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AFWAL ltr, 29 Jun 1984.

AD 922 832

AUTHORITY: AFWAL

ltr 29 Jan 84

ASD-TR-74-34

GUNFIRE EFFECTIVENESS AND ENVIRONMENTAL SUITABILITY OF VOID FILLER MATERIALS

September 1974

Final Report for Period October 1972 - September 1973

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

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: ASD-TR-74-34
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): GUNFIRE EFFECTIVENESS AND ENVIRONMENTAL SUITABILITY OF VOID FILLER MATERIALS

5. TYPE OF REPORT & PERIOD COVERED: Final Report, October 1972 - September 1973

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Floyd L. Cooper Jr., Capt USAF, ASD/YFE; Allan J. Ferrenberg, AFAPL/SFH; Philip A. House, AFML/MXE; Ralph W. Lauzze II, AFFDL/PTS; Charles C. Gebhard, AFFDL/PTS; AFSC, WPAFB, Ohio 45433

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Air Force Aero-Propulsion Laboratory (SFH)
Air Force Materials Laboratory (MXE)
Air Force Flight Dynamics Laboratory (FTS)
Air Force Systems Command, WPAFB, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
AFAPL - 30480756
AFML - 73810602
AFFDL - 43630123

11. CONTROLLING OFFICE NAME AND ADDRESS:
Aeronautical Systems Division (YFE)
Wright-Patterson Air Force Base, Ohio 45433

12. REPORT DATE: September 1974

13. NUMBER OF PAGES: 48

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report): Distribution Limited to U.S. Government Agencies Only; This report contains information on test and evaluation of military hardware; September 1974; Other requests for this document must be referred to Aeronautical Systems Division (YFCTD), Wright-Patterson Air Force Base, Ohio 45433

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Survivability/Vulnerability
Void Filler Materials
Fire Suppression
Aircraft Fuel Tank Protection
Gunfire Testing
Fragment Impacts
Environmental Testing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
Gunfire tests, using high speed fragments, 50 API, and 23MM HEI projectile threats, and environmental tests were conducted on a variety of candidate void filler materials to: (1) determine the effectiveness of these void filler materials in preventing fires in the dry bays surrounding F-15 fuselage fuel tanks when these tanks are impacted by enemy threats, and (2) determine the environmental suitability of these materials for permanent installation in the F-15. Two materials manufactured by the Scott Paper Company, Scott White and Charcoal Polyether Polyurethane foams, were both found to be highly effective

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20. as void filler materials in preventing fires, and were both found to be environmentally suitable for permanent installation in the F-15.

FOREWORD

The F-15 System Program Office wishes to express its appreciation for the truly outstanding support provided by the Air Force Flight Dynamics Laboratory, the Air Force Aero Propulsion Laboratory, and the Air Force Materials Laboratory in the successful accomplishment of the subject testing. The Laboratories found time within their busy schedules to fabricate articles and perform tests in a time frame compatible with F-15 objectives. The testing was accomplished under AFFDL Project Number 4363, AFAPL Project Number 3048, and AFML Project Number 7381.

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SECTION I

INTRODUCTION

On impact by hostile threat projectiles, unprotected aircraft fuel tanks are vulnerable to fires in dry bays (voids) which surround the fuel tanks. Fire ignitions can occur from incendiary type projectiles (i.e., API and HEI), or from flash producing impacts by high speed warhead fragments. The dry bays (voids) are those volumes formed with the fuel tank liner and adjacent aircraft structure such as formers, stiffners, bulkheads and aircraft skins.

Void filler materials can be installed in the dry bays to prevent fuel ignition from occurring outside fuel tanks when impacted by one or more of the above mentioned threats. One potential fire prevention mechanism of a void filler material is that it delays the proper fuel/air mixture from reaching the incendiary (or flash) source until the incendiary or flash dies out.

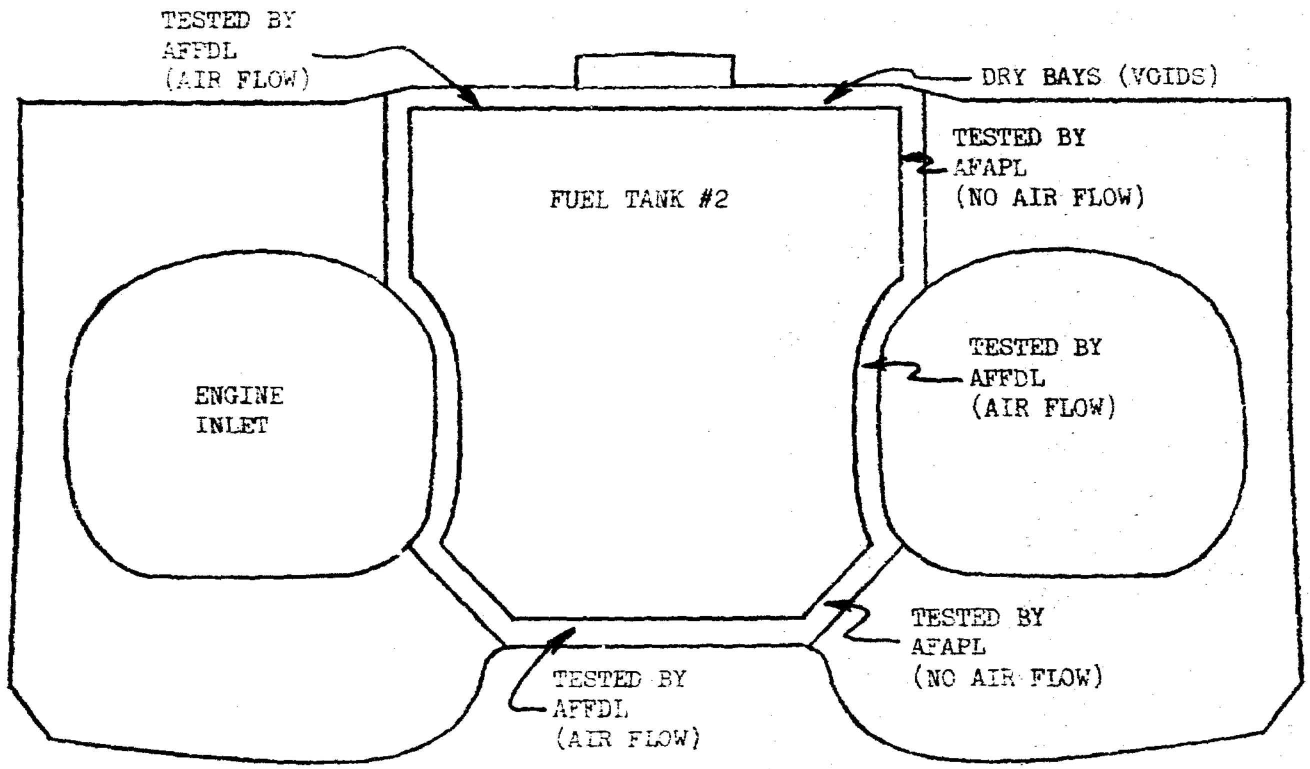
The purpose of this testing program was to: (1) determine the effectiveness of candidate void filler materials in preventing fires in the dry bays surrounding F-15 fuselage fuel tanks when these tanks are impacted by enemy threats, and (2) to determine the environmental suitability of these materials for permanent installation in the F-15.

In terms of aircraft kills, the primary threat to the F-15 is missile warhead fragments. For this reason the void filler test program was designed to protect against fragments. Testing with HEI was conducted to determine whether the void fillers could provide any additional protection against these threats.

The F-15 System Program Office initiated this program and served to guide and monitor the development and conduct of the tests. The tests were conducted in three parts by the Air Force Aero Propulsion Laboratory (AFAPL), the Air Force Flight Dynamics Laboratory (AFFDL) and the Air Force Materials Laboratory (AFML). The AFAPL tests were designed to screen the list of available void filler materials to (1) determine the relative effectiveness of each of the materials in preventing fires, (2) determine the baseline vulnerability of simulated F-15 fuel tank locations that are not wetted by external air flow, and (3) determine the vulnerability of these locations when protected by the most effective void filler material. The AFFDL tests were designed to simulate the F-15 fuselage fuel tank section of the aircraft, and to determine both the baseline vulnerability and protected vulnerability (using the most effective void filler from the AFAPL tests) with external air flow conditions. Figure (1) shows a typical fuel tank section and the corresponding areas of testing simulated by the AFAPL and AFFDL gunfire tests. The AFML tests were designed to determine the important physical characteristics of the most promising void filler materials when subjected to environments typical of those expected in operational aircraft.

FIGURE 1

AREAS OF TESTING BY LABORATORIES ON
TYPICAL F-15 FUEL TANK CONFIGURATION



SECTION II

AFAPL GUNFIRE TESTS

The tests were conducted in the AFFDL Ballistic Impact Test Facility at Wright-Patterson AFB. The AFAPL (and AFML) tests were performed to determine the more effective (and environmentally suitable) materials before proceeding with the more expensive AFFDL tests. All gunfire tests were performed under ambient air conditions, using JP-4 with an average fuel temperature of 90°F. F-15 fuel temperature is typically 70-110°F. All dry bays (voids) surrounding aircraft fuel tanks were configured to be two (2) inches thick. The F-15 normally has 2.0 inch thick dry bays formed by the fuel tank liner and adjacent aircraft skins. The fires encountered were classified as (1) self-extinguishing fires which would not result in aircraft kills, and (2) sustained fires which would result in aircraft kills. The presence and types of fires were determined from visual observation on closed-circuit TV monitors and from still, real-time, and high speed photographic coverage.

1. RELATIVE EFFECTIVENESS TESTS (50 API)

The relative effectiveness tests were designed to determine the relative effectiveness of void filler materials under worse case conditions against 50 API and were not designed to simulate the F-15. A list of candidate void filler materials was generated by the three AF Laboratories and the F-15 SPO for gunfire testing by AFAPL, See Table 1. These materials were chosen to represent the types of candidate materials available. The list included fiber mats (3M and GAF), rigid foam (Avco 5A43), and flexible foams (Scott Safom, Scott White and Charcoal Polyether, and Goodyear Purple). The Scott Charcoal Polyether was not discovered until late in the test program. It was added to the test program because of its similarity to the Scott White Polyether and because of reports by the manufacturer of good environmental characteristics.

Test Setup. The test fixture was a 100 gallon test tank configured with 2.0 x 16.4 x 16.75 inch dry bays. The fuel level was typically 1/3 to 2/3 full. The tests were conducted with no external air flow, and were shot at 0 degrees and 60 degrees obliquity angles from the normal to the impacted panels.

The tests were designed to generate a high baseline probability of fire using a 50 API (average velocity = 2800 fps) in an effort to better rate the relative effectiveness of the void fillers. For this reason, a .250 inch thick 2024-T3 aluminum striker plate was positioned two inches in front of the outside skin of the dry bay to obtain maximum functioning of the incendiary. For the same reason, no fuel bladders were used, and .090 inch thick 2024-T3 aluminum skins were utilized for the fuel tank liner and outside skin of the dry bay.

Table 1

Candidate Void Filler Materials

a) 3M Fiber Mat

b) GAF Fiber Mat

c) Scott SAFOM 10-PPI

d) AVCO Rigid Foam

e) Goodyear Purple Foam FCN-1

f) Scott White Polyether Foam 37-PPI

g) Scott Charcoal Polyether Foam 20-PPI

h) Scott Charcoal Polyether Foam 38-PPI

Discussion of Results. Tables 2 and 3 show the comparative results of testing at 0 degrees and 60 degrees respectively. Baseline testing without void filler materials resulted in 23 fires out of 27 tests, a computed probability of fire of approximately 85 percent.

The Scott White Polyether produced the most promising reduction in probability of fire. Testing with the Scott White Polyether resulted in 2 fires out of 21 tests, a computed probability of fire of approximately 10 percent. It is noted that no void fires occurred within the 2-inch dry bays during any test which utilized a void filler material. All of the fires which did occur with filler materials occurred outside the 2-inch dry bay.

In addition, the Scott flexible, open-pore foams were found to be effective in preventing or reducing the flow of fuel outside the dry bay through the entrance wound. This reduced the intensity of those fires which did ignite. In contrast, the Avco rigid foam cored out and funneled maximum fuel flow to the external fires.

Compression of the flexible foams (i.e., 5-10%) was found to improve the effectiveness in preventing fires and reduce fuel flow out of the entrance wound. In the haste of acquiring and testing the Scott Charcoal Polyether, the foam was inadvertently installed without compression. This could account for its poorer performance as compared to the Scott White Polyether which was under compression.

