTION LIVE MUNITIONS TESTING USING CF_3I

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INTRODUCTION

Historically, fuel fire explosion has been a major cause of aircraft losses in combat. To increase survivability, various techniques are used to reduce the vulnerability of the aircraft's fuel system to this significant threat effect. The F-16 weapon system relies on Halon 1301 to provide fuel cell inerting to protect the fuel system from explosions due to combat threats. Halon, the worst known ozone-depleting chemical, has been eliminated as part of an international agreement to cease man-made production of these types of chemicals. A ban on production that went into effect in 1994 has left only existing stocks of halon available to support halon use in essential applications such as aircraft fire and explosion suppression systems. As a result, all F-16s are dependent on a finite amount of halon available from Department of Defense stocks. However, these stocks may become useless as there are on-going preliminary discussions among some countries to ban the use of halon altogether.

A review of the F-16 fuel cell inerting technical characteristics and the overall fuel cell ullage inerting issues have resulted in a preliminary set of F-I6 fuel cell explosion suppression system requirements [1]. The review also highlighted information voids in baseline data that preclude immediate definition or specification of an optimum approach to replacement of the current halon inerting system. Therefore, a test program was conducted to (1) help determine the F-16 fuel "bare" system vulnerability behavior, (2) confirm (and quantify) the performance of the current F-16 halon inerting system, and **(3)** perform preliminary testing of candidate new alternative fire suppression systems.

A test series was planned to describe the F-16 fuel tank explosion suppression replacement and baseline characterization tests required to allow development of alternative approaches to the current F-16 Halon 1301 fuel tank inerting system. The test series was conducted to collect data to evaluate the vulnerability of the F-16 fuel system due to ballistic threat-induced fuel/air vapor explosions in the fuel tank ullages. The ullage explosion test series was conducted using Air Force Research Laboratory **(AFRL)** W-Tank to simulate sections of F-16 internal fuselage **AI** and F1 fuel tanks and **F-I6** wing fuel tanks. Explosion-initiation threats typically encountered by the F-16 while on user-specified missions were used in the ballistic tests. The test article contained **JP-8** or JP-8+100 fuel heated to a temperature and filled to a level defined by the 10% fuel state of the representative mission profile.

Three major technical objectives addressed in this test program were as follows:

- What level of protection does the current halon system provide against fuel system ullage fire/explosions compared to no inerting protection at all?
- What level of protection do alternative fire/explosion suppression candidates provide?

- What alternative fire/explosion suppression candidates should he investigated in more detail in follow-on testing’?

SYSTEM DEVELOPMENT

The F-16 aircraft has the capability to inert fuel tanks using Halon 1301. This system, shown in schematically in Figurc 1 [2], consists of a halon tank reservoir. a halon tlow control valve, solenoid operated shutoff valves and associated plumbing, electrical wiring, and switches. The halon reservoir is located in the wheel well area for easy access and rapid turnaround. The volume of halon reservoir is specified at a maximum of 340 in’ and the reservoir is pressurized by the vapor pressure of the halon. which varies from 560 psi at 150 °F to 17 psi at -40 “F. **A** 400-watt heater **is** installed to maintain reservoir pressures. A window with a hall float is incorporated into the reservoir tank to provide a liquid level indication at 235 in’ volume without the need for aircraft or ground electrical power. The reservoir also contains an integral pressure relief valve to relieve reservoir pressure at 600 psi, a threaded refill port with a zero leak valve for servicing. and a quick disconnect at the outlet port. The halon reservoir is mounted in the aircraft with locator pins and can be removed readily during the combat turnaround and replaced with a fully serviced unit. This can be accomplished simultaneously with aircraft refueling.

