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VULNERABILITY OF DRY BAYS ADJACENT TO
FUEL TANKS UNDER HORIZONTAL GUNFIRE

Robert G. Clodfelter

Air Force Aero Propulsion Laboratory
Wright-Patterson Air Force Base, Ohio

March 1973

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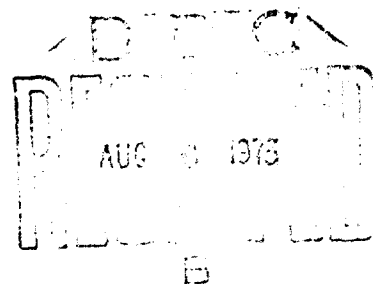
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TECHNICAL REPORT AFAPL-TR-72-83

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FUEL TANKS UNDER HORIZONTAL GUNFIRE**

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FOREWORD

This report was prepared by Robert G. Clodfelter of the Fire Protection Branch, Fuels and Lubrication Division, Air Force Aero Propulsion Laboratory. The work reported herein was accomplished under Project 3048, "Fuels, Lubrication, and Fire Protection," Task 304807, "Aerospace Vehicle Fire Protection."

This report covers research accomplished from March 1969 through October 1971 and was submitted by the author 21 April 1972.

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This technical report has been reviewed and is approved.

C. R. Hudson

C. R. HUDSON

Chief, Fuels and Lubrication Division

ABSTRACT

This report deals with the relative vulnerability to incendiary action of dry bays adjacent to fuel tanks as a function of fuel type. Cal .50 API horizontal gunfire was the threat; a high level of simulation was achieved by having air flow external to and in the dry bays. The results of a wide range of test conditions are presented. The overall conclusion of the investigation was that JP-8 fuel is less susceptible to fire and explosion induced by gunfire and should produce less aircraft structural damage than JP-4.

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SECTION I

INTRODUCTION

During March 1969 an extensive gunfire test program to evaluate the vulnerability of JP-4 and JP-8 fuels to external fires induced by incendiary gunfire was initiated with FAA (NAFEC), Atlantic City, New Jersey, by redirection of effort under an existing Delivery Order with the AFAPL. The term external fires refers to sustained burning outside the fuel tank (i.e., void space, dry bay areas) either within or outside the simulated aircraft structure. The program with the FAA represented an extension of a small-scale liquid space gunfire test effort conducted in-house by the Air Force Aero Propulsion Laboratory in 1968. During this preliminary testing, the low volatility fuel, JP-8, exhibited external sustained fires only 3.1% of the time, whereas the standard Air Force fuel, JP-4, sustained fires 68.6% of the time. The test article used in the initial program is shown in Figure 1 and details are given in Reference 1.

The FAA program used three larger replica test tanks with more realistic configurations and control of fuel system operating parameters (such as internal pressurization) and considered the effects of internal dry bay ventilation rates as well as airflow exterior to the simulated fuselage on the ignitability, flame propagation, and flame sustainment properties of JP-4 and JP-8 fuels. The FAA long-range gunfire test program involves several phases, but initial emphasis was directed to the fuselage replica tanks and the relative vulnerability of JP-4 and JP-8 fuels.

The purpose of this report is to provide a detailed assessment of the horizontal gunfire tests conducted by the FAA through June 1971.

The results presented herein include a refinement and an extension of the information given in AFAPL-TR-70-93 "AFAPL Aircraft Fire Test Program with FAA 1967-1970," dated June 1971.



Figure 1. Initial Test Article (17-Gallon Tank)

SECTION II

EXPERIMENTAL DESIGN

Several items must be considered in designing a gunfire test program to assess aircraft survivability/vulnerability. All programs have cost and time constraints. One approach that may be taken is to strive for a very high degree of simulation. Real aircraft fuel tanks may be used, but the threat and operational environment must also be simulated. Even with a very high degree of simulation of this environment, the test results are still estimates based on statistical sampling and can be statistically valid only with sufficient sampling. Many tests with a high level of simulation may conflict with the cost-time constraints; therefore, the scope of the test effort may have to be restricted in order to obtain valid results. Unfortunately, if the scope is too limited, making general conclusions applying to conditions not specified in the test would be impossible. This is true because high variance is associated with most response variables which quantify the projectile-fuel tank interaction, regardless of the level of simulation achieved in the test program.

The approach taken in this effort was to design an experiment which would be statistically valid yet provide general conclusions. Trade-offs were made in the level of simulation in order to accomplish as many tests under as wide a range of conditions as possible. The number of times each set of test conditions was repeated was based on statistical principles and a projection of the expected test results. In other words, if a large difference in response was expected between two sets of test conditions, a smaller number of repeats would be required than if only a small difference was expected. An example which illustrates this point is presented in Appendix IV. All factors which were not controllable, such as ambient temperature, projectile dynamics, etc., should have entered into the program in a random way. Complete randomization of the factors would have made the test sequencing unmanageable, and trade-offs again were required; however, some effort to randomize the uncontrollable parameters was included in the program to ensure that the test results were not biased by the uncontrollable factors.

SECTION III

TEST DESCRIPTION

The objective of the test program was to determine the relative vulnerability of JP-4 and JP-8 fuels to fires in areas outside the fuel tank (i.e., void space, and dry bay areas--also referred to as standoff). For most of the test program, the only variables were fuel type, void space volume, void space ventilation, and external airflow. All other factors were controlled at a fixed value. The following test conditions were established for the initial phase of the test program:

1. Fuels: JP-4 and JP-8 (118°F flash point)
2. Projectile type and velocity: Cal .50 API, 2400 ft/sec.
3. Projectile trajectory: Horizontal, impact angle of 30°.
4. Tank volume: Approximately 90 gallons
5. Fuel temperature: 90°F ± 5
6. Fuel tank pressure: 5 psig
7. Fuel height: 18 inches
8. Impact point: Center of liquid, approximately 9 inches below the fuel/ullage interface.
9. Ullage: 25% of tank volume
10. External air velocity: 0, 90, 125, and 300 knots
11. Standoff distance (striker plate to tank distance - also referred to as void space): 1, 4, and 9 inches
12. Void space ventilation:
 - a. 18 ACPM* at 90 knots external airflow and 4 inch test article
 - b. 75 ACPM at 90 knots external airflow and 4 inch test article
 - c. 58 ACPM at 300 knots external airflow and 4 inch test article
 - d. 180 ACPM at 300 knots external airflow and 4 inch test article
 - e. 23 ACPM at 90 knots external airflow and 9 inch test article
 - f. 96 ACPM at 90 knots external airflow and 9 inch test article

- g. 101 ACPM at 300 knots external airflow and 9 inch test article.
- h. 325 ACPM at 300 knots external airflow and 9 inch test article.

*ACPM - Air Changes Per Minute

The projectile velocity (2400 ft/sec) and striker plate (first impact surface consisting of 2 plates made of 0.125" and 0.090" 2024T3 aluminum) configuration were selected to give maximum incendiary functioning in the void volume. These were selected by making two shots into each of three standoff distances (1, 4, and 9 inches) at three projectile velocities (1800, 2400, and 2900 ft/sec) and noting the incendiary burn times. From the 18 shots, a projectile velocity of 2400 ft/sec produced the longest incendiary burn time (10 to 18 milliseconds, on the average). The biggest ignition source possible with a Cal .50 API, therefore, was available to ignite any fuel in the void space. External airflow around the test article was generated by ducting fan air from a TF-33 engine.

In addition to the above, a few tests were conducted with other test conditions: (1) polyurethane flame-arresting foam in the dry bay; (2) polyurethane flame-arresting foam in the fuel tank; (3) fuel temperature other than 90°F; (4) fuel tank pressure other than 20 psia; and (5) various sizes of dry bays on both the projectile exit side and projectile entrance side of the test article.

Photographic data was recorded by two cameras at 3500 and 7000 frames per second, color film. The test article was viewed through the plexiglass top plate. Overall film coverage was provided by a camera operating at 500 frames per second.

An overall view of the test range is given in Figure 2, and a typical test article designed to simulate a fuselage fuel tank is shown in Figure 3. Figure 4 shows the various test article configurations and gives a summary of the test conditions. Detailed test conditions and results are presented in Appendix I; additional background information on the test procedures are given in References 2 and 3. Appendixes II

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and III present two potential problem areas considered prior to detailed analysis of the test results. Appendix V gives the properties of the two fuels used in the test program.



