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INVESTIGATION OF THE FLAMMABILITY PROPERTIES OF HYDRAULIC FLUIDS

FINAL REPORT
AFLRL No. 70

by

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Experimental results are presented that indicate MIL-H-6083 (inhibited version of MIL-H-5606) could be more of a flammability hazard than some of the more recently developed fire-resistant hydraulic fluids in ground equipment vehicles. Routine laboratory experiments, as well as those designed to define mist flammability and impact dispersion, are described and the relevancy of the results obtained is discussed. Indications are that a more fire-resistant fluid could be developed to substantially reduce the fire-hazard vulnerability of ground combat vehicles.

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FOREWORD

This research program has been conducted under DoD Contract No. DAAK02-73-C-0221. The work was administered by the Fuels, Lubricants and Coatings Division (formerly Coatings and Chemicals Laboratory), Petroleum and Materials Department, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, with Mr. F.W. Schaekel serving as Contracting Officers' Technical Representative.

Acknowledgment is given to Mr. S.J. Lestz for coordinating and physically characterizing most of the fluid samples and maintaining liaison with field applications of such fluids; to Mr. D.C. Babcock for producing the photographs used in this report; and to Messrs. J.P. Pierce and J.A. Kachich, who performed the cited experiments. Acknowledgment is also given to Messrs. R.D. Quillian, Jr., J.T. Gray, and H.M. Ammlung for their encouragement and suggestions.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Investigations since the Arab-Israeli war have indicated a potentially serious problem arising from the use of the petroleum-based MIL-H-6083 hydraulic fluid in the U.S. battle tank, the M-60A1. The tank turret and gun control hydraulic systems seem especially vulnerable, and hostile gunfire penetration of the pressurized system is believed to have caused a flammable aerosol mist to form. This situation has led the U.S. Army to take a serious look and to recommend an immediate solution. Thus, an evaluation program was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) to define specific flammability properties and perform experiments to evaluate these properties of fluids that could possibly be considered as a suitable replacement to alleviate this hazardous situation. It is emphasized that this "stopgap" effort need not affect the long-range research program initiated in recent years to find a permanent replacement for MIL-H-6083.

BACKGROUND

Research for the last 25 years has been directed by USAF and USN at either making the MIL-H-5606 aircraft hydraulic fluid fire resistant or finding a suitable replacement that would meet the performance qualifications of this relatively inexpensive hydraulic fluid. Incidentally, MIL-H-6083 is essentially a MIL-H-5606 with the addition of a rust preventative to provide corrosion protection during intermittent use.

The U.S. Air Force began research in the mid-60's to develop a "fire-safe" hydraulic fluid, and its efforts produced a candidate designated as MIL-H-83282. This fluid comprises synthesized alpha olefin polymer molecules (subsequently hydrogenated) along with other ingredients. A more recent version of this fluid has rust inhibitor added to afford the corrosion protection required by the Army. Formulated fluids meeting this latter requirement were qualified under Frankford Arsenal Purchase Description 5136. This purchase description has been superseded by MIL-H-46170 "Fire-Resistant Hydraulic Fluid" (FRH).

The Navy, likewise, has directed research toward development of a "fire-safe" hydraulic fluid, and in the early 70's, developed a candidate fire-resistant hydraulic fluid based on organopolysiloxane (a silicone fluid). The silicones are known to be fire resistant, but the mechanical performance and lubricity of these fluids are also known to be poor. The candidate fluid developed by the Navy, designated NADRAUL MS-5, incorporated antiwear and rubber-swell additives and was proposed as a suitable replacement for MIL-H-5606. It reportedly contains approximately 89 percent chlorophenyl methylsilicone with the remainder comprising essentially antiwear and seal-swell additives.

APPROACH

Flammability studies conducted at AFLRL had been primarily in the area of diesel and turbine fuel fire safety. It was felt, however, that many of the same techniques developed to evaluate those fuels could be utilized to determine relative flammability differences between candidate hydraulic fluids. It should be noted here that the evaluations reported herein are concerned entirely with fluid flammability, and the problems associated with performance are not in this report.

In order to establish some reference background data, several typical MIL-H-5606 fluids, as well as the rust-inhibited version, MIL-H-6083, were obtained. These fluids are essentially light hydrocarbons with a flash point of approximately 120°C. The fluids were obtained from a current QPL and are available in the supply system. Another series of fluids was also evaluated, these being the alpha-olefin fluids, MIL-H-83282, which have been under development for several years by the Air Force and have been reported to have superior fire-safety characteristics.

