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HYDRAULIC FLUID FLAMMABILITY TEST (MIL-H-5606 VERSUS MLO 68-5)

DAMAGE MECHANISMS BRANCH
TECHNOLOGY DIVISION

TECHNICAL REPORT AFATL-TR-70-42

MAY 1970

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27

HYDRAULIC FLUID FLAMMABILITY TEST
(MIL-H-5606 VERSUS MLO 68-5)

Howard J. Knaggs, 2nd Lt, USAF

FOREWORD

This final report documents tests conducted during the period January 1970 through May 1970 under Project 2549G001 for a comparative study of the flammability between the standard military hydraulic fluid MIL-H-5606, and a prototype fluid, MLO 68-5, resulting from small arms fire. These test results are to be used as part of an overall study of MLO 68-5 being carried out by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

The author is indebted to Mr Robert F. Brandt (ATRD) for his aid in the statistical analysis of this report, to CMSgt Hubert A. Barton (ATRD), and to Mr John S. Byrne (ATRD) and the ATRD range personnel for their technical assistance on the project.

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This technical report has been reviewed and is approved.

CHARLES K. ARPKE, Lt Colonel, USAF
Chief, Technology Division

ABSTRACT

The tests documented were designed to make a side-by-side comparison of the flammability of standard hydraulic fluid, MIL-H-5606, and prototype fluid, MLO 68-5, resulting from small arms fire. Test data was generated by firing caliber .50 API (armor piercing incendiary) rounds into pressurized hydraulic reservoirs containing the fluids and recording the results on film. Conclusions drawn from the tabulated data indicate that, although there was no significant difference between the number of fires caused by the two fluids, the maximum burn areas caused by the MLO fluid were significantly less than those of the standard hydraulic fluid.

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TABLE OF CONTENTS

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SECTION I

INTRODUCTION

The tests documented in this report were designed to make a side-by-side comparison of the flammability of standard military hydraulic fluid, MIL-H-5606, and a prototype hydraulic fluid, MLO 68-5, resulting from small arms fire.

The equipment used for these tests consisted of the following:

- Guns: Two caliber .50 rifled Mann barrels mounted on Frankford Arsenal gun mounts, using electrical solenoids to trigger the firing pins.
- Reservoirs: Standard F-89D left-and right-hand aluminum reservoirs with approximate dimensions of 12.75 inches in length, 10.0 inches in diameter, and 0.0547 inch skin thickness.
- Striker Plates: F-89D hydraulic reservoir doors with dimensions of 7.00 X 5.75 X 0.1075 inches.
- Camera and Film: One tripod-mounted Milliken camera, Model 29655, running at 128 frames per second, Kodak Ektachrome EF film.
- Velocity Measurements: Two sets of printed circuit paper taped to a large steel frame 10 feet in length. As the bullet passed through the first paper a time counter started then stopped as the bullet passed through the second paper.
- Ammunition: Caliber .50 API (armor piercing incendiary) standard military rounds.
- Test Stands: Two old steel stools sunk rigidly in the ground and standing approximately two feet three inches high. The reservoirs were banded on top of the stand with steel bands and the striker plates were attached to two upright aluminum shafts located three inches in front of the reservoirs.
- Pressurizing System: A gas-engine driven, low-stage compressor to simultaneously pressurize the two reservoirs to 30 psig through a T-fitted one-half inch hydraulic hose.

SECTION II

PROCEDURES

The testing facility was set up as illustrated in Figure 1. The test procedure began by filling one reservoir with two gallons of standard hydraulic fluid and filling the other reservoir with two gallons of the MLO fluid. Each reservoir was then banded to the test stand, the guns bore-sighted to a point on the reservoirs which marked the midpoint of the fluid level, and the striker plates attached to the aluminum rods. The plates were perpendicular to the bore sight of each gun. Printed circuit paper was then taped to the 10-foot frame and wired up to the counters. The final step was to attach the hydraulic hose to each tank and simultaneously pressurize each to 30 psig. The guns were synchronized with the camera so that the camera was running for three seconds before the guns were fired. After each firing, the times on the counters were recorded and converted to velocity measurements. Visual observations were made of the damaged reservoirs, then the set-up procedure was repeated for the next shot. These test firings took place on 13 and 14 April 1970.