Figure 2. Overall View of Engine, Test Weapon, and Test Article

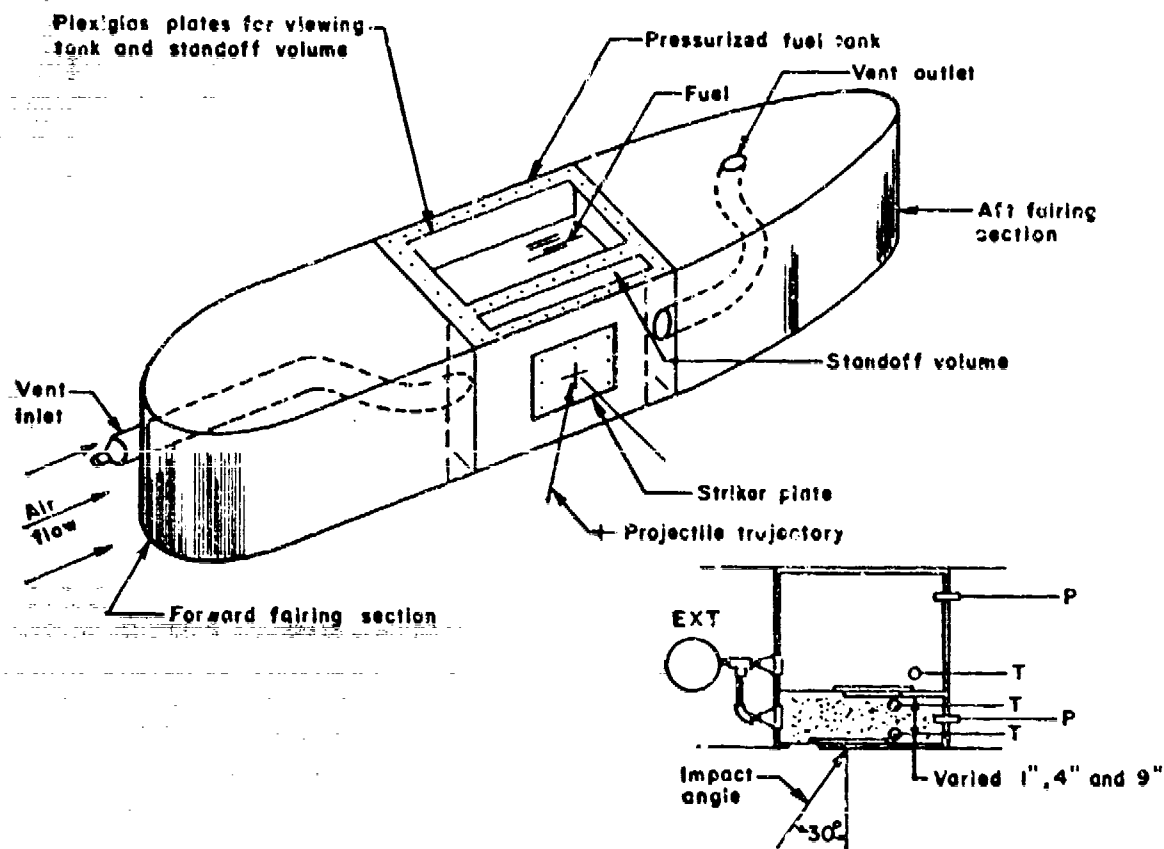


Figure 3. FAA Sunfire Test Article

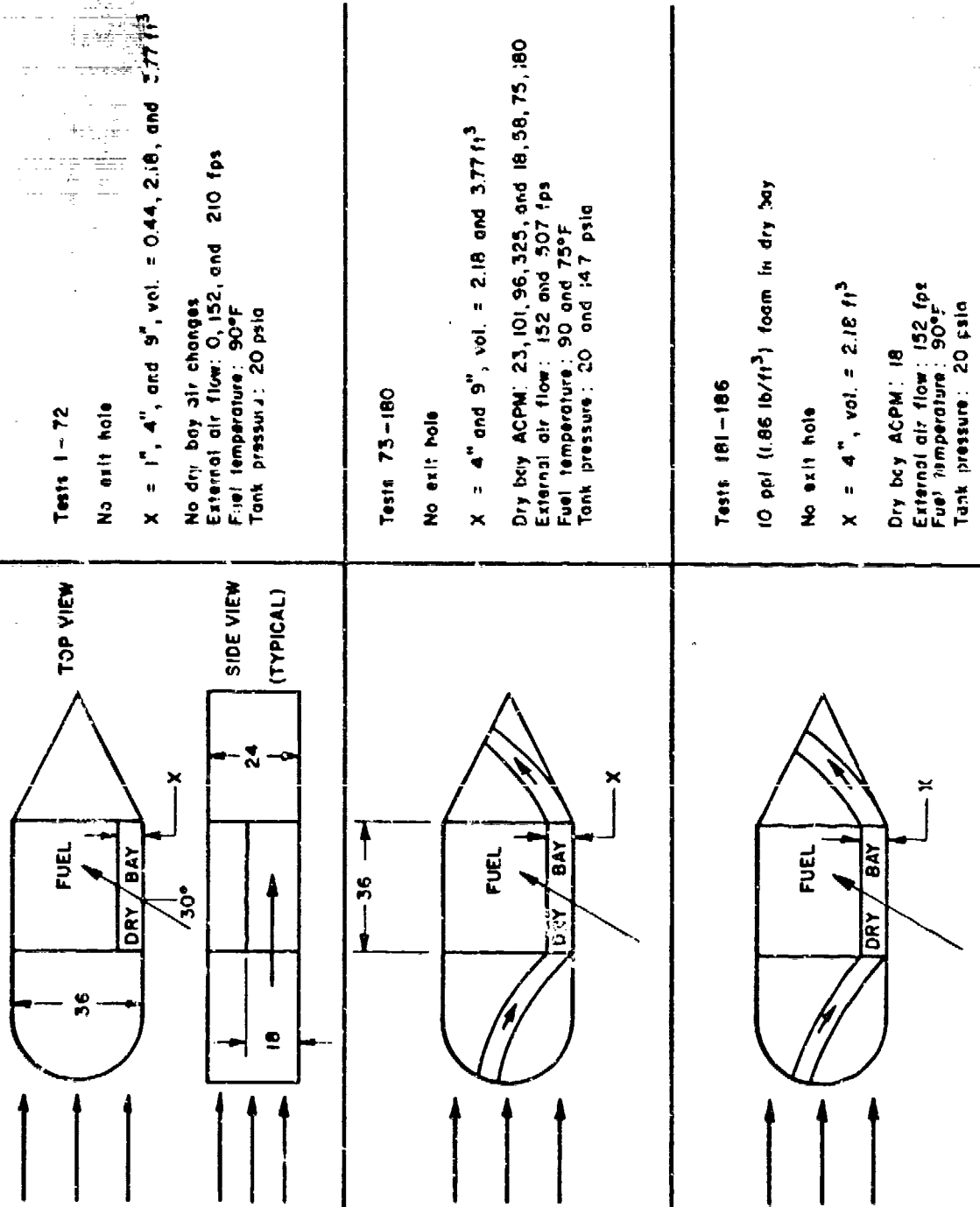


Figure 4. Summary of Test Conditions

Tests 187-192
10 ppl (1.86 lb/ft³) foam in fuel tank

No exit hole

X = 4", vol. = 2.18 ft³

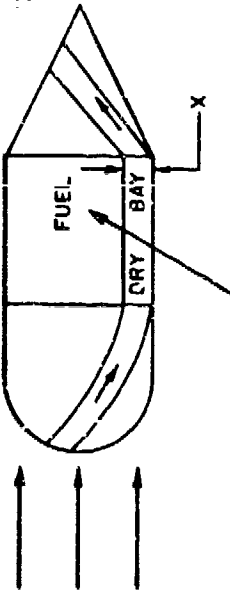
Dry Bay ACPM: 18

External air flow: 152 fps

Fuel temp: 90°F

Tank pressure: 14.7 psia

2" fuel depth



Tests 193-198

No exit hole

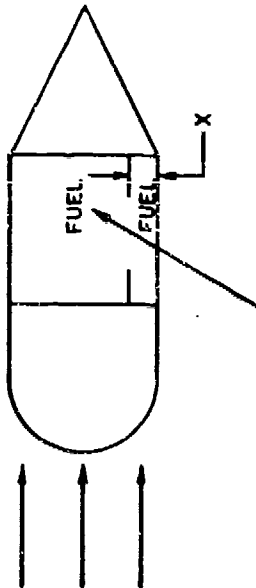
No dry bay

X = 9", vol. = 3.77 ft³

External air flow: 152 fps

Fuel temp.: 90°F

Tank pressure: 20 psia



Tests 201-212

X = 9", vol. 3.77 ft³

Dry bay ACPM: 0 and 23

External air flow: 152 fps

Fuel temp.: 90°F

Tank pressure: 14.7 psia

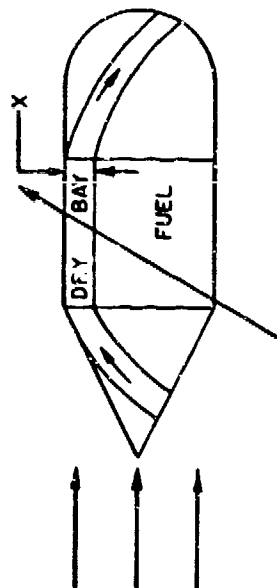
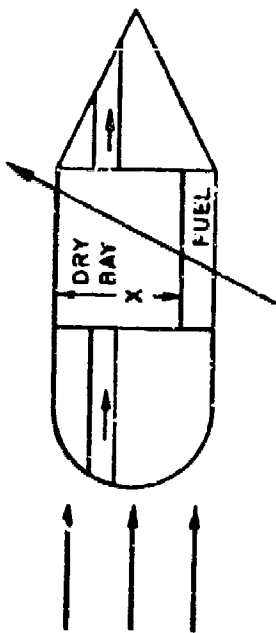


Figure 4. Continued

Tests 218 - 230

X = 27", vol. = 9.92 ft³

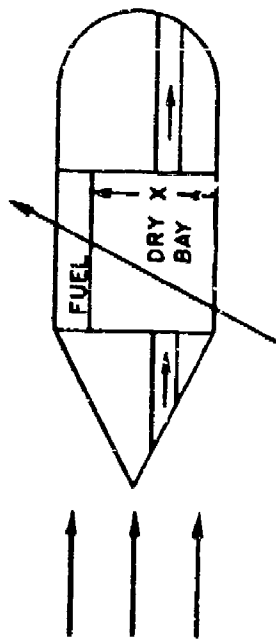
Dry bay ACPM: 0, 7, and 33
 External air flow: 152 fps
 Fuel temp.: 90°F
 Tank pressure: 14.7 psia



Tests 231 - 242

X = 27", vol. = 9.92 ft³

Dry bay ACPM: 0, and 7
 External air flow: 152 fps
 Fuel temp.: 90°F
 Tank pressure: 14.7 psia



Tests 243 - 254

X = 27", vol. = 19.3 ft³ (includes 10 ft³ hot section,
 coded as 27" H in data)
 Dry bay ACPM: 0, 4
 External air flow: 152 fps
 Fuel temp.: 90°F
 Tank pressure: 14.7 psia

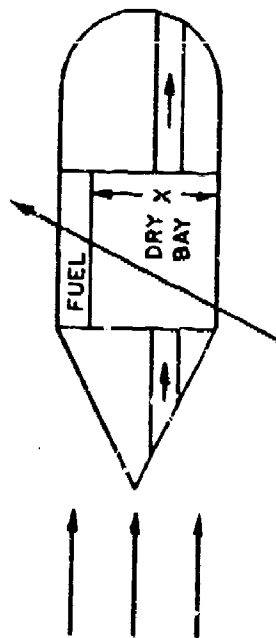


Figure 4. Continued

SECTION IV

STATISTICAL PROCEDURES

1. STATISTICAL METHODS

The first step in the analysis of the test results was to compare the recorded responses for the two fuels (JP-4 and JP-8) under identical initial conditions. Statistical methods were used in the comparison to assess the question, "If a difference between the response variables for the two fuels is noted, is the difference small enough that it could have occurred by chance or is it so large that it most probably is a true measure of the difference between the two fuels?" The following statistical expressions were used in this analysis (the reader may refer to the many textbooks on the subject for details).

The sample mean $\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$, where $X_1, X_2, \dots, X_n$ denote the responses of the random variable X , and n is the size of the sample, provides an unbiased and minimum variance estimate on the population mean μ , which is unknown.

$$\text{The sample variance } S^2 = \left[\sum_{i=1}^n (X_i - \bar{X})^2 \right] / (n - 1)$$

provides an unbiased estimate of the population variance σ^2 . Moreover if S_1^2 and S_2^2 are two independent estimates of the same unknown, σ^2 based on n_1 and n_2 samples, respectively, then

$$F = S_1^2 / S_2^2 \quad \text{or} \quad S_2^2 / S_1^2$$

(the ratio selected in such a way that the larger S^2 is in the numerator).

This yields an F with $n_1 - 1$ and $n_2 - 1$ degrees of freedom for the numerator and denominator, respectively, assuming $S_1^2 > S_2^2$, which could be compared with F distribution values for homogeneity of variance.

The T test which was used to test for the significant difference of means was based on the assumption that there was "homogeneity of variance." Thus, the F ratio was used as a measure to check the validity

of this underlying assumption. Values of the F ratio near one are desired. Once such an assumption is established as valid, then any difference in the data is solely due to the difference in means. In a large number of cases in Table I, the F ratio was not significant, which ensured homogeneity of variances. Hence we made a general assumption of "homogeneity of variance," which enabled us to use the T test for the difference in means.

The criterion for comparing the means was the Student T test.

$$T = \frac{|\bar{x}_1 - \bar{x}_2|}{\left(\frac{(n_1 - 1) \sigma_1^2 + (n_2 - 1) \sigma_2^2}{n_1 + n_2 - 2} \right)^{1/2}} \left(\frac{n_1 n_2}{n_1 + n_2} \right)^{1/2}$$

A T_c value was chosen to test the results. If the calculated T is less than T_c , there is probably no significant difference between the means. If the calculated T is larger than T_c , the two means are not necessarily different, but it provides a strong argument in favor of a difference.

A T_c value associated with the 95 percentile point was used in the comparison. This is equivalent to a 10% error for the "two-tail" problem of interest; that is, if 100 sets of response variables are to be compared, at least 90 sets would verify the conclusion and no more than 10 sets would not. Values of T_c are given in most statistical reference books as a function of degree of freedom ($DF = n_1 + n_2 - 2$) where, for our tests, n_1 is the number of tests with JP-4, and n_2 the number with JP-8.

The results of the statistical analysis for the two fuels are given in Tables I through V. Reference Appendix IV, which illustrates the inability to show a difference between means when that difference is small and only a limited number of tests are conducted.

2. TEST DESCRIPTION CODE

The following codes designate the items given under test conditions (a,b,c,d,e,f) in Tables I thru V.

- a = Fuel Type (4 = JP-4, 8 = JP-8)
- b = Fuel Temperature ($^{\circ}\text{F} \pm 5^{\circ}\text{F}$)
- c = Standoff Distance (inches) ex. 27 = 27 inches standoff front side
27B = 27 inches standoff back side
27H = 27 inches standoff front side
with hat section
- d = External air flow (Knots ± 10 knots)
- e = Air changes per minute in standoff (ACPM ± 2 ACPM)
- f = Initial fuel tank pressure (psia ± 2 psi)

3. ASSESSMENT OF RESULTS

The following discussion of the test results considers both the statistical information of Tables I thru V and other factors of the "real world" which could not be included in the statistical analysis.

a. Standoff Fire Duration (Table I)

From the "real world" point of view, it is possible for the Standoff Fire Duration to be dependent on the fuel type. Unfortunately, the total Standoff Fire Duration was unknown for several tests because the data camera ran out of film before the fire stopped. This occurred during 21 of 98 tests with JP-4 and 29 of 92 tests with JP-8, so about 1/4 of the input data indicated less than the actual standoff fire duration. With this limitation, the following general observations were made.

- a. At very low dry bay ACFM, the standoff fire duration for JP-8 was 2 to 5 times longer than for JP-4 (typically 350 vs 80 msec). JP-4 burns faster and thus depletes the available oxygen faster.

TABLE I
STANDOFF FIRE DURATION FOR JP-4 vs. JP-8 FUELS (MSEC)

No.	Test Description a b c d : f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T [*] _c	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
1	(-,90,9,0,0,20)	4	5	2211	61,627	71	310	27.9	1.68	1.90	
2	(-,90,9,90,0,20)	5	5	3724	8677	97	432	2.3	6.73**	1.86	
3	(-,90,9,90,23,20)	6	5	3190	436	312	279	7.3	1.24	1.83	
4	(-,90,9,90,96,20)	6	3	4217	1,318,169	207	1051	431.2	1.65	1.90	
5	(-,90,9,300,101,20)	6	6	9077	8103	239	262	1.1	0.43	1.81	
6	(-,90,91,300,325,20)	6	4	8200	554	163	65	14.8	2.53**	1.36	
7	(-,90,4,0,0,20)	6	6	35442	4116	252	403	8.6	1.87**	1.81	
8	(-,90,4,90,0,20)	5	6	4435	3975	75	330	1.1	6.50**	1.83	
9	(-,90,4,90,18,20)	5	4	18,404	8024	204	285	2.29	1.03	1.90	
10	(-,90,4,90,75,20)	3	4	3325	3,738,790	293	1333	1124	.91	2.02	
11	(-,90,4,300,58,20)	4	3	1304	4177	331	350	3.2	.51	2.02	
12	(-,50,4,300,180,20)	4	4	10,079	3,799,744	236	2580	3.77	2.40**	1.94	
13	(-,90,1,0,0,20)			Insufficient Data							
14	(-,90,1,90,0,20)			Insufficient Data							
15	(-,75,9,90,25,20)	2	2	6161	6845	257	378	1.1	1.50	2.92	

TABLE I (CONTINUED)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T_c^*	REMARKS
		JP 4	JP-8	JP-4	JP-8	JP-4	JP-8				
16	(-,90,9,90,23,15)	4	4	13,318	48,003	397	269	3.6	1.03	1.94	
17	(-,75,9,90,97,20)	3	2	2,473	13,945	249	380	5.6	1.80	2.35	
18	(-,90,9,90,97,15)	2	3	288	4,722	518	422	16.4	1.85	2.35	
19	(-,90,4,90,18,20)			Insufficient Data							10 PPI foam in standoff
20	(-,90,4,90,18,15)	3	3	56,785	176	169	477	322.0	2.24	2.13	10 PPI foam in tank
21	(-,90,0,90,0,20)	3	3		N/A						No standoff
22	(-,90,98,90,0,15)	3	3	0	0	0	0	U	U	2.13	9" standoff backside
23	(-,90,98,90,23,15)	3	3	0	0	0	0	U	U	2.13	9" standoff backside
24	(-,90,278,90,0,15)	3	3	0	8.3	0	1.7	U	1.00	2.13	27" standoff backside
25	(-,90,278,90,7,15)	3	2	50,181	45,000	129	150	1.1	.10	2.35	27" standoff backside
26	(-,90,278,90,33,15)	3	3	0	44,652	0	122	U	1.00	2.13	27" standoff backside
27	(-,90,27,90,0,15)	3	3	1,716	42,245	315	119	24.6	1.62	2.13	
28	(-,90,27,90,7,15)	3	3	34,961	35,557	215	217	1.02	0.02	2.35	
29	(-,90,27H,90,0,15)			Insufficient Data							27" standoff with hat section
30	(-,90,27H,90,4,15)			Insufficient Data							27" standoff with hat section

* T_c = T value at 25.0% (10% error - two tail)

** Values showing statistical differences

TABLE II
INCENDIARY BURN TIMES IN STANDOFF FOR JP-4 vs. JP-8 FUELS (MSEC)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T _c [*]	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
1	(-,90,9,0,0,20)	6	5	23	459	7	29	20.4	2.40 ^{**}	1.83	
2	(-,90,9,50,0,20)	6	5	306	437	22	52	1.4	2.66 ^{**}	1.83	
3	(-,90,9,90,23,20)	6	5	4	64	9	14	14.9	1.69	1.83	
4	(-,90,9,90,96,20)	6	4	125	0.7	21	7	186.9	2.48 ^{**}	1.86	
5	(-,90,9,300,101,20)	6	6	1	35	8	13	29.1	2.10 ^{**}	1.81	
6	(-,90,9,300,325,20)	6	4	89	234	20	27	2.6	.97	1.86	
7	(-,90,4,0,0,20)	6	6	82	37	32		2.2	4.61 ^{**}	1.81	
8	(-,90,4,90,0,20)	5	6	148	0.4	25	8	370.8	3.53 ^{**}	1.83	
9	(-,90,4,90,18,20)	5	5	17	2	10	7	7.9	1.42	1.86	
10	(-,90,4,90,75,20)	5	4	3	30	10	11	11	.22	1.90	
11	(-,90,4,300,58,20)	4	4	1	0.7	7	3	2	5.66 ^{**}	1.94	
12	(-,90,4,300,180,20)	4	4	5	16	9	15	3.2	2.43 ^{**}	1.94	
13	(-,90,1,0,0,20)	4	5	393	839	47	33	2.1	0.78	1.90	
14	(-,90,1,90,0,20)	3	4	86	0.7	12	2	127.5	2.14 ^{**}	2.02	
15	(-,75,9,90,23,20)	2	3	5	4	10	8	1.0	0.96	2.35	

TABLE II (CONTINUED)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T_c^*	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
16	(-,90,9,90,23,15)	4	4	2	3	10	8	1.6	1.44	1.94	10 PPI foam in standoff 10 PPI foam in tank
17	(-,75,9,90,97,20)	3	2	0.3	13	12	10	37.5	1.13	2.35	
18	(-,90,9,90,97,15)	3	3	2	4	7	8	1.9	0.22	2.13	
19	(-,90,4,90,18,20)			Insufficient Data							
20	(-,90,4,90,18,15)	3	3	2	1	7	8	2.3	.63	2.13	No standoff 9" S.O. backside 9" S.O. backside 27" S.O. backside 27" S.O. backside
21	(-,90,0,90,0,20)			N/A							
22	(-,90,98,90,0,15)	3	3	0	0	0	0	U	U	2.13	
23	(-,90,98,90,23,15)	3	3	0	0	0	0	U	U	2.13	
24	(-,90,278,90,0,15)	3	3	0.3	0.3	0.3	2	1.0	2.83**	2.13	27" standoff with hat section 27" standoff with hat section
25	(-,90,278,90,7,15)	3	2	7	.5	3	4	14	.25	2.35	
26	(-,90,278,90,33,15)	2	2	8	0	2	0	U	1.0	2.92	
27	(-,90,27,90,0,15)	3	3	1	19	7	5	14.3	0.90	2.13	
28	(-,90,27,90,7,15)	3	3	16	.3	4	4	49	00	2.13	27" standoff with hat section 27" standoff with hat section
29	(-,90,27H,90,0,15)			Insufficient Data							
30	(-,90,27H,90,4,15)			Insufficient Data							

