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BALLISTIC EVALUATION OF AIRCRAFT EXPLOSION SUPPRESSION MATERIALS

Charles L. Anderson Survivability/Vulnerability Branch Vehicle Equipment Division

January 1978

TECHNICAL REPORT AFFDL-TR-76-98

Final Report for Period December 1975 - March 1976



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This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

AMBROSE B. NUTT, Director Vehicle Equipment Division AF Flight Dynamics Laboratory

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FOREWORD

The effort described herein was performed by the Survivability/ Vulnerability Branch, Vehicle Equipment Division of the Air Force Flight Dynamics Laboratory. This effort was performed primarily to answer questions concerning the ballistic performance of hybrid polyether urethane foams as compared to polyester urethane foams. The program was performed at the direction of Mr. C. Anderson with the assistance of Mr. T. O. Reed of ASD/ENFEF.

This program was performed, in part, for the Joint Technical Coordinating Group for Aircraft Survivability. All financial support and the large majority of manpower support was provided by AFFDL/FES under Project Number 4363, Task 436301, and Work Unit 43630141.

The efforts described in this report were performed during the period of December 1975 to March 1976.

The author gratefully acknowledges the assistance of Messrs. T. O. Reed (ASD/ENFEF) and Mr. C. Harris (AFFDL/FES) for assistance in planning and managing this program; Mr. M. Gromosiak, Major Krobusek, Messrs. W. Gaines and W. Studebaker of the AFFDL Aircraft Survivability Research Facility for gunrange support.

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SECTION I

INTRODUCTION

The objectives of this program were to: (1) evaluate the ballistic performance of coarse and fine pore hybrid polyether urethane foams (i.e. blue foam) as compared to the coarse and fine pore polyester urethane foams (i.e. yellow and red foam); (2) perform a preliminary analysis of the ballistic performance of a new explosion suppression material called Explosafe (Vulcan Industrial Packaging Limited). The materials were tested using maximum flammable mixtures with mechanical damage and combustion overpressure as measures of performance.

The need to prevent explosions in the fuel tank ullage (the space above the fuel level which contains air and fuel vapors) of combat aircraft is of major importance if a survivable aircraft is to be obtained. Since the fuel system of any combat aircraft is the most vulnerable portion of the aircraft and occupies such a large fraction of the aircraft, it can be seen why a system to prevent explosions in the fuel tank ullage is the single most important survivability defense concept. The polyester urethane reticulated foams were introduced in the late 1960's and represented a significant contribution to the survivability of any combat aircraft using this material.

The primary drawback from using the foam is its weight and volume penalties, but nevertheless, the foam has been, and will continue to be incorporated into combat aircraft because of its effectiveness in

preventing explosions. This polyester urethane, in use since the initial application of foams in fuel systems, progressively undergoes chemical degradation when exposed to an elevated heat/humidity environment. This chemical degradation of the foam leaves it with little or no physical integrity.

This fact came to the forefront in the conflict in SEA due to the high humidity/temperature environment encountered there. The problems associated with the degrading of the foam succeeded in placing a lot of emphasis on development of new materials that do not degrade (i.e. has better hydrolytic stability). The blue foam (both coarse and fine pore) tested in this program is a prime candidate for replacing the polyester urethane foams. The blue polyether urethane foam is far less prone to degradation effects in a high temperature/humidity environment compared to the polyester. The currently formulated blue foam suffers from effects due to fuel environments. The foam swells in fuel and there is a decrease in tensile strength. It was thought that these characteristics would lead to a less viable flame and explosion suppressor. The reservations concerning the polyether foam dictated that a ballistic evaluation be performed to verify its performance.

Another type of material which has entered the picture recently is called "Explosafe". The "Explosafe" had been subjected to minimal ballistic testing prior to this program and therefore many questions existed as to its performance against various projectiles.

SECTION 11

TEST DESCRIPTION

1. EXPLOSION SUPPRESSION MATERIALS

The materials tested in this program include the polyester urethane reticulated foams, the hybrid polyether urethane reticulated foams, a polyester urethane reticulated foam coated with Astrocoat, and an aluminum metal flame arrestor called Explosafe. These reticulated foams will subsequently be referred to as polyether and polyester foams. The polyester foams were tested using coarse (6 pores per centimeter (ppc), veliow) and fine (10 ppc, red) pore foams. The polyether foams were tested using coarse (6 ppc) and fine (10 ppc) pore foams. Both pore size polyether foams were colored blue. Pertiment data on these foams are presented in Appendix IV. The polyester foam is presently covered by Military Specification MIL-B-83054A. The polyether foam will be added to this specification in the future. The Astrocoated foam tested here was made by coating buns of the red polyester foam. The coating process consists of dipping a bun of foam in a polyether urethane solution. This coating caused the red foam to take on a nearly black color. The Astrocoat was developed by Olin Matheson and the process by which the foam is dipped in the Astrocoating solution was developed by Hughes Aircraft under a contract from NASA, Ames.

The Explosafe aluminum metal arrestor is manufactured by Vulcan Industrial Packaging Limited, Canada. The material consists of single sheets of aluminum 0.076 mm thick which have several short cuts at

regular intervals to produce a single sheet of expanded metal mesh. These sheets are then stacked in bundles. Samples of all materials are shown in Figure No. 1.

There were two different configurations used for testing the explosion suppression materials. The first was the "egg crate" volding configuration which is depicted in Figure No. 2. This configuration consisted of 27 rectangular volds (17.8 cm x 17.8 cm x 20.3 cm) cut in the foam (resulting in 22.6% vold) and installed in the test specimen as Figure No. 2 depicts. The second was the solid packed configuration which was identical to that depicted in Figure No. 2 except that there were no voids cut in the foam. The Explosafe was tested in the solid packed configuration only and was installed in 14 bundles, each approximately 6.5 cm thick.

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Red Four (10 ppc)

Fine Pore Blue Foam (10 ppc)



Yellow Foam (6 ppc)

Coarse Pore Blue Foam (6 ppc)



Astrocoated Red Foam (10 ppe)

Explosafe Motal Arrestor

Figure 1. Explosion Suppression Materials Tested



Figure 2. "Egg Crate" Voided Foam Installation

2. TEST SPECIMENS

The tests described in this report were performed with two Tank Wall Simulators (TWS). TWS No. 1 was used for baseline tests and TWS No. 2 was used for comparison testing of the explosion suppression materials. Both TWS's were of identical basic construction consisting of four 6.35 mm thick reinferced steel sides with provisions for mounting replaceable aluminum test panels on the front and rear. The TWS is symmetrical from front to rear and side to side. See Figure No. 3. The tank was approximately a 0.91 moder cube having a total



Figure 3. Basic Tank Wall Simulator (TWS)

volume of 0.75 cubic meters. There were provisions for fueling and defueling at the top and bottom of the tanks. Several other small fittings were installed for pressure taps, thermolouping, atc. Two different materials were used for impact and exit panels; 7075-T6, 2.033 mm thick and 2024-T3, 1.803 mm thick. These panels were appropriately 91 cm x 91 cm single sheets of aluminum with no stiffeners incorporated. The TWS's were instrumented with two (2) pressure transducers for measuring combustion overpressures. Primarily, the transducers used were Statham Model PG 822 bonded strain gage type pressure transducers. Also used during the beginning of the program, were PCB Model 202A quartz piezoelectric pressure transducers. These piezoelectric transducers were used because the pressures from the HEI blast were unknown and the dynamic range far exceeded that of the strain gage type. These transducers were generally connected to the TWS via a 6 mm diameter flexible tube 35 cm long to isolate the transducers from shock and vibration. There were 4 thermocouples installed in the tank to monitor fuel and ullage temperatures. See Figure No.-4 month for instrumentation location and installation diagram.