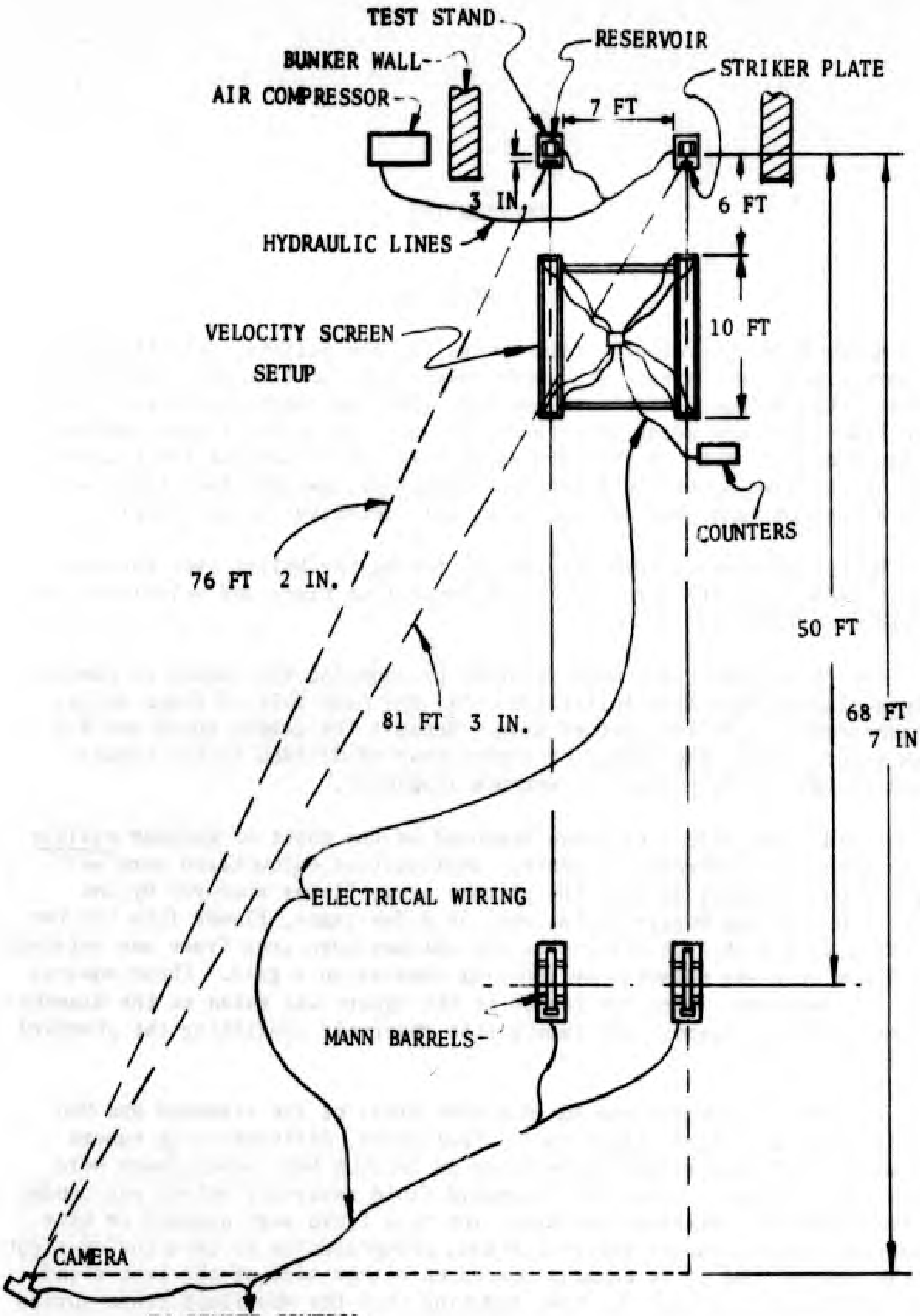


Figure 1. Test Set-Up (Located in Bunker Behind Bay 8, TA-22, Eglin Air Force Base)