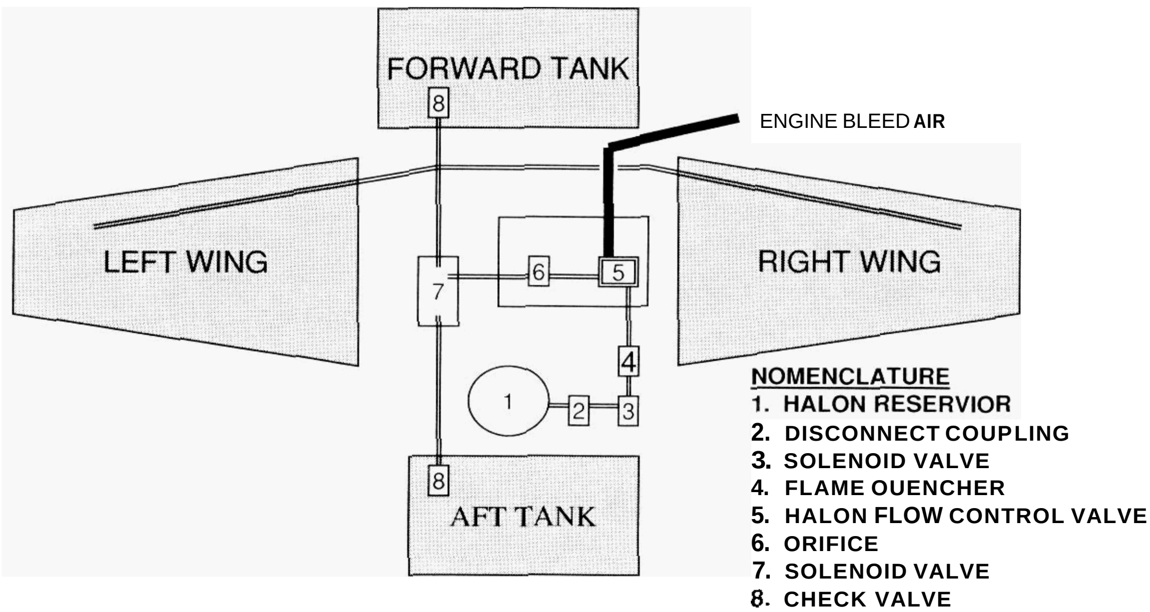


Figure 1. F-16 inertion system schematic

Upon selection of “Tank Inerting” on the fuel control panel in the cockpit. the halon system is activated. Electrical signals are provided to (1) the halon shutoff valve located in the vent tank to allow halon to tlow to the fuel tanks, (2) the initial inert solenoid valve to open, and (3) the internal tank vent and pressure control valve to reduce internal aircraft pressure. An airtlow within the tanks is produced as the internal tank pressure is reduced from roughly 5.5 psig to 2.0 psig and air **is** vented overboard. This assists in the distrihution of halon gas throughout the vapor space above the fuel. The initial inert valve opens for 20 sec to permit a quick dump of halon into the forward, aft, and internal wing tanks on the F-16. An inert atmosphere is quickly obtained. The halon flow control valve then mixes pressurization air from the environmental control system with Halon 1301, to maintain an inert atmosphere (with properly regulated valves), as fuel is consumed or the aircraft changes altitude. The fuel absorbs some of the halon supplied to the tanks, which is replaced by a continuous bleed of halon through an orifice in the vent tank plumbing.

In the unlikely event that fuel or fumes should leak backwards into the reservoir and be ignited by the heater, it was theorized that a fire could prorogate to the aircraft fuel tanks. To protect against this possibility, a flame arrestor is installed in the reservoir outlet line.

DEVELOPMENT TEST AND ANALYSIS

A comprehensive test and analysis program was planned to develop alternates candidates to Halon 1301 for fuel inerting. The data from the government test will aid the F-16 airframe contractor to complete Engineering Manufacturing Development of the preferred candidate. The contractor's integration work will include materials compatibility tests and studies, solubility characteristics in JP-8 and JP-4, and engine component tests. The focus of the government test program was live munitions testing.

In today's dynamic all changing global environment, the F-16 aircraft may encounter a variety of conventional (nonnuclear) terminal threat weapons. During its operational life, these threats may include both surface-to-air types and may be present at both high and low altitudes. The terminal threat weaponry the F-16 might encounter includes state-of-the-art technology air-to-air and surface-to-air ballistic weapons (guns), guided missiles, and directed energy weapons (DEW). Desert Storm experiences for the F-16 highlight the growing missile threat, close air support mission means surface-to-air guns are potential threats. Therefore, the threats used in the test series were missile warheads and anti-aircraft artillery (AAA). DEW threats were not examined.