TWS No. 1 incorporates a small electric fan dr.ven by an induction motor which produces no sparks. This fan was installed inside the tank approximately 15 cm from the top and front of the tank so that it would be out of the blast cone of the HEI and avoid damage. The fan was powered by 115 VAC and had a flow rate in excess of 14 liters/second which served to "mix-up" the ullage gaues. This issured a virtually homogeneous mixture of air and fuel vapors. This fan was removed for



FRONT VIEW

Figure 4. Instrumentation Locations

tests that did not require a stoichiometric fuel/air ratio. TWS No. 1 was used for; baseline tests with air only, for tests with no explosive vapors, and tests with no foam but with explosive vapors.

TWS No. 2 was used for all the tests with the explosion suppression materials which required stoichiometric fuel/air ratios. The primary difference between TWS No. 1 and TWS No. 2 is the elaborate circulation system incorporated in TWS No. 2. Due to the presence of internal foam inside the tank, the use of a fan as in TWS No. 1 was precluded. The system devised is depicted in Figure No. 5. It is composed of two electric fans in a 17.8 cm diameter duct above tank to provide circulation and eight 6.4 cm diameter pipes on each side of the tank for pulling ullage gases out and returning them to the other side of the tank. Valves were incorporated into each of the 16 pipes to isolate the circulation system prior to weapon firing. This system was sized to provide in excess of 14 liters/sec flow in order to adequately mix





the ullage gas and thereby ensure a homogeneous mixture of fuel vapors and air. In order to prevent a flame front from propagating into the circulation system the 6.4 cm diameter pipes were plugged with 10 cm of red foam at the inlet to the tank. The circulation system was modified extensively when repairs became necessary about midway through the testing. The modified system was basically the same except that the foam flame arrestor in the 7.4 cm diameter pipes was replaced with a 5 cm ball valve to positively isolate the circulation system from the tank during the ballistic tests. Also part of the ducting was redesigned and flexible hose replaced previous hard plumbed ducting. See Figure No. 6.

3. PROJECTILES TESTED

There were two different projectiles tested during the duration of the program. These were the 23 mm HEI (High Explosive Incendiary) and the 50 caliber API (Armor Piercing Incendiary). The 50-ealiber API was a standard U.S. domestic projectile 12.7 mm in diameter. The projectiles were tested without down loading the rounds which resulted in nominal projectile velocities of 990 meters/second for the 23 mm HEI and 848 meters/second for the 50 caliber API. The projectile velocities were not measured for these tests but are projected from a large data base from previous firings.

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"" " "Figure 6. Modified Circulation System

The specimen was modified slightly when impacted with the 50 caliber API. A 4.76mm aluminum plate (approximately 15 cm square) was taped to the front panel. The API projectile would then penetrate a total of 6.53mm of aluminum which is more than adequate to activate the incendiary. This was determined from data presented in AFML-TR-68-223. ÷.

The 23mm HEI is a Soviet built projectile which contains 171 grains of explosive/incendiary mix. The fuze is the MG25 and the projectile is an Anti Aircraft Artillery (AAA) type. The MG25 fuze will provide a nominal 20 cm delay between the front tank wall and the detonation point. This was evident when examining the solid packed foam configuration which provided an excellent witness as to detonation point. There have been several hundred tests performed with the 23mm HEI projectile at the AFFDL/ASRF and the reliability of the 20 cm delay at muzzle velocity has been well established.

4. ULLAGE SAMPLING SYSTEMS

The entire test program was dependent upon the ability to obtain and monitor the fuel/air ratio in the specimen so that a stoichiometric fuel/air ratio could be obtained. Due to its basic simplicity and need for no special instrumentation or equipment, it was decided to use a technique commonly referred to as a "bomb-sample" system. Basically the system consisted of a small pressure vessel approximately 262 milli-liters in volume into which ullage gases were drawn and then ignited with the peak overpressure being used to measure combustibility. The ullage sampling system was physically located

on the top of the TWS and all functions of the ullage sampling system were controlled remotely. These included solenoid operated values at both the inlet and outlet of the sample, a high energy spark ignitor which fires an automotive spark plug in the sampler, and other solenoid operated values controlling the source of the sample.

The system was modified twice so that three different systems were used during the program. The three different systems are depicted in Figure No.'s 7 and 8. System 1 sampled from a single point in the circulation system. The till is pressurized to 3.5 K Pa above atmospheric pressure in order for the ullage mixture to flow through the sampler. When a sample was taken, both inlet and outlet valves were opened and the ullage gases were allowed to flow through the sampler until a volume of gas equal to five times the volume of the ullage sampler (i.e. 1.31 liters) passed through (the flow rate was established using a rotometer during initial checkout). It was assumed that the flow through of 1.31 liters of gas would thoroughly purge the sampler of all gases present initially. After adequate flow through was obtained, the inlet valve was closed and the outlet valve was left open long enough for the sampler to be vented down to atmospheric pressure (all samples were tested at atmospheric pressure). Once the sampler was isolated (i.e. inlet and outlet valves closed) the spark ignition source was fired and the peak combustion overpressure was measured from an oscillograph recording of sampler pressure. The entire process required approximately three minutes to complete.



Figure 7. Ullage Sampling System No. 1 and 2



Figure 8. Ullage Sampling System No. 3

The measured ullage sampler overpressures were a function of the fuel/air ratio. The highest overpressures occur at a fuel/air ratio which will be referred to as "optimum for combustion". The overpressures obtained from mixtures any leaner or richer would result in a lower overpressure. This "optimum for combustion" mixture is near stoichiometric but not exactly stoichiometric. For reasons of reaction kinetics this "optimum for combustion" mixture is slightly richer than stoichiometric. The procedure in these tests was to initially fuel the TWS with JP-4 at a low enough temperature to ensure that the mixture would be on the lean side. Then with ambient temperatures generally higher than 0°C, the fuel would warm up and the fuel/air ratio woc?" slowly increase. As this occured, the ullage sampler overpressures were monitored until they peaked out, signalling an "optimum fer combustion" mixture. The projectile was then launched immediately.

System 2 consisted of a slight modification to System 1, so that the sample could be selected from either of two locations (the circulation system or the top center rear void in the foam). This modification was performed so as to provide additional data on the homogeneity of the fuel/air ratio throughout the tank.