SECTION III

DATA ANALYSIS

Aside from the velocity time counts for the bullets, all other data on burn times, burn areas, etc. were taken from the film record of the shots. This method of analysis has many limiting characteristics. All burn times and burn areas were taken only as long as the flames appeared in the picture. Much of the burn areas were either outside the picture area or obscured by the bunker wall. Therefore, maximum burn times and burn areas for each shot are, at best, only relative to each other.

Bullet velocities were recorded by timing the bullet over the ten feet between velocity screens. These respective times and velocities are recorded in Table I.

The flame burn times were recorded by counting the number of camera frames elapsed from fire initiation until the main bulk of flame either disappeared or left the picture area. Because the camera speed was 128 frames per second, the number of frames counted divided by the camera speed yields the burn times in seconds (Table I).

Fluid flame burn areas were measured at the point of maximum visible flame area in the burning sequence. Difficulties encountered here were flame area extending outside the picture area, flames obscured by and reflecting off the bunker walls, and, in a few cases, flames from the two fluids mixing with each other once the maximum burn area frame was obtained. The flame area was measured by counting squares on a grid. These squares were unit measures where the length of the square was taken as the diameter of the reservoir nearest the camera (the reservoir containing the standard fluid).

In order to compare the maximum burn areas of the standard and MLO fluids and assign approximate square foot areas, differences in camera distance to reservoirs and differences in maximum burn area planes were taken into account. First, the standard fluid reservoir set-up was chosen as the standard. Maximum burn areas for this fluid were assumed to have occurred in the plane of the test stand, perpendicular to the line-of-sight of the camera, and to be equally spaced on either side of the test stand as illustrated in Figure 2. Now, assuming that the MLO fluid flame spread equally around the MLO test stand, the square of the ratio of the distances from the camera to the reservoirs, times the burn area for the MLO shots, would correct for the perspective error in the original area measurements. In shots No. 9 and No. 11 the MLO reservoirs did not explode and, consequently, concentrated the flame out of the plane of the test stand. For these two shots the plane of reference was moved six feet forward from the MLO test stand. A new perspective correction factor was then established for those two shots.

By knowing the diameter of the hydraulic reservoir (10 inches), the area of the unit square was calculated as 0.694 square feet. Using this figure, the approximate maximum burn area, corrected for perspective arror was calculated. The percentage of burn area of each maximum flame to the area of the camera frame in which flame might have been seen (excluding area from butt wall left to the edge of the frame) was also figured. The percentage of burn areas and maximum burn areas in square feet and unit squares (corrected and uncorrected) appear in Table I. Mathematical details for perspective error calculations are included in Appendix I

In order to reach some legitimate conclusions from the tabulated data, several simple statistical tests were run.

The first test was made to determine whether or not there was any significant difference in the number of fires caused by incendiary bullets hitting the standard or MLO hydraulic fluids. Using the Fisher Exact Probability Test[1], a 2 x 2 contingency table was set up. Data for the 2 x 2 table consisted of observing the film record and recording every time either fluid showed any sign of flame. Results of this test prove or disprove to a desired confidence level the null hypothesis, H_o, that a significant difference exists in the number of fires caused by the standard and MLO fluids. The results indicate no significant difference between the number of fires caused by the two fluids (see Appendix II for mathematical details).

The second test was performed to indicate whether or not a significant difference existed in the maximum burn areas caused by the two fluids. The Median Test[1] was used for this analysis. This test consists of ranking the two fluids together from the smallest to the largest burn area, then using the rank numbers in the Fisher test to disprove the H_o that the two fluids were drawn from the same population with regard to burn area. The test results indicate with a 99% confidence-level that the maximum standard fluid burn area is larger than the maximum MLO fluid burn area.