2. RELATIVE EFFECTIVENESS TESTS (HIGH SPEED FRAGMENTS)

As a follow-on to the previous testing against 50 API projectiles, this series of tests was performed to assess the performance of the more effective Scott Polyether foams against high speed fragment impacts. The Avco 5A43 rigid foam was also tested for comparison purposes.

Test Setup. The test setup is the same as that used for the 50 API tests, with one exception: the tanks are impacted by single, 207 grain Mil Spec fragments with an average impact velocity of 5000 fps. Because the fragments generate impact flashes with the dry bay skins, no striker plate is utilized.

Discussion of Results. Tables 4 and 5 show the results of testing at 0 and 60 degrees respectively. As shown in the tables, baseline testing without void filler materials resulted in 17 sustained fires out of 20 tests, or an overall probability of fire of 85 percent.

The Scott White and Charcoal foams were both found to be highly effective in preventing fires. Testing with the Scott Charcoal Polyether resulted in one fire from 9 tests. Testing with the Scott White Polyether resulted in no fires out of 20 tests, or an overall probability of fire of zero percent. In comparison, the Avco rigid foam resulted in 2 fires from 12 tests. As with the 50 API tests, no fires occurred within the 2-inch dry bays during any test utilizing void filler materials.

TABLE 2

Void Filler Material Relative Effectiveness Test
(50 API at 0 Degree Obliquity)

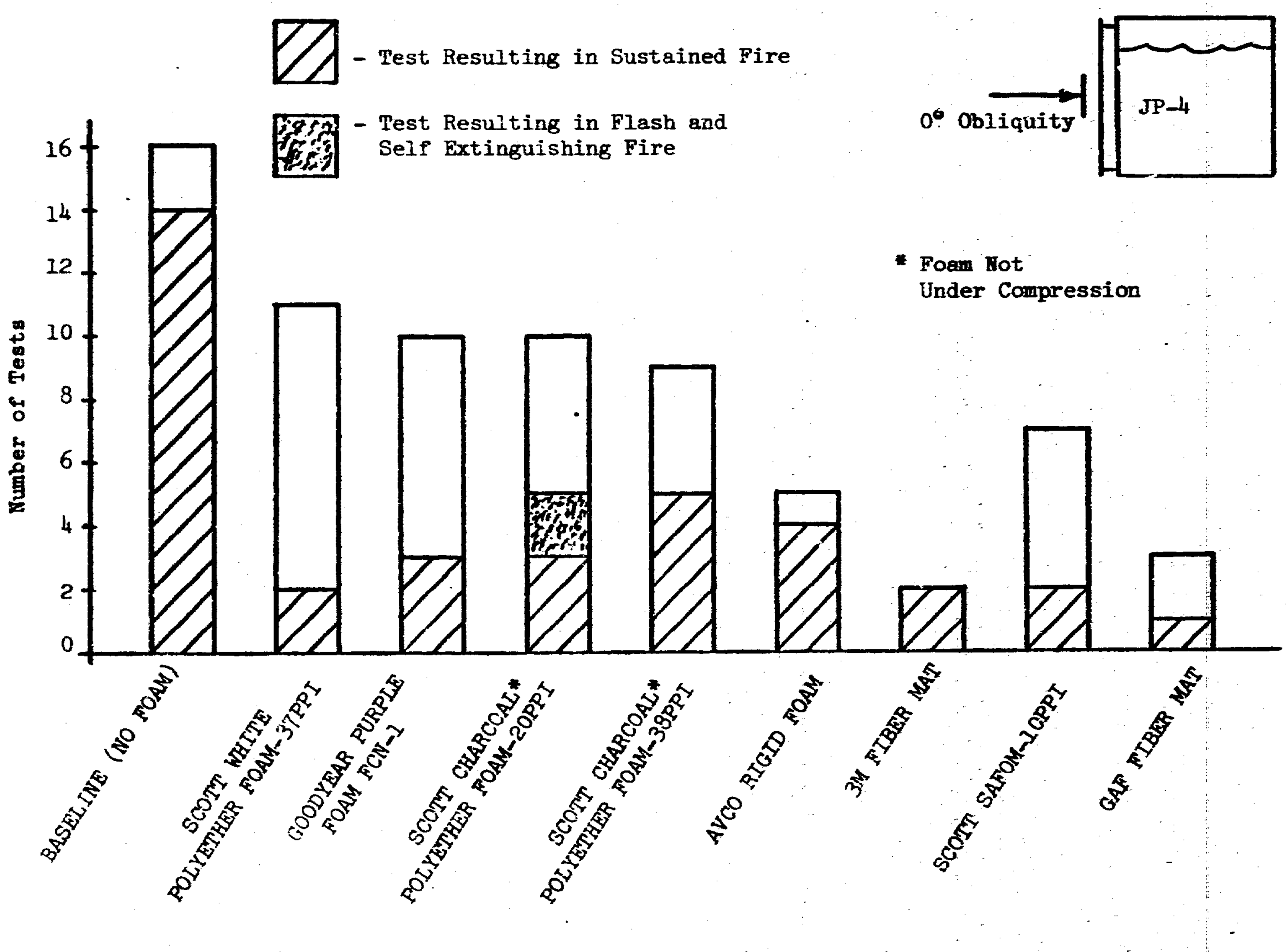


TABLE 3

Void Filler Material Relative Effectiveness Test
(50 API at 60 Degree Obliquity)

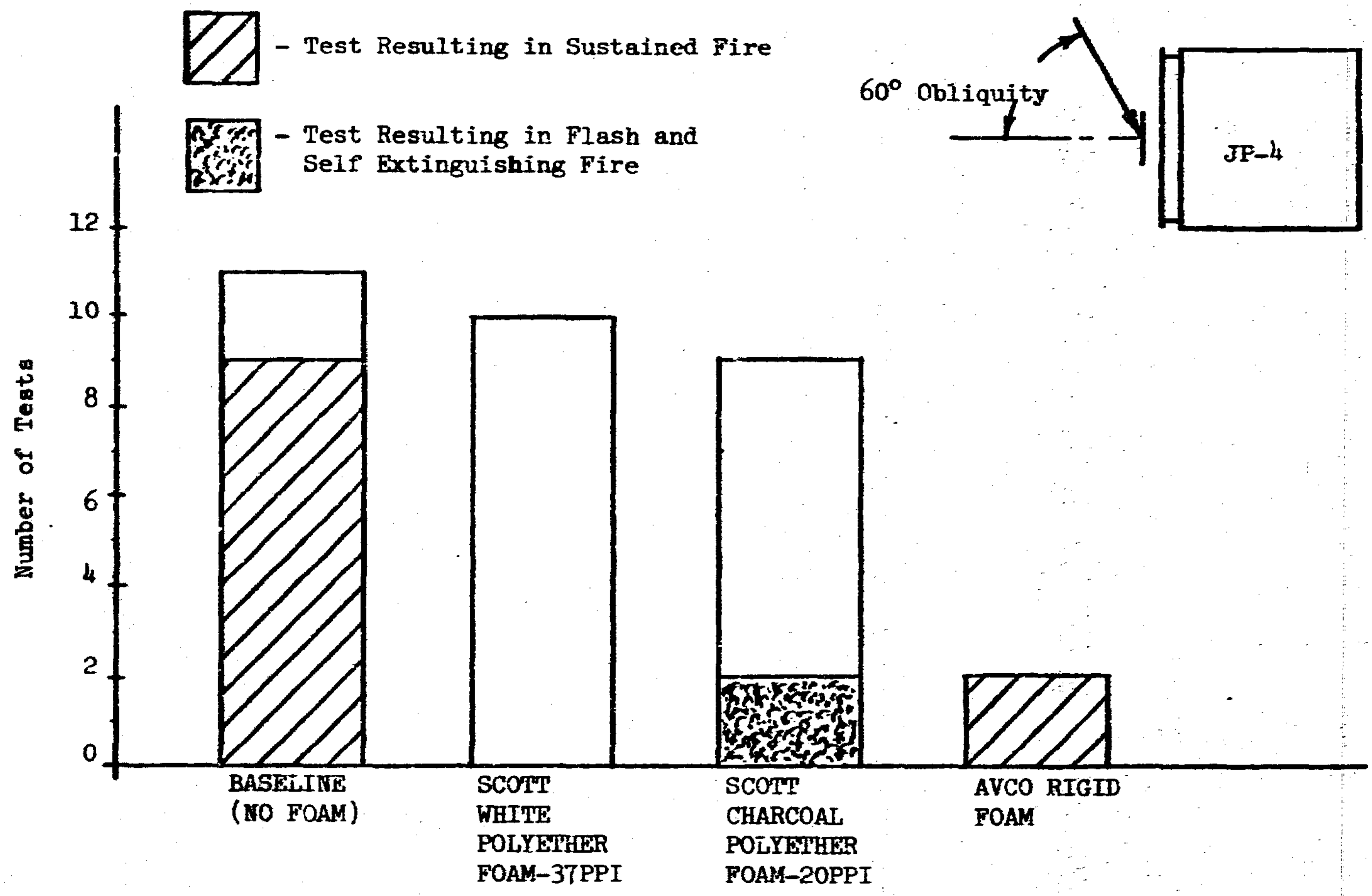


TABLE 4

Void Filler Material Relative Effectiveness Test
(High Speed Fragments at 0 Degree Obliquity)