System 3, Figure No. 8, has the capability to select samples from any of nine locations in the tank. The major difference between this system and previous ones is that the ullage sampler was evacuated to less than .4 K Pa absolute pressure and then filled with the fuel/air mixture from the tank via one of nine supply lines. The control of the entire system, including monitoring combustion overpressures, was

done via a digital data acquisition and control system. This system was composed of an HP 2100 mini-computer with associated analog-todigital converters, relay outputs, and data logging devices. The system was programmed to scan up to all nine locations and print out the results in real time. The program description and listing is included in Appendix 7. The speed at which samples could be taken was slower than expected due mainly to the restriction of flow through the very small orifice valves and to a lesser extent, the restriction in the small (1.59mm) diameter tubing. The small diameter tubing was used to keep the volume in the lines between the sampler and the TWS to a minimum (longest line was 0.7% of sample volume). The sizing of the valves in future experiments should be done so that the valves represent a small portion of the total restriction. It is felt that sampling speed can be raised to six or more per minute as opposed to the sampling speed of one every 45 seconds stained in this program.

5. TEST SET-UP/PROCEDURES

The test specimen was installed in the Air Force Flight Dynamics Laboratory/Aircraft Survivability Research Facility (AFFDL/ASRF), Range No. 3. The TWS was situated in the middle of the floor on a stand which raised the TWS 61 cm off the floor. This was done in order for the center of the TWS to be at the same level as the weapon. The weapon was placed outside the facility approximately ten meters from the TWS. See Figure No. 9.



Figure 9. Overall Test Set-Up at AFFDL/ASRF Range No. 3

Figure No. 9 does not depict a steel protective deflector plate immediately in front of the TWS. This deflector plate was incorporated into the test set-up at a later time. The weapon and tank were oriented to produce an impact obliquity of 0° (i.e. perpendicular).

Two 16mm motion picture cameras were used to record the events on both the front and rear aluminum walls of the TWS. These cameras used color film and were operated at 250 frames per second. There were four 500 watt lights used to illuminate each wall.

The procedures followed for each test which required a fuel/air mixture were as follows:

- 1. Fill and drain the TWS with JP-4 conditioned to a temperature range of -18°C to 7°C depending on ambient temperature.
- 2. Open isolation valves on circulation system where applicable.
- 3. Start fans in circulation system.
- 4. Pressurize the TWS to 3.5 K Pa if applicable.
- 5. Analyze ullage samples until an "optimum for combustion" fuel/air ratio is reached.
- 6. Ginse isolation values on circulation system if applicable.
- 7. Fire weapon.

This procedure varied slightly for some of the tests. For example, Tests No. 1 through 5 were done without foam and did not incorporate the circulation system. Test No. 4 was performed with JP-4 fuel but only approximately 20 liters of fuel was in the TWS. For Test No. 6, foam was used but the specimen was filled and drained with JP-5 (high flash point hydrocarbon) so that the foam could be wetted without producing an explosive mixture. For Tests No. 25 through No. 30 the

TWS was not pressurized since it was not needed for ullage sample system operation. These test-to-test particulars are addressed in detail in Section 111.

The tests with blue form and the Astrocoated form went through a special procedure prior to the standard ones listed here. It was determined in specific tests by Mr. T. O. Reed (ASD/ENFEF) that blue foam, when immersed in fuel, loses approximately 43% of its tensile strength in a very short period of time. These test data are presented in Appondix D. These dats indicate that the loss in tensile strength occurs in approximately 15 minutes after immersion in the fuel. Due to this high loss in tensile strength when immersed in fuel, it was felt that the polyether foam should be tested under conditions which would ensure that the loss in tensile strength had occurred prior to projectile impact. There were two procedures used to ensure this loss in tensile strength. These wore: (1) the TWS was filled with JP-4 at approximately 38°C and allowed to set for one hour prior to the standard fueling procedure, (2) the TWS was filled with JP-4 at ambient temperature and allowed to set overnight and tested the following morning. Astrocoated foam was treated in the same manner because the coating, "Astrocoat" is a polyether urothane. The exact method used for each test with the polyether forms or the Astrocoated form is detailed in the results summary of this report, Section 111.4.

SECTION 111

RESULTS

1. BASELINE TESTS

The object of the baseline tests was to obtain an adequate understanding of the measured dynamic pressures resulting from the detonation of the 23 mm HEI projectile inside the TWS and to perform an undefended test (i.e. no feam, with stelehoimetric mixture) with a 50 cal. AP1 and a 23 mm HEI. The two undefended tests were done in order to underscore the need for fuel tank inerting. The tests No. 1 - 6, 21, 24 fall under the baseline category.

Test No. 1 through 4 were performed with 7075-T6 aluminum front and roar panels. These panels fractured very badly due to the properties of the 7075-T6 and therefore the material for the front and rear panels was changed to 2024-T3. The results of tests No. 1 through 4 will not be discussed in any detail since they were repeated with 2024-T3 aluminum panels. During these four tests the instrumentation was debugged and it was felt that the combustion overpreasures could be easily distinguished from the blast shock wave type pressures. Figure No. 10 illustrates the difference in the response of the two materials. Both panels shown were from the rear of the TWS and had been subjected to a 23 mm HE1 detonation inside the TWS with air only (no feam or fuel). The panel on the left was from Test No. 5 (2024-T3) and the panel on the right was from Test No. 3 (7075-T6).

The change to 2024-T3 aluminum panels prompted a repeat of the baseline tests due to the greatly increased tolerance of 2024-T3 to



Figure 10. Comparison of 2024-T3 (Test No. 5, left) and 7075-T6 (Test No. 3, right) Response to the 23 mm HE1

ballistic damage. Test No. 5 was the first test run with 2024-T3 panels. It was performed to see what pressure histories were obtained with no foam and no fuel vapors present when a 23 HEI is detonated in the TWS. Figure No. 11 is a graph of pressure versus time for Test No. 5 and depicts a series of pressure oscillations which are attributed to the blast shock wave reverberating inside the tank. Also evident is an abrupt increase in quasi-static pressure at impact which then decays through venting. With this data superimposed upon a gentle (by comparison) pressure rise due to the combustion overpressure, it was assumed that the two different frequency signals could be easily distinguished, during the baseline tests with fuel. . 4 to 1 to 1

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Test No. 6 was performed next to answer the question of what the presence of internal foam does to the measured overpressures due solely to 23 HEI detonation. Figure No. 12 is a graph of pressure versus time for this test and depicts a short pressure excursion followed by the decay of the initial 5 K Pa static pressure. As compared to the pressure history with no foam in the tank it can be seen that the foam greatly attenuates blast pressures. These data meant that there should be no trouble whatsoever recording combustion overpressures during the foam tests.

Tests No. 21 and 24 are baseline tests which consisted of impacting a tank containing an "optimum for combustion" fuel/air ratio with 50 cal. API and a 23mm HEI. The TWS for both tests did not contain any foam, so for all practical purposes, the tanks were fuel air bombs.







Figure 12. Pressure History for Test No. 6 (23 mm HEI with Foam)

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Figure No. 13 is a composite graph of pressure versus time for test No. 21 and 24. The peak pressures for both tests were approximately the same at 330 and 340 K Pa for Tests No. 21 and 24 respectively. Both curves exhibit a very rapid drop in pressure after the peak which is attributed to the abrupt failure of the rear wall in both cases. However, the striking difference between the two pressure histories is in the rise times. The API projectile produced a rise time of 32 milliseconds while the HEI projectile produced a rise time of approximately 6 milliseconds. The extremely fast rise time with the HEI is attributed to the size of the ignition source as compared to an API projectile. The larger the ignition source, the less time required for the total combustion process. Figure No. 14 indicates the severity of the damage resulting from these tests. As can be seen, almost the entire rear wall of the tank was blown out. The results depicted in Figure No. 14 are typical for both Test No. 21 and 24.