Samples of the "fire-safe" fluid, MS-5, developed by the Navy and a commercial aryl phosphate ester fluid, used by many U.S. commercial airlines, were also included in this series of evaluations. While reviewing the chemical and physical properties that a good hydraulic fluid should have, it became evident that a family of synthetic engine oils, already in the supply system, could perhaps be used. These fluids, which use synthesized hydrocarbon or ester-base stock materials, would meet (or could be expected to meet, in some cases) the new arctic engine and transmission oil requirement, MIL-L-46167. A more complete compilation of the physical and chemical properties of these military engine oils has been reported by Hopler and Lestz.(1)* These fluids exhibit not only good physical and chemical properties, but also appear to have good flammability ratings with more than 95°C (apx) gain in flash point over the conventional MIL-L-6083 fluid. Therefore, this new series of fluids has provided additional potential candidates to fulfill the additional fire-safety requirement, thus possibly eliminating the need for introducing a new product into the supply system.

EXPERIMENTAL

While it is understood that the flash point of a material is not a direct indication of its fire-safety properties, some general benefit should be gained by a nominal 95°C higher flash point. Therefore, the flash points of these different fluids were measured using the Cleveland Open Cup D-92 Method. Another evaluation that was made was the fire resistance of mist that could be formed by a ruptured hydraulic fluid line. This simulation was accomplished by using the mist-flashback apparatus, which was developed and refined as part of the Army's modified helicopter fuel program. The apparatus and procedure are described in Appendix A and in more detail in AFLRL Interim Report No. 25, dated December 1973 (DDC No. AD 776965).

In brief, the apparatus and procedure can best be described as a hydraulic motor-driven capillary syringe with air streams impinging on the sample jet to effect misting. This fuel mist passes through a gas flame sheet which acts as the ignition source. The flammability of the sample is assessed by the extent of flashback from the ignition source toward the capillary nozzle. This flammability rating (flashback distance) has proved to be a very accurate, reliable tool to assess fuel mist-flammability characteristics.

Another evaluation that was performed on these candidate samples was the impact dispersion test. Basically, this test utilized a 2-liter sample in a glass container that is dropped from 6 meters onto a steel target plate (imbedded in concrete). The target plate has an open-flame ignition source. This ignition source is a 70 X 96-cm rectangle made of 1.25-cm pipe with gas jet holes drilled on two sides. The gas-air mixture is controlled by a

*Superscript numbers in parentheses refer to the List of References at the end of this report.

venturi valve similar to those used in domestic furnaces. This test simulates shearing effects that a fluid could be subjected to in event of extreme fuel tank damage (or hydraulic fluid line rupture). A more detailed description is given in Appendix B.

The mist flashback apparatus was developed at AFLRL to assess a fuel's mist flammability; therefore, the results obtained were peculiar to that specific system. In order to compare hydraulic fluid results obtained with the mist flashback apparatus with experiments conducted in other laboratories, a standard test was desirable for cross comparison. Therefore, the high-temperature/high-pressure spray ignition procedure (Federal Standard No. 791B Method 6052) was selected. This procedure was designed to simulate the rupture of a hydraulic fluid line under pressure with the formation of a spray that could be very flammable. Since a direct comparison was desired, an exact duplicate of the apparatus was fabricated. Thus, results obtained could be compared to those obtained in other laboratories as well as with the mist-flashback and impact-dispersion techniques developed in this laboratory.

The autoignition temperatures of some of the fluid samples were measured using an apparatus constructed in this laboratory. This procedure is an adaptation of the ASTM D2155 procedure and utilizes a 90-cc aerosol reaction vessel and a microsyringe for sample injection. Sample size variation is according to D2155 with the exception that when the minimum AIT is reached, at least ten repetitions on a "go or no go" basis are accomplished. These results are evaluated utilizing the "up and down" method which allows a more precise statistical evaluation of the results.[2]

DISCUSSION

From past experience on the modified fuel program, low mist-flashback ratings indicate a less flammable fuel (in a misting situation). This same principle applies to the hydraulic fluids; however, the numerical rating assessed the modified fuels may not apply at exactly the same level. Therefore, the entire series had to be run before comparative evaluations could be made. A screening process, combining the results of the mist flashback, impact dispersion and high-pressure spray ignition tests, correlates well with the experience of other laboratories.

Table 1 lists the fluids that were evaluated in this program. Tables 2, 3, and 4 illustrate the results of these three separate evaluations, and one can readily see the correlation obtained between them, although the high-pressure spray ignition test is far less definitive than the other two.