* T_c = T value at 95.0% (10% error - two tail)

**Values showing statistical difference

TABLE III

INITIAL EXTERNAL FUEL SPRAY TIME FOR JP-4 vs. JP-8 FUEL (MSEC)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T_c^*	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
1	(-,90,9,0,0,20)	5	5	9,435	241,065	99	1,028	25.6	4.15**	1.86	
2	(-,90,9,90,0,20)	5	5	141,879	88,872	401	532	1.6	0.61	1.86	
3	(-,90,9,90,23,20)	3	2	25,541	242	219	316	105.5	.82	2.35	
4	(-,90,9,90,96,20)	6	4	10,178	25	126	34	407.1	1.80	1.86	
5	(-,90,9,300,101,20)	6	6	7,131	5,801	121	126	1.2	0.11	1.81	
6	(-,90,9,300,325,20)	6	4	25,902	684	121	103	37.9	.22	1.86	
7	(-,90,4,0,0,20)	6	6	50,244	187,793	309	587	3.7	1.40	1.81	
8	(-,90,4,90,0,20)	5	6	49,197	43,620	249	845	1.1	4.59**	1.83	
9	(-,90,4,90,18,20)	6	6	150	3,209	61	57	17.8	0.15	1.81	
10	(-,90,4,90,75,20)	5	4	3,930	9,559	86	191	2.4	1.97**	1.90	
11	(-,90,4,300,58,20)	4	2	321	0	39	22	U	1.23	2.13	
12	(-,90,4,300,180,20)	4	4	172	209	29	37	1.2	0.82	1.94	
13	(-,90,1,0,0,20)	4	5	1,444	523	19	35	2.8	0.78	1.90	
14	(-,90,1,90,0,20)	3	4	508	110,257	46	312	217	1.35	2.02	
15	(-,75,9,90,23,20)	1	3	U	148,933	234	763	U	U	2.92	

TABLE III (CONTINUED)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T _c *	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
16	(-,90,9,90,23,15)	4	1	2,798	U	276	604	U	U	2.35	10 PPI foam in standoff 10 PPI foam in tank
17	(-,75,9,90,97,20)	3	3	132,933	221,449	639	843	1.7	0.59	2.13	
18	(-,90,9,90,97,15)	2	2	20,808	1,976,072	552	2,026	95	1.48	2.92	
19	(-,90,4,90,18,20)	3	2	14,196	2,178	172	113	6.5	0.64	2.35	
20	(-,90,4,90,18,15)			Insufficient Data							
21	(-,90,0,90,0,20)	3	3	0	0	0	0	U	U	2.13	No standoff
22	(-,90,98,90,0,15)	3	3	0	0	0	0	U	U	2.13	9" standoff backside
23	(-,90,98,90,23,15)	3	3	0	0	0	0	U	U	2.13	9" standoff backside
24	(-,90,278,90,0,15)	3	3	0	0	0	0	U	U	2.13	27" standoff backside
25	(-,90,278,90,7,15)	3	2	0	0	0	0	U	U	2.35	27" standoff backside
26	(-,90,272,90,33,15)	3	3	0	0	0	0	U	U	2.13	27" standoff backside
27	(-,90,27,90,0,15)			Insufficient Data							
28	(-,90,27,90,7,15)			Insufficient Data							
29	(-,90,27H,90,0,15)			Insufficient Data							
30	(-,90,27H,90,4,15)			Insufficient Data							

*T_c = T value at 95.0% (10% error - two tail)

**Values showing statistical difference

TABLE IV
TIME TO MAXIMUM STANDOFF PRESSURE FOR JP-4 vs. JP-8 FUEL (MSEC)

No.	Test Description P C A C F	N		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T [*] T _C	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
1	(-90,0,0,0,20)	4	5	4,203	1,824	58	84	2.3	0.71	1.90	
2	(-90,5,90,0,20)	6	5	1,359	700	55	77	1.9	1.11	1.83	
3	(-90,9,90,20,20)	5	5	292	226	33	36	1.3	0.35	1.86	
4	(-90,9,90,96,20)	6	4	783	78	32	18	10.0	0.94	1.86	
5	(-90,9,300,101,20)	6	5	305	40	32	29	7.6	0.41	1.83	
6	(-90,9,300,325,20)	6	3	52	.33	35	26	157.2	2.00 ^{**}	1.90	
7	(-90,4,0,0,20)	6	4	78	6,967	27	76	89.3	1.48	1.86	
8	(-90,4,90,0,20)	3	2	3	41	20	27	13.5	1.81	2.35	
9	(-90,4,90,18,20)	6	5	1,353	105	58	101	12.9	2.52 ^{**}	1.83	
10	(-90,4,90,75,20)	5	4	927	329	83	44	2.8	2.27 ^{**}	1.90	
11	(-90,4,300,58,20)	4	4	9	461	58	82	53.2	0.53	1.94	
12	(-90,4,300,180,20)	4	4	1,622	2,444	57	71	1.5	0.42	1.94	
13	(-90,1,0,0,20)			Insufficient Data							
14	(-90,1,90,0,20)			Insufficient Data							
15	(-75,9,90,23,20)	2	3	545	91	48	40	6.0	0.53	2.35	

TABLE IV (CONTINUED)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T _C *	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
16	(-,90,9,90,23,15)	4	4	96	355	28	43	3.7	1.41	1.94	10 PPI foam in standoff 10 PPI foam in tank
17	(-,75,9,90,97,20)	3	3	17	9	53	47	1.9	1.91	2.13	
18	(-,90,9,90,97,15)	3	3	21	30	46	25	14.1	2.06	2.13	
19	(-,90,4,90,18,20)				Insufficient	Data					
20	(-,90,4,90,18,15)	3	3	14	2	37	35	6.1	0.57	2.13	
21	(-,90,9,90,0,20)	3	3		N/A						No standoff
22	(-,90,98,90,0,15)				Insufficient	Data					9" standoff backside
23	(-,90,98,90,23,15)				Insufficient	Data					9" standoff backside
24	(-,90,278,90,0,15)				Insufficient	Data					27" standoff backside
25	(-,90,278,90,7,15)	1	1	U	U	86	79	U	U	U	27" standoff backside
26	(-,90,278,90,33,15)	0	1	U	U	U	316	U	U	U	27" standoff backside
27	(-,90,27,90,0,15)	3	2	4,789	7,688	139	72	1.6	0.97	2.35	
28	(-,90,27,90,7,15)	2	3	1,250	5,200	103	77	4.2	0.46	2.35	
29	(-,90,27H,90,0,15)	2	3	1,152	6,480	147	177	5.6	0.48	2.35	27" standoff with hat section
30	(-,90,27H,90,4,15)	3	3	252	7,783	92	114	30.9	0.43	2.13	27" standoff with hat section

*T_C = T value at 95.0% (10% error - two tail)

**Values showing a statistical difference

TABLE V
MAXIMUM STANDOFF PRESSURE RISE FOR JP-4 vs. JP-8 FUEL (psf x 10)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		$\bar{r}$ Ratio	T	T_c^*	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
1	(-,90,9,0,0,20)	4	5	18,244	2,569	229	108	7.1	1.88	1.90	
2	(-,90,9,90,0,20)	6	5	18,653	1,115	231	102	16.7	2.05**	1.83	
3	(-,90,9,90,23,20)	6	5	370	1,299	54	82	1.49	1.43	1.83	
4	(-,90,9,90,96,20)	6	4	369	455	61	67	1.23	0.46	1.86	
5	(-,90,9,300,101,20)	6	5	82	325	64	56	4.0	0.87	1.83	
6	(-,90,9,300,325,20)	6	3	9,856	1,185	129	201	8.3	1.20	1.90	
7	(-,90,4,0,0,20)	6	6	21,473	3,076	250	119	7.0	2.05**	1.81	
8	(-,90,4,90,0,20)	5	6	31,889	1,088	137	744	29.3	0.10	1.83	
9	(-,90,4,90,18,20)	6	5	306	190	40	52	1.6	1.29	1.83	
10	(-,90,4,90,75,20)	5	4	2,129	1,276	64	71	1.7	0.25	1.90	
11	(-,90,4,300,58,20)	4	4	71	156	45	61	2.2	2.13**	1.94	
12	(-,90,4,300,180,20)	4	4	2,613	1,748	77	54	1.5	0.72	1.94	
13	(-,90,1,0,0,20)	3	4	17	259	5	18	14.9	1.37	2.02	
14	(-,90,1,90,0,20)	4	4	4	268	9	24	73.0	1.82	1.94	
15	(-,75,9,90,23,20)	2	3	1,800	709	102	57	2.5	1.49	2.35	

TABLE V (CONTINUED)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T _c *	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
16	(-90,9,90,23,15)	4	4	120	260	58	57	2.2	0.10	1.94	10 PPI foam in standoff 10 PPI foam in tank
17	(-75,9,90,97,20)	3	3	201	516	73	96	2.6	1.51	2.13	
18	(-90,9,90,97,15)	3	3	36	952	66	123	26.5	3.16**	2.13	
19	(-90,4,90,18,20)	3	3	9	0	3	0	U	1.89	2.13	
20	(-90,4,90,18,15)	3	3	1	9	11	15	7.0	2.47**	2.13	
21	(-90,0,90,0,20)	3	3		N/A					2.13	No standoff
22	(-90,98,90,0,15)	3	3	0	0	0	0	U	U	2.13	9" standoff backside
23	(-90,98,90,23,15)	3	3	0	33	0	3	U	1.00	2.13	9" standoff backside
24	(-90,278,90,0,15)	3	3	0	0	0	0	U	U	2.13	27" standoff backside
25	(-90,278,90,7,15)	3	2	1,412	26,912	24	116	19.1	1.02	2.35	27" standoff backside
26	(-90,278,90,33,15)	3	3	3	265	1	11	88.4	1.09	2.13	27" standoff backside
27	(-90,27,90,0,15)	3	3	69	1,669	337	27	24.1	12.89**	2.13	27" standoff with hat section 27" standoff with hat section
28	(-90,27,90,7,15)	2	3	613	50	117	17	12.2	7.05**	2.35	
29	(-90,278,90,0,15)	3	3	73,625	1,460	271	114	53.8	0.96	2.13	
30	(-90,278,90,4,15)	3	3	11,191	1,873	265	58	1.0	3.14**	2.13	

*T_c = T value at 95.0% (10% error - two tail)

**Values showing a statistical difference

b. At high dry bay ACPM, no clear difference exists between the two fuels, although as ACPM increases, the burn times generally tend to increase for both fuels.

b. Incendiary Burn Time in Standoff (Table II)

It was not expected that incendiary burn time would be a function of fuel type. Although the statistical results show cases where it appears significant, the direction of significance was mixed. Under five test conditions the incendiary burn time was significantly longer for JP-4, and under five other test conditions it was significantly longer for JP-8. These mixed results were most likely due to our inability to read the film properly and determine the difference between incendiary burn and fuel fire. Moreover, out of the 10 test conditions where significant difference in the means is seen, as evidenced by the larger T value, 8 also show a significantly larger F value, which explains the mixed results as being due to the masking effect of the variance. In other words, the significant difference in the means is well within the variability seen in the two distributions. Thus, the difference in the means cannot prove that either JP-4 or JP-8 affected the incendiary burn time.

c. Initial External Fuel Spray Time (Table III)

This factor was the time for the fuel to be seen on the external surface of the test article, as determined from film analysis. This time would be expected to be a function of the fire in the dry bay. At the very low dry bay ACPM, the initial external fuel spray time was significantly longer for JP-8 than for JP-4. This agrees with a previous conclusion, which showed that the fire duration for JP-8 was significantly longer at very low dry bay ACPM. At high ACPM, the spray time was independent of fuel type, although it tended to decrease for both fuels as ACPM increased and standoff distance decreased.

d. Time to Maximum Standoff Pressure (Table IV)

It is possible that the time to maximum standoff pressure is dependent on fuel type. Three cases show significance, but an evaluation of all cases as a whole does not prove a dependence on fuel type.

Of the 3 anomalous cases, two have a significantly larger F ratio. This explains the fact that the significant difference shown by the T value is masked by the corresponding F value.

e. Maximum Standoff Pressure Rise (Table V)

The maximum pressure in the dry bay was of major interest in the test program for assessing the difference between the two fuels. Eight cases show significance; in five of these, the higher pressures were obtained with JP-4. Data for these cases are as follows:

CASE No.	Test Description	Mean psi	
		JP-4	JP-8
2	(-,90,9,90,0,20)	23.1	10.2
7	(-,90,4,0,0,20)	25.0	11.9
11	(-,90,4,300,58,20)	4.5	6.1
18	(-,90,9,90,97,15)	6.6	12.3
20	(-,90,4,90,18,15)	1.1	1.5
27	(-,90,27,90,0,15)	33.7	2.7
28	(-,90,27,90,7,15)	11.7	1.7
30	(-,90,27H,90,4,15)	26.5	5.8

Case 20 may be eliminated because an overpressure of 1.5 psi should be within the capability of most aircraft structures. This case was a vapor shot with 10 PPI reticulated polyurethane foam in the fuel tank, and severe foam damage occurred during all three tests with JP-4; little foam damage occurred with JP-8. Of the remaining seven cases, JP-4 produced higher pressures in five, with a mean average overpressure of 18.7 psi, compared to 7.2 for JP-8.

Unfortunately, several cases had relatively high F values, which weakens the conclusion that JP-4 gives a statistically significant higher standoff pressure rise. Further analysis is required to resolve this.

Table VI presents the statistical results for the standoff overpressure for various combinations of the test conditions: Case 31 is a comparison of the two fuels for all test conditions. Case 32 considers all "Standard Tests" (i.e., all tests with the standoff on the front side, which excludes Cases 19 thru 26). Cases 33 through 37 are a breakdown of Case 32 by size of standoff.

Case 31 (all tests) shows that JP-4 having a higher overpressure than JP-8 is a significant result. Case 32 (Standard Tests) shows a significantly higher mean overpressure for JP-4, with only a 2.5% error possible, due to experimental chance. The remaining cases of Table VI indicated that for JP-4 the overpressure increased as the volume of the dry bay increased. This trend was not observed for JP-8.