Figure 13. Comparison of Overpressure Histories (50 cal. API and 23 mm HEI, Stoichiometric Mixture, no Foam)



Figure 14. Test No. 24, Rear Wall Failure

2. COMPARISON OF FOAMS

As was stated earlier the objective of this program was to evaluate the ballistic performance of the new polyether urethane (blue) foam against the polyester urethane foams (red and yellow). The results of the foam tests will be included in this section along with the results of the Explosafe tests.

The criteria used for evaluation of the explosion suppression materials include combustion overpressure and physical damage to the materials. The combustion overpressure data will be used as the primary measure of performance and the mechanical/physical damage will be secondary and serve to back-up the overpressure data. The motion picture coverage will also be used for a rough cross check of results since any combustion overpressures occurring in the TWS will be easily seen with the two cameras.

The description of the results will be broken down into the following series; fully packed foam, voided (egg crate) foam, Astrocoated red foam, and Explosafe. A summary of the results is presented in Section III.4. Test Results Summary. Listed is a pressure decay time which can be used to identify minimal combustion inside the TWS that does not produce a measureable overpressure.

a. Fully Packed Foam

There were four tests performed in this series; Test No. 11 (red foam), Test No. 16 (yellow foam), Test No. 17 (fine pore blue foam), and Test No. 18 (coarse pore blue foam). Each of these tests
was performed only with the 23mm HEI projectile (50 cal. API not used for this series). The results for all four tests were virtually identical. Figure No. 15 is a graph of pressure versus time for this series of tests. The pressure histories for each of the tests fell within the band indicated. The mechanical/physical damage to the foam for each test was also virtually identical. There was no noticeable difference between the polyether and the polyester foams in the size of the pocket produced by the 23mm HEI detonation. Figure No. 16 and 17 are photographs of the different pockets. The volume of foam wiped out was approximately 1.1 liters. Figure No. 18 and 19 compare the damage to the exit panels for the tests performed in this series.



Figure 15. Overpressure Histories for Fully Packed Foam (23 mm HEI)



Figure 16. Comparison of Blast Pockets, Red Foam (Test No. 11, left), Fine Blue Foam (Test No. 17, right)



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Figure 17. Comparison of Blast Pockets, Yellow Foam (Test No. 16, left), Coarse Blue Foam (Test No. 18, right)



³³igure 18. Comparison of Exit Panels, Coarse Blue Foam (Top, Test No. 18) and Yellow Foam (Bottom, Test No. 16), Fully Packed Configuration



Figure 19. Comparison of Exit Panels, Fine Blue Foam (Top, Test No. 17) and Red Foam (Bottom, Test No. 11), Fully Packed Configuration

b. Voided Foam

There were nine tests performed in this suries; Tests No. 7 and 8 (red foam), Tests No. 9 and 10 (yellow foam), Tests No. 12, 13 and 15 (fine pore blue foam), and Tests No. 14 and 19 (coarse pore blue foam). Each type of foam was tested with both the 50 cal. API and the 23mm HEI. Test No. 13 is a repeat of Test No. 12 due to the failure of the incendiary in the 50 cal. API to activate properly on Test No. 12 (activated near the rear wall). Some variation in results were encouptered. However, in no case did the combustion overpressure exceed the flame tube test data presented in Appendix B. These data were gathered using the test techniques described in MIL-B-83054A. ÷.

The results will be discussed for each projectile independently. The 50 cal. API projectile generally produced very little, if any, combustion overpressure with one exception. That exception was for Test No. 9 with the yellow foam when a 27.8 K Pa overpressure was recorded. This overpressure is in the range of what can be expected as the data in Appendix B show.

The physical damage to the foam for this test consisted of singeing on the surface of the foam voids caused by the combustion of the fuel/air mixture. The singeing was not present on any of the other eight tests in this series. The motion picture data corroborates the pressure data, showing smoke being forced out of the entrance and exit holes for an extended period of time.

It should be noted that on Test No. 12 (improper API functioning), the fine pore blue foam actually burned in the tank (smoldering) for approximately 90 seconds. This produced a burned out pocket shown in Figure 20.



Figure 20, Test No. 12, Burned Out Pocket

This reaction, whereby the foam smolders is usually confined to tests with dry foam but there have been other occurrences of red foam actually smoldering after ballistic impact.

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The results with the 23mm HE1 were very similar to those obtained with the 50 cal, AP1. The 23mm HE1 did not produce any significant overpressures. Some overpressure was recorded for each of the tests and is summed up in a pressure history curve presented in Figure 21.



Figure 21. Overpressure Histories for Voide4 Form (23 mm HEF)

The combustion overpressure data from each of the foar tests with 23mm HEI foll within the band shown. Note the faster decay time for this data as opposed to the API which is attributed to the face-cased venting via the multiple fragment holes in the rear panel. Figures No. 22 and 23 compare the same to the exit panels for tests performed with 23mm HEI in this series.



Figure 22. Comparison of Exit Pauels, Fine Blue Foam (Top, Test No. 15) and Red Foam (<u>Bottom</u>, Test No. 8), Egg Grate Voiding Configuration

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Figure 23. Comparison of Exit Panels, Coarse Blue Foam (Top, Test No. 14) and Yellow Foam (Bottom, Test No. 10), Egg Grate Voiding Configuration

All of the photographic data corroborates the pressure data which indicates no significant combustion overpressures. The initial increase in pressure shown in Figure No. 21 is attributed to blast products or to limited combustion of fuel vapor in the immediate vicinity of the blast. There was definitely no flame propagation inside the TWS as a result of the 23mm HEI impacts.

There was one factor affecting the combustion overpressures in this series that should be noted. This series of tests was performed with the initial circulation system. The initial circulation system, which was actually part of the TWS, had a volume equal to 20% of the basic TWS. But, there was no combustion in the circulation system due to foam plugs at the entrance and exit of each tube. Therefore, the circulation system served as a volume into which any overpressures in the tank could relieve and thereby effectively lower the peak pressure.

c. Astrocoated Red Foam

There were two tests performed in this series; Test No. 25 (50 cal. API) and Test No. 26 (23mm HEI). The foam configuration for these tests was the "egg crate" voiding. The basic TWS was changed slightly for this series and all later tests. The circulation manifold was isolated from the main tank beginning with this series of tests as is explained in Section II of this report.

The results for these two tests were slightly different from the previous voided foam tests. The amount of physical/mechanical damage

from the 23mm HEI was unchanged, but the overpressures for both projectiles was higher than the average for'the voided foam series. The pressure history for these tests is presented in Figure No. 24. Figure No. 25 is a photograph showing the damage to the exit panel for the two tests performed in this series. 院議院は日間月日、

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Figure 24. Overpressure Histories for Astrocoated Foam

These overpressures are slightly higher and can be attributed, at least in part, to the isolation of the circulation system which permitted some pressure relief on previous tests. These two tests were performed in succession and the foam was not changed between the 50 cal. API impact and the 23mm HEI. After the 23mm HEI test the tank was opened and the foam examined. Singeing of the foam was observed on two of the rear pieces of foam indicating combustion had taken place. The movie data also corroborated the overpressure data for the 50 cal. API test by indicating sustained venting from the exit holes. The pressure and movie data indicate that the foam singeing occurred with 50 cal. API and not with the 23mm HEI.