The final statistical test was made to determine if there was any correlation between timed length of burn and maximum burn area for the two fluids. Using the Spearman Rank Correlation Test[1], the maximum burn areas for each separate fluid were ranked from the smallest to the largest, then the corresponding burning times were ranked from the shortest to the longest. The tabled results as shown in Appendix II were then used to determine the Rank Correlation coefficient. The coefficient was then compared to Table P, Reference 1 for correlation of results. The test showed that for the 95% confidence level both fluids exhibit burn time as a function of maximum burn area. Mathematical computations appear in Appendix II.

TABLE I. DATA TABLE

Shot No.	Fluid	Bullet Data: Time (μsec over 10 Ft)	Bullet Data: Vel (fps)	Flame Data: Burn Time: Frame Counts	Burn Time: Sec	Maximum Burn Area: Uncorr Sq Count	Maximum Burn Area: Corr Sq Count	Maximum Burn Area: Sq Ft	Pct Burn Area
1	Std	3264	3064	201	1.57	26.2	26.2	16.8	15
	MLO	3202	3123	215	1.68	41.1	46.8	30.0	23
2	Std	3248	3079	0	0	0	0	0	0
	MLO	3197	3128	22	0.17	0.5	0.6	0.4	0
3	Std[2]	3250	3077	100	0.78	6.0	6.0	3.8	3
	MLO	3184	3141	0	0	0	0	0	0
4	Std	3264	3064	156	1.22	38.6	38.6	24.7	22
	MLO	3182	3143	30	0.23	0.5	0.6	0.4	0
5	Std	3258	3069	130	1.02	19.6	19.6	12.5	11
	MLO[3]								
6	Std	3415	2928	205	1.60	89.5	89.5	57.3	51
7	Std	3222	3104	258	2.02	59.4	59.4	38.0	34
	MLO	3235	3091	9	.07	0.7	0.8	0.5	0
8	Std	3202	3123	191	1.49	45.6	45.6	29.2	26
	MLO	3254	3073	70	0.55	13.2	15.0	9.6	8
9	Std	3236	3090	198	1.55	60.0	60.0	38.4	22
	MLO	3274	3054	178	1.39	26.2	24.6[4]	15.7	15.
10	Std	3203	3122	298	2.33	83.8	83.8	53.6	31
	MLO	3263	3065	0	0	0	0	0	0
11	MLO	3245	3082	140	1.09	25.2	23.7[4]	15.2	14

FOOTNOTES:
1. This percent burn area (to nearest 1%) is based on percent uncorrected squares counted to the total visible burn area possible for each frame (equal to 175.4 squares).
2. This shot is the fourth film sequence and was unpressurized. Was not used in any analysis.
3. Gun did not fire.
4. These reservoirs did not explode. Their corrected square counts were based on another perspective error factor as mentioned in the data analysis.