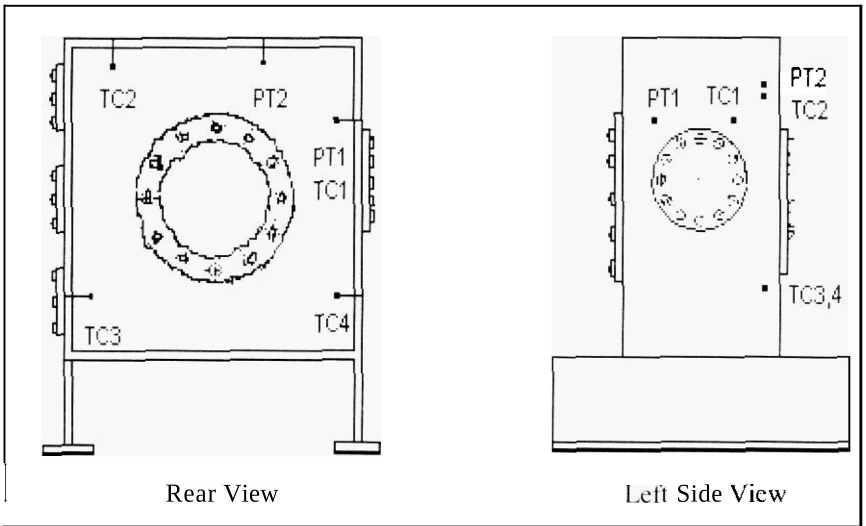
The ballistic threats and guided missiles can be divided into three major categories by weapon type: high explosive (HE) projectiles, nonexplosive or armor piercing projectiles and HE missile warheads (fragments). The HE incendiary (HEI) AAA threats were not a focus due to the limited budget of this test program. Tests were performed using 12.7 mm armor piercing incendiary (API) projectile, 23 mm API, 1 IO-grain missile fragments, 150-grain missile fragments. and 300-grain missile fragments.

The tests simulate the case of an F-16 in an air-to-ground close air support mission. This mission is representative of F-16 experience in Desert Storm. The mission, used to design and size the current halon inerting system, is the scenario used for previous vulnerability analyses and live fire tests for the F-16 weapon system.

Fuel and ullage temperature is a critical parameter, which drives the ullage fuel/air ratio. The F-16 fuel system is designed to operate in temperature ranges from -65 "F to +160 "F. Fuel temperature at threat impact is dependent on the temperature of the fuel at take-off. The fuel temperature on the ground is dependent upon the ambient temperature of the day (*i.e.*, a cold day or a hot day). The tlight altitude and duration will alter this initial temperature. The fuel temperatures selected for ullage testing (105, 125, 145, and 165 %) are based upon likely flight conditions for the selected mission profile. Previous AFRL test data for B-l program office [3] showed JP-8 fuel experienced very little pressure increases below 105 °F (leaner fuel vapor vol.%).

The fuel system vent and pressurization system is designed to keep internal pressure between 4.7 and 6.4 pounds per square inch gage (psig) for normal operations and between 1.0 and 3.0 psig or between 5.5 and 7.2 psi absolute (psia) for combat conditions. The ullage pressure was evaluated **at** approximately 3.0 psig, which is a representative pressure maintained by the F-16 for the selected mission profile. An equivalent stoichiometric ullage fuel/air mixture for the given fuel temperature and ullage pressure was used for testing. A fan was located inside the tank to ensure an even fuel/air mixture of the ullage.

The ullage tcst article consists of **a** 100-gallon rectangular tank (W-Tank), which simulates the basic configuration of an F-16 fuselage fuel tank (Figure 2). The lank measures 20 in from front wall to back wall and 38 in wide and high. The JP-8 ullage tcst article will contain **a** 4 in fuel level measured from the bottom of the W-Tank. The impact location on the target striker plate is 16 in above this level. The striker plates used in the test were removable, representative **of** the F-16 wing and fuselage skin thickness, and varied from 0.125 to 0.500 in thick. The tank has window ports for external viewing by various cameras.



PT = Strain Gauge Pressure Transducer
TC = Thermocouple

Figure 2. W-Tank schematic.