Incidentally, Table 5 is a compilation of flammability data obtained by U.S. Army Ballistics Research Laboratories (BRL)[3,4] using both incendiary and open flame ignition sources on fluids sprayed through the "BRL" nozzle. The table presents data on some of the same samples that were analyzed in the AFLRL program and is included for cross comparison. There was an apparent discrepancy in that in some cases (every case with MIL-H-6083) there was a self-sustaining flame after the ignition source was removed. This was a direct reflection of the type of nozzle that generated the mist. As mentioned previously, the "BRL nozzle" was an oil burner nozzle that injected a 90-deg cone, thus forming a much more flammable mist. Other BRL data show that with the standard nozzle used in the Test

TABLE 1. HYDRAULIC FLUID SAMPLES STUDIED

Sample No.	Sample Designation	Fluid Description
1	MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft Missile & Ordnance (OHA)
2		Hydraulic Fluid, Petroleum Base, Aircraft Missile & Ordnance (OHA)
3		Hydraulic Fluid, Petroleum Base, Aircraft Missile & Ordnance (OHA)
4	MIL-H-6083	Hydraulic Fluid, Petroleum Base, For Preservation & Operation (OHT)
5	MIL-H-83282	Hydraulic Fluid, Synthetic Hydrocarbon Base, Aircraft
6	FA-PD-5136[a]	Sample 5 modified by addition of 2.5% wt rust inhibitor
7	MIL-H-83282	Hydraulic Fluid, Synthetic Hydrocarbon Base, Aircraft
8	FA-PD-5136[a]	Sample 6 modified by addition of 2.5% wt rust inhibitor
9	—	98% vol Sample 8 + 2% vol Sample 4
10	—	95% vol Sample 8 + 5% vol Sample 4
11	—	90% vol Sample 8 + 10% vol Sample 4
12	—	80% vol Sample 8 + 20% vol Sample 4
13	—	70% vol Sample 8 + 30% vol Sample 4
14	FA-PD-5136	Hydraulic Fluid, Rust Inhibited, Fire-Resistant, Synthetic Hydrocarbon
15	FA-PD-5136	Hydraulic Fluid, Rust Inhibited, Fire-Resistant, Synthetic Hydrocarbon
16	FA-PD-5136	Hydraulic Fluid, Rust Inhibited, Fire-Resistant, Synthetic Hydrocarbon
17	"MS-5"	NADRAUL Silicone Fluid
18	—	Experimental Silicone Fluid A
19	—	Experimental Silicone Fluid B
20	—	Commercial High-Density Phosphate Ester
21	MIL-L-2104C	Lubricating Oil, Internal Combustion Engine, Tactical Service (OE/HDO-10)
22	MIL-L-10295A[b]	Lubricating Oil, Internal Combustion Engine, Sub-Zero (OES)
23	APG-PD-1	Lubricating Oil, Internal Combustion Engine, Sub-Zero
24	MIL-L-46167[a]	Lubricating Oil, Internal Combustion Engine, Arctic (OEA)
25	MIL-L-46152	Lubricating Oil, Internal Combustion Engine, Admin Service, 10W-30
26	MIL-L-46167[a]	Lubricating Oil, Internal Combustion Engine, Arctic (OEA)
27	APG-PD-1	Lubricating Oil, Internal Combustion Engine, Sub-Zero
28	MIL-L-46152	Lubricating Oil, Internal Combustion Engine, Admin Service, 10W-30

[a]Candidate formulation not yet qualified.
[b]MIL-L-10295A was superseded with issuance of MIL-L-46167.

Method 6052, there were no sustained fires in 288 experiments using both MIL-H-6083 and MIL-H-83282, thus agreeing with the results obtained at AFLRL. It may be of interest to mention that the only fluid that was evaluated that did give sustained fires in the Test Method 6052 was a turbine fuel with a flash point of around 52°C.

The MIL-H-83282 fluids that were evaluated did show an increase in fire safety over the MIL-H-5606 fluids that were analyzed at the same time. Also, an additional improvement was determined for the inhibited version of the MIL-H-83282 fluid, thereby showing some beneficial synergistic effects by adding the 2.5 percent wt barium dinonylnapthalene sulfonate to serve as a rust inhibitor. The results of all evaluations are compiled in Table 2 and indicate that the rust inhibitor causes a reduction, not only in the mist flammability, but also in the resistance to mist formation during impact dispersion. For basic background data, three different samples of MIL-H-5606 fluid and one sample of MIL-H-6083 fluid were obtained from different vendors listed in the QPL. Very little differences were determined among the samples, and the flammabilities were all greater than the MIL-H-83282 fluid. As shown in Table 6, there is an increase of approximately 120°C in the flash point of MIL-H-83282 fluids relative to MIL-H-6083 fluids.

Another aspect given consideration was the fire-safe quality remaining in a hydraulic fluid (MIL-H-83282) during the first changeover period where carryover contamination with low percentages of MIL-H-6083 was possible. Therefore, dilution of MIL-H-83282 fluid with various concentrations of MIL-H-6083 fluid up to 30 percent (vol) was evaluated using the impact dispersion procedure. As indicated in Table 2, the break point is somewhere between 5 to 10 percent before the MIL-H-83282 hydraulic fluid loses its fire-safe quality. However, it is felt that with reasonable care, the remaining level of MIL-H-6083 fluid will be below 5 percent after flushing with MIL-H-83282 fluid during initial changeover.