Figure 25. Exit Panel, Astrocoated Red Foam, Egg Crate Voiding-Configuration (Test No. 26)

d. Explosafe

There were three tests performed in this series; Test No. 20 and 27 (50 cal. API) and Test No. 28 (23mm HEI). Each test was conducted with the Explosafe "solid packed" in the TWS and the same set of Explosafe was used for all three tests. The results for Test No. 20 will be treated separately due to the unusual results. Test No. 20 was conducted using the TWS which incorporated the original circulation system. This circulation system could not be isolated from the TWS and therefore used small pieces of red foam to prevent flames from entering the circulation system. On this particular test the flame front propagated into the circulation system and produced an explosion which caused significant damage to the circulation system. The fact that the flame front traveled to the side of the tank indicates that combustion occurred throughout most of the tank. The pressure data is of questionable value due to the explosion in the manifold and therefore very little could be deduced from this test as to performance of the metal arrestor.

The test of the metal arrestor with 50 cal. APT was repeated after the TWS was repaired and the modified circulation system installed. Test No. 27 was the repeat of Test No. 20 and resulted in no measurable overpressures. This indicates that there was no significant combustion in the TWS, which is contrary to the results of Test No. 20. The mechanical damage to the metal arrestor from the 50 cal. AP1 consisted of a hole completely through the metal arrestor ranging from 2 to 4 cm in diameter. Test No. 28 was performed with the 23mm HE1 but

unfortunately no overpressure data was recorded due to a magnetic tape transport malfunction. But, from movie data, it was determined that there were no significant combustion overpressures due to the obvious lack of any venting gases. The mechanical damage to the metal arrestor was significantly worse than observed with the foam. Figure No. 26 is a photograph showing the large cavity in the Explosafe from the HEI blast. Figure No. 27 is a photograph showing the damage to the exit panel for Test No. 27 and 28.

3. DRY FOAM TESTS

The combustion overpressure data for this overall program generally ran lower than predicted from flame tube data. The primary reason for the difference is that these tests were conducted using wet foam (holding JP-4) as opposed to dry foam in the flame tube tests. Wet foam is a better flame arrestor than dry foam.

Test No. 29 (50 cal. API) and Test No. 30 (23mm HEI) were performed to verify this phenomena if possible. For these tests JP-4 was pumped into the bottom of the tank only (approximately 40 liters) and the vapors



Figure 20. Blast Pocket in Explosate



Figure 27. Exit Panel, Solid Packed Explosafe (Test No. 28)

dispersed via the circulation system. Test No. 29 and 30 both resulted in a significant increase in the combustion overpressure. Both tests were performed with coarse blue foam in the "egg crate" voiding configuration and there was singeing of the foam throughout the tank which indicated combustion occurred in a large majority of the TWS. Figure No. 28 shows a pressure history for both tests performed in this series. Figure No. 29 is a photograph showing the damage to the exit panel for Test No. 30, performed with the 23mm HEI.



Figure 28. Overpressure Historica for Dry Foam

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Figure 29. Exit Panel, Dry Foam, Coarse Blue Foam, Egg Crate Voiding Configuration (Test No. 30)

		Cometers				.022 sec. rise time, complete failure of both walls			.032 sec. rise time, rear wall failure only	.006 sec. rise time, rear wall failure only			overnight soak	1 hour soak é 38°C
stion	Decay	Sec.	N/A	N/A	N/A	1	x/a	X/A	1	1	-35	.30	.27	. 38
Combu	Over	rress. K Pa	N/A	N/A	S/A	280	N/Å	N/A	330	340	4.1	3.7	2.3	2.7
		2 .	r-1	ч	4		1	I		п	2	2	2	м
	Front/	Rear Wall	7075- 76	7075- T6	7075- T6	7075- T6	2024- T3	2024- T3	2024- T3	2024- T3	2024- T3	2024- T3	2024- T3	2024- T3
Initial	Tank	Press. K Pa	20.6	3.5	3.5	3.5	3.5	3.5	3.5	0	3.5	3.5	3.5	3.5
-	Fuel/	Air Ratio	N/A	8/8	N/A	Optia.	N/A	N/A	Optra-	Opta.	Opta.	Optm.	Optm.	Optra.
-		Fueling Proced.	попе	none	none	20 ltr JP-4	none	F,Drain JP-5	12 ltr JF-4	20 ltr JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4
-		Voiding Config.	N/A	N/N	N/A	K/A	N/A	Egg-Crt Void	N/A	N/A	Solid	Solid	Solid	Solid
•		Foam	pone	none	none	anon	none	coarse blue	none	none	red	yel- lov	fine blue	coarse blue
-		Threat	23 HEI	23 HEI	23 HEI	50 cal API	23 REI	23 HEI	53 cal API	23 HEI	23 REI	23 HEI	23 HEI	23 HEI
-		Test No.	10	02	60	z	05	8	21	24	11	16	17	18
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4. TEST RESULTS SUMMARY

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	Comments	Tank not opened between tests,	Foam singeing present	Tank not opened between tests No. 9 and 10	Tauk not opened between tests No. 9 and 10	I hr soak @ 38°C Pocket of foam burned at top rear, API didn't activate on front wall	l hour soak ê 38°C	1 nour soak ê 38°C	overnight soak	l hour soak ê 38°C	overnight soak Tank not opened between tests	overnight soak Singeing ch rear pieces of foam
istion	Decay Time sec.	.42		1.55	~	E	. 28	¥.	¥.	-49	1	1
Combt	Over Fress. K Pa	3	5.2	28	5.4	2.5	0	4.4	4.4	0	4-6	7.2
	This No.	2	5	~	~	8	44	8	7	7	2a	23
	Front/ Rear %all	2024-	2324- 13	-2024- 73	2024- T3	2024- T3	2024- T3	2024- T3	2024- 13	2024- T3	2024- T3	2024- T3
Initial	Tank Press. K Pa	3.5	3.5	3.5	3.5	3.5 2	3.5	3.5	3.5	3.5	0	ы
	Fuel/ Air Ratio	Opta.	Sette.	Opta.	Set .	e H	Optia.	Opte.	Jptra.	Optm.	Opta.	Optia.
	Fueling Proced.	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain 19-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4	F/Drain JP-4
	Voiding Config.	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Void	Egg-Crt Yoid	Egg-Crt Void
	Foam Type	red	red	yel- lou	yel- lou	fine blue	fine blue	coarse blue	fine blue	coarse blue	coated red	coated red
	Threat	50 cal API	23 HEI	5C cal API	23 HEI	50 cal API	50 cel API	23 HET	23 HEI	50 cal API	12.7 nPT	23 HEI
	Test No.	07	80	60	10	12	13	14	IJ	19	25	26
	mbol beblov							19180 (180)	POT 2HA F Dog			

