Report No. NA-69-10
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FINAL REPORT

Contract No. FA68NF-269

Project No. 520-005-01X

INVESTIGATION OF MODIFIED TURBINE FUELS FOR REDUCTION OF CRASH FIRE HAZARD

MAY 1969

Prepared for

DEPARTMENT OF TRANSPORTATION
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National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

by

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FOREWORD

This report was prepared by The Western Company for the Federal Aviation Administration. The work effort was part of a program of the Engineering and Safety Division, Aircraft Development Service, Washington, D.C. The work was administered under the direction of Mr. Ralph A. Russell who served as project engineer for the Propulsion Section, Aircraft Branch, Test and Evaluation Division, National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

ABSTRACT

Fifty-five modified fuels were tested and rated for their ability to reduce aircraft post-crash fires. The candidate fuels were subjected to a seven-part rating scheme in which combustion and physical properties were examined under both static and dynamic conditions. Measurements were made of flash point, rate of vapor release, burn rate, surface flame propagation rate and fuel spread rate (ignited), as well as fireball size under impact conditions (drop test) and fireball size with sample propelled by a catapult device. Fuels gelled with either alkyl-hydroxybutyramides, amine diisocyanates, Al-2-ethylhexanoate (aluminum octoate) or a styrene-type polymer as well as an emulsified fuel were found to provide marked safety benefits. The alkyl-hydroxybutyramide gels, the amine diisocyonates, and the emulsion had a firm, or stiff, consistency which would present a serious tank feed-down problem in present aircraft. The polymer gel was pourable but contained harmful sodium and required a relatively high polymer concentration, and the polymer was not compatible with the de-icer contained in JP-4. The aluminum octoate gel was selected as the best of the candidate fuels tested. It was pourable, provided marked safety benefits, required only a low concentration (1%), was stable, noncorrosive and was easily prepared.

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INTRODUCTION

Efforts to improve aircraft safety and reduce loss of life and property continue on many fronts. Improvements in aircraft design and components, navigation aids, traffic control, airports, and aircrew training have all contributed to increased safety in air travel. In one particular area, that of "crash worthiness," much has been learned about the magnitude of forces which certain components in various configurations will withstand without failure. This knowledge has led to improved materials and designs. The problem of "crash worthiness" as related to post-crash fire has been attacked by eliminating ignition sources, fuel tank inerting, providing rupture resisting tanks, improving passenger protection and exit, and by using less volatile kerosene-base fuel (Jet A).

Post-crash fires still occur eventhough Jet A is indeed less volatile and, in bulk, more difficult to ignite; however, under the conditions prevailing in a crash situation, dynamic forces act to produce fuel mist, spray and vapors which can readily be ignited. Under crash conditions, fuel properties other than volatility become important. Liquid fuels which have been changed physically by gelation or emulsification have their tendency to mist and spray greatly reduced. A considerable amount of work has ~~been~~ done in fuel solidification processes and the operation of turbine engines with gelled and emulsified fuels. These investigations have shown that some modified fuels exhibit significant reduction over liquid fuels in their tendency to mist and spray, and, therefore, to ignite. Some gels and emulsions have been burned in aircraft turbine engines with very little reduction in performance. Literature references are cited in the Bibliography.

Despite the successes in demonstrating safety benefits and engine operation of modified fuels, many questions remain. For instance, the relationships between measurable physical, mechanical, and chemical properties and the corresponding combustion properties of modified fuels have not been fully defined. Other problem areas include fuel tank feed down of high-consistency fuels, and the tendency of some gels to separate free fuel in storage, especially when subjected to vibration and slosh conditions. In some engine tests, the safety fuels were observed to break down in the fuel filters and contribute to filter plugging. Another feature of high-consistency fuels is their ability to suspend solid matter. Any foreign matter in a fuel system (rust, etc.) is picked up and carried to the filters or nozzle and may cause plugging.

The difficulties involved in the use of modified safety fuels do not appear to be insurmountable. Identification of the best fuel modification technology available is a necessary step to providing improved fuel safety. This report presents the results of an investigation in this direction. The objective of the investigation was to identify, from all available sources by valid testing and screening techniques, a turbine fuel-modifier system which would provide crash-fire hazard reduction and to subject the highest ranked candidate to operational testing to determine its usability in existing aircraft. The basic scheme of examination for the comparative rating, was developed by the Bureau of Mines under an agreement with the Federal Aviation Administration. Additional methods and equipment were developed during the performance of the contract and are described in the body of this report.

Work began on this contract 29 September 1967. A list of candidate fuel modifiers was submitted to the FAA on 9 February 1968 and the results of the fuel rating portion of the effort were submitted to the FAA on 16 July 1968. Shortly thereafter, the top ranked fuel was subjected to a full-scale engine test by the FAA. The fuel was found to possess spray properties which prevented proper atomization at the nozzle, therefore operation of the engine was not satisfactory. Subsequently the remainder of the contract was terminated by the FAA and the proposed operational testing phase was not carried out.