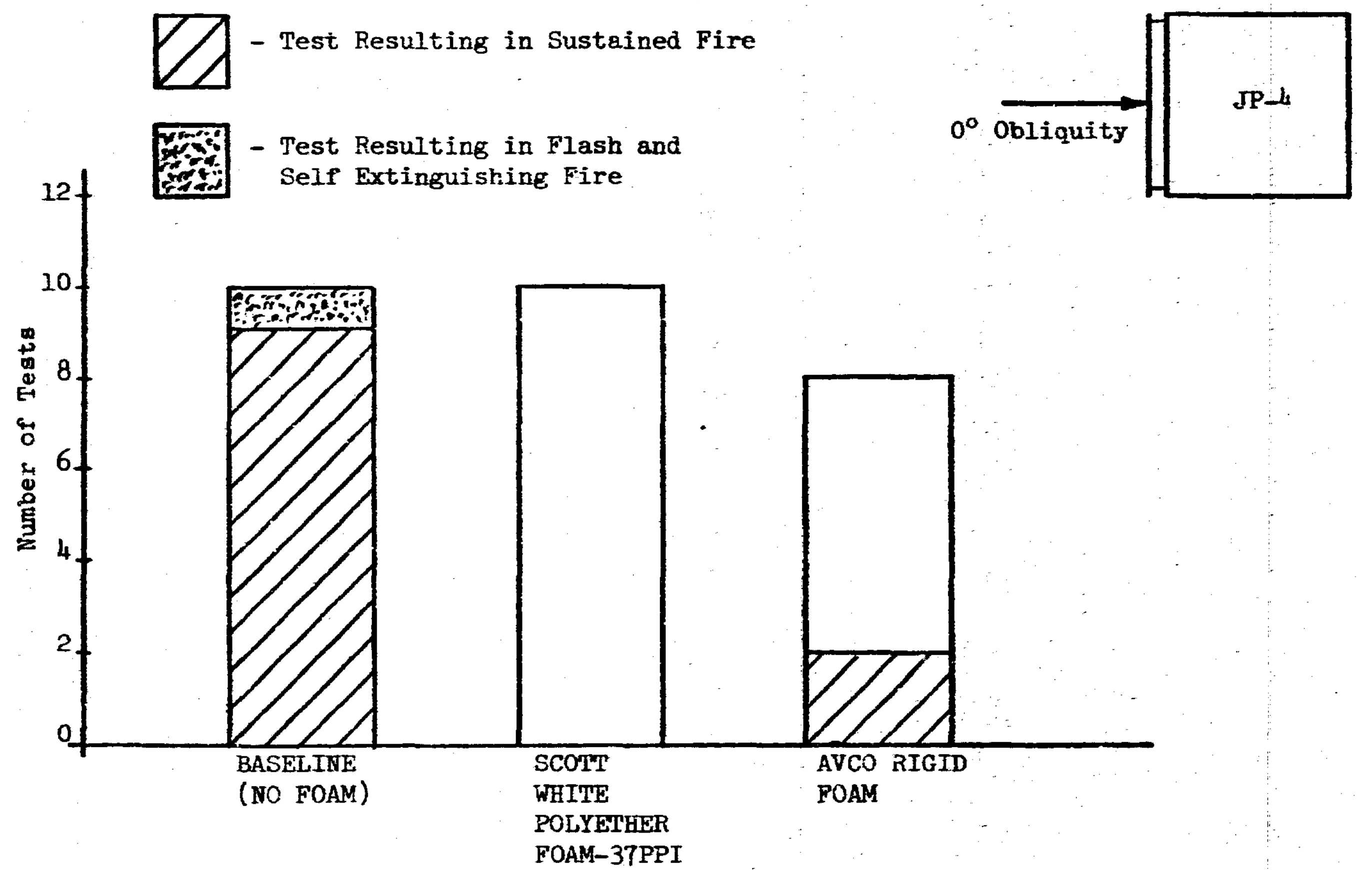
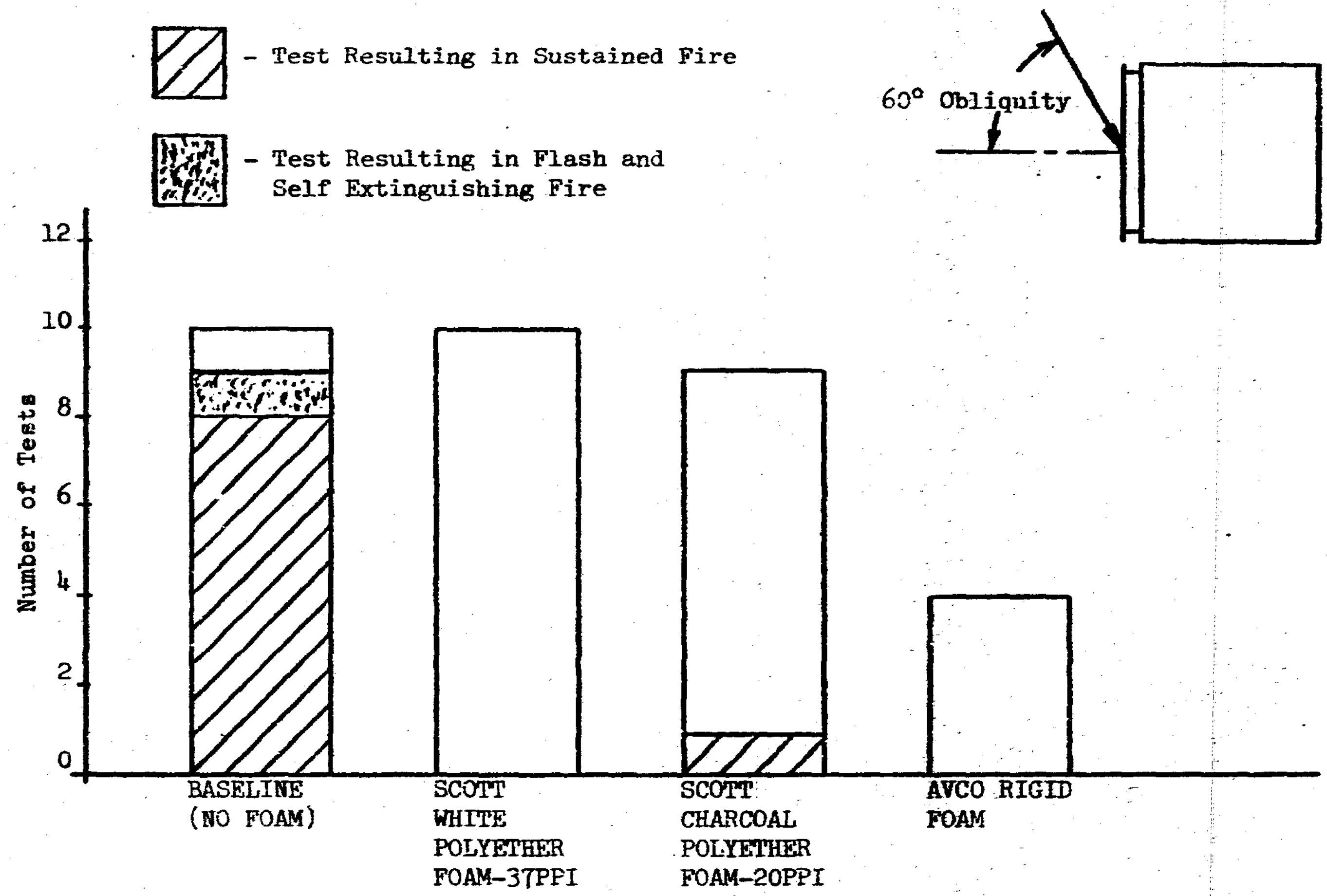


TABLE 5

Void Filler Material Relative Effectiveness Test
(High Speed Fragments at 60 Degrees Obliquity)



The Scott White and Charcoal Polyether foams were also found to be highly effective in preventing or reducing the flow of fuel outside the dry bay through the entrance wound.

3. SIMULATED F-15 FUEL TANK TESTS (HIGH SPEED FRAGMENTS)

These tests were designed to determine the baseline and protected (using Scott White Polyether Foam) probability of fire of simulated F-15 fuel tank configurations against high speed fragment impacts under conditions of no external air flow. Due to the limited range time available for simulated F-15 testing, the testing with void filler materials was limited to the White Polyether. However, based on the previous relative effectiveness tests, the results from the White Polyether should be similar to that expected for the Charcoal Polyether.

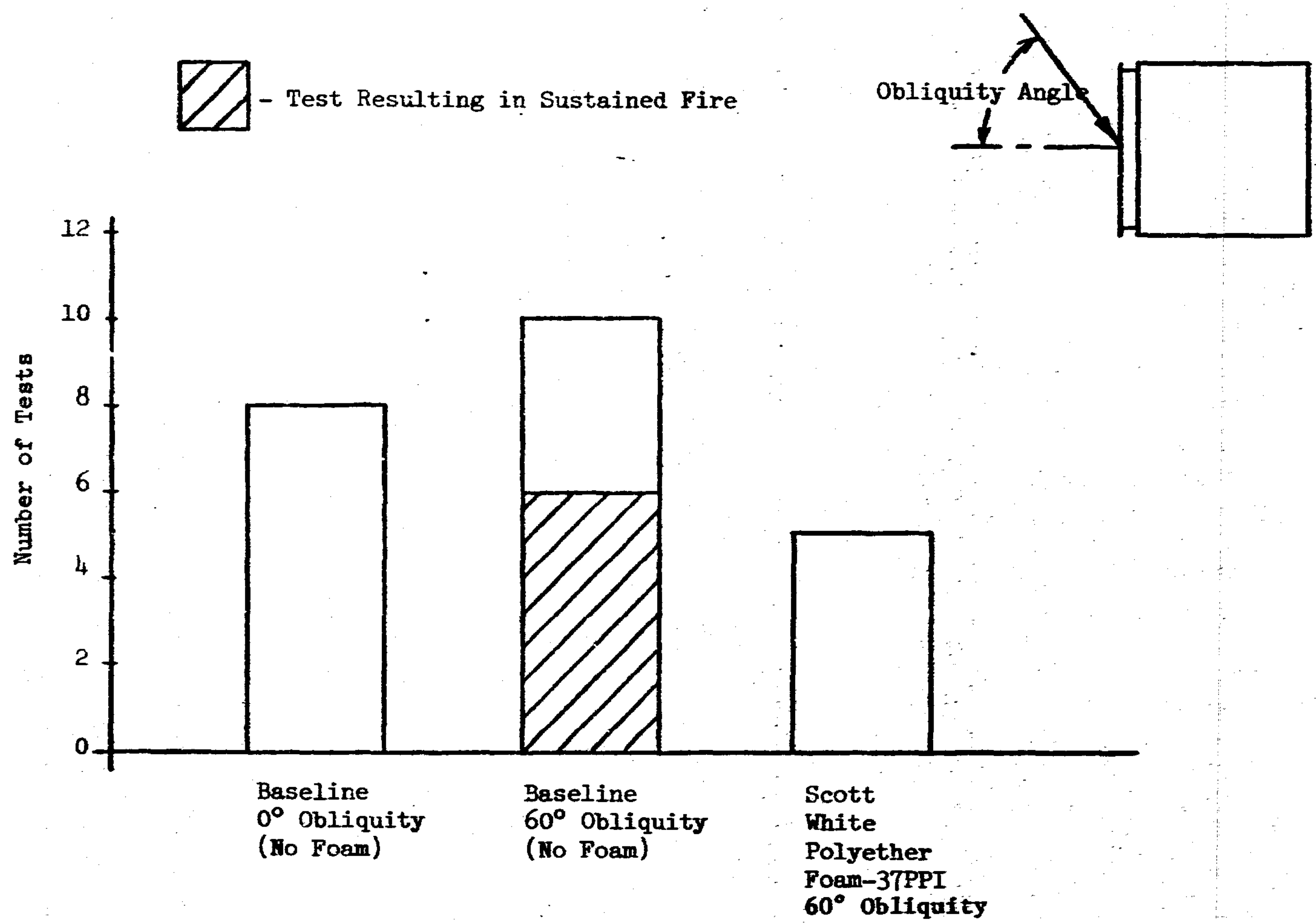
Test Setup. The test setup is similar to that used in the relative effectiveness tests, except that F-15 type materials were used. The outside skin of the dry bay was .050 inch thick 2024-T62 (typically .032 - .052 in F-15). The fuel tank liner, which makes up the inner skin on the dry bay, was .020 7075-T6 (same as tank #2, 3a, 3b in F-15; tank #1 is .016 thick). Conolite backing board and Goodyear self-seal bladder FTL-102 were utilized (same as F-15). The tanks were impacted by single, 207 grain Mil Spec fragments with an average impact velocity of 5000 fps.

Discussion of Results. Table 6 shows the results of baseline testing at 0 and 60 degrees obliquity, and protected testing with Scott White Polyether at 60 degrees obliquity. Baseline testing at 0 degrees resulted in no fires out of 8 tests. At 60 degrees the baseline testing resulted in 6 fires out of 10 tests. Overall, the baseline testing resulted in 6 fires out of 18 tests, or an overall probability of fire of 33 percent. Because the 60 degrees baseline testing produced a significant fire potential, the protected testing was conducted at 60 degrees. At this angle the Scott White Polyether foam was tested in 5 shots and resulted in no fires.

The Scott White Polyether foam was also found to be highly effective in preventing or reducing the flow of fuel outside the dry bay through the entrance wound.

TABLE 6

Simulated F-15 Tests
(High Speed Fragments)



SECTION III

AFFDL GUNFIRE TESTS

These tests were conducted in the Vertical Range (#3) of the AFFDL Ballistic Impact Test Facility at Wright-Patterson AFB. The Vertical Range utilizes ducted, by-pass air from a TF-33 engine to produce airflow over the simulated F-15 test specimen. This airflow was passed over the top and bottom of the fuel tanks, and through the simulated F-15 engine air inlet.

Figures 2 and 3 illustrate the configuration of the test specimen. As with the AFAPL tests, the fuel was heated to the typical F-15 temperature of 90°F. Two sizes of fuel tanks were tested; one had 240 gallons capacity, representing F-15 tank #2, and the other had 120 gallons capacity, representing F-15 tank #3a. The tanks were completely filled with JP-4, as are the main feed tanks (tanks 2, 3a and 3b) in the F-15. The fuel tanks were surrounded by nominal 2 inch thick F-15 dry bays, which were divided by stiffeners spaced 7 inches apart (spacing typical of F-15). The same or similar skins, stiffeners, rivet patterns, materials, spacings and dimensions that are on the F-15 were used in designing and fabricating the simulated F-15 test specimen. Internal red reticulated foam was installed in the top of the fuel tanks to 8 inches below the top centerline of the tank (same installation as F-15 tanks 2 and 3a). The engine air inlets were designed to duplicate the actual F-15 dimensions, and to produce air inlet/fuel tank pressure differentials typical of the F-15 under combat conditions. Mil Spec epoxy paint was applied to all external and air inlet skins (same as F-15, including colors). The presence and types of fires were determined from visual observation, closed-circuit TV monitors, thermocouples throughout the dry bays, IR visual display, and still, real-time, and high-speed photographic coverage. More details in the individual test setups are given below for the top, bottom and engine inlet tests. As a result of the earlier AFAPL relative effectiveness tests, the Scott White Polyether foam appeared to be the most promising void filler for testing in the AFFDL tests. Though later AFAPL testing on the Scott Charcoal Polyether showed this material to be comparable in effectiveness to the White Polyether, the White Polyether had already been purchased for testing. Therefore, the AFFDL tests were conducted on the White Polyether to yield effectiveness results representative of both the White and Charcoal Polyethers. Limited "proof" testing was conducted on the Charcoal Polyether to verify that it performed similar to the White Polyether.