The aircraft internal fuel level state is assumed to he 10%. which leaves ullage volumes in the F-16 fuel tanks. JP-8 and JP-8+100 fuel was used in testing as is the case in the operational F-16 aircraft.

Airflow would have a small effect on the severity of an ullage explosion. The small entrance holes caused by the threats used in the ullage test series do not allow significant airflow to enter the test article and significantly change the fuel/ air ratio. The pressure exerted on the test article by the airtlow would he insignificant compared to the internal pressure associated with a fuel/air explosion. Damage areas. including metal skin that would protrude into the airflow, should not be increased. Based on this information, airflow was not applied to the test article.

Test instrumentation was kept to a minimum with some redundancy. Thermocouples were used to acquire temperature data of the fuel and ullage. Piezoelectric pressure transducers were used to acquire pressure data and characterize fast response shock wave phenomena associated with an explosion. Pressure and temperature time histories and fuel/air vapor in the W-Tank were collected to characterize the ignition event. In addition, the temperature-time histories and video footage were examined for indications of a sustained fire following the impact event. Flash detectors indicated the time of the flash from a fragment impact incendiary functioning for an API projectile. Gun brakes paper over the target and a light screen between the muzzle and target were used to measure the projectile/fragment velocity. Prior to each test, the amount of agent was measured using partial pressure into the tank, and a sample was obtained in a Tedlar Sampling Bag. The Tedlar sampling bags were analyzed by the University of Dayton Research Institute using a gas chromatograph with flame ionization detection sampling analysis technique.

The test program consisted of over 250 shots between all candidate alternative agents including C_2F_5H (HFC-125), C_3F_8 (FC-218), and CF_3I, as well as baselining CF_3Br (Halon 1301). These data will be used by F-16 airframe contractor to characterize the survivability and vulnerability of the **F-16** aircraft using an alternate agent. The preferred agent based on testing to date and environmental friendliness is CF_3I.

The sensitivity of the CF_3I agent in JP-8 fuel to temperature is shown in Figure **3.** The temperature peaks near the stoichiometric temperature of JP-8. **All** previous verification testing was completed with JP-4 fuel [4,5]. JP-8 is flammable at higher temperatures than JP-4, which is one reason why JP-8 is considered safer for operations such as ground refueling.

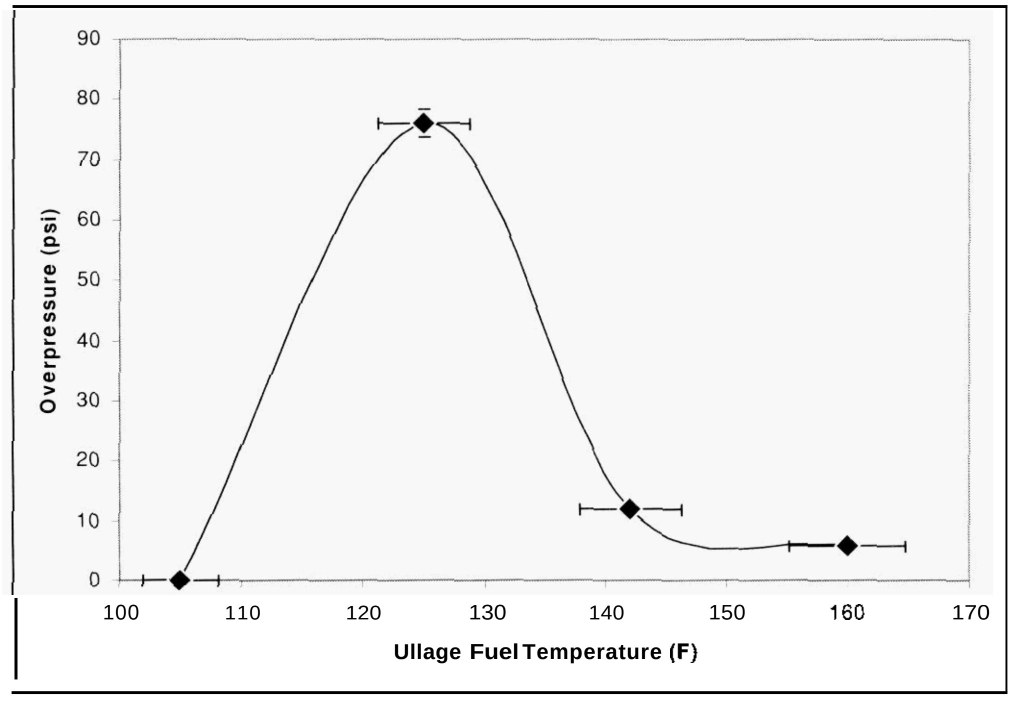


Figure 3. Temperature sensitivity (CF_3I concentration: 7%; 0.250 in panel; threat: 12.7 mm).