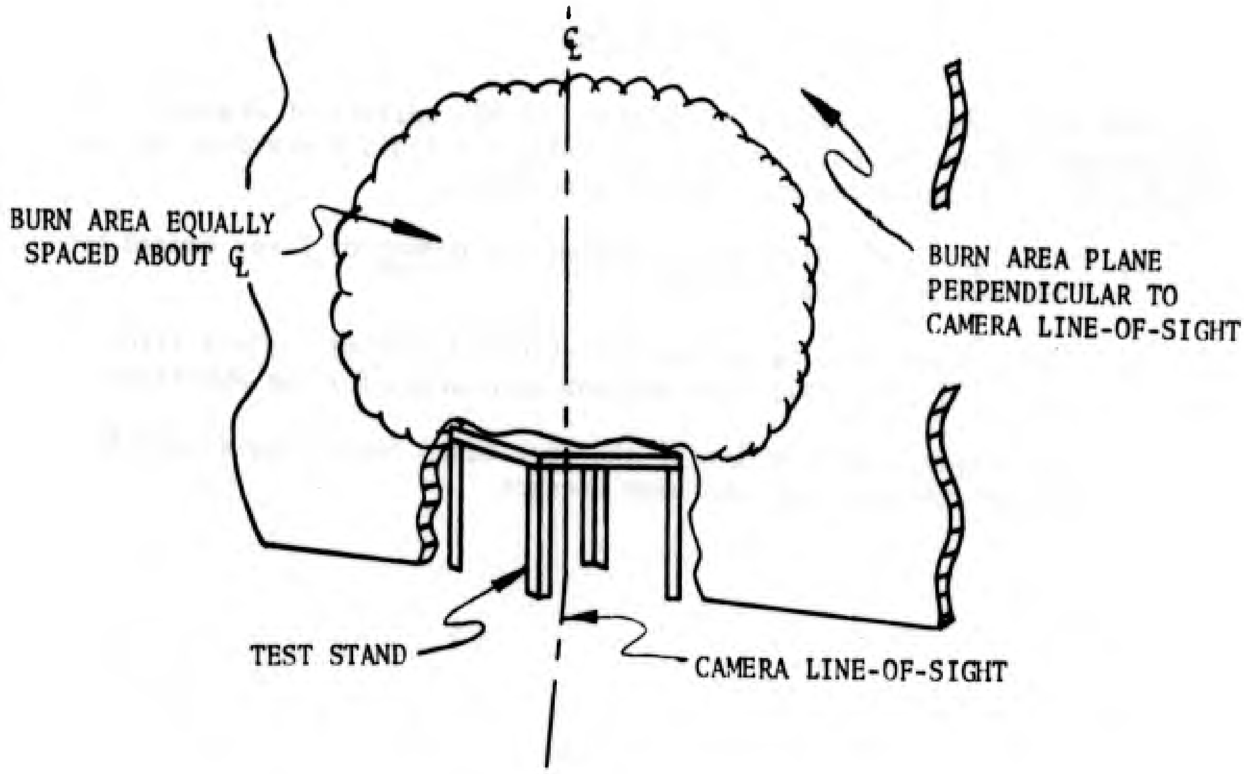


Figure 2. Perspective for Comparing Burn Areas

SECTION IV

CONCLUSIONS

For the stated conditions of caliber .50 API bullets at standard velocities entering 30 psig pressurized hydraulic fluid reservoirs in the fluid level, the following conclusions were reached:

1. No significant difference between the number of fires caused by the two fluids was observed.

2. The maximum burn areas for the standard hydraulic fluid fires appeared larger than the maximum burn areas for the MLO fires.

3. It appears that the longer the fire burns for either fluid the larger the maximum burn area becomes.

SECTION V

RECOMMENDATIONS

The tests show approximate results for only one test condition. Other test conditions may be desirable to show fluid comparisons for different caliber ammunitions (possibly .223, .30, and 20mm) and other reservoir conditions such as pressurized with bullet entering above the fluid level or unpressurized with bullet impingement above and below the fluid level.

The test set-up would probably yield better results if:

- The test stands were away from any interference such as the bunker walls
- The test stands were separated at least another ten feet
- The camera was mounted between and above the gun mounts and allowed to cover a viewing area of approximately 40 feet

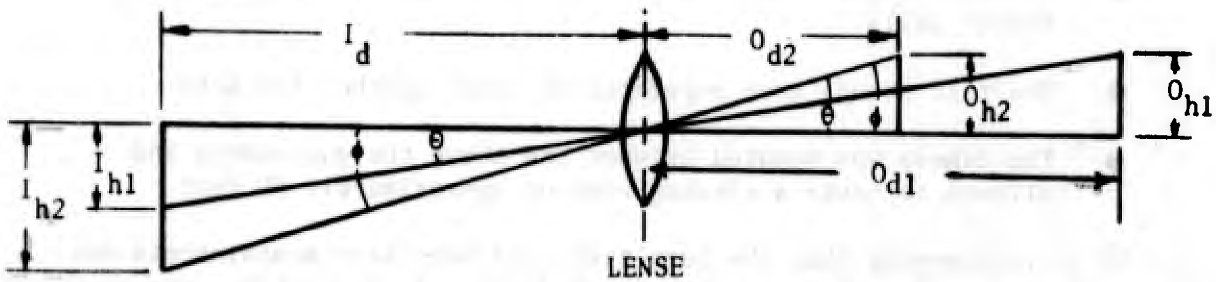
It is recommended that the burn times and burn area measurements not be used in any mathematical analysis such as average burn times, etc. because of the many variables used to arrive at the numbers. This is the reason for using nonparametric statistics to arrive at conclusions for these tests. These statistical results can yield general information without commitment to possibly incorrect mathematical numbers.