1. TOP IMPACTS INTO SIMULATED F-15 FUEL TANKS

These tests were designed to determine the baseline and protected (using Scott White Polyether Foam) probability of fire of the top of simulated F-15 fuel tank configurations against high speed fragment impacts. For comparison purposes, the Avco 5A43 rigid foam was also tested. In addition, the top was tested against 23MM HEI air-to-air rounds to determine if the foams offered any additional protection against this threat.

FIGURE 2

Simulated F-15 Test Specimen with Threat
Impact Locations for Top and Side Tests

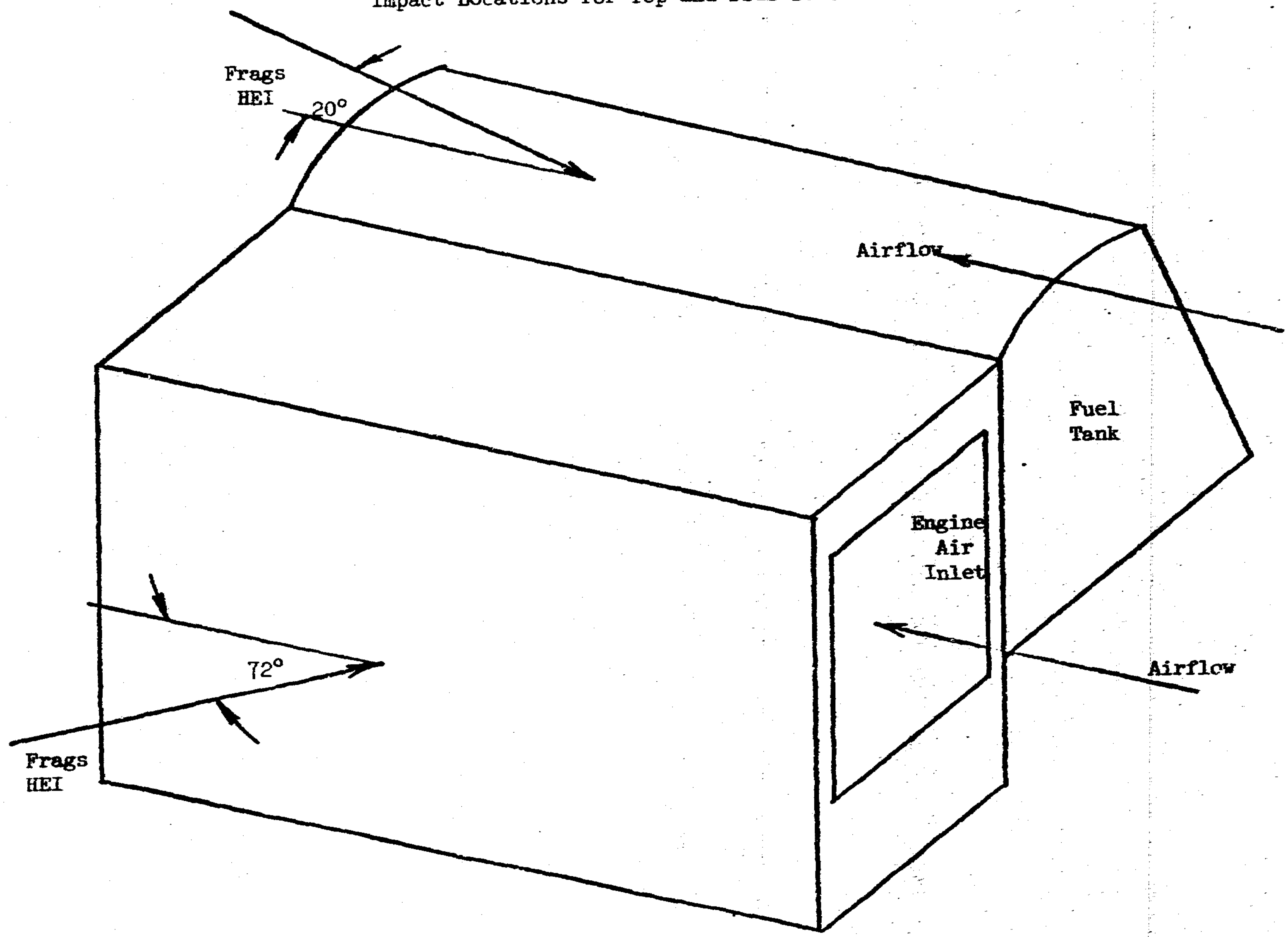
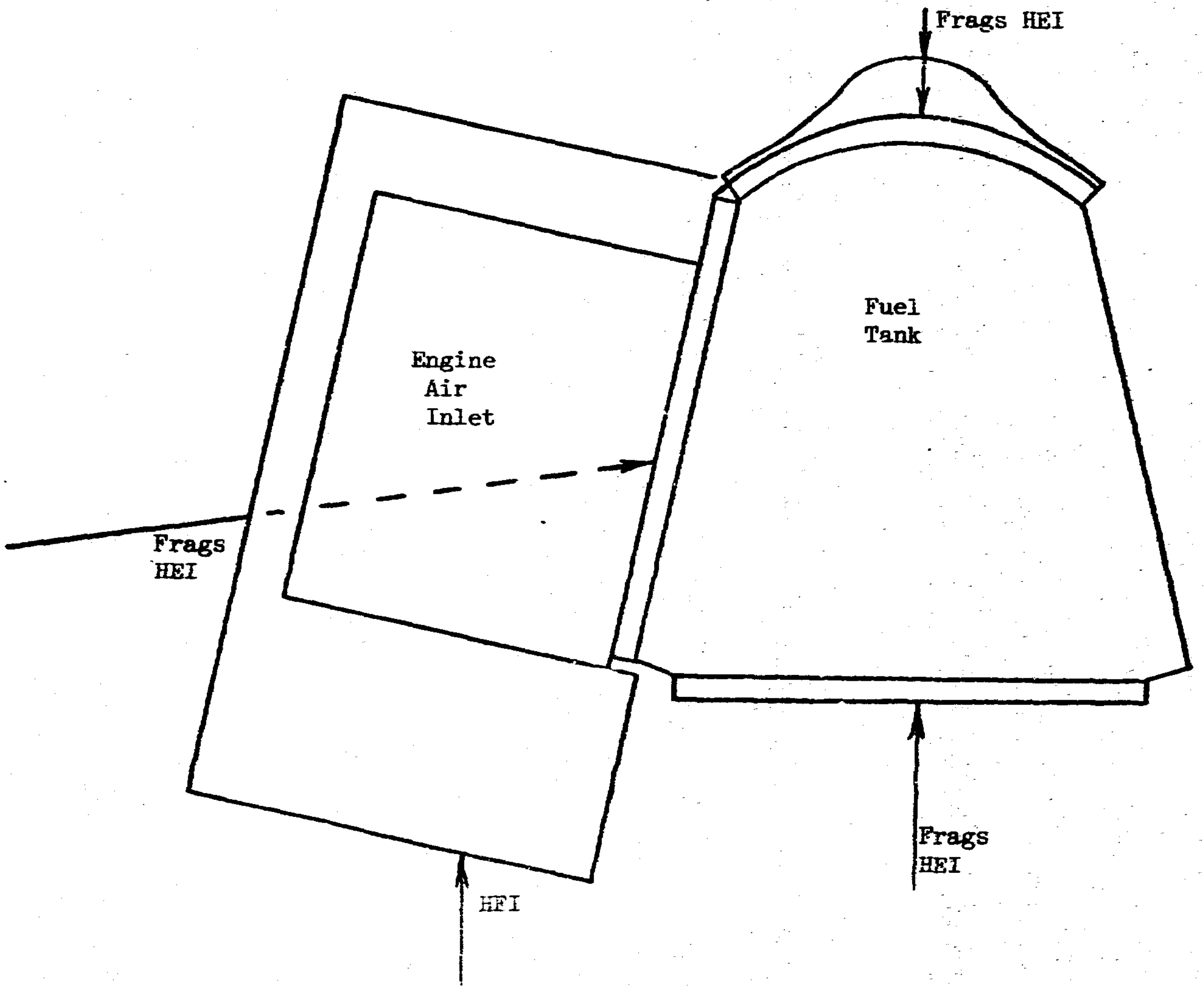


FIGURE 3

Simulated F-15 Test Specimen with Threat
Impact Locations for Top, Side and Bottom Tests



Test Setup. The top was configured with Goodyear tear resistant (FTL-102) bladder, a .020 7075-T6 tank liner with a .050 7075-T6 doubler to duplicate chem-milling around stiffeners, .100 gage stiffeners, and a .032 2024-T8 outer skin. In addition, a series of tests were performed using .071 8MnTi and .040 2024-T8 fairings installed over the outer skin to duplicate areas around the speed brake. Except for the 2024-T8 skins which are 2024-T62 on the F-15, all other materials, gages, and spacings are the same as the F-15. Air flow was blown over the top external skin at approximately 300 knots.

High speed fragments and 23MM HEI threats were fired into the top at approximately 70 degrees obliquity from the normal to the surface. The high speed fragments were fired in pairs (2) simultaneously with an average impact velocity of 5000 fps. The fragments impacted within approximately six inches of one another. Two sizes of fragments were fired; two 130 grain fragments and two 180 grain fragments. The 23MM HEI rounds were fired with two different fuses; the A-23 point detonating fuse and the B-23 delayed fuse.

Discussion of Results. Tables 7 and 8 show the results of testing with fragments and 23MM HEI rounds respectively. Baseline testing with fragments resulted in 5 self extinguishing fires out of 7 tests. An important feature discovered from these tests was that these self extinguishing fires resulted in little or no structural damage. The tests indicate that the top of the fuel tanks have low vulnerability to damaging external fires caused by fragment impacts. The testing with Scott White Polyether foam resulted in 2 self extinguishing fires out of 4 tests. The Scott foam tended to increase the fire hazard over that demonstrated without foam since the fires tended to burn longer with the foam. When the foam burned, it caused the flame to linger longer. However, it should be noted that the foam burning caused no apparent structural damage and always self extinguished with just limited, localized burning. It is important to note that this foam burning was peculiar only to the top shots. No foam fires were ignited with fragments on any side or bottom shots during either the AFFDL or AFAPL gunfire testing. Using the Avco rigid foam as the void filler in two shots resulted in no fires. These limited tests indicate that the Avco 5A43 void filler foam may offer some protection in reducing or preventing ignition of void fires caused by fragment impacts into the top of the fuel tanks. Additional useful information was obtained from 3 tests on the F-15 tank fixture, but with 2 psig pressurization in the fuel tanks. These tests do not represent the F-15, but were conducted to determine if tank pressurization significantly affected fire ignitions. The tests were: (1) baseline, (2) defended with Scott White Polyether foam, and (3) defended with Avco rigid foam. All three tests resulted in flash fires which self-extinguished. The tank pressurization did not significantly effect the resulting fires.

Baseline testing with the 23MM HEI rounds resulted in one sustained fire from two tests. The fire resulted from the dalayed fuse (B-23) round, and the no-fire resulted from the point detonating fuse (A-23)

TABLE 7

Fragment Impacts Into the Top of Simulated F-15 Fuel Tanks (High Speed Fragments at 70 Degrees Obliquity)