The first of the fire-safe hydraulic fluids that are intended to meet the MIL-H-46170 (inhibited version of MIL-H-83282) specifications were received (under FA-PD-5136) and evaluated using the impact dispersion procedure (Table 2). These three fluids all received a "B" rating and appeared similar to those evaluated in the initial phase of the program.

Table 3 illustrates the fire-safe quality of another series of fluids, these being primarily synthetic. The first fluid was a silicone fluid, developed by the Navy (designated MS-5). This fluid had excellent flammability properties as indicated by both the mist flashback and impact dispersion evaluations. Although there are other considerations such as viscosity, this fluid could possibly become an acceptable replacement for MIL-H-5606 or MIL-H-6083 fluids. This fluid, incidentally, gave very good results on the high-pressure spray apparatus.

The two samples of silicone fluid received from one supplier were evaluated and, as indicated in Table 3, received "B" and "C" impact dispersion test ratings. They also received 1.0 and 2.8 mean in., respectively, mist flashback ratings which also indicate a difference in degree of mist flammability. The high-pressure spray ratings were similar for both of these samples.

A commercial phosphate ester hydraulic fluid, used by some airlines, rated as well as or better than the inhibited version of MIL-H-83282 (Table 2). Incidentally, the mist flashback test could not be used since the reference grid was obscured by smoke produced in the test procedure. This is not a normal response, and this hydraulic fluid is the only sample that has ever given this type of results. This sample did, however, rate the best on the high-pressure spray apparatus.

Table 4 summarizes the flammability data on the arctic engine oils evaluated in this program. The purpose of this phase of the study was to examine the possibility of utilizing fluids already in the system as fire-safe replacements for MIL-H-6083. These same fluids were used in the AFLRL hydraulic and power transmission fluid (HPTF) evaluation program[1], and results were generally encouraging. The mist flashback results ranged from 1 to 2 in., and the impact dispersion ratings were mostly "A" ratings (no pilot flame enlargement); some of these fluids were synthetic base stock, others were synthesized hydrocarbon base stock, and some were mixtures of the two. The only other fluid that had equally good fire-safety characteristics was the silicone fluid, MS-5.

TABLE 2. SUMMARY OF FLAMMABILITY DATA OF HYDRAULIC FLUIDS

Sample No.	Fluid Designation or Description	Mist Flammability, Mean In. Flashback	Impact Dispersion Flammability Rating[a]	High-Pressure Spray Ignition Rating[b]
1	MIL-H-5606	3.0	C	–
2	MIL-H-5606	3.5	C	–
3	MIL-H-5606	2.8	C	–
4	MIL-H-6083	4.1	C	I
5	MIL-H-83282	2.3	B	–
6	FA-PD-5136[c]	2.0	A	–
7	MIL-H-83282	2.8	B	I
8	FA-PD-5136[c]	2.8	d	I
9	98% Sample 8, 2% Sample 4	d	B	d
10	95% Sample 8, 5% Sample 4	d	B	d
11	90% Sample 8, 10% Sample 4	3.2	C	d
12	80% Sample 8, 20% Sample 4	d	C	d
13	70% Sample 8, 30% Sample 4	d	C	d
14	FA-PD-5136	d	B	d
15	FA-PD-5136	2.7	B	I
16	FA-PD-5136	d	B	d
20	Commercial High-Density Phosphate Ester	e	B	III

[a]A. No pilot flame enlargement.
B. Pilot flame dimensions less than doubled.
C. Pilot flame dimensions more than doubled.
D. Pilot flames totally obscured by transient mist fireball.
E. Coalesced fireball with simultaneous pool burning.
[b]Federal standard 791B, Method 6052.
I. Ignition at pilot–flame self-extinguishing.
II. Ignition at pilot–pulsating flame.
III. No ignition at pilot.
[c]Candidate fluid not yet qualified.
[d]Insufficient sample.
[e]Too much smoke to obtain rating.

TABLE 3. SUMMARY OF FLAMMABILITY DATA OF EXPERIMENTAL SYNTHETIC FLUIDS

Sample No.	Fluid Designation or Description	Mist Flammability, Mean In. Flashback	Impact Dispersion Flammability Rating[a]	High-Pressure Spray Ignition Rating[b]
17	MS-5	1.3	A	II
18	Experimental Silicone Fluid A	1.0	B	I
19	Experimental Silicone Fluid B	2.8	C	I

[a]A. No pilot flame enlargement.
B. Pilot flame dimensions less than doubled.
C. Pilot flame dimensions more than doubled.
D. Pilot flames totally obscured by transient mist fireball.
E. Coalesced fireball with simultaneous pool burning.
[b]Federal Standard 791B, Method 6052.
I. Ignition at pilot–flame self-extinguishing.
II. Ignition at pilot–pulsating flame.
III. No ignition at pilot.