TABLE VI
MAXIMUM STANDOFF PRESSURE RISE FOR JP-4 vs. JP-8 FUEL (psi x 10)

No.	Test Description a h c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T _c [*]	REMARKS
		JP-4	JP-8	JP-4	JP-8	JP-4	JP-8				
31	All Tests	126	112	13,780	5,590	99	73	2.47	1.99 ^{**}	1.65	Sign. at 2.5% error
32	Standard Tests only	105	91	14,395	5,424	118	85	2.65	2.25 ^{**}	1.65	
33	All 9" Standoff	55	42	9,094	7,996	113	104	1.14	.45	1.66	Front side only
34	All 4" Standoff	31	29	14,646	2,541	106	89	5.76	.69	1.67	Front side only
35	All 1" Standoff	8	8	16	234	6	21	14.6	2.64 ^{**}	1.76	Front side only
36	All 27" Standoff	5	6	14,818	716	249	22	20.7	4.48 ^{**}	1.83	Front side only
37	27" Standoff	6	6	35,939	2,285	268	86	15.7	2.28 ^{**}	1.81	Hat section on front

* T_c = T value at 95.0% (10% error - two tail)

** Value shows statistical difference

SECTION V

ANALYSIS OF TEST RESULTS

1. TEMPERATURE EFFECT ON STANDOFF OVERPRESSURE

An initial fuel temperature of 90°F was selected as the baseline temperature for the test program. The selection of this temperature was a trade-off between the most probable operational fuel temperature, and a temperature easily controlled in a test program. It is easier to heat fuel above ambient temperature than to cool it. In addition, we felt that the severity of the reactions for JP-8 would be less at lower temperatures, and those from JP-4 would be greater. To assess the effects that initial fuel temperature could have on the test results, we conducted several tests with both fuels at 75°F. The results of these tests are given in Table VII. There is no clear statistical evidence of the effect of fuel temperature on standoff overpressure for either fuel, although JP-4 tended to produce higher overpressures at the lower temperature. No trend was observed with JP-8.

2. TANK PRESSURE EFFECT ON STANDOFF OVERPRESSURE

A baseline initial fuel tank pressure of 20 psia was used during the first half of the program, based on the operational consideration that the positive pressure in the fuel tanks of most aircraft is in the range of 1-1/2 to 15 psi. About halfway through the test program, several tests were conducted at 15 psia and the results were compared, as shown in Table VIII. There is a clear indication that the standoff overpressure is not dependent on initial tank pressure for JP-4. Case 45 was significant, showing the lower initial tank pressure for JP-8 produced the higher standoff overpressure; case 44, however, indicated the reverse, although not at a significant level. Some unique cross-coupling between initial pressure and dry bay ACPM for JP-8 may have produced this result, although the test data was too limited to come to a definite conclusion. From an overall assessment of Table VIII, we conclude that no dependence of standoff overpressure on initial tank pressure was actually proven for either fuel. The second half of the program, however, was conducted at an initial fuel tank pressure of 15 psia.

TABLE VII

TEMPERATURE EFFECT ON MAXIMUM STANDOFF PRESSURE RISE (psi x 10)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T_c^{**}	REMARKS
		75°F	90°F	75°F	90°F	75°F	90°F				
38	(4,75,9,90,23,20) vs (4,90,9,90,23,20)	2		1800		102		2.07	1.84	1.94	
39	(4,75,9,90,96,20) vs (4,90,9,90,96,20)	3		201		73		1.83	0.92	1.90	
40	(8,75,9,90,23,20) vs (8,90,9,90,23,20)	3		709		57		1.83	1.03	1.94	
41	(8,75,9,90,96,20) vs (8,90,9,90,96,20)	3		516		96		1.13	1.73	2.01	
* T_c = T value - t 95.0% (10% error - two tail)											

TABLE VIII
INITIAL TANK PRESSURE EFFECT ON MAXIMUM STANDOFF PRESSURE RISE (psi x 10)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T _c *	REMARKS
		15 psia	20 psia	15 psia	20 psia	15 psia	20 psia				
42	(4,90,9,90,23,15) vs. (4,90,9,90,23,20)	4		120		58		7.25	0.26	1.85	
43	(4,90,9,90,97,15) vs. (4,90,9,90,97,20)	3		36		66		10.3	0.43	1.90	
44	(8,90,9,90,23,15) vs. (8,90,9,90,23,20)	4		260		57		5.0	1.29	1.90	
45	(8,90,9,90,97,15) vs. (8,90,9,90,97,20)	3		952		123		2.09	2.88**	2.01	

* T_c = T value at 95.0% (10% error - two tail)

** Value shows statistical difference

3. EXTERNAL AIRFLOW EFFECT ON STANDOFF OVERPRESSURE

The amount of external airflow over the test article was not expected to affect the overpressure in the standoff. Eight cases (46 - 53) where direct comparisons could be made are shown in Table IX. The statistical results verify the expected results; however, the external airflow was expected to affect the degree and type of fire outside the test article. As noted in the Remarks, all sustained external fires occurred with no external airflow. A complete list of test conditions which produced sustained external fires is given below:

<u>TEST DESCRIPTION</u>	<u>NO. OF SUSTAINED EXTERNAL FIRES</u>
(4,90,9,90,0,20)	1
(4,90,9,0,0,20)	3
(4,90,4,90,75,20)	1
(4,90,1,0,0,20)	3
(4,100,1,0,0,20)	1
(4,90,0,90,0,20)-(no standoff)	2
(4,90,27,90,0,15)	1
(4,90,27,90,4,15)	1
(4,90,27,90,7,15)	2
(8,90,27,90,0,15)	2

Sustained external fires were defined as having a duration of two seconds or longer. In most cases beyond two seconds, it was impossible to determine whether the fire was being sustained by the fuel of the test article or the fuel on the pad. When a sustained fire was noted, it was standard test procedure to increase the external airflow to about 200 knots and wait 30 seconds, which extinguished the fire in about 50% of the cases. In the remaining cases, the Fire Department extinguished the fire after about 5 minutes elapsed time with zero airflow.

Out of a total of 34 tests with no external airflow, 7 resulted in sustained external fires; of 174 tests conducted with 90 knots external airflow, 10 sustained external fires; of 6 tests conducted at 125 knots and 38 tests conducted at 300 knots external airflow, none sustained external fires. From this we concluded that the probability of sustained external fires occurring outside the test article was reduced as external

TABLE IX
EXTERNAL AIR FLOW EFFECTS ON MAXIMUM STANDOFF PRESSURE RISE (psi x 10)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)	MEAN ($\bar{X}$)		F Ratio	T	T [*] _C	REMARKS
46	(4,90,9,0,0,20) vs. (4,90,9,90,0,20)	4	6	18244	229	231	1.02	0.02	1.86	± S.E.F.** at 0 knots 0 S.E.F. at 90 knots
47	(4,90,9,90,96,20) vs. (4,90,9,300,101,20)	6	6	369	61	64	4.5	0.31	1.81	0 S.E.F. at 90 knots 0 S.E.F. at 300 knots
48	(4,90,4,0,0,20) vs. (4,90,4,90,0,20)	6	5	21473	250	137	1.49	1.16	1.83	0 S.E.F. at 0 knots 0 S.E.F. at 90 knots
49	(4,90,1,0,0,20) vs. (4,90,1,90,0,20)	3	4	17	5	9	4.7	1.66	2.01	3 S.E.F. at 0 knots 0 S.E.F. at 90 knots
50	(8,90,9,0,0,20) vs. (9,90,9,90,0,20)	5	5	2569	108	102	2.3	0.21	1.86	0 S.E.F. at 0 knots 0 S.E.F. at 90 knots

TABLE IX (CONTINUED)

No.	Test Description a b c d e f	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T_c^*	REMARKS
51	(8,90,9,90,96,20) vs. (8,90,9,300,101,20)	4		455		67		1.4	0.81	1.90	0 S.E.F. at 90 knots
			5	325		56					0 S.E.F. at 300 knots
52	(8,90,4,0,0,20) vs. (8,90,4,90,0,20)	6		3076		119		2.8	0.94	1.81	0 S.E.F. at 0 knots
			6	1088		144					0 S.E.F. at 90 knots
53.	(8,90,1,0,0,20) vs. (8,90,1,90,0,20)	4		259		18		1.0	0.48	1.94	0 S.E.F. at 0 knots
			4	268		24					0 S.E.F. at 90 knots

* T_c = T value at 95.0% (10% error - two tail)

** S.E.F. Sustained External Fire

airflow increased. It should be noted that out of a total of 133 tests with JP-4 fuel, 15 sustained external fires, whereas out of 119 tests with JP-8, only 2 sustained external fires.

4. EFFECT OF VOID SPACE AIR CHANGES PER MINUTE ON STANDOFF OVERPRESSURE

The ACPM in the standoff was varied over a wide range of test conditions for both fuels. Results indicated the following.

For zero ACPM, the void space was essentially a sealed container. For the tests with a positive ACPM, the void space was modified to accept ram air from the external airflow and to dump the exit air overboard. Figures 5, 6, and 7 show the resulting void space overpressure as a function of ACPM for both JP-4 and JP-8 in four different test articles. The case numbers are shown for reference to test conditions presented previously. Some of the plotted points are a combination of cases, since the test conditions were similar except for the external airflow, and this, as indicated previously, had little effect on overpressure.

After reviewing these figures and considering the standard deviation (σ), we determined that the conditions for the tests listed in Table X should be analyzed for statistical significance. Based on the information of Table X, we noted the following:

a. For JP-4 in the 9 inch standoff, there was a large decrease in overpressure at moderate ACPM (23 to 100) compared to that at zero ACPM. No positive comparative statement can be made for the high ACPM (325).

b. For JP-8 in the 9 inch standoff, there was a small decrease in overpressure at moderate ACPM (~100) compared to that at zero ACPM. The maximum overpressure occurred at the high ACPM (325).

c. In the 4 inch standoff, both JP-4 and JP-8 experienced a decrease in overpressure at moderate ACPM (18 to 180) compared to that at zero ACPM.

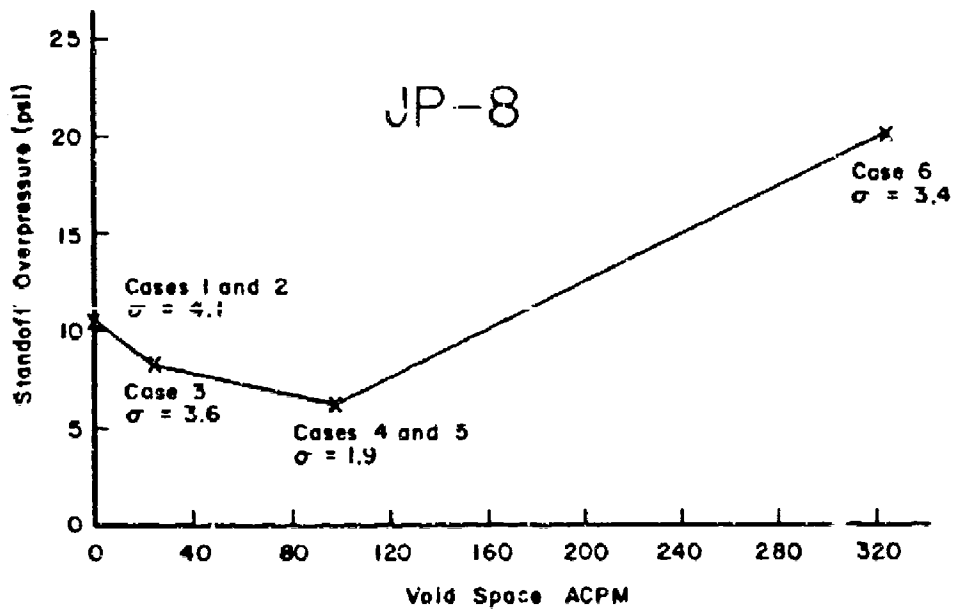
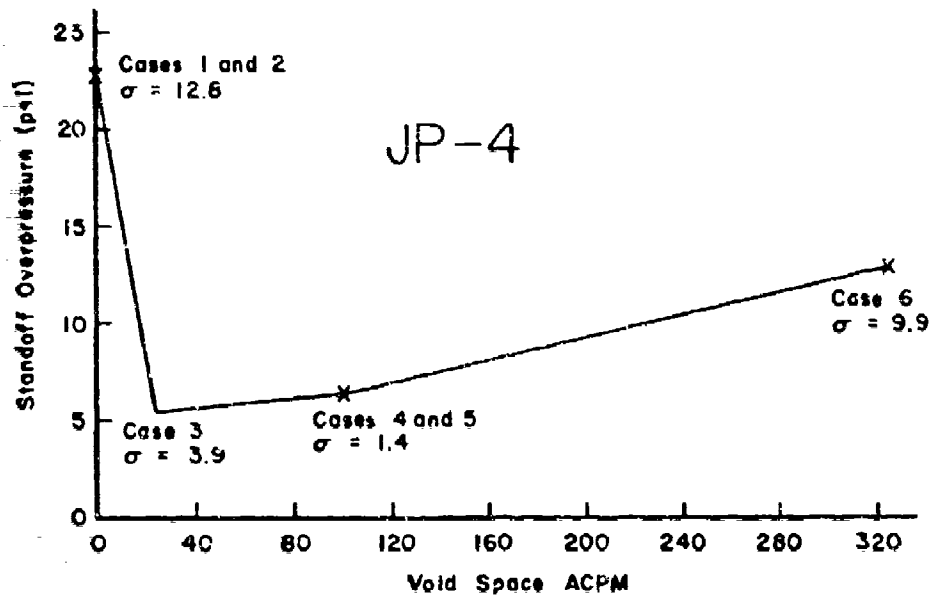


Figure 5. Overpressure vs. ACPM for JP-4 and JP-8 Fuels in 9-Inch Standoff

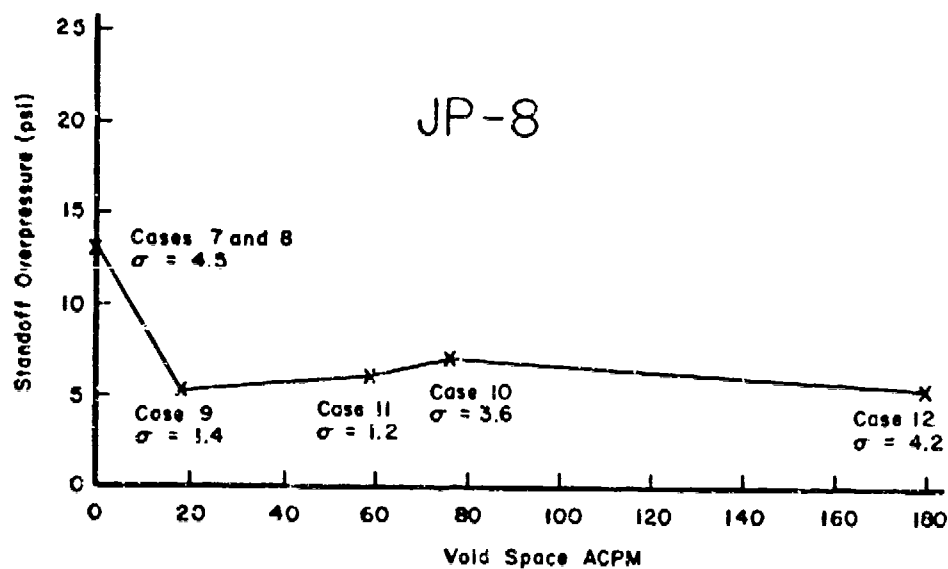
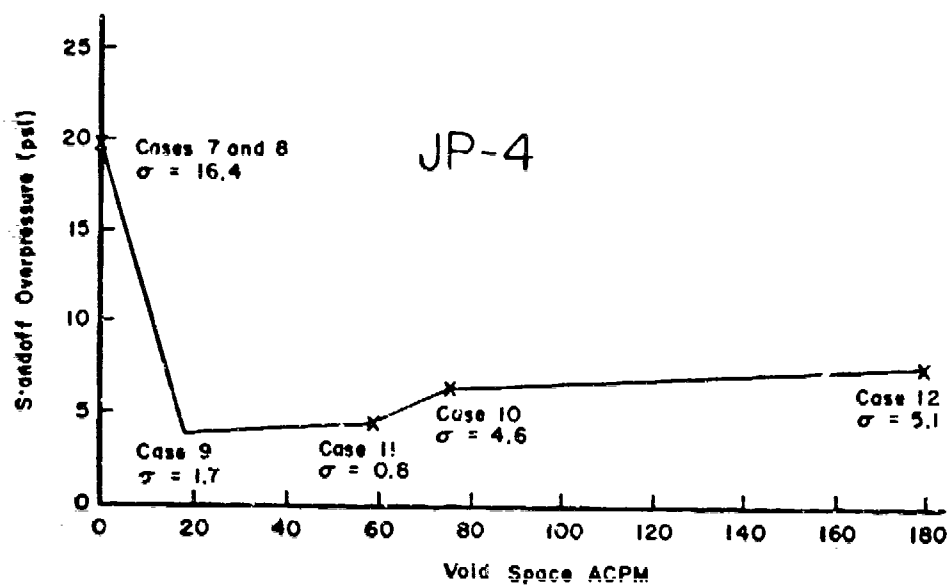