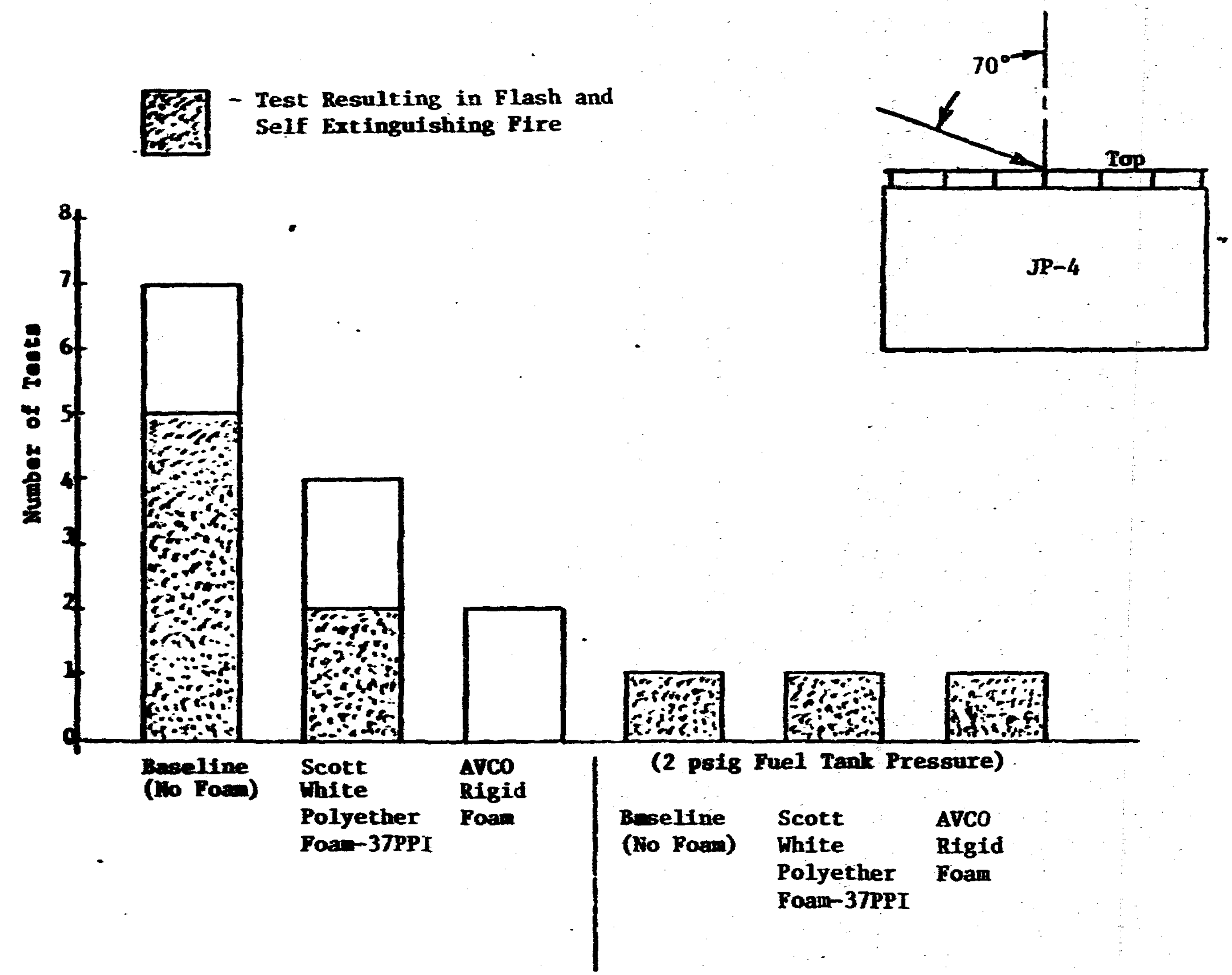
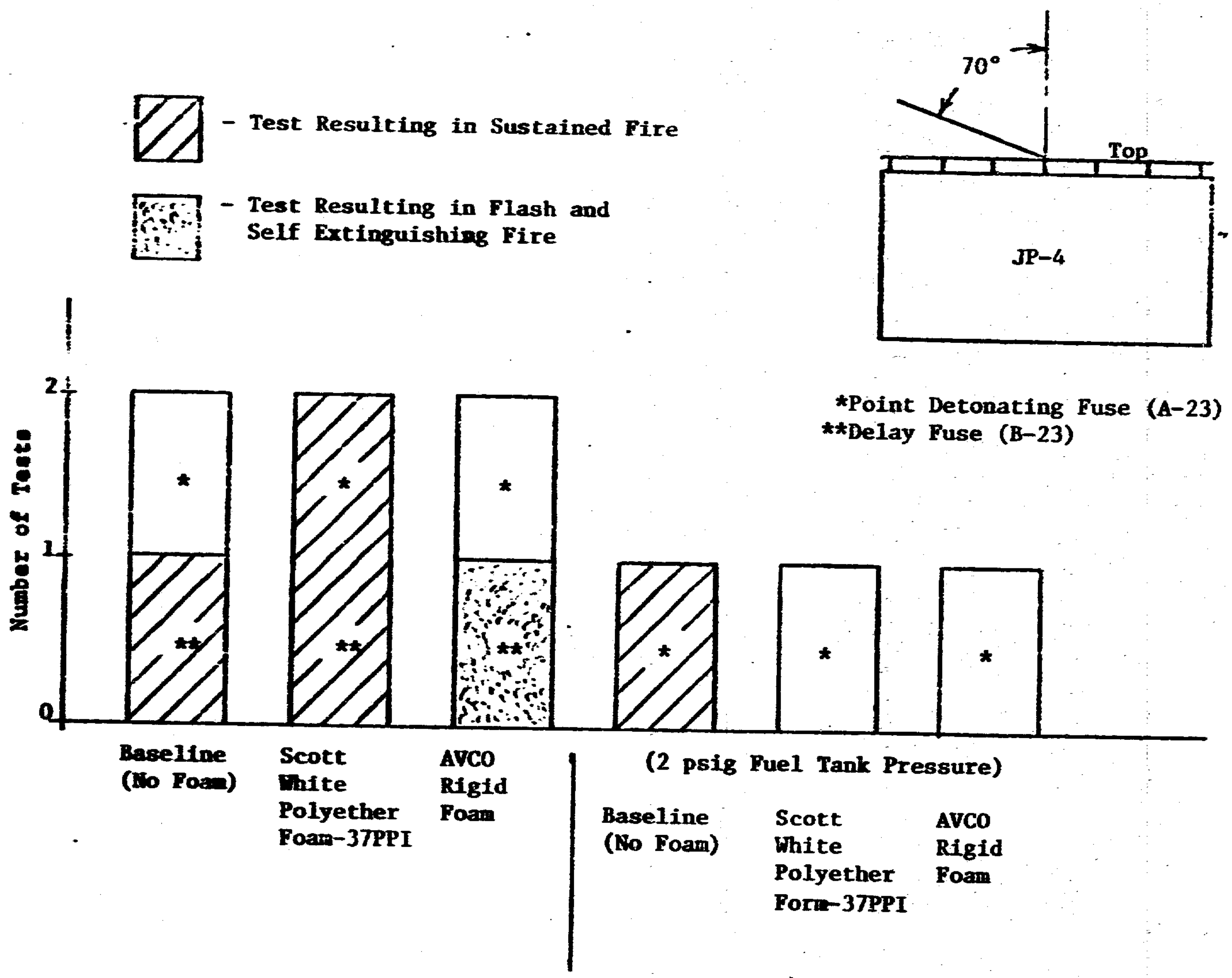


TABLE 8

HEI Impacts Into the Top of Simulated F-15 Fuel Tanks
(23MM Air-to-Air HEI at 70 Degrees Obliquity)



round. The delayed fuse round produced more structural damage and appeared to provide an increased chance of fire over the point detonating round. In two tests conducted using both types of fuses against the Scott White Polyether foam, both tests resulted in sustained fires. The damage from both 23MM fuse combinations was so extensive as to destroy and blow out portions of the void filler foam such that the fire protection feature of the foam was lost. In two tests conducted using the point detonating round against the Avco rigid foam, one test resulted in no fire and the other resulted in a flash fire which self extinguished. As with the fragment tests, three tests were performed using 2 psig tank pressurization. The baseline testing with no foam resulted in a sustained fire, whereas one test each with Scott and Avco foam resulted in no fires.

Because of the apparent low vulnerability of the top of the fuel tanks to fragment induced fires and because of little or no protection offered by the Scott foam against direct 23MM HEI hits on the fuel tanks, no benefit is achieved from installing the Scott foam on the top of the fuel tanks.

2. BOTTOM IMPACTS INTO SIMULATED F-15 FUEL TANKS

These tests were designed to determine the baseline and protected (with Scott White Polyether Foam) probability of fire of the bottom of simulated F-15 fuel tank configurations against high speed fragment impacts. Tests were also conducted with the Avco 5A43 rigid foam for comparison purposes. As with the shots into the top, the bottom was tested against 23MM HEI air-to-air rounds to determine if the foams offered any protection against direct hits from this threat.

Test Setup. The bottom was configured with Goodyear self-seal bladder (FTL-102), Conolite B33FG1W backing board, a .020 7075-T6 tank liner with a .050 7075-T6 doubler, .100 gage stiffeners, and a .032 2024-T8 outer skin. As with the top skins, the only F-15 skin not exactly duplicated in the tests was the 2024-T8 outer skin, which is 2024-T62 on the F-15. All other materials, gages and spacings were the same as the F-15. On certain tests, the material used for the fuel tank liner and the internal foam configuration were changed as follows;

(a) For three tests (each resulting in no fire) against fragments, the .020 7075-T6 tank liner was replaced with .020 2024-T3. The tests included one each with baseline, Scott White foam, and Avco foam.

(b) For two 23MM HEI tests, one each with Scott White foam and Avco rigid foam, the tank was completely filled with red reticulated foam.

Air flow was blown over the bottom external skin at approximately 300 knots.

High speed fragments and 23MM HEI threats were fired into the bottom at approximately 34 degrees obliquity. The 130 grain and 180 grain fragments were both fired in simultaneous pairs in the same manner as the top shots. The 23MM HEI rounds were equipped with A-23 point detonating fuses.

Discussion of Results. Tables 9 and 10 show the results of testing with fragments and 23MM HEI rounds respectively. Baseline testing with fragments resulted in 2 sustained fires out of 6 tests. Testing against fragments with the Scott White Polyether foam resulted in no fires out of 5 tests. Likewise, testing against fragments with Avco rigid foam resulted in no fires out of 4 tests. The Scott White Polyether foam and Avco rigid foam were both completely effective in preventing fires from high speed fragments impacting the bottom of the fuel tanks.

The limited testing with 23MM HEI rounds indicated that the bottom of the fuel tanks were highly vulnerable to damaging void fires. As with the testing on the top, the Scott foam was overpowered by the 23MM HEI and thus lost its fire protection capability. The Scott foam appeared to offer little or no fire protection capability against direct hits with 23MM HEI. Of three tests conducted with Avco rigid foam, only one test resulted in fire. The Avco foam appeared to offer a significant degree of protection to the bottom of the fuel tanks against direct hits from the 23MM HEI, point detonating round.

3. SIDE IMPACTS INTO SIMULATED F-15 FUEL TANKS

These tests were designed to determine the baseline and protected (with Scott White Polyether Foam) probability of fire of the side of simulated F-15 fuel tank configurations against high speed fragment impacts. Two proof tests were conducted with Scott Carcoal Polyether foam to verify that it performed similar to the White Polyether. The Avco 5A43 rigid foam was also tested for comparison purposes. The side was further tested against 23MM HEI air-to-air and AAA rounds to determine if the foams offered any protection against near-miss detonations within the adjacent, simulated engine air inlet.

Test Setup. The side was configured with a sumulated F-15 engine inlet having inlet air flow. A variety of fuel pressure and inlet air pressure combinations were tested to represent typical pressure differentials between the fuel tank and engine inlet under F-15 flight conditions of M .85 to 10,000 ft altitude with 0 to 6 g's normal acceleration. The side skins, bladder and backing board were the same as used on the bottom tests. The engine inlet size, skin thicknesses and materials were also the same as used in the F-15. Engine inlet air flow velocity was approximately 300 knots.