TABLE 4. SUMMARY OF FLAMMABILITY DATA
OF ARCTIC ENGINE OILS

Sample No.	Fluid Designation or Description	Mist Flammability, Mean In. Flashback	Impact Dispersion Flammability Rating[a]	High-Pressure Spray Ignition Rating[b]
21	MIL-L-2104	1.8	A	—
22	MIL-L-10295A	2.7	B	—
23	MIL-L-46167	1.3	A	I
24	MIL-L-46167	1.3	A	—
25	MIL-L-46152	2.0	B	I
26	MIL-L-46167	1.5	A	I
27	MIL-L-46167	1.7	A	—
28	MIL-L-46152	1.3	A	III

[a]A. No pilot flame enlargement.
B. Pilot flame dimensions less than doubled.
C. Pilot flame dimensions more than doubled.
D. Pilot flames totally obscured by transient mist fireball.
E. Coalesced fireball with simultaneous pool burning.
[b]Federal Standard 791B, Method 6052
I. Ignition at pilot–flame **self-extinguishing.**
II. **Ignition at pilot–pulsating flame.**
III. No ignition at pilot.

TABLE 5. PRELIMINARY BRL HYDRAULIC FLUID FLAMMABILITY DATA[a]

Category	MIL-H-5606 OHA	MIL-H-6083 OHT	MIL-H-83282	MIL-H-83282	MS-5	APG PD-1
Sustained Fires[b]	8	23	13	31	11	7
Total Shots,	10	23	18	104	109	56
%	80	100	72	30	10	13
Non-Sustained Fires[c]	None	None	4	73	—	5
Total Shots,	—	—	18	104	—	56
%	—	—	22	70	—	9
Median Duration of Non-Sustained Fires	None	None	8.0 Sec	3.5 Sec	0.6 Sec	2.0 Sec

[a]Vulnerability assessments performed using either a 30-cal M-14 API Projectile or an open-flame pilot in the mist produced from the BRL nozzle.
[b]Defined as–"Continues to burn after dissipation of ignition source until flow of high-pressure fluid at nozzle source terminates."
[c]Defined as–"Extinguishes after a *short time* after elimination of ignition source *but* prior to termination of fluid flow."

Table 6 is a compilation of inspection data for some of the fluids. It shows a gain in flash point of approximately 120°C for MIL-H-83282 over MIL-H-5606. It also shows the autoignition temperature of MIL-H-83282 to be approximately 150°C higher than that of MIL-H-5606. It was interesting to note that the significant change in autoignition temperature of the blends of MIL-H-83282 and MIL-H-5606 occurred at about the 10-percent MIL-H-6083 concentration level.

TABLE 6. INSPECTION DATA FOR INVESTIGATED FLUIDS

Sample No.	Fluid Designation or Description	Flash Point, °C	Viscosity, cSt at 37.8°C	API Gravity, 15.6°C	Autoignition Temperature, °C
1	MIL-H-5606	115	14.2	31.2	241
2	MIL-H-5606	107	14.1	34.0	—
3	MIL-H-5606	105	14.5	31.1	—
4	MIL-H-6083	104	14.5	32.9	241
5	MIL-H-83282	221	15.7	36.4	382
6	FA-PD-5136 Candidate	224	17.3	35.3	—
7	MIL-H-83282	230	15.6	35.2	371
8	FA-PD-5136 Candidate	218	14.3	34.0	412
9	98% Sample 8, 2% Sample 4	—	—	—	396
10	95% Sample 8, 5% Sample 4	—	—	—	396
11	90% Sample 8, 10% Sample 4	—	—	—	767
12	80% Sample 8, 20% Sample 4	—	—	—	258
13	70% Sample 8, 30% Sample 4	—	—	—	245
17	MS-5	249	56.9	0.0	368
18	Experimental Silicone Fluid A	293	34.8	25.1	397
19	Experimental Silicone Fluid B	244	16.4	28.0	424
20	Commercial High-Density Phosphate Ester	185	11.8	3.2	—
21	MIL-L-2104C	222	46.3	28.5	—
22	MIL-L-10295A	149	24.6	27.7	247
23	APG-PD-1	249	28.6	20.8	443
24	MIL-L-46167	227	43.1	23.5	—
25	MIL-L-46152	213	38.2	30.2	—
26	MIL-L-46167	233	43.0	31.8	422
27	APG-PD-1	221	35.0	28.5	—
28	MIL-L-46152	210	57.0	28.9	388

RECOMMENDATIONS

While there are many other considerations that must be addressed before a solution can be determined, it appears that a significant improvement in fire safety can be gained by simply changing to a different fluid. Hence, an integrated approach that includes other factors such as hot-surface ignitability, low-temperature performance, seal compatibility, etc., should be undertaken prior to final selection of a "fire-safe" hydraulic fluid. There is no doubt, however, that MIL-H-6083 is not a "fire-safe" fluid, and therefore, a suitable permanent replacement should be sought.