Figure 6. Overpressure vs. ACPM for JP-4 and JP-8 Fuels in 4-Inch Standoff

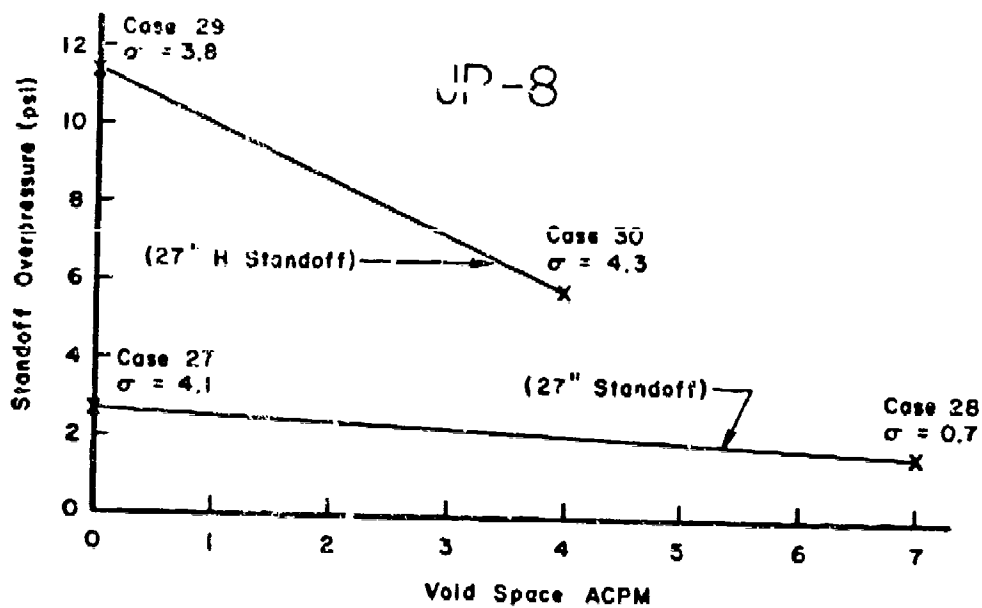
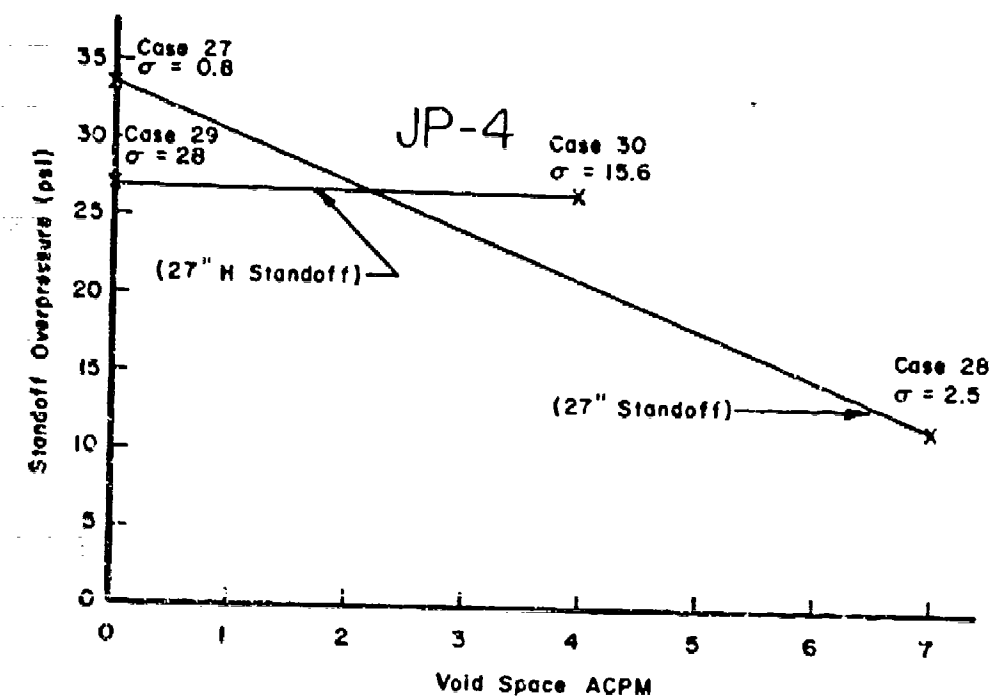


Figure 7. Overpressure vs. ACPM for JP-4 and JP-8 Fuels in 27-Inch and 27H Standoff

TABLE X
EFFECT OF ACPM ON MAXIMUM STANDOFF PRESSURE RISE
(psi x 10)

No.	Test Description	n		VARIANCE (σ^2)		MEAN ($\bar{x}$)		F Ratio	T	T _c *	REMARKS
54	JP4, Cases 1&2 vs 3	10	6	16446	870	231	54	18.9	3.28**	1.76	
55	JP4, Cases 1&2 vs 4&5	10	12	16446	207	231	62	79.4	4.53**	1.72	
56	JP4, Cases 1&2 vs 6	10	6	16446	9855	231	129	1.7	1.66	1.76	
57	JP8, Cases 1&2 vs 4&5	10	9	1649	364	105	61	4.5	2.96**	1.74	
58	JP8, Cases 1&2 vs 6	10	3	1646	1185	105	201	1.4	3.70**	1.80	
59	JP8, Cases 4&5 vs 6	9	3	364	1185	61	201	3.3	10.83**	1.81	
60	JP4, Cases 7&8 vs 9	11	6	26985	306	199	40	88.3	2.33**	1.75	
61	JP8, Cases 7&8 vs 9	12	5	2059	190	132	52	10.8	3.79**	1.75	
62	JP4, Case 27 vs 28	3	2	69	612	337	117	8.8	15.29**	2.35	
63	JP8, Case 29 vs 30	3	3	1460	1873	114	58	1.3	1.69	2.13	

*T_c = T value at 95.0% (10% error - two tail)

**Value shows statistical difference

d. In the 27 inch standoff, JP-4 experienced a large decrease in overpressure with small ACPM compared to that at zero ACPM, but in the 27 inch H Standoff experienced no difference between small ACPM and zero ACPM.

e. In the 27 inch and 27 inch H standoffs, JP-8 experienced no significant difference between zero ACPM and the small ACPM.

The foregoing statements apply to specific tank configurations and therefore are of little general value. We attempted to obtain more information by assuming that the amount of fuel entering the dry bay was to some degree independent of tank configuration, and that the volume of airflow in the dry bay determined the size of the flammability region and therefore the overpressure. Figure 8 gives the results of the effort and Table XI the statistical information. This analysis provided little additional insight, although it showed that at an airflow of 60 to 80 ft³/min, JP-4 reached a peak of overpressure whereas JP-8 hit a minimum. These airflows should be considered in any additional testing to determine the effect of airflow on dry bay overpressure.

5. DAMAGE POTENTIAL

Considering standoff overpressure as the critical parameter for comparing the two fuels was predicated on potential damage to the aircraft structure and danger of implosion of a fuel tank. In general, fuel tanks are designed to withstand a higher internal than external overpressure. Figure 9 was developed for the "Standard Test Conditions" to show the probability of a given overpressure or greater occurring as a function of overpressure. As may be seen, the probability of JP-4 is higher than for JP-8, particularly in the range of 10 to 40 psi. This figure, however, does not tell the complete story; the first step in arriving at a Total Damage Potential term requires that the probability distribution for the standoff overpressure for each fuel be established. Figure 10 gives the probability distribution developed from a histogram of the test data. By definition, the total probability must be unity, therefore the area for the two fuels must be equal.

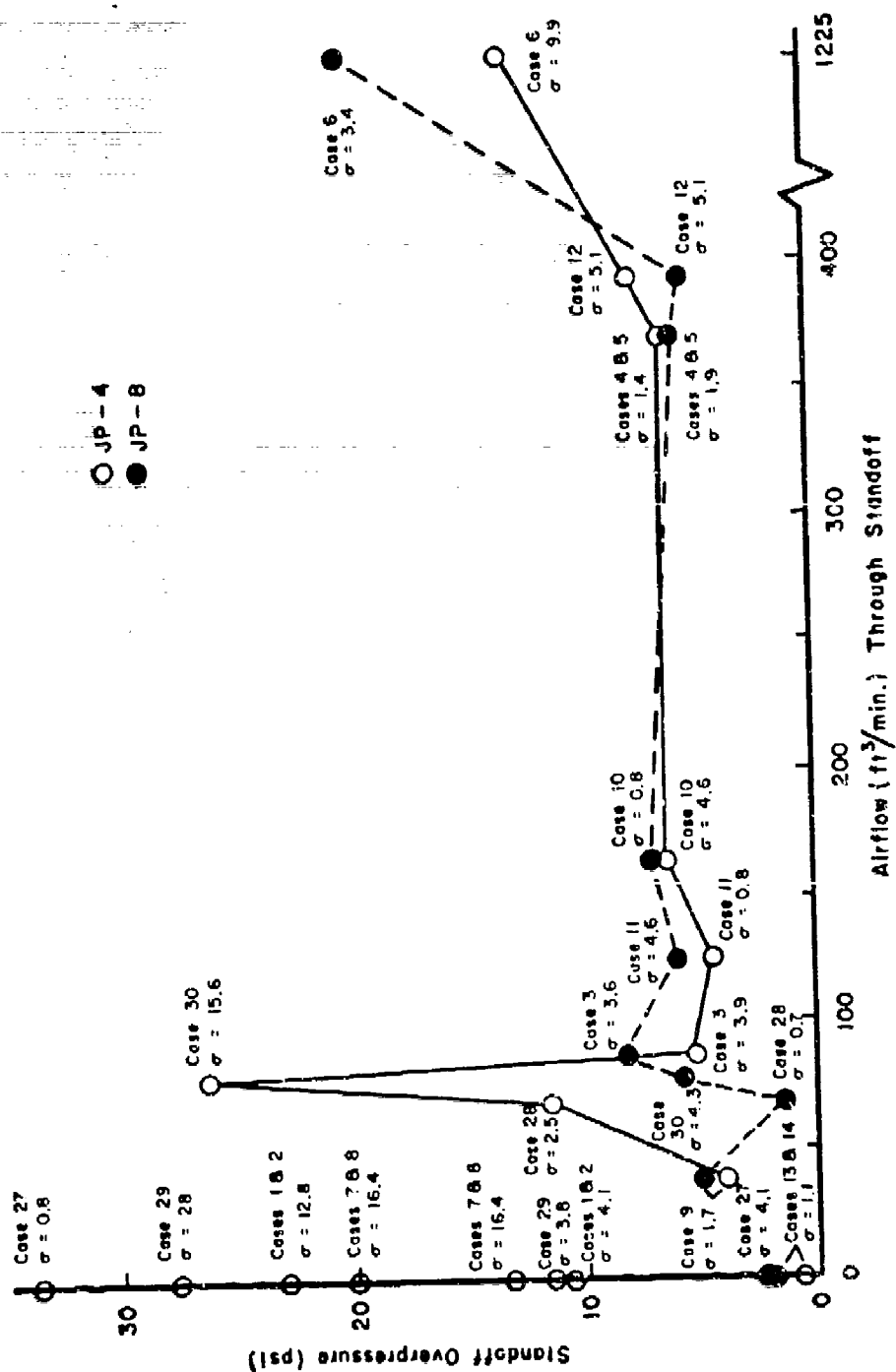


Figure 8. Overpressure vs. Air Flow in Standoff

TABLE XI
AIR FLOW EFFECT ON MAXIMUM STANDOFF PRESSURE RISE

No.	Test Description	n		VARIANCE (σ^2)		MEAN ($\bar{X}$)		F Ratio	T	T _c *	REMARKS
64	JP4, Cases 1&2 vs 7&8	10	11	16446	26985	231	199	1.6	0.77	1.73	
65	JP4, Cases 7&8 vs 13&14	11	7	26985	12	199	7	2285.	3.06**	1.75	
66	JP4, Cases 1&2 vs 27	10	3	16445	69	231	337	237.2	1.40	1.80	
67	JP4, Case 27 vs 29	3	3	69	78625	337	271	1134.	0.58	2.13	
68	JP4, Case 3 vs 9	6	6	870	306	54	40	2.9	1.04	1.81	
69	JP4, Case 9 vs 28	6	2	306	613	40	117	2.0	4.99**	1.94	
70	JP4, Case 28 vs 30	2	3	612	11191	117	256	18.3	1.86	2.35	
71	JP8, Cases 1&2 vs 7&8	10	12	1646	2059	105	132	1.3	1.44	1.72	
72	JP8, Cases 7&8 vs 13&14	12	8	2059	234	132	21	8.8	6.62**	1.74	
73	JP8, Cases 1&2 vs 27	10	3	1646	1669	105	27	1.0	3.41**	1.80	
74	JP8, Case 27 vs 29	3	3	1669	1460	27	114	1.1	3.82**	2.13	
75	JP8, Case 3 vs 9	5	5	1299	190	82	52	6.8	1.75	1.86	
76	JP8, Case 9 vs 28	5	3	190	50	52	17	3.8	3.96**	1.94	
77	JP8, Case 28 vs 30	3	3	1873	50	58	17	37.2	1.61	2.13	

*T_c = T value at 95.0% (10% error - two tail)

**Values show statistical difference

Since the force acting on a surface that tends to produce failure is proportional to the overpressure, a Damage Potential term ($DP_{\Delta P}$) may be defined for each overpressure. The point to be made here is that a high overpressure will result in more damage to the aircraft than a smaller overpressure. With this assumption, $DP_{\Delta P}$ was defined as $P_r \Delta P$, and the results are shown on Figure 11. A total Damage Potential may then be defined as a function of safe overpressure; the safe overpressure is dependent on the design of a particular tank and is defined as the pressure below which no damage occurs. The total Damage Potential (TDP) therefore is:

$$TDP = \sum_{\Delta P_{Safe}}^{\Delta P_{\infty}} DP_{\Delta P} \quad \text{or} \quad \sum_{\Delta f_{Safe}}^{\Delta P_{\infty}} P_r \Delta P$$

The results of this calculation are shown in Figure 12. JP-4 has a higher potential for damage than does JP-8, which was verified by the test article damage experienced during the test program.