TABLE 9

Fragment Impacts Into the Bottom of Simulated F-15 Fuel Tanks

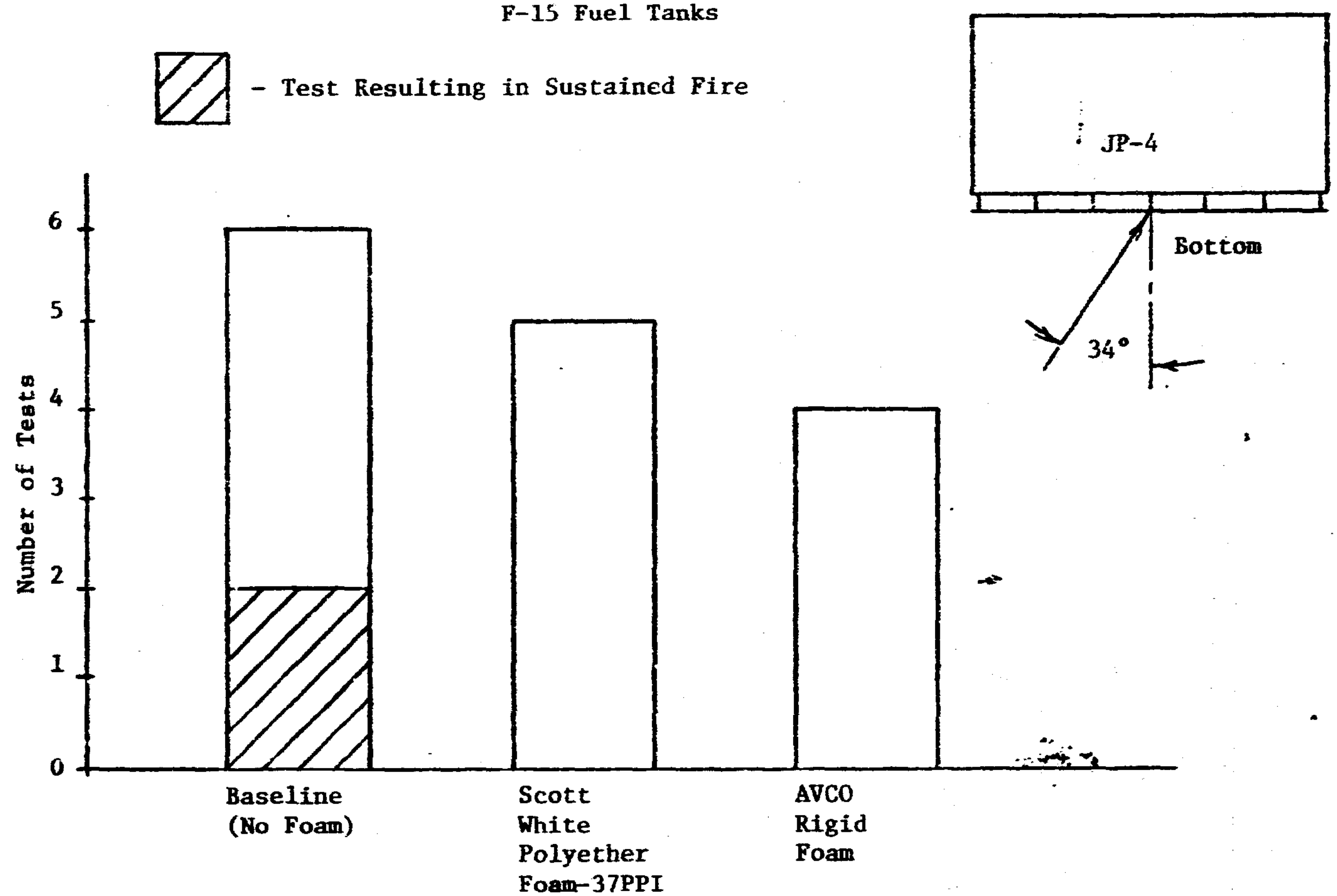
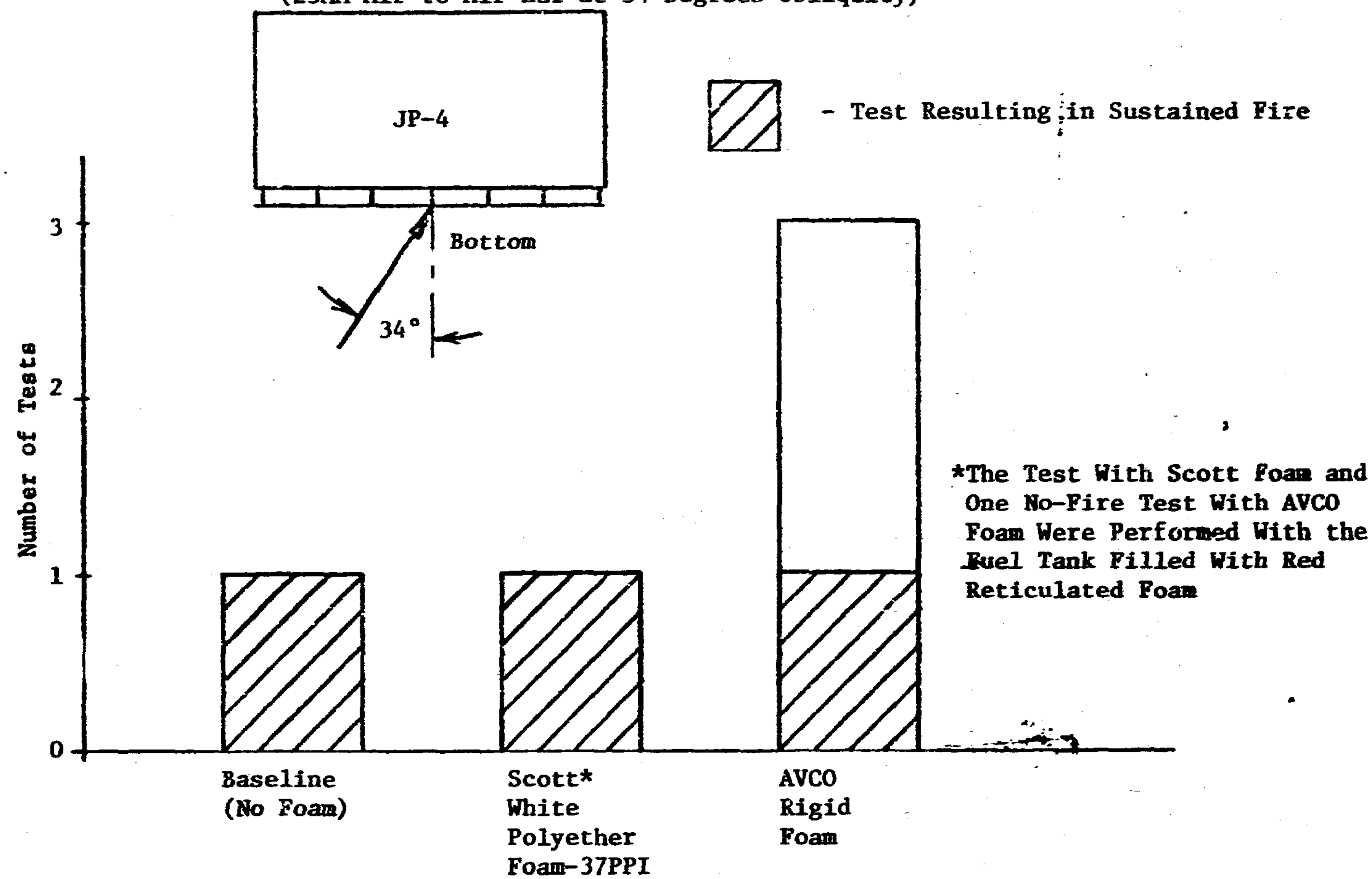


TABLE 10

HEI Impacts Into the Bottom of Simulated F-15 Fuel Tanks
(23MM Air-to-Air HEI at 34 Degrees Obliquity)



The high speed fragments and 23MM HEI rounds were fired into the side at approximately 28 degrees obliquity. The 23MM HEI AAA rounds were also fired into the bottom of the engine inlet so that the fragment spray peppered the side of the fuel tank. The 23MM HEI air-to-air rounds were equipped with the A-23 point detonating fuse and the B-23 delayed fuse. The 130 grain and 180 grain fragments were both fired in simultaneous pairs in the same manner as the top and bottom shots.

Discussion of Results. Tables 11 and 12 show the results of testing with fragments and 23MM HEI rounds respectively. Baseline testing with fragments resulted in one sustained fire and 9 flash and self-extinguishing fires out of 11 tests. These tests indicate that, with fragment impacts, the probability of sustained fire in the inlet or in the dry bay between the fuel tank and inlet is small. Because of the high probability of fire ignition (sustained and self extinguishing), a potential concern exists that the flash and self-extinguishing fires might propagate through drain holes and sustain in other locations in the actual F-15. Since these other locations were not simulated in the test fixture, no conclusions can be drawn about this possibility of an increased fire hazard. Testing with the Scott White Polyether foam resulted in no sustained fires and only one flash fire out of 10 tests. Two proof tests with the Scott Charcoal Polyether foam and three tests with the Avco rigid foam resulted in no fires. All three foams are highly effective in reducting or preventing the ignition of fires caused by fragment impacts into the side of the fuel tanks.

Baseline testing with the three types of HEI rounds demonstrated that the delayed fuse 23MM HEI air-to-air and the 23MM AAA (which also has delayed fusing) is considerably more effective in igniting sustained fires than is the point detonating 23MM air-to-air round. Of three baseline tests with the point detonating 23MM round, two self-extinguishing fires were ignited. Whereas, of three baseline tests with the delay fuse 23MM air-to-air round, two sustained fires resulted. Also, two baseline tests with the 23MM AAA resulted in one sustained fire. For the air-to-air rounds, the increase in effectiveness resulted from the difference in position of the HEI detonation caused by the difference in fusing. The point detonating round detonated on the outer skin of the engine inlet, whereas the delay fuse round detonated inside the engine inlet. The real surprise in this entire test program was the effectiveness of the Scott and Avco foams in preventing fires from the near-miss detonation of the 23MM HEI around the F-15 fuel tanks. Of the 7 tests with Scott White Polyether foam and 2 tests with Avco rigid foam, no fires were ignited.

TABLE 11

Fragment Impacts Into the Side (Engine Inlet) of Simulated F-15 Fuel Tanks (Impacts at 28 Degrees Obliquity)

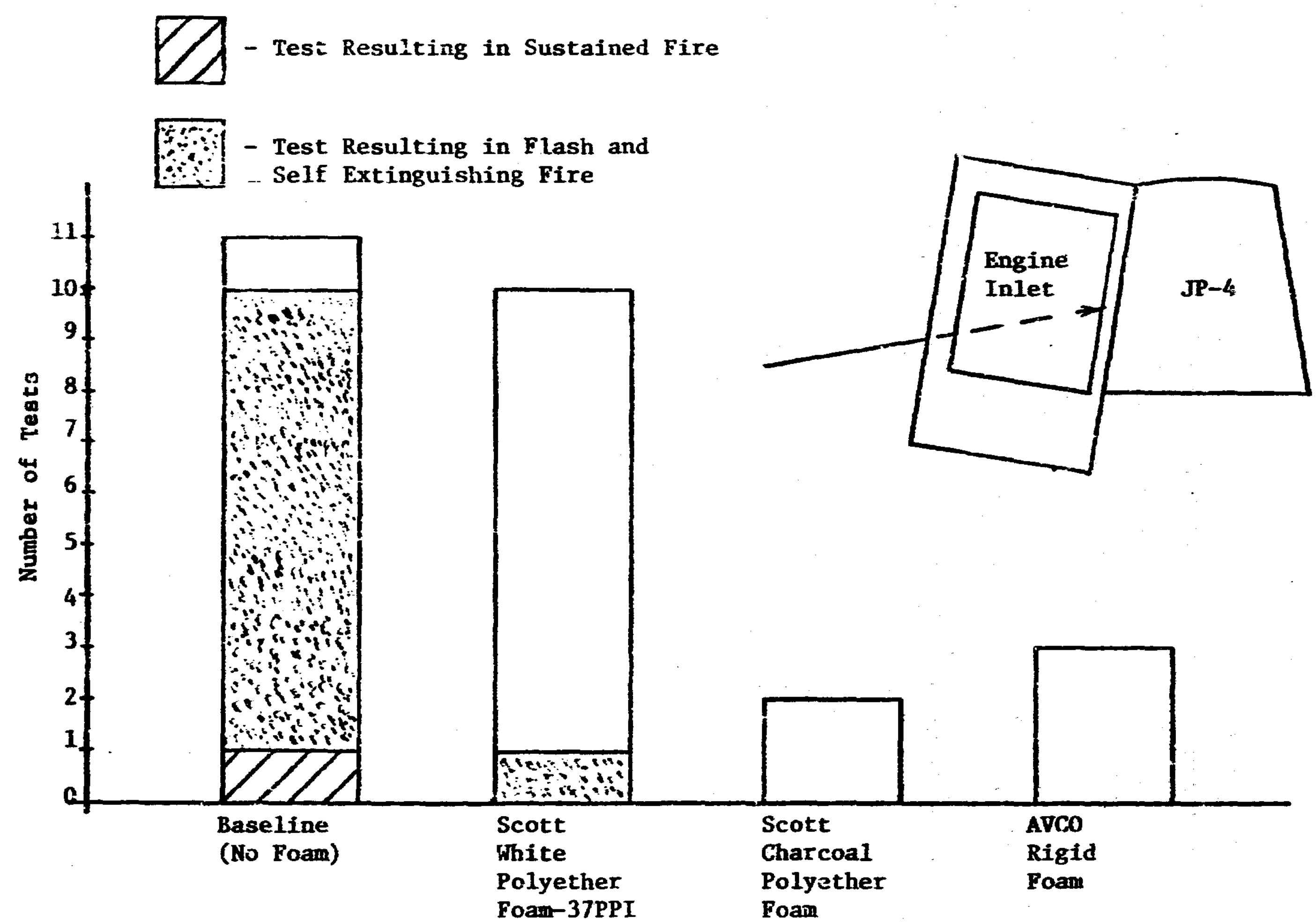
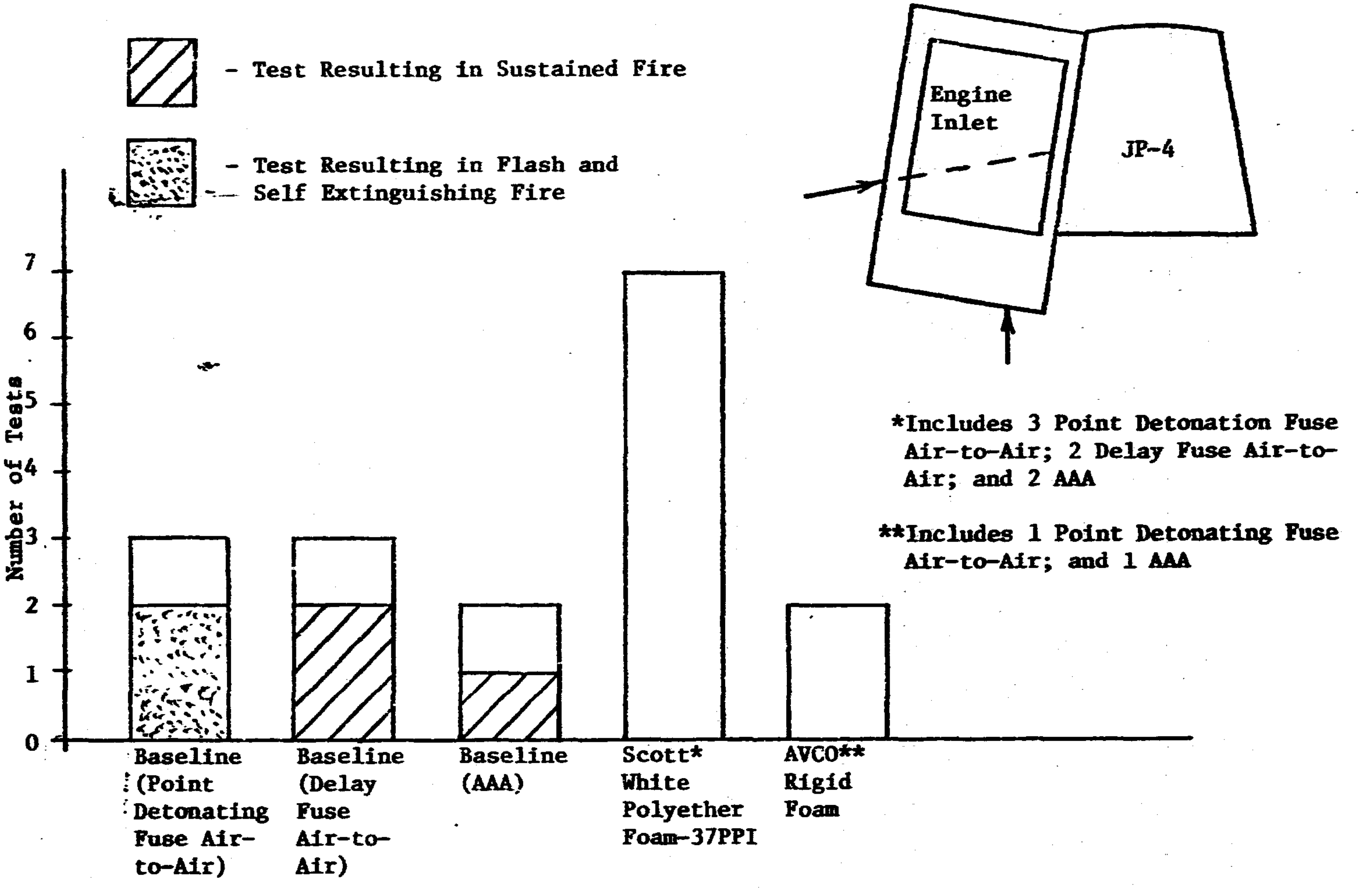