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APPENDIX A

Mist Flashback Technique

In order to assess differences in flammability characteristics among the mist form of various flammable liquids, a quantitative technique based on flame flashback was developed in this laboratory. In this technique, three intersecting air streams impinge upon the liquid fuel issuing at a steady flow rate from the tip of the capillary tube, causing the liquid stream to break up (into a mist if no antimist agent is present). As illustrated in Figure A-1, an ignition source is positioned perpendicular to the fuel-air jet 30 cm downstream from the air impingement point. This pilot flame is developed by a horizontal pipe having a series of orifices, providing a natural gas-air flame sheet. In operation with either volatile or kerosene-type jet fuels, the mist is ignited as it passes through the pilot flame sheet, and a relatively large flame brush develops downstream of the pilot flame. This flame, which is shown in Figure A-2, is about the same for JP-4R as for JP-8R neat fuels. Depending upon the relative fuel and air rates, intermittent flames propagate upstream from the pilot toward the fuel-air source. This "flashback" can be measured by observations along a horizontal line of sight perpendicular to the fuel-air jet. A video camera and a video tape recorder are utilized for recording the phenomena occurring during each experiment so that data reduction may be accomplished during subsequent video playback, using slow motion (and stop action as necessary). In essence, a mist flashback rating, expressed as a mean distance of flashback, is assigned to the fuel. This average rating is based on triplicate experiments, each conducted at three different misting air rates, ranging from relatively low to extremely high shear conditions.

The sensitivity of this measurement technique is best illustrated by describing results obtained with a series of 14 base-fuel samples, all meeting Jet A or the tentative JP-8