Generally, a fuel/air mixture will react if an ignition source, such as 12.7 mm **API,** is introduced into a mixture. The rate of energy release by the reaction will be dependent on the fuel/air ratio and the temperature of the ignition source. In our test series, the fuel/air ratio, which is described in the following formula. was kept relatively constant.

$$F/A = \frac{\text{(Volume percent of fuel)(Molecular weight of fuel)}}{\text{(Volume percent of air)(Molecular weight of air)}}$$

A reaction in a fuel/air mixture, the fuel/air ratio of which is stoichiometric, will consume all the reactants as the I25 "F test points show. If a reaction occurs **in** a lean fuel/air mixture. less than stoichiometric, there is an excess of oxygen that must he heated to the product temperature by the heat generated by the reaction [6]. The 105 °F test points results are such a case. In a reaction of rich fuel/air ratio, greater than stoichiometric. there is an excess of fuel vapor that will not react. This is because insufficient oxygen is present. The energy release **is** less again. resulting in a final temperature less than stoichiometric, as are the 165 "F test points. The maximum final temperature actually occurs at a fuel/air ratio just rich of stoichiometric because of the differences in specific heats of combustion products that occur. As a result, final temperatures and pressures will be dependent on the fuel/air ratio of the mixture. At fuel/air ratios near the lean and rich flammability limits, modest pressure rises (less than 10 psi) were experienced, while for fuel/air ratios near stoichiometric. the pressure was above 20 psi.

The sensitivity to panel thickness shown in Figure 4, is dependent on the threat. This again will be a function of the fuel/ air mixture to react with the ignition source, e.g., the thermal energy deposited by a ballistic threat. The thermal energy deposited by the ignition source was affected by the size of the fragment, the velocity of the fragment, and the thickness of the ullage rank wall striker plate. The test data would suggest that the concentration of energy obtained with a 12.7 mm API has a greater chance of reaching a stoichiometric mixture than does *a* 300-grain missile fragment. The velocity of the 12.7 mm API was about 2500 ft/sec (fps), while the 300-grain missile fragment was about 5500 fps.

The sensitivity to concentration **is** again related to the fuel/air mixture and thermal energy. Figure 5 shows for the given test point that stoichiometric mixture is possible below 6% concentration. Above 6% concentration. the amount of agent increases the molecular weight of air creating a lean stoichiometric mixture and a modest pressure rise of less than 10 psi.

SUMMARY/CONCLUSIONS

The technical objectives of the test program were met. An agent is required to protect the fuel from overpressure. Using the original threats of the JP-4 verification at a concentration of 5%, the baseline agent of Halon 1301 prevented an overpressure in JP-8. Alternative suppression agents were characterized for live munitions. Preliminary analysis indicates CF_3I will be able to replace Halon 1301 with minor airframe system modifications. The F-16 airframe contractor is continuing *to* refine this analysis to an Engincering Manufacturing Development status. CF_3I offers an environmentally friendly answer to fire suppression for the F-16, while working within existing airframe requirements and specifications.