4. TEST RESULTS SUMMARY (Continued)

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		Comments			Circulation manifold explosed	Care material need as in	DELLE MALET TAT AND AN AN	Test No. 29	c	Same material user as the	Test %o. 20 & 27		Cinceine throughout This	99	Singeing throughout TWS,	Eren Liverad hadly	toge antien neuro			
stion	Decay	Time	sec.		1			2/A			Ø		 				ا			
Combu	Over	Press.	K Pa		۱			0			ß		÷.	2		i	75			
		THS	No.		2			23	I	_	2a			P 7		,	23			
	Front/	Rear	Wall	2024-	13		2024-	E		120.24-	T3	1000	-4707	۲ ۲	2026-	1 1 1	13			
Initial	Tank	Press.	K Pa		-3.5			0			D		(þ		,	0			
	Fuel/	AİT	Ratio		Optm.			Optm.			Optie.			i E E			Opta.	•		
-		Fueling	Proced.	F/Drain	JP-4		F/Drain	JP-4		5/Drain	JP-4		40 Itr	JP-4			17-4L			
		Voiding	Config.		Solíd		Solid			Solid			Solid		Egg-Crt	Void	4	Egg-Crt Void		
-		Foam	Type	Fmlo-	safe		Fralo-	safe			safe		coarse	blue		ccarse	blue			
•		Tureat	5	100	API		50 03	APT			23 HEI		50 cal	API			23 HEI			
		Tact	No.	28 27 28			28			29			õ							
•	ry Poam Explosate								1											

4. TEST RESULTS SUMMARY (Concluded)

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SECTION IV

DISCUSSION OF RESULTS

The single most important aspect of these tests was controlling and monitoring the ullage fuel/air ratio in the TWS. The use of internal foam or metal arrestor complicated this task. If no foam was used, as in some of the preliminary tests, the controlling of the mixture would be fairly easy. It was found that a simple small fan can be incorporated into the ullage space to effectively "mix up" the ullage to ensure a homogeneous fuel/air ratio. With the foam present. in the tank, a fan inside will not effectively circulate the mixture due to the high restriction to flow which the foam presents. The system that was developed for this mixing effectively pulls gases out of one side of the tank and returns the gases in the opposite side of the tank resulting in the circulation of gases in a loop. It was felt that this circulation system does an extremely effective job at "mixing up" the ullage gases. This was proven with the nine point ullage sampling system on several tests. Before the circulation fans were started samples were taken which indicated large differences in the fuel/air ratio throughout the tank. Within three minutes after the circulation fans were started the fuel/air ratios were equalized throughout the tank. It is a quite reasonable assumption that the optimum conditions for combustion in the TWS will correspond to the highest overpressures in the ullage sampler. It is the authors' opinion that this ullage sampling system is extremely effective and yet very simple in theory and practice.

The results of the comparisons of the foams indicate that there is no discernible difference in performance between the polyether urethane and the polyester urethane. One of the criticisms of the polyether urethane foams was that they would lose a significant amount of tensile strength in the presence of JF-4. However, there was no apparent increase in damage to the polyether foams as opposed to the polyester type. Also, from handling and observing the foams after removal from the TWS, there appeared to be no difference whatsoever between the two types of foam. In fact, it is the authors' opinion that if both types of foam were of the same color, it would be virtually impossible to distinguish the two types either before or after a test.

The motion picture coverage was very valuable in corroborating the TWS overpressure histories from pressure instrumentation data. In every case where there was no sustained combustion overpressure the motion picture coverage indicated no gases being forced out of the entrance and exit holes or only an initial spurt immediately after the 23 mm HEI blast. If a sustained combustion overpressure was indicated on the instrumentation the motion picture coverage clearly indicated gases being forced from entrance and exit holes for an extended amount of time.

The mechanism by which the foam prevents flame fronts from propagating or explosions from occurring was of some interest in this program. The combustion overpressure data from the tests in this program were generally lower than anticipated, and in most cases there were no combustion overpressures at all. This raised the question of

what is the difference between these tests and those tests done in the flame tube at AFAPL? The main difference is the use of ballistic projectiles in this program as opposed to a spark ignition source in the flame tube tests. However, the 50 cal. API and the 23mm HEI used in this program produce a larger and more intense ignition source than a spark and would therefore tend to produce higher overpressures and not lower ones. The venting from the entrance and exit holes and into the circulation system in some tests effectively lowered the overpressures but not to the extent that was seen. The only other major difference was the fact that the foam was wetted with JP-4 in these tests where as the foam in the flame tube is tested dry. The two tests conducted with dry foam in this program succeeded in verifying that the wet foam does perform significantly better. One theory as to how the foam works Is that the foam itself acts as a heat sink to which heat from the flame front is transferred. This heat transfer from the flame lowers the temperature of the reaction enough to slow the reaction rate dramatically or actually stop the reaction totally. Some of the factors which would affect this would be surface to volume ratio of the heat sink (i.e. foam and/or fuel droplets), specific heat of the heat sink (Cp), and the latent heat of vaporization of the fuel. The wet foam has more mass and therefore is a greater heat sink. It also effectively increases the surface to volume ratio of the foam. The specific heat of urethane and fuel are approximately the same, therefore the fuel would not effectively increase the specific heat of the foams.

There is a difference in the amount of fuel retained in the foam depending upon the drain rate. Drain rate will be defined, for the

purposes of this report, as the rate at which the level of the liquid JP-4 drops through the foam. For this program the drain rates were in the neighborhood of 15 cm per minute and were not controlled or thought to be of any significance during the initial test planning or most of the testing. Only after the overpressure data was observed to be low for nearly all tests was this considered. Drain rates in the neighborhood of 2.3 cm per minute are considered to be typical in most aircraft which is significantly lower than used for these tests. It was documented by Mr. T. O. Reed (ASD/EN) via simple fuel retention tests (data presented in Appendix C) that there is an average 25% increase in fuel retention at a drain rate of 14 cm/minute as opposed to a 2.3 cm/minute rate. There could conceivably be a difference in the performance of the foam with different amounts of fuel retention. This was not investigated since it was felt that it was beyond the scope of the program. -

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The photographs of the exit panel damage, which are presented in Section III, do not indicate any clear differences in damage levels between polyether and polyester foams. There are some small differences between the photographs presented, but these differences do not follow any pattern and are attributed to test-to-test variations in damage. Also, the tests with Astrocoated foam, dry blue foam, and Explosafe did not exhibit any marked changes in exit panel damage. Therefore, for all of the explosion suppression materials tested, there did not appear to be any marked difference in exit panel damage.

It should be noted that the results obtained (the overpressure histories in particular) are peculiar to this test set-up and can very

well be different for a different test specimen. For example, the overall volume and the amount of venting will have a significant impact on the overpressure history. These tests are meant to be used as a basis for comparing different explosion suppression materials within the test program. Any comparison of results between test programs must be done carefully.

SECTION V

CONCLUSIONS.

From the results of the tests conducted in this program the following conclusions are presented:

1. The new hybrid polyether urethane foams (i.e. blue foams) performed as well as the standard polyester urethane foams (i.e. red and yellow foams) ballistically.

2. The hybrid polyether urethane form experienced a loss in tensile strength when in a fuel environment. This roduction in tensile strength was not enough to affect the ballistic performance of the hybrid polyether urethane form.