APPENDIX I

DETERMINATION OF PERSPECTIVE ERROR CORRECTION FACTORS

A. Correction factor for all MLO flames except shots No. 9 and No. 11.

1. Using the following optical diagram, certain geometrical relationships may be obtained.



I_h = IMAGE HEIGHT O_h = OBJECT HEIGHT

I_d = IMAGE DISTANCE O_d = OBJECT DISTANCE

From similar triangles:

$$\tan \Theta = \frac{O_{h1}}{O_{d1}} = \frac{I_{h1}}{I_d}$$

$$\tan \phi = \frac{O_{h2}}{O_{d2}} = \frac{I_{h2}}{I_d}$$

Now:

$$O_{h2} = O_{h1}$$

So:

$$O_{h2} = O_{h1} = \frac{I_{h2}}{I_d} O_{d2} = \frac{I_{h1}}{I_d} O_{d1}$$

Therefore:

$$\frac{O_{d1}}{O_{d2}} = \frac{I_{h2}}{I_{h1}}$$

2. Because the area of a square = $(\text{height})^2$, the square of $\frac{O_{d1}}{O_{d2}}$ will correct for the perspective error in area.

3. Let α = perspective error correction factor:

Therefore:

$$\alpha = \left(\frac{O_{d1}}{O_{d2}}\right)^2 = \left(\frac{975}{914}\right)^2 = 1.14$$

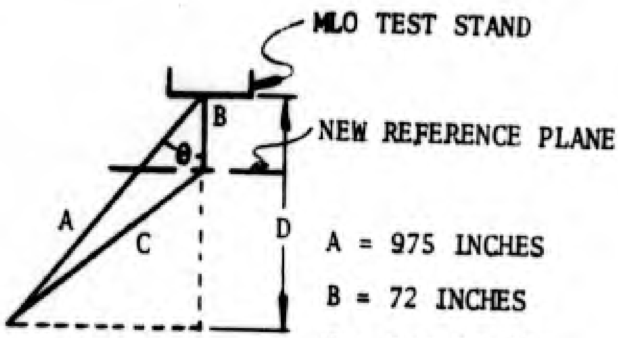
This α factor times the uncorrected square count for all MLO flames (except on shots No. 9 and No. 11) will yield the corrected square count as seen on the data chart.

B. Correction factor for MLO shots No. 9 and No. 11.

1. For these two shots, the plane of reference was moved forward from the MLO stand six feet for reasons explained in Section III.

2. Using the diagram below and the law of cosines:

$$C^2 = A^2 + B^2 - 2AB\cos\theta$$



A = 975 INCHES

B = 72 INCHES

C = 947 INCHES

D = 823 INCHES

$$\cos\theta = \frac{823}{975} = 0.844$$

$$C^2 = (975)^2 + (72)^2 - 2(975)(72)(0.844)$$

$$= 896,560$$

So:

$$C = 947 \text{ Inches}$$

3. Using the new distance of 947 inches and the $\left(\frac{O_{d1}}{O_{d2}}\right)^2$ relation derived above, a correction factor may be assigned for shots No. 9 and No. 11 as:

$$\beta = \left(\frac{O_{d1}}{O_{d2}}\right)^2 = \left(\frac{947}{975}\right)^2 = 0.94$$

This β factor times the uncorrected square counts for MLO shots No. 9 and No. 11 will yield the corrected squares count for those two shots as shown in Table I.