The ratio of percentage of damage to the test article by JP-4 vs. that by JP-8, as given in Table XII, was 2.39. The ratio of area under the curves of Figure 12 for the two fuels was 2.45. The closeness of this comparison was somewhat surprising. Although there is no absolute measure for damage potential, these results should give a good relative measure for the two fuels.

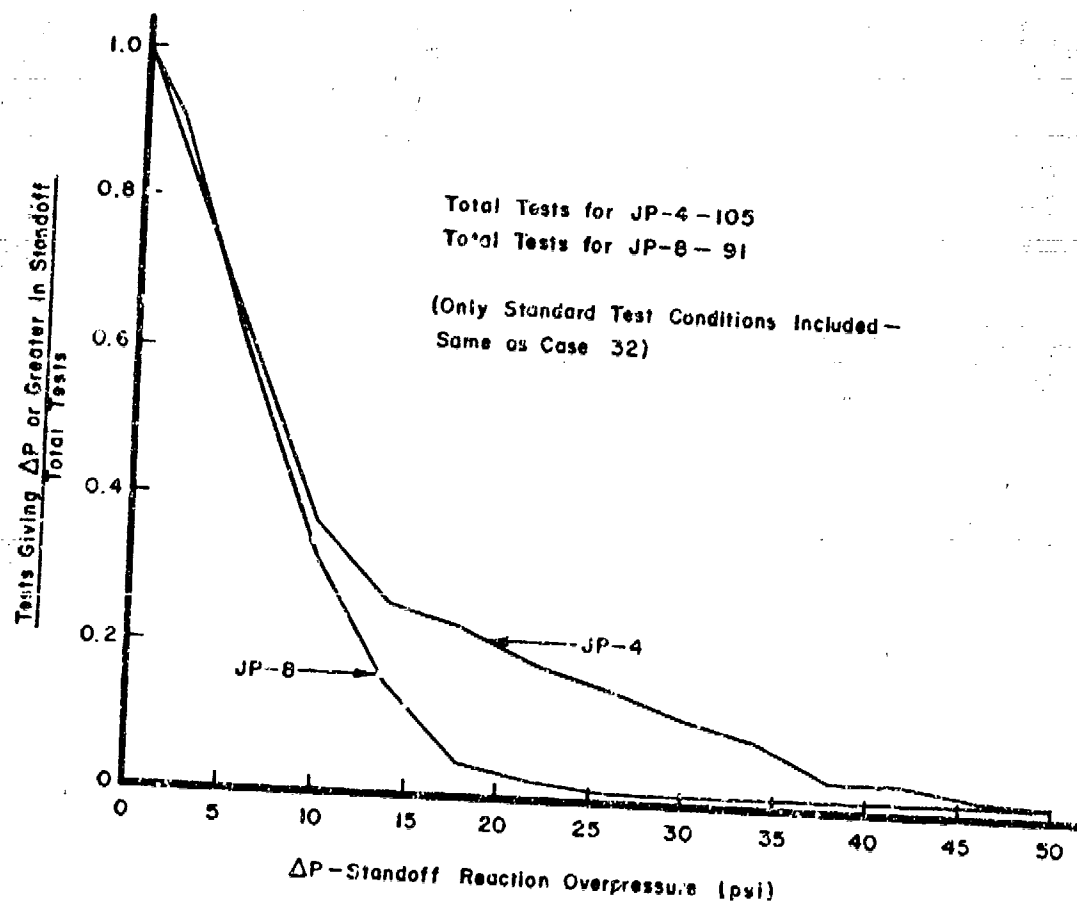


Figure 9. Probability of a Given Overpressure or Greater Occurring

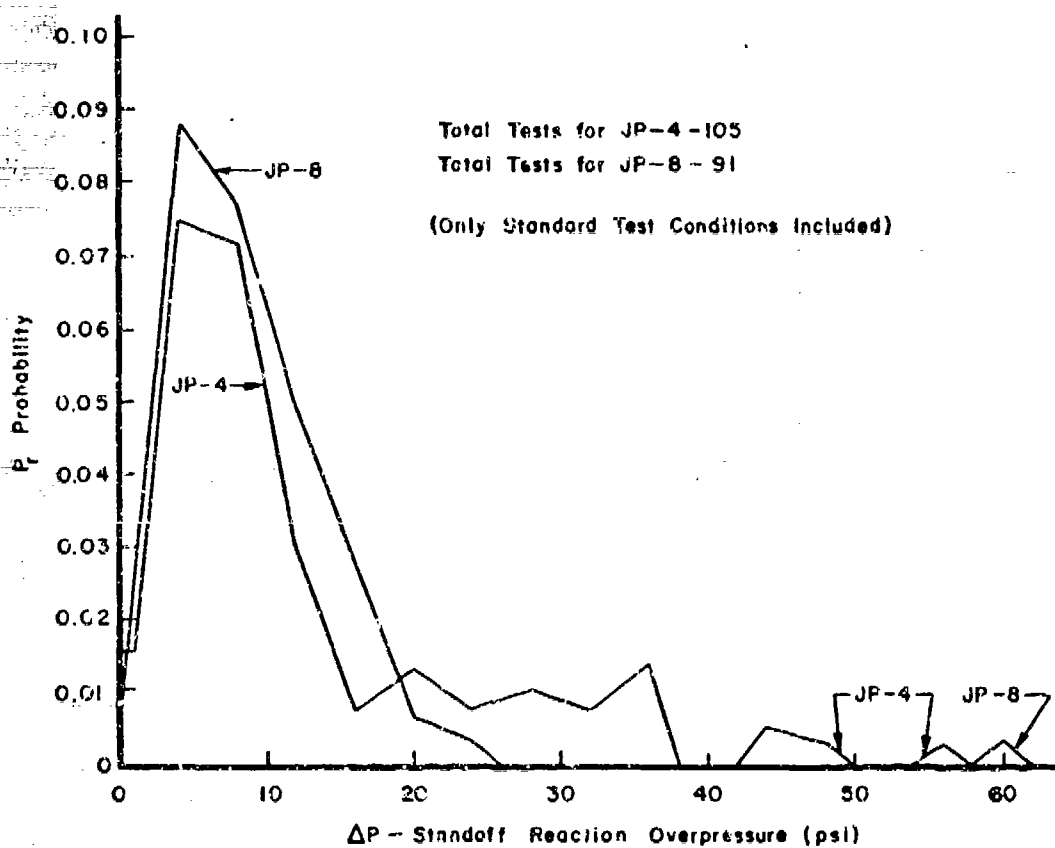


Figure 10. Probability Distribution for Standoff Overpressure

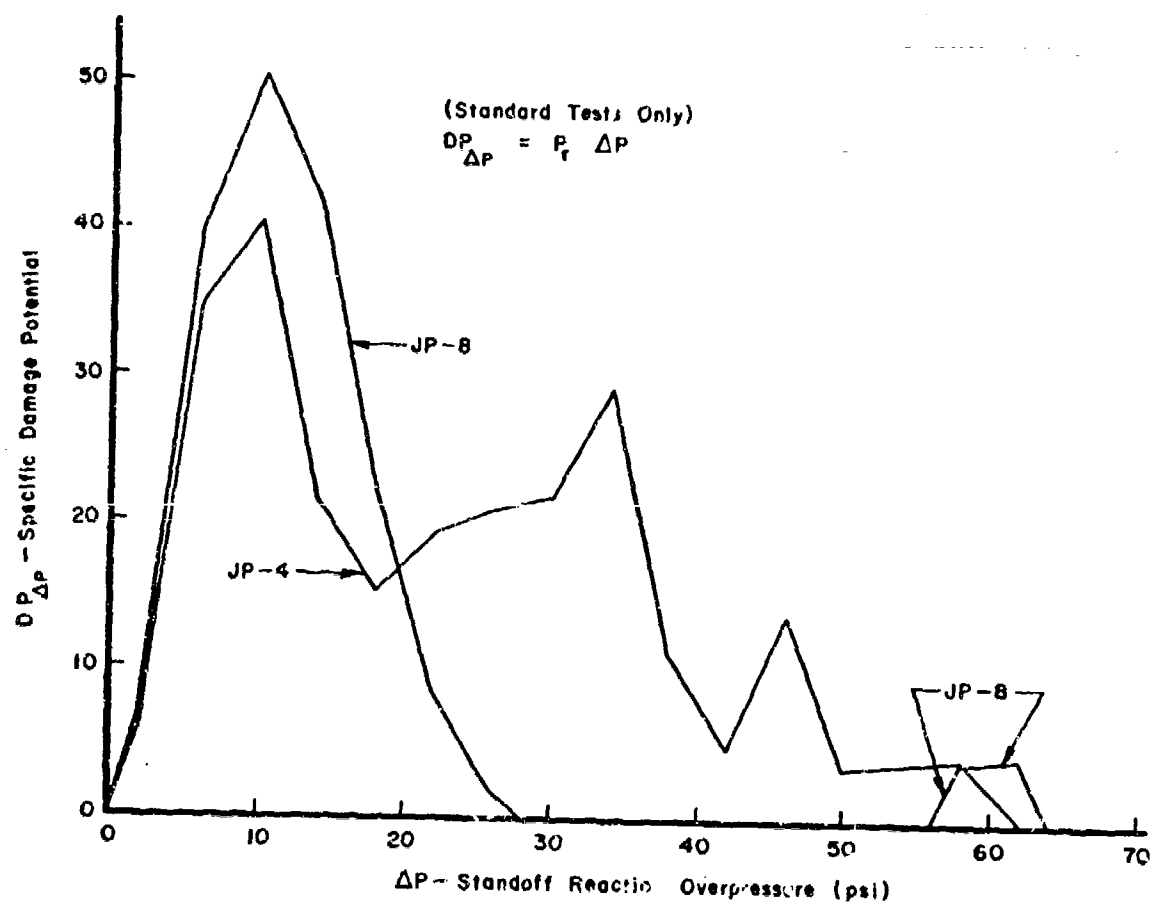


Figure 11. Specific Damage Potential for Each Standoff Overpressure

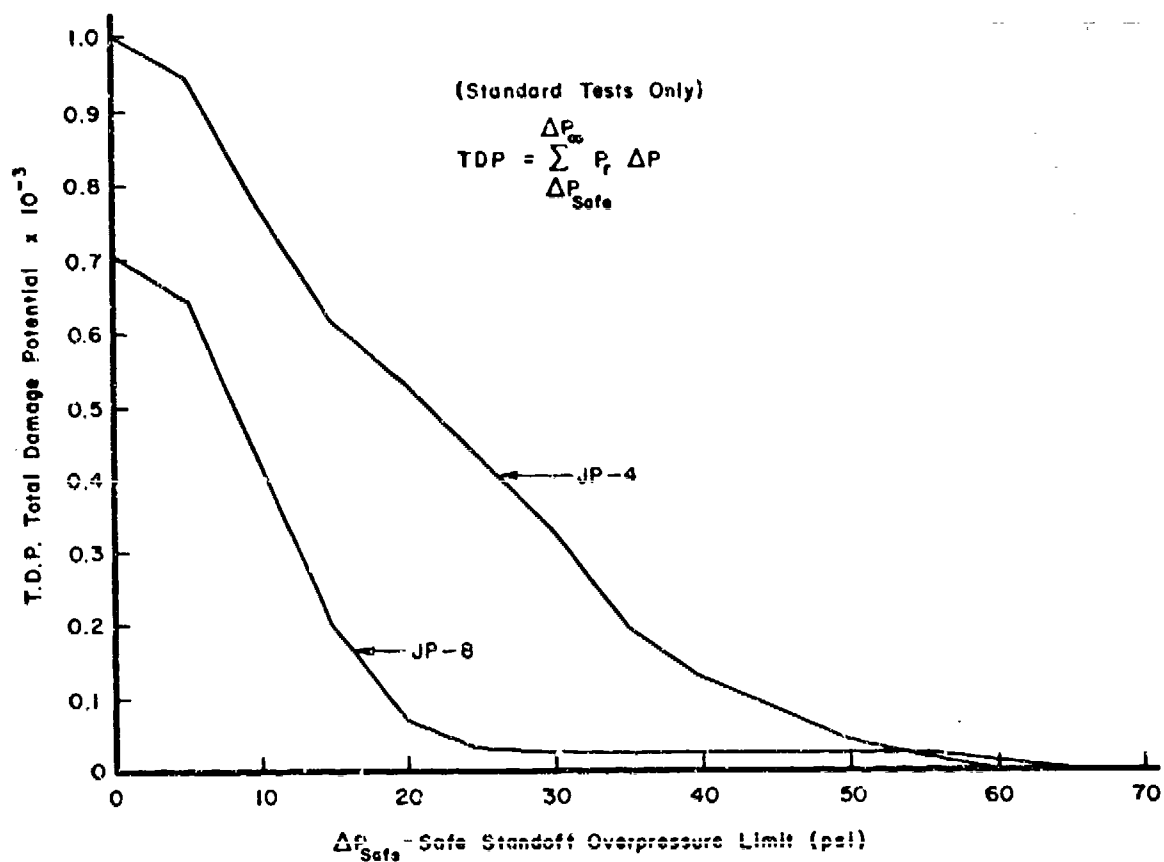


Figure 12. Total Damage Potential vs. Safe Standoff Overpressure Limit

6. OTHER FACTORS

Table XII summarizes results for factors not previously discussed. Of particular interest is that twice as many external flash fires occurred with JP-8 than with JP-4, whereas over six times as many sustained external fires occurred with JP-4.

Although all the test articles were constructed of heavy gauge steel and were designed for repeated gunfire testing, several failures did occur. There was a significantly larger number of tank failures associated with the JP-4 shots than with JP-8. These failures (16 with the JP-4 and 6 with JP-8) included blowing off the strike-plate, (which is equivalent to failure of the external skin of the aircraft), broken tank pressurization line, failure of the void space exhaust ventilation tube, and structural damage to the basic test article.