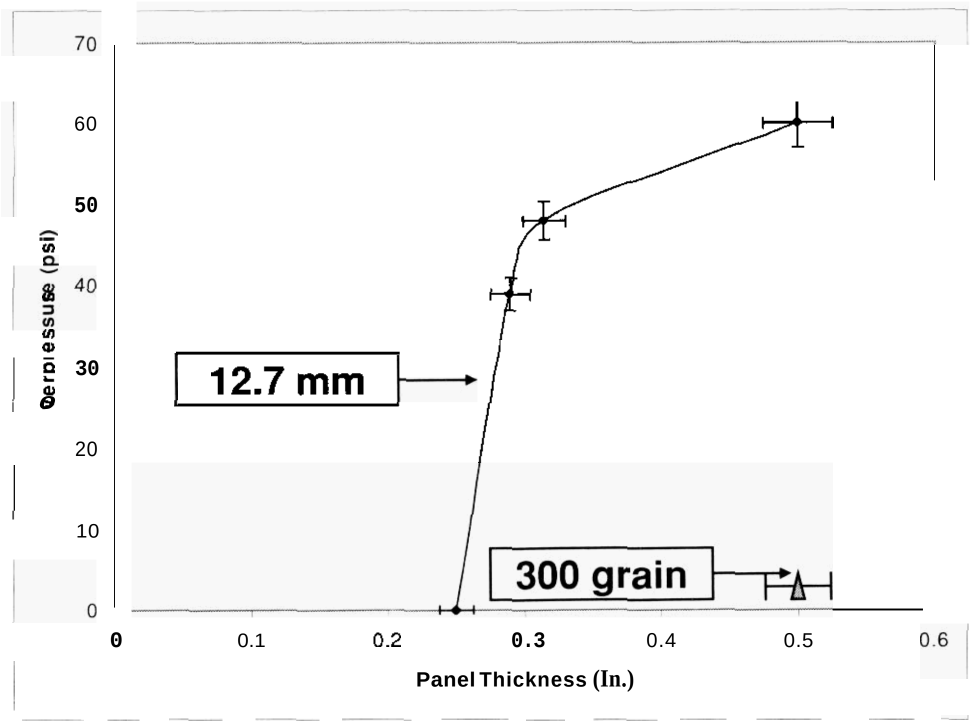


Figure 4. Panel thickness sensitivity (CF_3I concentration: 8%: ullage temperature 125 "F; threat: 12.7 mm and 300 grain).

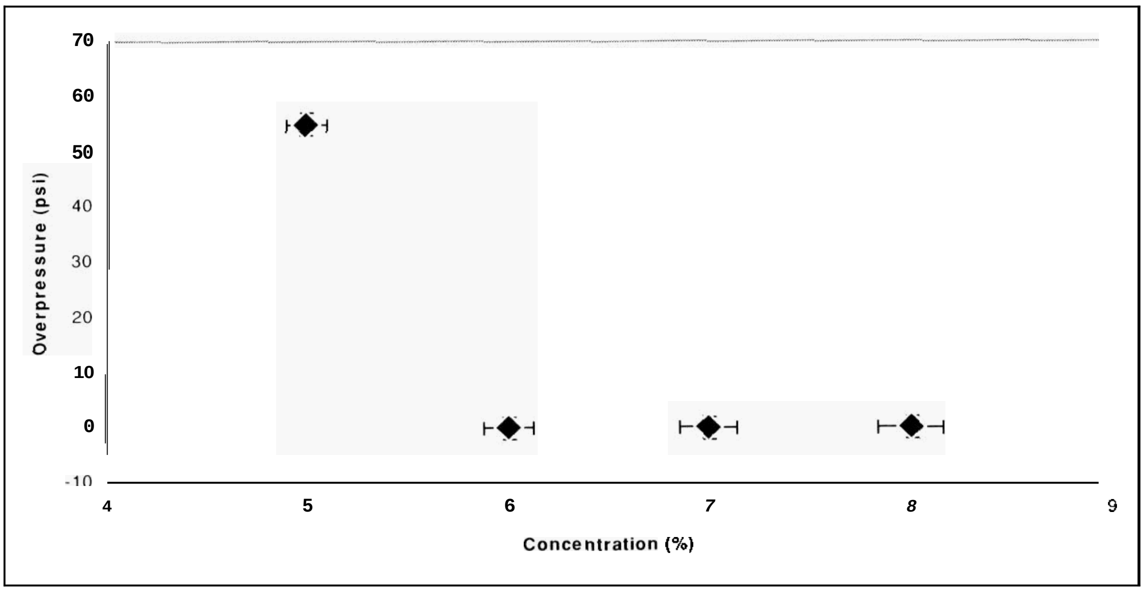


Figure 5. Concentration sensitivity (ullage temperature: 125°F; 0.500 in panel: threat: 300 grain).

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