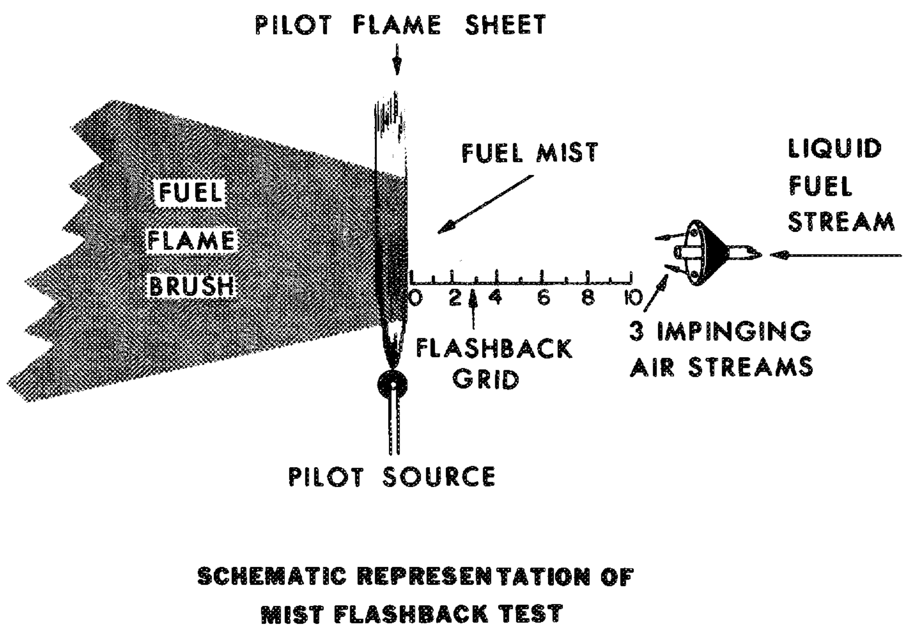


FIGURE A-1. SCHEMATIC REPRESENTATION OF MIST FLASHBACK TEST

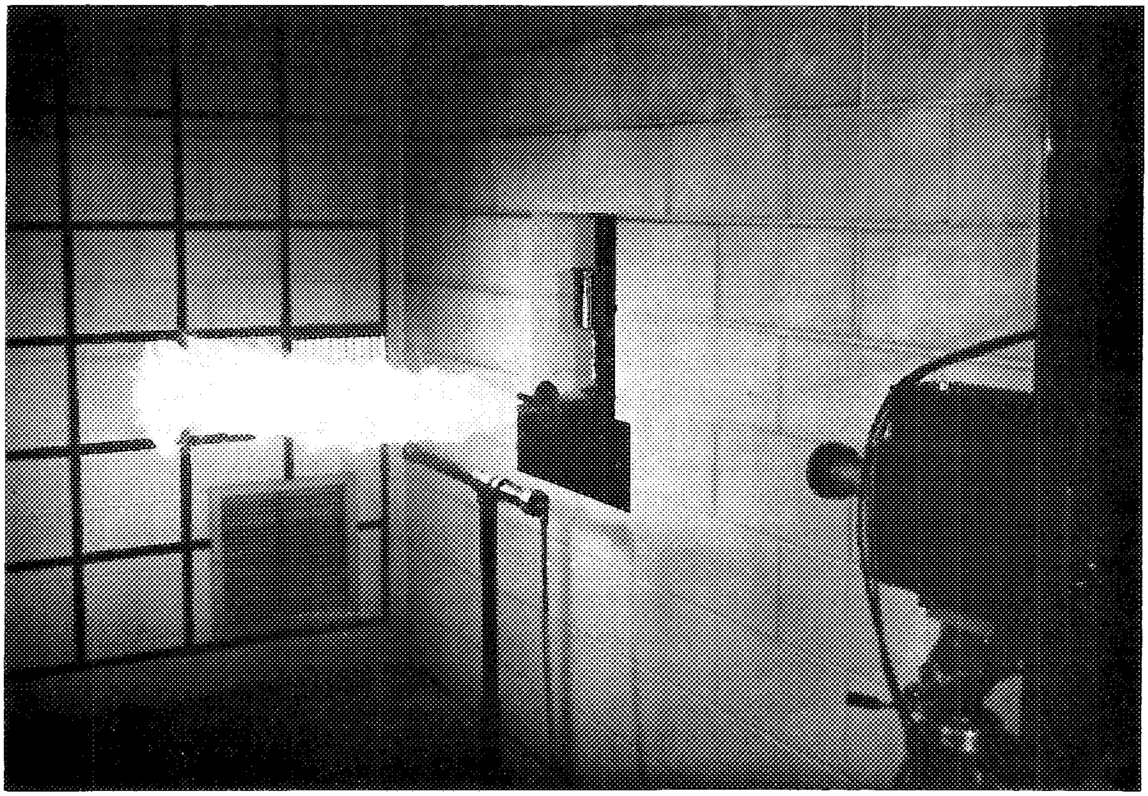


FIGURE A-2. PHOTOGRAPH OF A MIST FLASHBACK TEST WITH NEAT JP-8

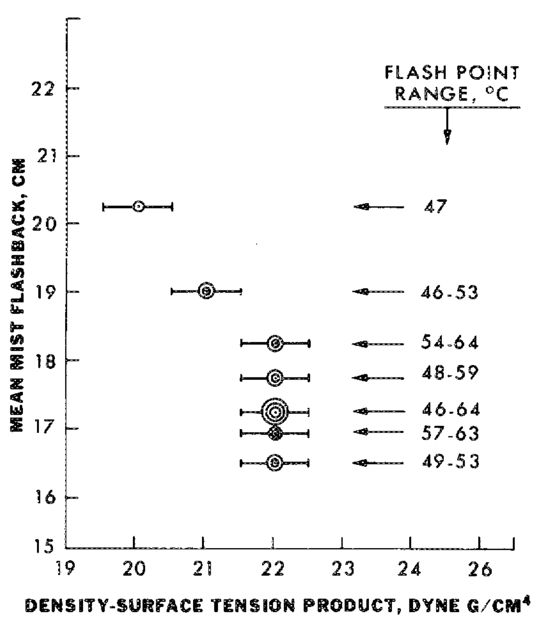


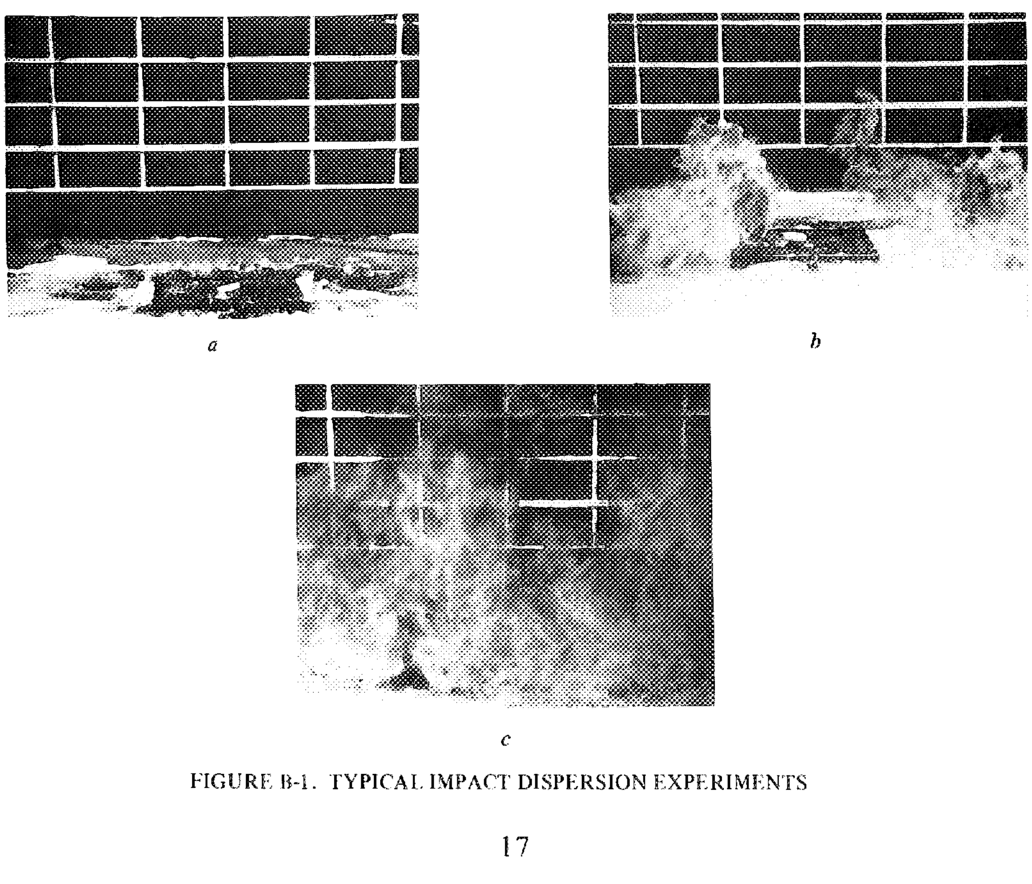
FIGURE A-3. MIST FLASHBACK PROPERTIES OF VARIOUS JP-8 AND JET A FUELS

specification. In Figure A-3, it can be seen that the extent of mist flashback with JP-8 neat fuels ranges from 16.5 cm (6.5 in.) to 20 cm (8 in.). It should be noted that JP-8 produces a mist flashback of 21 cm (8.2 in.) in this test procedure. Hence, the most flammable JP-8 fuel shown in this figure is almost indistinguishable from JP-4 under misting conditions. On the other hand, the majority of the fuel samples were significantly less flammable in the mist form than this most flammable JP-8 fuel. As illustrated in the figure, the flash points of these various samples ranged from 46° to 64°C (114° to 148°F), and no correlation between flash point and mist flashback is evident. The data in Figure A-3 are presented in terms of the product of surface tension and density; however, it is emphasized that the controlling physiocochemical properties for mist flammability have not yet been established, and the presentation is made on this basis only as a graphical convenience. Fuel mist flammability data obtained with this apparatus are presented elsewhere in this report.

APPENDIX B

Impact Dispersion Test

Impact dispersion experiments are conducted in a well ventilated enclosed facility developed for this purpose. These tests involve allowing a 2-liter glass vessel, containing about 1.2 kg of fuel, to fall freely 6 meters onto a steel target plate, embedded in concrete and surrounded on two