Another factor not discussed previously was the pressure rise in the fuel tank. No overpressure was observed for either fuel due to a fuel reaction inside the fuel tank; this was expected due to the design of the experimental program. This is not to say that no overpressures were measured in the fuel tank, but that the overpressures measured resulted from projectile dynamics and not from fuel reactions, as expected. The statistical results for the fuel tank overpressure are as follows:

	<u>JP-4</u>	<u>JP-8</u>
No. of Tests	105	89
Mean Overpressure (psi)	2.61	2.29
Variance (psi)	39.1	20.4
F ratio		1.91
T value		0.40

TABLE XII
SUMMATION OF RESULTS

	JP-8		JP-4	
	Test	%	Test	%
Total Number of Tests	119		133	
Tests With Unknown or Unrecorded External Fires	0	0.00	0	0.00
Tests That Result in No External Fire	102	85.71	110	82.71
Summation of Flash, And Flash And Pit Fires (Less Than 2 Seconds)	15	12.61	8	6.02
Summation of Sustained Fires, Delayed Fires, And Fires And Explosions	2	1.68	15	11.28
<u>Tests That Resulted in External Fires</u>				
Flash Fire (Less Than 2 Seconds)	15	12.61	8	6.02
Flash And Pit Fire	0	0.00	0	0.00
Delayed Fire	0	0.00	0	0.00
Fire And Explosion	0	0.00	0	0.00
Sustained Fire (Greater Than 2 Seconds)	2	1.68	15	11.28
<u>Tests That Resulted in Internal Fires</u>				
Unknown Internal Reaction	13	10.92	8	6.02
No Internal Reaction	17	14.29	18	13.53
Reaction In Fuel Tank Only	0	0.00	0	0.00
Reaction In The Entrance Standoff	83	69.75	105	78.95
Reaction In The Standoff + Fuel Tank	2	1.68	1	.75
Reaction In The Exit Standoff	4	3.36	1	.75
Reaction In The Exit Standoff + Fuel Tank	0	0.00	0	0.00
Test Article Damage	6	5.04	16	12.03

SECTION VI

CONCLUSIONS

1. At very low dry bay ACPM, the standoff fire duration was longer for JP-8 than for JP-4. There was no clear difference between the two fuels at high ACPM.
2. The incendiary burn time of the CAL .50 API was not affected by fuel type.
3. At very low dry bay ACPM, the time for the JP-8 fuel to be seen on the external surface of the test article was longer than for JP-4. At high ACPM the time was independent of fuel type.
4. The time to maximum standoff overpressure was independent of fuel type.
5. Thirty different sets of test conditions were evaluated for each fuel, and in 7 of these a significant difference occurred in the standoff overpressure between the two fuels. For these seven cases, JP-4 had a mean value of 18.7 psi as compared to 7.2 psi for JP-8.
6. For the "Standard Tests" (i.e., all tests with the standoff on the front side) JP-4 gave higher standoff overpressure than JP-8 at the 97.5% confidence level. The mean value was 11.8 psi for JP-4 and 8.5 psi for JP-8.
7. For the vapor shots with 10 ppi reticulated polyurethane foam in the fuel tank, severe foam damage occurred with all three JP-4 tests, whereas little damage occurred with the three JP-8 tests.
8. The effectiveness of 10 ppi reticulated polyurethane foam in the 4-inch standoff in preventing dry bay overpressure and fire was the same for both fuels.

9. The fire and dry bay overpressure conditions were more severe when the dry bay was located on the entrance side than on the exit side. This was true for both fuels. As the distance the projectile traveled in the fuel prior to impacting the exit dry bay increased, the amount of fire and overpressure decreased. During all tests in this program, maximum incendiary action occurred at initial projectile impact; therefore the vulnerability of exit dry bays requires additional investigation.

10. There was no clear statistical proof of the dependence of standoff overpressure on fuel temperature (75°F vs. 90°F) for either fuel, although a trend was indicated for JP-4 to produce higher overpressures at lower temperature.

11. No dependence of standoff overpressure on initial tank pressure (15 psia vs. 20 psia) was proven for either fuel.

12. Although some information was generated on the effect of dry bay ACPM on overpressure for specific test articles, no general conclusions were established.

13. An analysis of the standoff overpressures showed that, on the average, the damage potential of JP-4 was 2.45 times that of JP-8. Actual test article damage experience during the test program resulted in a value of 2.39.

14. Sustained external fires occurred in 11.28% of the tests with JP-4 and in only 1.68% for JP-8.

15. The general conclusion of this program was that JP-8 is less susceptible to fire and explosion induced by gunfire and structural damage should be less than that with JP-4. Many other factors, however, must be considered in the determination of the overall desirability of JP-8. A report on this subject is planned for the near future.

APPENDIX I

TEST RESULTS

The following codes were used in the test results given in this appendix.

<u>CODE</u>	<u>DEFINITION</u>
2	TYPE OF TEST
2	STATIC TEST WITH AIR VELOCITY (FAA TEST)
	TYPE OF FUEL
400	JP4
800	JP8 (118 DEG FLASH)
	TANK TYPE
30	FAA TANK-30 GAL (27 IN. STANDOFF AT ENTRANCE)
31	FAA TANK-30 GAL (27 IN. STANDOFF AT EXIT)
32	FAA TANK-30 GAL (27 IN. STANDOFF AT ENTRANCE WITH 10 CU. FT. HAT SECTION)
80	FAA TANK-80 GAL (9 IN. STANDOFF AT ENTRANCE)
81	FAA TANK-80 GAL (9 IN. STANDOFF AT EXIT)
106	FAA TANK-106 GAL (4 IN. STANDOFF AT ENTRANCE)
130	FAA TANK-130 GAL (1 IN. STANDOFF AT ENTRANCE)
135	FAA TANK-135 GAL (NO DRY BAY)
	TRAJECTORY PHASES
11	VAPOR
22	LIQUID
	SECOND TEMPERATURE
	TYPE 2 TEST - AMBIENT AIR TEMPERATURE
	FUEL AND SECOND TEMPERATURE
*	INDICATES TEMPERATURE APPROXIMATE
	STRIKER PLATE TYPE
42	2024-T3 ALUMINUM
73	2024-T3 ALUMINUM + 10PPI EXTERNAL FOAM
	PROJECTILE TYPE
53	50 CAL. API
	PROJECTILE VELOCITY
*	INDICATES VELOCITY APPROXIMATE
	TANK FILLER
100	NONE
200	R.P. FOAM 10 PPI

<u>CODE</u>	<u>DEFINITION</u>
	EXTERNAL FIRE TYPES (FIRE TYPE)
1	NO FIRE
2	FLASH FIRE (LESS THAN 2 SECONDS)
3	SUSTAINED FIRE
4	DELAYED FIRE
5	FLASH AND PIT FIRE
6	FIRE AND EXPLOSION
7	UNKNOWN REACTION
	INITIAL TANK PRESSURE (PSIA)
-1	INDICATES UNKNOWN INITIAL TANK PRESSURE
	MAIN TANK PRESSURE RISE (PSI)
-1	INDICATES UNKNOWN PRESSURE RISE
	TIME TO MAXIMUM PRESSURE RISE MAIN TANK (SECONDS x 100)
	INDICATES UNKNOWN TIME TO MAXIMUM PRESSURE RISE
	INTERNAL REACTION (INT REA)
1	UNKNOWN REACTION
2	NO REACTION
3	FUEL TANK REACTION
4	ENTRANCE STANDOFF REACTION
5	ENTRANCE STANDOFF & FUEL TANK REACTION
6	EXIT STANDOFF REACTION
7	EXIT STANDOFF & FUEL TANK REACTION
8	LARGE SUSTAINED FIRE (GREATER THAN 2 SECONDS)
	CRITERIA I
-1	INDICATES UNKNOWN CRITERIA VALUE
	INCENDIARY FUNCTION
1	STANDOFF (YES) TANK (YES) EXTERNAL (YES)
2	STANDOFF (YES) TANK (YES) EXTERNAL (NO)
3	STANDOFF (YES) TANK (NO) EXTERNAL (YES)
4	STANDOFF (YES) TANK (NO) EXTERNAL (NO)
5	STANDOFF (NO) TANK (NO) EXTERNAL (NO)
6	STANDOFF (NO) TANK (NO) EXTERNAL (YES)
7	STANDOFF (NO) TANK (YES) EXTERNAL (NO)
8	STANDOFF (NO) TANK (YES) EXTERNAL (YES)
9	NO STANDOFF TANK (NO) EXTERNAL (YES)
	SPECIAL TEST CONDITIONS
2	STATIC TEST WITH AIR FLOW
	ULLAGE ATMOSPHERE
21	NORMAL AIR
	CRITERIA II
-1	INDICATES UNKNOWN CRITERIA VALUE
	STANDOFF FIRE DURATION (MILLISECONDS)

<u>CODE</u>	<u>DEFINITION</u>
	CRITERIA III
-1	INDICATES UNKNOWN CRITERIA VALUE INCENDIARY BURN TIME (MILLISECONDS)
	CRITERIA IV
-1	INDICATES UNKNOWN CRITERIA VALUE INITIAL EXTERNAL FUEL SPRAY TIME (MILLISECONDS)
-3	NO INITIAL EXT. FUEL SPI. AY
	CRITERIA V
-1	INDICATES UNKNOWN CRITERIA VALUE TIME TO MAXIMUM STANDOFF PRESSURE RISE (MILLISECONDS)
	CRITERIA VI
-1	INDICATES UNKNOWN CRITERIA VALUE MAXIMUM STANDOFF PRESSURE RISE (PSI x 10)
	CRITERIA VII
-1	INDICATES UNKNOWN CRITERIA VALUE SECONDARY STANDOFF PRESSURE RISE (PSI x 10)
	CRITERIA VIII
-1	INDICATES UNKNOWN CRITERIA VALUE TIME TO SECONDARY STANDOFF PRESSURE RISE (MILLISECONDS)
	CRITERIA IX
-1	INDICATES UNKNOWN CRITERIA VALUE VOID SPACE AIR CHANGES (CHANGES/MIN)
	CRITERIA X
-1	INDICATES UNKNOWN CRITERIA VALUE AIR VELOCITY (FT/SECOND)

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TEST CONDITIONS AND RESULTS

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WELD CRACKED AT BOTTOM OF TANK, PROBABLY WEAKED BY PRESSURE RISE IN TEST 37

02/16/72		TEST		TYPE		FUEL		TANK		FILL		PRESS		TIME		INT		CRIT		X	
NO	TEST	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE
NO	TEST	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE
61	2	400	170	98.0	42	215	1.00	30	53	2400*	100	2	20.0	.8	-1	4	3				
61	2	-1	21	16	5*	-1			10	0	0	0	10.0	0	0	152					
62	2	400	170	98.0	42	215	1.00	30	53	2400*	100	1	20.0	.4	-1	4	-1				
62	2	-1	21	-1	-1	-1			9	0	0	0	10.0	0	0	152					
63	2	400	170	98.0	42	215	1.00	30	53	2400*	100	1	20.0	0.0	-1	4	1				
63	2	-1	21	1	60	-1			13	0	0	0	10.0	0	0	152					
64	2	400	170	98.0	42	215	1.00	30	53	2400*	100	2	20.0	.5	-1	1	3				
64	2	-1	21	16	74	-1			39	0	0	0	10.0	0	0	0					
65	2	400	170	98.0	42	215	1.00	30	53	2400*	100	1	20.0	.4	-1	4	3				
65	2	-1	21	16	60	-1			4	0	0	0	10.0	0	0	0					
66	2	400	170	98.0	42	215	1.00	30	53	2400*	100	2	20.0	.4	-1	1	3				
66	2	-1	21	70	76	-1			24	0	0	0	10.0	0	0	0					
67	2	400	170	98.0	42	215	1.00	30	53	2400*	100	2	20.0	-1.0	-1	4	3				
67	2	-1	21	70	0	-1			-1	0	0	0	10.0	0	0	0					
68	2	400	170	98.0	42	215	1.00	30	53	2400*	100	1	20.0	0.0	-1	4	3				
68	2	-1	21	94	64	-1			6	0	0	0	10.0	0	0	0					
69	2	400	170	98.0	42	215	1.00	30	53	2400*	100	1	20.0	.4	-1	4	3				
69	2	331*	21	7	705	-1			39	0	0	0	10.0	0	0	152					
70	2	400	170	98.0	42	215	1.00	30	53	2400*	100	1	20.0	.4	-1	4	1				
70	2	271	21	1	132	-1			24	0	0	0	10.0	0	0	152					

* STANDOFF PRESSURE LINE BLOWN OFF ON PREVIOUS SHOT

TEST NO	TEST TYPE	FUEL TANK	FUEL TANK	TEMP	ICND	STOVEP	PLATE	(PROJECTILE)	FILL	FIRE	TANK	PRESS	TIME	INT	CRIT	SEE
NO	TEST TYPE	TYPE	TYPE	PHASE	FUEL	THICK	THICK	ANGLE	(TYPE)	(WEL)	(PSIA)	(PSI)	(S+100)	MAX	P	REA
TEST NO	SPEC	CRIT	ULL	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT
NO	TEST	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE
91	2	400	40	60.0	22	90*	72	62	.215	9.00	70	53	2400*	100	1	20.0
91	2	411	21	16	76	24						64	0	0	0	18.0
92	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
92	2	415	21	6	42	20						74	0	0	0	18.0
93	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
93	2	402	21	0	156	23						70	0	0	0	18.0
94	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
94	2	412	21	8	72*	64						64	0	0	0	18.0
95	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
95	2	413	21	8	204	76						44	0	0	0	18.0
96	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
96	2	414	21	6	54	23						66	0	0	0	18.0
97	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
97	2	410	21	8	44	25						60	0	0	0	18.0
98	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
98	2	417	21	8	176	14						74	0	0	0	18.0
99	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
99	2	411	21	16	722	30						56	0	0	0	18.0
100	2	400	40	60.0	22	90	46*	62	.215	9.00	70	53	2400*	100	1	20.0
100	2	414	21	26	40	70						66	0	0	0	18.0

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TEST NO	SPEC CONT ULL	FUEL TANK VOL	TEST TYPE	TYPE	CRIT V	CRIT W	(VIBRATION)	(SLOSH)	CRIT VI	CRIT VII	FILL TYPE	FIRE TYPE	TANK DEPTH	PRESS RISE	TIME MAX P	INT CRIT I	* SEE DATA SHEET
							(CPM) (IN) (DEG)	(PREQ AMO) (PREQ ANG) (COM) (DEG)			(FPS)		(IN)	(PSIA) (PSI)(S*100)			
131	2 900 106 80.0	72	70	60*	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3
131	2 106 21	0	K	24					73	C	0		10.0		10	152	
132	2 900 106 80.0	72	95	60*	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3
132	2 270 21	6	26	101					54	0	0		14.0		10	152	
133	2 900 106 80.0	72	90	60*	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3 *
133	2 40* 21	7	34	114					44	C	0		18.0		10	152	
* FLAMES SHOT OUT EXHAUST PIPE DUE TO STANDOFF FIRE																	
134	2 900 106 80.0	72	87	67	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3
134	2 277 21	7	22	117					56	0	0		11.0		50	507	
135	2 900 106 80.0	72	93	67	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3 *
135	2 375+ 21	4	-1	77					46	0	0		18.0		50	507	
* LEAK IN TANK																	
136	2 900 106 80.0	72	95	67	42	.215	4.00 30		53	2400*	100	1	20.0	.4	-1	4	3
136	2 -1 21	7	22	74					44	0	0		19.0		50	507	
137	2 900 106 80.0	72	90	61	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3 *
137	2 370+ 21	2	-1	57					74	0	0		18.0		50	507	
* FIRE IN STANDOFF CONTINUED AFTER ENGINE SHUTDOWN, EXTINGUISHED ITSELF																	
138	2 900 106 80.0	72	90	64	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3 *
138	2 275 21	6	200	26					24	0	0		18.0		75	152	
* BAD LEAK IN TANK																	
139	2 900 106 80.0	72	90	60	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3
139	2 412+ 21	0	50	30					111	36	30		14.0		75	152	
140	2 900 106 80.0	72	90	60	42	.215	4.00 30		53	2400*	100	1	20.0	0.0	-1	4	3
140	2 415+ 21	11	256	56					74	0	0		14.0		75	152	

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02/16/72		*****																				*****	
TEST	TYPE	FUEL	TANK	FUEL	TANK	FILL	FIRE	TANK	PRESS	TIME	INT	CRIT	SEE				DATA						
NO	TEST	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	TYPE	SHEET										
		*****															*****						
TEST	CODE	CRIT	ULL	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT	CRIT				X						
NO	TEST	II	ATON	II	IV	W	VI	VII	VIII	IX	X	X											
		*****															*****						
253	2	400	12	21.0	22	45	45	42	215	27.00	10	53	2400	100	1	15.0	22.4	11	1	-1			
253	2	-1	21	-1	-1	46	155	0	0	0	16.0	4											
254	2	400	12	21.0	22	45	64	62	215	27.00	10	53	2400	100	1	15.0	31.2	11	1	-1			
254	2	-1	21	-1	-1	49	365	0	0	0	14.0	4											

APPENDIX II

POSSIBLE CONTAMINATION OF JP-8
TEST BY PREVIOUS JP-4 TEST

Although it was standard procedure to completely wash the test article with water between tests to remove all fuel and fuel vapor, it was of concern that the first shot in a JP-8 test series may in some way be contaminated by the previous JP-4 test series. To investigate this possibility, the standoff pressure rise of several "first shots" of a JP-8 series which were preceded by a JP-4 shot was compared to the standoff pressure rise of the "last shots" of the several JP-8 series of interest. The results of the analysis is shown by Table XIII. Since no significance is shown, we concluded that the JP-8 tests were not contaminated by previous JP-4 tests and the water wash was sufficient.