APPENDIX II

STATISTICAL ANALYSIS TO DETERMINE THE NUMBER OF BURNS IN BURN AREAS

1. Fisher Test for Number of Burns.

A. Using Reference 1, a 2x2 contingency table is formed as shown below.

	No Fire	Fires	Total
MLO	2	8	10
Standard	1	8	9
Total	3	16	19

B. The exact probability of the above permutation happening is given by the hypergeometric distribution:

$$P = \frac{(A+B)!(C+D)!(A+C)!(B+D)!}{N!A!B!C!D}$$

Where:

	-	+	Total
Group I	A	B	A+B
Group II	C	D	C+D
Total	A+B	B+D	N

Therefore:

$$P_1 = \frac{10!9!3!16!}{19!2!8!1!8!} = 0.4180$$

C. In order to find the probability of any other <u>more extreme</u> condition occurring without changing any column total, 2x2 tables of more extreme conditions are formed and their probability of occurrence is calculated. In this case only, one more extreme condition can exist as shown below:

	No Fire	Fires	Total
MLO	3	7	10
Standard	0	9	9
Total	3	16	19

Therefore:

$$P = \frac{10!9!3!16!}{19!3!0!7!9!} = 0.1238$$

D. The sum of the exact probability of the test conditions occurring and those of all other more extreme conditions occurring yields:

$$P = P_1 + P_2 = 0.4180 + 0.1238 = 0.5418$$

If the above is the probability that this or more extreme conditions could occur, then 1-P is the probability they will not occur.

So:

$$1-P = 1-0.5418 = 0.4582$$

E. Because this test attempts to prove the null hypothesis that all samples were drawn from the same population, the 1-P figure is the level of confidence that, indeed, the samples tested were not from the same population. This 0.4582 figure is only one-half the comparatively low 90 percent confidence level sometimes used. It must, therefore, be concluded that the two fluids are not significantly different with respect to the number of fires they produce.

2. Median Test for Maximum Burn Area.

A. Using reference 1, a table of maximum burn areas is set up for both fluids. The respective areas of the two fluids are then ranked, beginning with the smallest burn area being ranked first. In case of two or more identical burn areas, each tied areas is given the average of the rank numbers they would have occupied.

Maximum Burn Areas $(Ft)^2$			
Standard Fluid	(Rank Number)	MLO Fluid	(Rank Number)
16.8	(9)	30.0	(12)
24.7	(10)	0.4	(1.5)
12.5	(6)	0.4	(1.5)
57.3	(16)	2.7	(4)
38.0	(13)	0.5	(3)
29.2	(11)	9.6	(5)
38.4	(14)	15.7	(8)
53.6	(15)	15.2	(7)

B. Using the Fisher Test as described above, a 2x2 contingency table is created by counting the number of ranks of, say MLO, that are equal to or below the median number (eight in this case). The chart is filled in as indicated and a procedure similar to that described above is followed to find the exact probability and all other more extreme probabilities of occurrence of the tabled conditions shown below.

(1) Test conditions

	MLO	Standard	Total
> Median	7	1	8
< Median	1	7	8
Total	8	8	16

$$P_1 = \frac{8!8!8!8!}{16!7!1!7!1!} = 0.004973$$

(2) More extreme conditions

	MLO	Standard	Total
> Median	8	0	8
< Median	0	8	8
Total	8	8	16

$$P_2 = \frac{8'8'8'8'}{16'8'0'0'8'} = 0.000078$$

(3) Total probability of exact or worse conditions

$$P = P_1 + P_2 = 0.004973 + 0.000078 = 0.005051$$

C. The 1-P probability = 1-0.005 = 0.995, which indicated that to a 99 percent confidence level there is a significant difference in the two fluids with respect to maximum burn area.

3. Spearman Rank Correlation Test for Correlation Between Length of Time and Maximum Burn Area.

A. Using reference 1, a chart is filled in with the burn areas for each fluid being ranked from the smallest to the largest burn areas, and corresponding burn times for each fluid being ranked from the shortest to the longest burn times. The difference between the burn area rank and the corresponding burn time rank is then found for each shot (represented by d_i). The charts for both fluids are shown below.