3. The ballistic performance of the Astrocoated red foam is equal to that of the uncoated red foam.

4. The limited data indicates that the metal arrestor, Explosafe, works as an explosion suppressant material, but a broader data base is needed before it can be incorporated into any weapon system.

5. The performance of foam is significantly increased when it is wetted with JP-4.

6. In the fully packed configuration, the coarse and fine pore foam perform equally well. In the voided configuration, up to 22.6%, both coarse and fine pore foam perform adequately with insignificant differences.

SECTION VI

RECOMMENDATIONS

Due to the marked increase in the level of ballistic performance of the foam when wet, it is suggested that a separate program be conducted to investigate in detail the effects of fuel retention. The program should attempt to quantify the increases in performance as a function of fuel retention and investigate the use of higher voiding percentages and/or larger pore size foams since present technology is probably in an "overkill" mode. Many present aircraft installations are probably accepting higher fuel retention/weight penalties than necessary.

In any future experiments with foam in any type of tank where JP-4 is being used and an optimum fuel/air ratio is required, it is recommended that a circulation system be incorporated into the test specimen. There could be several improvements made to this system which would significantly reduce the complexity of the system. Primarily, a better fan or blower could be found which would pump approximately 14 liters/ second at a reasonably high Δp across the fan or blower. It was the lack of a capability to produce a high Δp across the fans used in this test which dictated the use of the large diameter ducts so that flow restrictions could be minimized.



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APPENDIX A

ULLAGE SAMPLING SYSTEM

Controlling Program

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Main Program Bomb

This program controls entrance into one of four tasks by requesting input from TTY (type in number 1, 2, 3, or 4).

Task	#
Initiate	1
Calibrate	2
Manua1	ч
Scan	4

TASK 61 Initiate

The TTY will ask for the program constants to be input on the photo reader. Input will be free field and will require 4 data points.

ISUCT, IFILT, CS, LOOKT CR LF

ISUCT = time in seconds needed to vacuum out the sample

IFILT = time in seconds to fill the sample

CS = value of the cal stop is psi-

LOOKT = number of times thru loop to lock for peak pressure

TASK #2 Calibrate

The TTY will request pressure channel be zeroed. Press <u>RUN</u> when zeroed. Then the TTY will request pressure channel be set on desired cal step. Press <u>RUN</u> when properly calibrated. The TTY will then print the voltage at zero and at the cal step.

TASK #3 Manual

Under this task bits 4 thru 14 on the SW register are output to the relay card thereby controlling the eleven valves only. It also monitors bit 0 for abort commands. All other bits are masked out and control nothing.

TASK #4 Scan

This task scans all 9 sampling ports taking bomb samples at each port. This task simply is composed of a do loop for the 9 samples. Each time through the loop the sample is readied for the ignition and then sparked and the peak pressure is recorded.

0801		PROGRAM BOMB	CAL LOOKT, IDATA	
0002		COMMON ISUCT, IFILT, ZERO, CS	J GALJ LUUK IJ I DKIK	
8883	10	IF(ISSW(3))12,20		
0004	12	WPITE(2,15)	*** * * * * * * * * * * * * *	· .
8685	15	FORMAT("# TASK"//"]		SCAN")
9996	1	"2 CALIBRATE"/"3	MANUAL 7 4	5074.
0000	20	WRITE(2,30)		
000 ·	30	FORMATC"ENTER TASK #"		
0000	•••	READ(1,*)IT		
0007		1F(1T-2)40,50,60		
0010	ስወ	WRITE (2,35)		
0011	26	FORMATC"INPUT CONSTANT TAP	E ON PHOTO READER)
0012	35	DEAD(5. #) ISUCT, IFILT, CS, LC	OKT	
0013				
8814				
0015	50			
0016				
0017	60	IF(IT-4)/0,00		
0018	70	CALL MANUL		
9019		GO TO 10		
0020	80	CALL SCAN		
0021		GO TO 10		
8022		END		

•

•

0001	ASMB, F	• B	
6662		NAM	VAIT
0003		ENT	VAIT
0004		EXT	• ENTR
0005	ICNTR	BSS	2
0006	WAIT	NOP	
0007		JSB	• ENTR
00 08		DEF	ICNTR
0009		LDA	ICNTR, I
0010		CMA	
0011		INA	
0012		STA	JCNTP
0013		LDA	ICNTP+1,I
0014		OTA	10B
0015	LOOP	STC	10B,C
0016		SFS	10E
ØØ17		JMP	*-1
6018		I SZ	JCNTR
0019		JMP	LOOP
0020		JMP	VALT, I
0021	JCNTP	DEC	Ø
90 55		END	

```
SUBROUTINE SCAN
0001
            DIMENSION IV(9), PMAX(9)
0002
            COMMON ISUCT, IFILT, ZEPO, CS, CAL, LOOKT, IDATA
0003
0004
            IV(1)=20020B
0005
            IV(2)=200406
0006
            IV(3)=20100B
0097
            IV(4)=20200B
            IV(5)=20400E
0008
0009
            IV(6)=21000B
6010
            IV(7)=22000B
6011
            IV(8)=24000B
0012
            IV(9)=30000B
         11 WRITE(2,10)
0013
0014
         10 FORMAT("PRESS RUN TO SACN")
0015
            PAUSE
     C CHICK FOR ABORT
0016
0017
            IF(ISSW(0))100,12,12
0018
     · [********************************
0019
         12 DO 99 I=1,9
0020 C OPEN V10, V11
0021
            CALL RELAY(60000B)
0022
            CALL WAIT(ISUCT, 4)
0023 C CHECK FOR ABORT**********
0024
            IF(ISSW(0))13,14,14
0025
         13 CALL RELAY(0)
0026
            GO TO 30
0027
         14 CONTINUE
0029
      C CLOSE VII, LEAVE VIØ OPEN, OPEN V(I)
0030
            CALL RELAY(IV(I))
0031
            CALL WAIT(IFILT, 4)
0032
      CLOSE ALL VALVES, START OSCILLOGRAPH
0033
            CALL RELAY(1B)
0034
            CALL WAIT(5,3)
      C TURN ON SPARK, TURN OFF OXCILLOGRAPH START PULSE
0035
0036
            CALL RELAY(100000B)
0037
            PMAX(I) = \emptyset.
0038
            DO 98 J=1,LOOKT
0039
            CALL ADC
            X=IAND(IDATA, 177700B)
0040
0041
            PCUR=((X/3276.8)-ZERO)+CS/CAL
0042
            IF(PMAX(I)-PCUR) 50,98
0043
         50 PMAX(I)=PCUE
0044
         98 CONTINUE
0045 C STOP SPARK, STOP OSCILLOGRAPH
0046
            CALL RELAY(10B)
0047
            CALL WAIT(1,3)
0048
            CALL RELAY(0)
         99 CONTINUE
0049
0050
            IF(ISSW(1))20,30,30
0051
         20 WRITE(2,25)
0052
         25 FOPMAT(" #1
                            #2
                                  #3
                                        #4
                                               #5
                                                     #6",
           1 **
                 #7
0053
                              #9"//>
                        #8
0054
         30 1=1-1
0055
            WRITE(2)35)(PMAX(K))K=1,1)
0056
         35 FOPMAT(9(F4.1,2X)//)
0057
            IF(ISSW(2))11,100,100
0058
        100 CONTINUS
0052
            PETHEN
```