TABLE XIII

MAXIMUM STANDOFF PRESSURE OF
FIRST VERSUS LAST JP-8 SHOT OF A SERIES

First Test		Last Test	
Test No.	Pressure Rise (psi X 10)	Test No.	Pressure Rise (psi X 10)
13	167	18	27
25	87	30	113
43	44	48	76
64	38	68	6
80	40	85	58
128	32	133	48
163	32	168	48
Variance	2515	1181	
Mean	62	54	
F Ratio - 2.1		T Value - 0.43 T_c - 1.78	

APPENDIX III

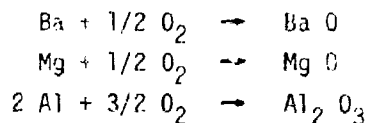
OXYGEN DILUTION DUE TO INCENDIARY FUNCTIONING

The projectile velocity, impact angle, and strike plate thickness were determined by tests to provide maximum functioning in the dry bay of the incendiary mix associated with the CAL .50 API. This was done to provide the "biggest match" possible for fuel ignition in the dry bay. Since the incendiary is fuel rich, some oxygen in the dry bay may enter into the reaction. In addition, the products of the reaction may tend to dilute the oxygen concentration. If the oxygen concentration is reduced to below 12% by volume, no fuel reaction can be expected (Reference 4). The following analysis addresses these questions as a first approximation, and the results are presented in Figure 13. As may be seen in this figure, all the test articles and associated dry bays used in this program should have had sufficient oxygen to support a fuel reaction. This figure gives minimum values of O_2 remaining, and since only a small part of the incendiary reacts in the dry bay, the results are conservative. The following calculations were used to develop Figure 13.

The incendiary mix, IM-11, of the CAL .50 API weights 1.0 gram and has the following composition:

50% by weight Ba $(NO_3)_2$
 25% by weight Mg
 25% by weight Al

For complete combustion of the incendiary mix the following reaction must be considered:



Gram Moles initially present in 1.0 gm of incendiary

$$\frac{.5 \text{ gms. Ba (NO}_3)_2}{261.3 \text{ gms./gm. mole Ba (NO}_3)_2} = 1.92 \times 10^{-3} \text{ gm moles Ba (NO}_3)_2$$

$$\frac{.25 \text{ gms. Mg}}{24.3 \text{ gms./gm mole Mg}} = 1.027 \times 10^{-2} \text{ gm moles Mg}$$

$$\frac{.25 \text{ gms. Al}}{26.98 \text{ gms./gm mole Al}} = 0.927 \times 10^{-2} \text{ gm moles Al}$$

gm moles O_2 present in 0.5 gm of $Ba(NO_3)_2$

$$\frac{3 \text{ moles } O_2}{1 \text{ mole Ba (NO}_3)_2} \times 1.92 \times 10^{-3} \text{ gm moles Ba (NO}_3)_2 = 5.76 \times 10^{-3} \text{ gm moles } O_2$$

gm moles N_2 present in 0.5 gm of $Ba(NO_3)_2$

$$\frac{1 \text{ mole } N_2}{1 \text{ mole Ba (NO}_3)_2} \times 1.92 \times 10^{-3} \text{ gm moles Ba (NO}_3)_2 = 1.92 \times 10^{-3} \text{ gm moles } N_2$$

Total gm moles O_2 required for complete reaction

Ba requires	.00096	gm moles O_2
Mg requires	.00513	gm moles O_2
Al requires	.00695	gm moles O_2
	<u>.01304</u>	Total gm moles O_2 required

Total gm moles of additional O_2 required from the air

$$\begin{array}{rcl} .01304 & \text{total gm moles } O_2 \text{ required} & \\ - .00576 & \text{gm moles } O_2 \text{ existing in mix} & \\ \hline .00728 & \text{additional gm moles } O_2 \text{ required} & \end{array}$$

Vol. of O_2 needed from air at 25°C per 1 gm incendiary

$$V_{O_2} = \frac{nRT}{P}$$

$$V_{O_2} = (.00728 \text{ gm moles } O_2 \text{ required})$$

$$\left(\frac{.08205 \text{ atm} \cdot \text{liter}}{\text{gm mole} \cdot ^\circ\text{K}} \right) \left(\frac{.0353 \text{ ft}^3}{\text{liter}} \right) \frac{(296^\circ\text{K})}{(1 \text{ atm})}$$

$$V_{O_2} = 6.28 \times 10^{-3} \text{ ft}^3 \text{ needed from air}$$

Vol. of N_2 released during reaction at 2000°K

$$V_{N_2} = (.00192 \text{ gm moles } N_2 \text{ released})$$

$$\left(\frac{.08205 \text{ atm} \cdot \text{liter}}{\text{gm mole} \cdot ^\circ\text{K}} \right) \frac{(2000^\circ\text{K})}{(1 \text{ atm})} \left(\frac{.0353 \text{ FT}^3}{\text{liter}} \right)$$

$$V_{N_2} = .0111 \text{ ft}^3 \text{ } N_2 \text{ released}$$

Since the following oxides will be solids they will not dilute the dry bay oxygen:

$Al_2 O_3$ Boiling Point = 3500°C

Ba O Boiling Point = 2000°C

Mg O Melting Point = 2800°C

Now let V_R = the final O_2 volume % in the dry bay - FT^3

V_D = Volume of the dry bay - FT^3

$$V_R = \frac{.21 V_D (\text{initial } O_2 \text{ Vol.}) - .00628 \text{ FT}^3 (O_2 \text{ needed from air}) \times 100\%}{V_D - .00628 \text{ FT}^3 (O_2 \text{ needed from air}) + .0111 \text{ FT}^3 (N_2 \text{ released})}$$

$$V_R = \frac{.21 V_D - .628}{V_D + .00482}$$

This equation was used to develop Figure 13.

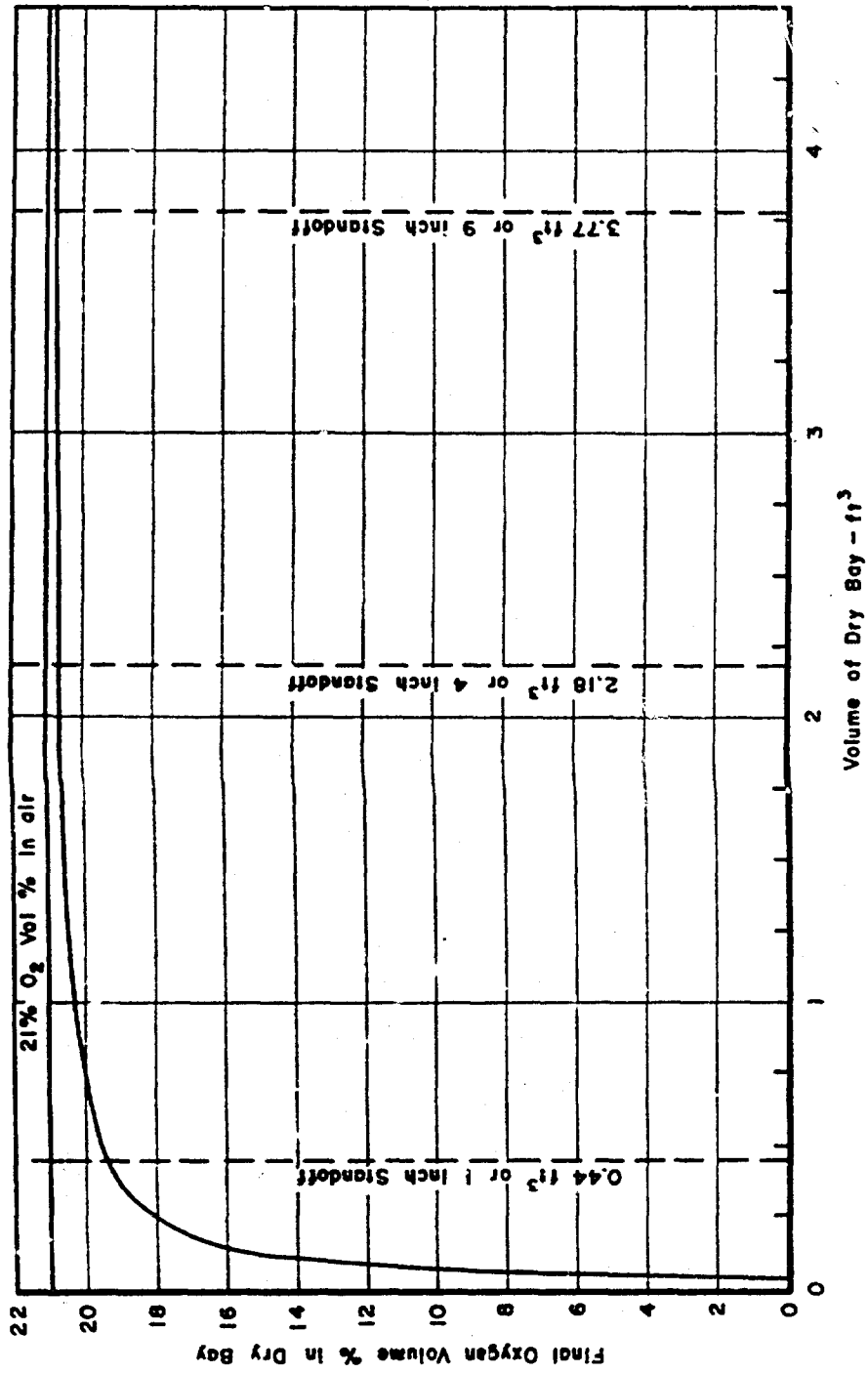


Figure 13. Final Oxygen Volume Percent in Dry Bay After Incendiary Reaction

APPENDIX IV
SAMPLE STATISTICAL PROBLEM

We generated a sample set of data to obtain some insight into the results that could be expected from the use of statistical methods. Twelve random numbers (A in Table XIV) were selected, ranging from 0 to 35, which was the expected range of overpressure for the standoff volume. The numbers for comparison were defined as $B = 0.6A$. Therefore, by definition, the difference between any set of A and B numbers was 40%. It was then assumed four tests were conducted giving the first two responses of both A and B. A statistical analysis was performed on the results. This was repeated assuming eight additional tests. In the final step it was assumed that twelve more tests were conducted. The statistical results for the sample problem are given in Table XIV. As may be seen, the defined difference between A and B was not shown in the calculated T value until all 24 tests were conducted.

Another sample problem was also conducted (results not shown) with the same values of A but with $B = 0.8A$. The same procedure was applied, and even after 24 tests the T value did not show the defined 20% difference between A and B as significant.

The foregoing example was generated to illustrate that it is difficult to prove with high confidence a difference between two fuels if that difference is relatively small and only a limited number of tests are conducted; the smaller the difference, the more tests are required to prove a significant difference.

TABLE XIV
 SAMPLE STATISTICAL PROBLEM (RANDOM NUMBERS 0 TO 35)
 $B = 0.6A$ (BY DEFINITION)

No.	Test Description		VARIANCE		MEAN		F Ratio	T Value	T_c	REMARKS
	A	B	A	B	A	B				
1	34.0	20.4	200.0	72.0	24.0	14.4	2.78	1.43	2.92	Based on 4 tests
	14.0	8.4								
2	11.0	6.6	123.5	44.4	14.3	8.6	2.78	1.28	1.81	Based on 12 tests
	18.0	10.8								
	2.0	1.2								
	7.0	4.2								
3	17.0	10.2	98.6	35.5	14.7	8.8	2.78	1.91	1.72	Based on 24 tests
	19.0	11.4								
	1.0	0.6								
	30.0	18.0								
	11.0	6.6								
	12.0	7.2								

APPENDIX V

PROPERTIES OF JP-4 AND JP-8 FUELS

At the present time the United States Air Force uses JP-4 (Commercial Designation: JET B), a wide-cut distillate fuel, as its preferred operational fuel. JP-4 was adopted back in the early 1950's, and its properties were selected to maximize worldwide availability while fulfilling aircraft operational performance requirements. The proposed replacement fuel, JP-8, has lower volatility, and its properties were determined by worldwide availability, operational performance, and fire safety considerations. The comparative properties of JP-4 and JP-8 are given in Table XV.

TABLE XV
PROPERTIES OF JP-4 AND JP-8 FUELS

	JP-4*	JP-8*	JP-4 SPEC.	PROPOSED JP-8 SPEC.
Flash Point (°F)	-20	118	----	105-150
Distillation (°F)				
(a) Initial Boiling Point	140	314	----	----
(b) End Point	455	508	----	550
*Gravity (°API)	54.4	43.8		39-51
Freeze Point (°F)	-80	-65	-76 max.	-54 max.
Aromatics	11.4	16	25 max.	25 max.
Clefin	1	2	----	5 max.
Viscosity (Centistokes at -30°F)	2.4	8	----	15 max.
Reid Vapor pressure (psf at 100°F)	2.6	<0.1	2.0-3.0	----
Density (lbs/gal)	6.41	6.81	6.25-6.68	6.46-6.91
Heat of Combustion				
(a) BTU/lb	18,714	18,559	18,400 min.	18,400 min.
(b) BTU/gal	119,557	125,830	----	----
Autoignition Temp. (°F)	~484 min.	~473	----	----
Burning Velocity- Vapor-Air Mixture (ft/sec)	~1-2	~1-2	----	----
Flame Spread Rate, Quiescent Liquid, 80°F (ft/min)	~750	~25	----	----
* TYPICAL OF FUEL USED IN FAA TEST PROGRAM				

REFERENCES

1. G. W. Gandee "Evaluation of Fire Saft Fuels," paper presented at the Industry-Military Jet Fuel Quality Symposium, October 22, 23, and 24, 1968, San Antonio, Texas.
2. AFAPL-TR-70-93, AFAPL Aircraft Fire Test Program with FAA, 1967-1970, June 1971.
3. APFH-TM-70-34, "Evaluation of JP-8 Versus JP-4 Fuel for Enhancement of Aircraft Combat Survivability," June 1970.
4. AFAPL-TR-70-82, Influence of Fuel Sloss Upon the Effectiveness of Nitrogen Inerting for Aircraft Fuel Tank, February 1971.