TABLE 12

HEI Impacts Into the Side (Engine Inlet) of Simulated F-15 Fuel Tanks (23MM Air-to-Air HEI and 23MM AAA HEI)



SECTION IV

AFML ENVIRONMENTAL TESTS

The tests were conducted through the facilities of the University of Dayton under contract with the Air Force Materials Laboratory (AFML). A list of candidate materials was generated by the three AF Laboratories and the F-15 SPO, and these materials were subjected to 4 types of environmental tests. These tests were: (1) fluid absorption and retention, (2) accelerated humidity aging, (3) high temperature, and (4) low temperature. As a result of the AFAPL and AFFDL gunfire tests, the Scott Polyether foams (White and Charcoal) and the Avco 5A43 rigid foam were shown to be more effective in preventing fires than the other materials. For this reason, emphasis in environmental testing was placed on these three materials. The other materials which performed poorly in either the gunfire tests or in certain environmental tests were not subjected to all the environmental tests. The environmental tests conducted on these other materials can be found in AFML-TR-73-283. In addition, the Avco 5A43 rigid foam failed to withstand the high temperature tests designed to simulate aerodynamic heating on the F-15. Therefore, the environmental tests on the Avco 5A43 foam are also presented in AFML-TR-73-283. The following tests describe the results obtained from environmental testing on only the Scott White and Charcoal Polyether foams which were found to be more effective than the other materials in both the gunfire and environmental tests.

1. FLUID ABSORPTION AND RETENTION TESTS

Test Setup. The tests consisted of submerging the materials for 48 hours at 77°F in the following fluids: (1) water, (2) JP-4, (3) MIL-L-7808 lubricating oil, and (4) MIL-H-5606 hydraulic fluid.

Discussion of Results. Tables 13 to 17 and Tables 18 to 21, respectively, show the physical measurements taken after testing both the White and Charcoal foams. With the White foam, the water immersion did not cause much change in tensile strength, but the change after testing in the other fluids was somewhat significant. Whereas with the Charcoal foam, the tensile strength stayed at acceptable levels after testing in all fluids. All the tensile strengths with the Charcoal foam were better than with the white foam under the same conditions. It was felt that some of the loss in tensile strength of the White foam would be removed if the material was allowed to remain in air for a period of time prior to tensile testing. The foam was tested in this manner and the test results are shown in Table 17. As seen in this table, there was some increase in the tensile strength using this method of test. There was considerable weight pickup with all fluids using the White foam, but this was given up by the the foam except for the lubricating oil and hydraulic fluid. The Charcoal foam, on the other hand, demonstrated considerably less weight pickup than with the White foam. In general, the White and Charcoal foams both exhibited acceptable properties in all the tests.

TABLE 13

FLEXIBLE POLYETHER POLYURETHANE FOAM (WHITE) IN WATER

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	13.7 psi
Original Elongation	275%
Original Density	1.59 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in Water	
Upon Removal	
Tensile Strength	11.6 psi
Elongation	282%
Weight Change	356.3%
Volume Change	-5.7%
Density	7.66 Pounds/Cubic Foot
1 Hour Later	
Weight Change	305.6%
Volume Change	-0.5%
Density	6.46 Pounds/Cubic Foot
24 Hours Later	
Weight Change	5.9%
Volume Change	-0.9%
Density	1.69 Pounds/Cubic Foot
30 Days Later	
Weight Change	0.2%
Volume Change	-2.0%
Density	1.61 Pounds/Cubic Foot

TABLE 14

FLEXIBLE POLYETHER POLYURETHANE FOAM
(WHITE) IN JP-4 FUEL

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
Original Density	1.58 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in JP-4	
Upon Removal	
Tensile Strength	5.1 psi
Elongation	147%
Weight Change	196.8%
Volume Change	16.0%
Density	4.04 Pounds/Cubic Foot
1 Hour Later	
Weight Change	85.3%
Volume Change	19.2%
Density	2.46 Pounds/Cubic Foot
24 Hours Later	
Weight Change	20.6%
Volume Change	15.6%
Density	1.64 Pounds/Cubic Foot
30 Days Later	
Weight Change	0.1%
Volume Change	0.0
Density	1.58 Pounds/Cubic Foot

TABLE 15

FLEXIBLE POLYETHER POLYURETHANE FOAM
(WHITE) IN MIL-L-7808 LUBIRCATING OIL

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
Original Density	1.58 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in MIL-L-7808	
Upon Removal	
Tensile Strength	6.5 psi
Elongation	122%
Weight Change	461.6%
Volume Change	11.8%
Density	7.94 Pounds/Cubic Foot
1 Hour Later	
Weight Change	348.3%
Volume Change	13.4%
Density	6.26 Pounds/Cubic Foot
24 Hours Later	
Weight Change	233.0%
Volume Change	12.3%
Density	4.69 Pounds/Cubic Foot
30 Days Later	
Weight Change	102.2%
Volume Change	11.7%
Density	2.85 Pounds/Cubic Foot

TABLE 16

FLEXIBLE POLYETHER POLYURETHANE FOAM (WHITE) IN MIL-H-5606 HYDRAULIC FLUID

Sample Dimensions: 1" x 1" x 2 "

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
Original Density	1.58 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in MIL-H-5606	
Upon Removal	
Tensile Strength	7.2 psi
Elongation	176%
Weight Change	451.6%
Volume Change	12.0%
Density	7.78 Pounds/Cubic Foot
1 Hour Later	
Weight Change	379.7%
Volume Change	10.5%
Density	6.87 Pounds/Cubic Foot
24 Hours Later	
Weight Change	262.5%
Volume Change	11.7%
Density	5.13 Pounds/Cubic Foot
30 Days Later	
Weight Change	54.3%
Volume Change	6.7%
Density	2.30 Pounds/Cubic Foot

TABLE 17

FLEXIBLE POLYETHER POLYURETHANE FOAM
(WHITE) ADDITIONAL TENSILE STRENGTH TESTS

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
After Aging 48 Hours at 77°F in Water Then 24 Hours Air Dry at 77°F	
Tensile Strength	17.0 psi
Elongation	275%
After Aging 48 Hours at 77°F in JP-4 Then 24 Hours Air Dry at 77°F	
Tensile Strength	8.1 psi
Elongation	115%
After Aging 48 Hours at 77°F in MIL-L-7808 Then 24 Hours Air Dry at 77°F	
Tensile Strength	9.1 psi
Elongation	140%
After Aging 48 Hours at 77°F in MIL-H-5606 Then 24 Hours Air Dry at 77°F	
Tensile Strength	9.0 psi
Elongation	164%

TABLE 18

FLEXIBLE POLYETHER POLYURETHANE FOAM
(CHARCOAL) IN WATER

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	17.2 psi
Original Elongation	211%
Original Density	1.50 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in Water	
Upon Removal	
Tensile Strength	16.9 psi
Elongation	199%
Weight Change	271.5%
Volume Change	-1.7%
Density	5.68 Pounds/Cubic Foot
1 Hour Later	
Weight Change	192.3%
Volume Change	0.4%
Density	4.37 Pounds/Cubic Foot
24 Hours Later	
Weight Change	0.1%
Volume Change	2.2%
Density	1.47 Pounds/Cubic Foot
30 Days Later	
Weight Change	0.2%
Volume Change	4.8%
Density	1.44 Pounds/Cubic Foot

TABLE 19

FLEXIBLE POLYETHER POLYURETHANE FOAM
(CHARCOAL) IN JP-4 FUEL

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	17.2 psi
Original Elongation	211%
Original Density	1.47 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in JP-4	
Upon Removal	
Tensile Strength	10.9 psi
Elongation	146%
Weight Change	66.4%
Volume Change	13.3%
Density	2.15 Pounds/Cubic Foot
1 Hour Later	
Weight Change	30.7%
Volume Change	16.2%
Density	1.65 Pounds/Cubic Foot
24 Hours Later	
Weight Change	7.4%
Volume Change	10.9%
Density	1.42 Pounds/Cubic Foot
30 Days Later	
Weight Change	-0.1%
Volume Change	3.8%
Density	1.41 Pounds/Cubic Foot

TABLE 20

FLEXIBLE POLYETHER POLYURETHANE FOAM (CHARCOAL) IN MIL-L-7808 LUBIRCATING OIL

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	17.2 psi
Original Elongation	211%
Original Density	1.47 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in MIL-L-7808	
Upon Removal	
Tensile Strength	8.7 psi
Elongation	116%
Weight Change	238.9%
Volume Change	7.6%
Density	4.64 Pounds/Cubic Foot
1 Hour Later	
Weight Change	193.5%
Volume Change	8.4%
Density	3.99 Pounds/Cubic Foot
24 Hours Later	
Weight Change	93.8%
Volume Change	13.0%
Density	2.53 Pounds/Cubic Foot
30 Days Later	
Weight Change	53.9%
Volume Change	14.2%
Density	1.98 Pounds/Cubic Foot

TABLE 21

FLEXIBLE POLYETHER POLYURETHANE FOAM
(CHARCOAL) IN MIL-H-5606 HYDRAULIC FLUID

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	17.2 psi
Original Elongation	211%
Original Density	1.48 Pounds/Cubic Foot
After Aging 48 Hours at 77°F in MIL-H-5606	
Upon Removal	
Tensile Strength	9.8 psi
Elongation	116%
Weight Change	150.6%
Volume Change	7.5%
Density	3.45 Pounds/Cubic Foot
1 Hour Later	
Weight Change	135.1%
Volume Change	9.0%
Density	3.19 Pounds/Cubic Foot
24 Hours Later	
Weight Change	70.5%
Volume Change	10.9%
Density	2.27 Pounds/Cubic Foot
30 Days Later	
Weight Change	12.1%
Volume Change	3.3%
Density	1.60 Pounds/Cubic Foot

To test the affects of higher fluid temperatures on the absorption and retention properties of the foams, similar tests were run using JP-4, MIL-L-7808, and MIL-H-5606 at 140°F for 168 hours. The results of these tests are shown in Tables 22 and 23 respectively for the White and Charcoal foams. Neither foam was affected any more in this test than it had been by the previous testing at 77°F. Results for the Charcoal foam were slightly better than those obtained for the White foam.