0001		SUBROUTINE CALIB	
		COMMON IL, J. ZEFO, CS, CAL,	L, IDATA
0002	~	ODEN VI THEU VIQ	
0003	C C	CALL DELAY (3776RE)	
0004		$\frac{1}{100} \frac{1}{100} \frac{1}$	
0005		WRITECZITET	S PUN">
888¢		10 FURMARC SEPU TIEST TO	
0007		PAUSE	
8968		IFCISSW(0))50/15	
0009		15 ZEP0=0.	
00 I Ø		DO 16 I=1,10	
0011		CALL ADC	
0012		CALL WAIT(1,3)	
8613		X=IAND(IDATA, 1777008)	
0014		16 ZERO=ZERO+X/32768.	
8815		WRITE(2,30)	
8016		30 FORMAT("CAL. CH.#0",")P	RESS FUN
0017		PAUSE	
0018		CAL=0	
8819		DO 31 I=1,10	
0020		CALL ADC	
0021		CALL WAIT(1,3)	
0022		X=IAND(IDATA, 1777008)	
0023		31 CAL=CAL+X/32768.	
0024	С	CLOSE VI THRU VIØ	
0025		CALL RELAY(Ø)	
0026		WRITE(2,35)ZEFO,CAL	
0027		35 FORMAT(F4+2,4X,F4+2)	
0028		50 CONTINUE	
0029		RETURN	
0030		END	56

and president and the second
0001	ASMB,	R, B					-
0002	* TAK	ES ON	E READ	ING	FFOM	СН	Ø
0003		NAM	ADC				
6684		ENT	ADC				
0005		COM	1(3))1	DATA	1		
0006	ADC	NOP					
0007		LDA	MODE				
0008		OTA	118				
0009		STC	11B,C				
0010		SFS	11B				
0011		JMP	*-1				
0012		LIA	11B				
0013		STA	I DATA				
0014		ISZ	ADC				
0015		CLA					
0016		OTA	11B				
0017		CLC	11B				
0018		JMP	ADC, I				
0019	MODE	OCT	20000				
0020		END					

0001	ASMB, F	E B	
0002		NAM	PELAY
0003		ENT	RELAY
0004	•	EXT	• ENTR
0005	JR	BSS	1
0006	RELAY	NOP	
0007		JSB	. EN TR
0008		DEF	JR
0009		LDA	JF,I
0010		OTA	15B
0011		JMP	RELAY, I
0012		END	

0001	ASMB, F	R. B	
0002		NAM	MANUL
0003		ENT	MANUL.
0004	MANUL	NOP	
0005		ISZ	MANUL
0006	LOOP	LIA	1
0007		SLA	
0008		JMP	MANUL, I
0009		AND	=B77760
0010		OTA	15B
0011		JMP	LOOP
0012		END	
APPENDIX B

FLAME ARRESTOR TEST DATA

AFFDL-TR-76-98



AFFDL-TR-76-98

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APPENDIX C

FUEL RETENTION VS DRAIN RATE TEST DATA

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FUEL RETENTION VS DRAIN RATE TEST DATA

Test performed by T. O. Reed (ASD/EN) in Feb 1976 to investigate the effects of drain rate on fuel retention.

Type Foam	Drain Rate <u>(inches/minute)</u>	Fuel Retention (Vol %)
Coarse Blue	.9	1.89
Coarse Blue	5.5	2.30
Fine Blue	.9	2.70
Fine Blue	5,5	3,60
Yellow	.9	. 90
Yellow	5.5	1.30
Red	.9	2,91
Red	5.5	2.94

AFPENDIX D

PHYSICAL PROPERTIES OF FOAM AND EXPLOSAFE

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Foar Soak Time	Foam [.D. # W906K(3-1)	Foam I.D. # W906K(10-1)	Foam I.D. # N263 (Bun 2)	Foam I.D. f 1904K (Bun 6)	Foam I.D. # 1905K (Bun K-2)
BASELINE	17.5 psi	21.3 psi	I7.4 psf	18.2 psi	21.6 psi
15 MINUTES	11.7 psf	12.5 psi	11.0 psi	9.5 psi	12.6 psi
1 HOUR	11.2 psi	12.1 psi	9.9 psí	10.0 psi	12.6 psi
4 HOURS	II.2 psi	il.9 psi	10.8 psi	10.1 psi	12.8 psi
24 HOURS	11.5 psi	11.4 psf	10.6 psi	10.3 psi	13.3 psf
MAX. Z LOSS FROM BASELINE	367	297	421	287	223

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JP-5 fuel soak at Room Temperature (72°F), all tension data vet except baseline tests run Jun 1975 by Mr. T. O. Reed

TEST CONDITIONS:

(ASD/ENFEF).

VET TENSION PROPERTIES JP-5 FUEL SOAK DATA

KYBRID POLYETHER URETHANE FOAM

AVERAGE LOSS IN TENSILE STRENGTH = 42.87

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PHYSICAL PROPERTIES OF FOAM

DATA SUMMARY

	Ye ID #W8	11ow 52K (2-2)	Coars ID #W9	e Blue 06K(3-1)	R0 1D #W8	•d 181K(2~4A	Fine ID #V	≥ Blue 1906K(8~3)	Astrocoated Red
PROPERTY	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY
DENSITY (1b/ft ³)	1.34	-	1.38	-	1.36	-	1.385	-	2.15
A1R PRESSURE DROP, AVERAGE (inches H ₂ 0)	0.155		0.200		0,289		0.264		0.252
TENSILE Strength (psi)	25.3	26.0	18.2	10.2	26.2	28.5	22.7	13.0	31.4
COMPRESSION LOAD DEFLECTION @ 25% (psi) 65% (psi)	0.40 0.60	0.40 0.58	0.57 0.945	0,30 0,545	0.40	0.37 0.56	0.58 0.925	0.35 0.585	-
TEAR STRENGTH (1b/in)	6.8	7.1	5.2	2,4	6,0	6.3	5.51	2.90	
FLAMMABILITY (in/min)	8,52		10.2	448-844 918 918 919 - 514	8,96	*	10.37	ngan gili Anan dha dirang ngandan.	an a
COMPRESSION SET (%)	31.9	-	18.9	-	25,1	-	10,9		1997 - 2009 - 2015 - 2017 - 20
VOLUME SWELL	•	+ 1.4	-	+ 15,1		+ 0,5		+ 16.2	

Wet data obtained after JP-4 fuel soaking 1-3 hrs. @ room temperature. See Military Specification for explanation of properties/tests.

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PHYSICAL PROPERTIES OF EXPLOSAFE (Properties of Material as Tested)

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DATA SUMMARY

PROPERTY	VALUE
DENSITY (1b/ft)	2.62
AIR PRESSURE DROP, AVERAGE (inches H ₂ 0)	.154
VISUAL POROSITY (PPI)	1.3 LWD, 3.5 SWD
ALLOY	SAE 3003 ALLOY H-24 TEMPER
THICKNESS UNEXPANDED (inches)	.003

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