Standard Fluid

Max Burn Area $(Ft)^2$	(Rank)	Burn Time (Sec)	(Rank)	d_i	d_i^2
16.8	(2)	1.57	(5)	-3	9
24.7	(3)	1.22	(2)	1	1
12.5	(1)	1.02	(1)	0	0
57.3	(8)	1.60	(6)	2	4
38.0	(5)	2.02	(7)	-2	4
29.2	(4)	1.49	(3)	1	1
38.4	(6)	1.55	(4)	2	4
53.6	(7)	2.33	(8)	-1	1

$\Sigma d_i^2 = 24$

MLO Fluid

Max Burn Area $(Ft)^2$	(Rank)	Burn Time (Sec)	(Rank)	d_i	d_i^2
30.0	(8)	1.68	(8)	0	0
0.4	(1.5)	0.17	(2)	-0.5	0.25
0.4	(1.5)	0.23	(3)	-1.5	2.25
2.7	(4)	0.76	(5)	-1	1.00
0.5	(3)	0.07	(1)	2	4.00
9.6	(5)	0.55	(4)	1	1.00
15.7	(7)	1.39	(7)	0	0
15.2	(6)	1.09	(6)	0	0

$\Sigma d_i^2 = 8.50$

B. Using the relationship for the Spearman Coefficient given in Reference 1:

$$r_s = \frac{\Sigma x2 + \Sigma y2 - \Sigma d_i2}{2\sqrt{\Sigma x^2 \ \Sigma y^2}}$$

Where:

$$\Sigma x^2 = \frac{N3-N}{12} - \Sigma T_x$$

$$\Sigma y^2 = \frac{N3-N}{12} - \Sigma T_y$$

And:

$$\Sigma T_x = \Sigma\left(\frac{t_x{}^3 - t_x}{12}\right)$$

Where t_x = number of rank ties for each tie in x.

$$\Sigma T_y = \Sigma\left(\frac{t_y{}^3 - t_y}{12}\right)$$

These relations may be used for each fluid to give the following results:

(1) For standard fluid from the preceding chart:

$$N = 8;\ T_x = 0;\ T_y = 0$$

$$\Sigma x^2 = \frac{8^3 - 8}{12} = 42.000$$

$$\Sigma y2 = \frac{8^3 - 8}{12} = 42.000$$

$$r_s = \frac{42.00 + 42.00 - 24.00}{2\sqrt{(42.00)^2}} = 0.714$$

(2) For MLO fluid:

$$N = 8;\ T_y = 0;\ T_x = \frac{2^3 - 2}{12} = 0.50$$

$$\Sigma x^2 = \frac{N^3 - N}{12} - \Sigma T_x = 42.00 - 0.50 = 41.50$$

$$\Sigma y^2 = 42.00$$

$$r_s = \frac{41.50 + 42.00 - 8.50}{2\sqrt{(41.50)\ (42.00)}} = 0.898$$

C. To test the significance of r_s as explained in Reference 1. check Table P at the significance level of $\alpha = 0.05$. For N = 8, the critical value of $r_s = 0.643$. Because both the r_s numbers for standard and MLO fluids are above this critical $r_s = 0.643$, this implies that to the 95 percent confidence level there exists a correlation between length of burn time and maximum burn area for both fluids.

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13. ABSTRACT

The tests documented were designed to make a side-by-side comparison of the flammability of standard hydraulic fluid, MIL-H-5606, and prototype fluid, MLO 68-5, resulting from small arms fire. Test data was generated by firing caliber .50 API (armor piercing incendiary) rounds into pressurized hydraulic reservoirs containing the fluids and recording the results on film. Conclusions drawn from the tabulated data indicate that, although there was no significant difference between the number of fires caused by the two fluids, the maximum burn areas caused by the MLO fluid were significantly less than those of the standard hydraulic fluid.

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