2. ACCELERATED HUMIDITY AGING TESTS

Test Setup. Samples of the foams were placed in a humidity chamber at 160°F and 95% relative humidity (R.H.). One set of the samples was removed at 30, 60, 120, and 180 day intervals and the following properties were tested: (1) Tensile strength, (2) Elongation, (3) Weight change, (4) Volume change, and (5) Density. A second set of the samples was removed at the same intervals, allowed to stand at 77°F and 50% R.H., and then the following properties were tested: (1) Weight change, (2) Volume change, and (3) Density.

Discussion of Results. The test results after humidity aging the White and Charcoal foams are shown in Tables 24 and 25 respectively. For the White foam, the tensile strength stayed at an acceptable level even through 180 days in the humidity chamber. For the Charcoal foam, the tensile strength determinations at 30 and 60 days was inadvertently missed; however, a tensile strength determination was made after 120 days at 160°F and 95% R.H., and the Charcoal appears to be about equal to the White foam. It had been claimed that the polyether foam would badly degrade if it was exposed to fuel and then subjected to humidity. A test was conducted to see if this was true, and the results are given in Table 26. In this test, the tensile specimens were soaked in JP-4 for 7 days at 77°F. Some of these specimens were then tested upon removal and the tensile strength was 7.7 psi. The rest of the specimens were exposed to 160°F and 95% R.H. for 30 days. These specimens had a tensile strength of 12.7 psi which is the same as was obtained on samples exposed to the humidity chamber for 30 days without any fuel aging. It was therefore concluded that the polyether foam if previously wetted with fuel was not severely degraded in humidity. The weight increase on both foams was not high. There was slightly more weight pickup with the Charcoal foam than with the White, but the amount was not significantly greater.

3. HIGH TEMPERATURE TESTS

Test Setup. These tests were set up to simulate aerodynamic heating temperature effects on the foams for the cumulative expected F-15 exposure over a ten year period. The temperatures and corresponding time periods of exposure for the tests are shown in Table 27.

TABLE 22

FLEXIBLE POLYETHER POLYURETHANE FOAM
(WHITE), HIGHER TEMPERATURE FLUID AGING

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
After Aging 168 Hours at 140°F and 24 Hours Cooling in JP-4	
Original Density	1.61 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	6.7 psi
Elongation	102%
Weight Change	98.7%
Volume Change	22.4%
Density	2.61 Pounds/Cubic Foot
30 Days Later	
Weight Change	1.0%
Volume Change	0.9%
Density	1.61 Pounds/Cubic Foot
After Aging 168 Hours at 140°F and 24 Hours Cooling in MIL-L-7808	
Original Density	1.66 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	8.5 psi
Elongation	115%
Weight Change	235.2%
Volume Change	15.7%
Density	4.82 Pounds/Cubic Foot
30 Days Later	
Weight Change	74.2%
Volume Change	22.0%
Density	2.38 Pounds/Cubic Foot

(CON'T)

After Aging 168 Hours at 140°F and 24 Hours Cooling in MIL-H-5606

Original Density	1.66 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	7.2 psi
Elongation	120%
Weight Change	145.4%
Volume Change	11.6%
Density	4.82 Pounds/Cubic Foot
30 Days Later	
Weight Change	15.5%
Volume Change	7.8%
Density	1.76 Pounds/Cubic Foot

TABLE 23

FLEXIBLE POLYETHER POLYURETHANE FOAM
(CHARCOAL) HIGHER TEMPERATURE FLUID AGING

Sample Dimensions: 1" x 1" x 2"

	TEST RESULTS
Original Tensile Strength	17.2 psi
Original Elongation	211%
After Aging 168 Hours at 140°F and 24 Hours Cooling in JP-4	
Original Density	1.65 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	10.8 psi
Elongation	105%
Weight Change	43.4%
Volume Change	16.3%
Density	1.81 Pounds/Cubic Foot
30 Days Later	
Weight Change	-0.7%
Volume Change	-3.4%
Density	1.51 Pounds/Cubic Foot
After Aging 168 Hours at 140°F and 24 Hours Cooling in MIL-L-7808	
Original Density	1.46 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	11.0 psi
Elongation	114%
Weight Change	207.7%
Volume Change	6.3%
Density	4.23 Pounds/Cubic Foot
30 Days Later	
Weight Change	41.7%
Volume Change	8.1%
Density	1.92 Pounds/Cubic Foot

(CON'T)

After Aging 168 Hours at 140°F and 24 Hours Cooling in MIL-H-5606

Original Density	1.48 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	8.9 psi
Elongation	153%
Weight Change	147.5%
Volume Change	8.5%
Density	3.36 Pounds/Cubic Foot
30 Days Later	
Weight Change	12.2%
Volume Change	-1.2%
Density	1.68 Pounds/Cubic Foot

TABLE 24

FLEXIBLE POLYETHER POLYURETHANE FOAM
(WHITE) IN HUMIDITY

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
After Aging 30 Days at 160°F and 95% Relative Humidity	
Original Density	1.60 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	13.5 psi
Elongation	252%
Weight Change	30.7%
Volume Change	5.1%
Density	1.99 Pounds/Cubic Foot
30 Days Later	
Weight Change	-0.4%
Volume Change	2.5%
Density	1.56 Pounds/Cubic Foot
After Aging 60 Days at 160°F and 95 Relative Humidity	
Original Density	1.59 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	10.0 psi
Elongation	210%
Weight Change	51.1%
Volume Change	1.3%
Density	2.37 Pounds/Cubic Foot
30 Days Later	
Weight Change	-0.8%
Volume Change	-0.7%
Density	1.59 Pounds/Cubic Foot

(CON'T)

After Aging 120 Days at 160°F and 95 Relative Humidity

Upon Removal

Tensile Strength	8.1 psi
Elongation	216%

After Aging 180 Days at 160°F and 95% Relative Humidity

Upon Removal

Tensile Strength	7.6 psi
Elongation	179%

TABLE 25

FLEXIBLE POLYETHER POLYURETHANE FOAM
(CHARCOAL) IN HUMIDITY

	TEST RESULTS
Original Tensile Strength	17.2 psi
Original Elongation	211%
After Aging 30 Days at 160°F and 95% Relative Humidity	
Original Density	1.59 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	18.9 psi
Elongation	153%
Weight Change	36.8%
Volume Change	9.9%
Density	1.98 Pounds/Cubic Foot
30 Days Later	
Weight Change	0.0%
Volume Change	7.9%
Density	1.48 Pounds/Cubic Foot
After Aging 60 Days at 160°F and 95% Relative Humidity	
Original Density	1.60 Pounds/Cubic Foot
Upon Removal	
Tensile Strength	
Elongation	
Weight Change	65.4%
Volume Change	7.3%
Density	2.46 Pounds/Cubic Foot
30 Days Later	
Weight Change	-0.3%
Volume Change	6.3%
Density	1.50 Pounds/Cubic Foot

(CON'T)

After Aging 108 Days at 160°F and 95% Relative Humidity

Tensile Strength	10.9 psi
Elongation	156%

After Aging 120 Days at 160°F and 95% Relative Humidity

Upon Removal

Tensile Strength	8.3 psi
Elongation	148%

TABLE 26

FLEXIBLE POLYETHER POLYURETHANE FOAM (WHITE), COMBINED FUEL AND HUMIDITY AGING

	TEST RESULTS
Original Tensile Strength	15.7 psi
Original Elongation	275%
After Aging 7 Days at 77°F in JP-4	
Tensile Strength	7.7 psi
Elongation	134%
After Aging 7 Days at 77°F in JP-4, Then 30 Days at 160°F and 95% R.H.	
Tensile Strength	12.7 psi
Elongation	231%
After Aging at 160°F and 95% R.H.	
For 30 Days	
Tensile Strength	13.5 psi
Elongation	252%
For 60 Days	
Tensile Strength	10.0 psi
Elongation	210%

TABLE 27

HEAT CYCLING FROM AERODYNAMIC HEATING
OF FLEXIBLE POLYETHER POLYURETHANE FOAMS
(WHITE AND CHARCOAL)

TEST - 40 Cycles at (A) 420°F for 10 min.

(B) 350°F for 70 min.

(C) Cooling Period to Room Temperature

Discussion of Results. Both the White and Charcoal foams performed quite well and maintained flexibility. Discoloration was the only visible change noted.

4. LOW TEMPERATURE TESTS

Test Setup. The test consisted of bending foam samples over a mandrel at -65°F.

Discussion of Results. Both the White and the Charcoal foams performed quite well with no cracking or breaking.

SECTION V

SUMMARY OF RESULTS

In the AFAPL gunfire tests, the overall baseline probability of fire against high speed fragments and 50 API projectiles was 74 percent (48 fires from 65 tests). Of the eight types of void filler materials tested, the Scott White Polyether was found to be the most effective and most promising material for preventing fires. Proof testing with the Scott Charcoal Polyether foam demonstrated similar results as those obtained with the White foam. Using the Scott White Polyether in tests similar to the baseline tests resulted in an overall probability of fire of 4 percent (2 fires from 46 tests). Of these tests, 20 tests were against high speed fragments and resulted in no fires, or an overall probability of fire of zero percent. Against the high speed fragments, the Scott White Polyether foam was completely effective in preventing fires. Also, both Scott flexible, open-pore foams were found to be highly effective in preventing or reducing the flow of fuel outside the dry bay through the entrance wound. This significantly reduced the intensity of those fires which did ignite. In addition, it was found that compression of the flexible foams (i.e., 5-10%) improved the effectiveness in preventing fires and reduced fuel flow out of the entrance wound.

In the AFFDL gunfire tests into the top of simulated F-15 fuel tanks, it appeared that the top of the tanks had very low vulnerability to damaging fires from high speed fragment impacts. All fires that did ignite on the top tended to self extinguish with no structural damage. Therefore, it is unnecessary to install void filler foam over the top of F-15 fuselage fuel tanks to protect against fragment threats. Also, it was found that the Scott White foam offered little if any protection for the top of the fuel tanks against direct hits by the 23MM air-to-air HEI round. The 23MM detonation destroyed the foam and its fire protection features. In summary, the Scott foam should not be installed on the top of F-15 fuselage fuel tanks. On the other hand, the AFFDL tests into the side and bottom of simulated F-15 fuel tanks yielded results similar to those obtained in the AFAPL tests. Specifically, the Scott White and Charcoal foams are highly effective in preventing fires from high speed fragment impacts into the side and bottom. In addition, it was found that the Scott foams are completely effective in preventing fires from the near-miss detonation of 23MM air-to-air and AAA HEI rounds around aircraft fuel tanks.

In the AFML tests, the Scott White and Charcoal foams were subjected to fluid absorption and retention, accelerated humidity aging, high temperature and low temperature tests, representing a range of environmental conditions which could be expected in the F-15. The Scott foams performed extremely well in all tests, and would therefore be suitable for permanent installation in the F-15, with no detrimental effect on F-15 performance, maintainability, reliability, or safety.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

The Scott White and Charcoal Polyether foams are both highly effective as void filler materials in preventing fires in the dry bays surrounding the sides and bottom of F-15 fuselage fuel tanks when these tanks are impacted by missile warhead fragments, 50 API projectiles and near-miss detonations of 23MM HEI rounds. In addition, these foams are environmentally suitable for permanent installation in the F-15.

Based on the highly successful results from gunfire and environmental testing, the Scott Polyether foams should be considered for possible application to all combat aircraft which have requirements for fire protection of fuel tanks against enemy threat projectiles and warhead fragments.