sides by gas pilot flames. The relatively low vertical velocity of 11 meters per second developed during this free fall corresponds to total occupant survivability during a vertical helicopter crash, but it is near the onset of marginal survivability. The glass containers are filled to an ullage of about 2 percent of the total volume for each test. A television camera (with zoom lens) is located about 6 meters from the impact point, and this is used to document the test results on video tape. A background grid provides a dimensional frame of reference, and subsequent examination of the video tape by slow motion (and stop action) provides reduced data. Tests are conducted at several different temperature levels, from about 25° to 90° by preheating the fuel sample and the steel target plate to the desired temperatures. Because of the only slight effects of antimist fuels on the pilot flames, the following data reduction system was devised for placing the impact dispersion results on a somewhat quantitative basis. A rating from "A" through "E" is assigned to the results of each experiment depending upon the observed flammability characteristics. These range from "no pilot flame enlargement" for highly effective antimist fuels (Figure B-1a) through "pilot dimensions less than doubled," "pilot flames totally obscured by transient mist fireball" [neat, low-volatility fuels (Figure B-1b)], to "coalesced fireball with simultaneous pool burning" [volatile liquid fuels (Figure B-1c)]. This method of quantifying the results of impact dispersion tests has proved useable and correlatable with other experimentally measured flammability properties.



a *b* *c*

FIGURE B-1. TYPICAL IMPACT DISPERSION EXPERIMENTS

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