TESTS AND RESULTS

Liquid hydrocarbons are useful as internal combustion and turbine engine fuels by virtue of their ability to vaporize and form combustible mixtures with air. These mixtures burn with stable flames and provide high heat output. Many of the characteristics of fuels currently in use are maintained within limits prescribed in military and ASTM specifications. Some of the more important characteristics are vapor pressure, flash point, density and viscosity. Suitable values of these and other properties insure the proper operation of pumps, meters, nozzles, carburetors etc. in the intended engine. In general, alterations to these properties by gelation or emulsification are desired to change the mechanical behavior and combustion properties to produce controlled-flammability fuels. Changes to a liquid fuel which would reduce its rate of vaporization, reduce the spill area and lower the rate of combustion per unit area would provide safety benefits in a crash situation.

A methodology of testing and rating of fuels (both liquid and modified) for their safety fuel potential was developed for FAA by the Bureau of Mines. This testing and rating scheme was used (along with one additional test) to examine a large number of candidates under this contract.

SELECTION OF CANDIDATES FOR EXAMINATION

A list of fuel modifiers was prepared for possible testing and evaluation. Materials were selected from the literature, from government sources, from the recommendation of several manufacturers, and from in-house experience. Selection was made on the basis that the material had the possibility (however remote) of providing safety benefits. Gelling agents, emulsifiers, thickeners, and inhibitors were selected. Most of the materials listed can be simply dissolved in liquid fuels to provide fuel modification. However, no modifier was excluded from the list because of complicated preparation technique or high concentration of agent. All candidates considered are listed in Table I as either Gel (gelling agents), Thick (thickener), Emul (emulsifier) Visco (viscoelastic) or an Inhib (inhibitor) along with descriptive data and preparation techniques.

PREPARATION OF TEST SAMPLES

JP-4 turbine fuel was selected for use in this program. Since JP-4 contains volatile components, precautions had to be taken to see that they were not driven off during sample preparation. The loss of "light ends" would change the

TABLE I

CANDIDATE SAFETY FUELS

Type	No.	Description	Conc. %	Preparation
-	1	Turbine Engine Fuel	-	-
Gel	2A	Al-2-ethylhexanoate (aluminum octoate)	1.0	Stir
Gel	4A/4B	Styrene type polymer	3.35	Blend
Gel	5	N-Coco-gamma-hydroxybutyramide (6% H_2O, PH 9.0) (FAA-1069.1)	1.5	Stir, heat
Gel	6	N-alkyl-gamma hydroxybutyramide	1.5	Stir, heat
Gel	7	N-alkyl-gamma hydroxybutyramide	1.5	Stir, heat
Gel	8	N-alkyl-gamma hydroxybutyramide	1.5	Stir, heat
Gel	9	N-alkyl-gamma hydroxybutyramide	1.5	Stir, heat
Gel	10	N-alkyl-gamma hydroxybutyramide	1.5	Stir, heat
Gel	11	Alkyl hydroxybutyramide	1.5	Stir, heat
Gel	12	Unknown (polyglycol?)	1.0	Stir, heat
Gel	13	61% lauryl, 25% myristyl, 13% palmital alcohol	5.0	Stir, heat
Gel	14	99% lauryl alcohol	5.0	Stir, heat
Gel	15	99% lauryl alcohol	5.0	Stir, heat
Gel	16	Low MW polyethylene	1.0	Stir
Gel	18	Rubber compound	3.0	Stir, allow to stand

TABLE I (Continued)

Type	No.	Description	Conc. %	Preparation
Gel	20	Proprietary (The Western Company)	13.0	Proprietary
Gel	21	Proprietary (The Western Company)	21.4	Proprietary
Gel	22	Commercial myristic acid and diethylenetriamine	3.3 1.7	Stir until dissolved Stir
Gel	23	Commercial myristic acid and diethylenetriamine	3.3 1.7	Stir until dissolved Stir
Gel	24	Commercial stearic acid and diethylenetriamine	3.5 1.5	Stir until dissolved Stir
Gel	26	Commercial linoleic acid and diethylenetriamine	3.3 1.7	Stir until dissolved Stir
Gel	27	1, 6-Hexanediamine and hexametlylene diisocyanate	2.0 2.0	Stir until dissolved Stir
Gel	28	2-ethylhexyl-3-aminopropylether and hexamethylene diisocyanate	2.8 1.3	Stir until dissolved Stir
Gel	29	2-ethylhexyl-3-aminopropylether and aniline and toluene diisocyanate	2.0 0.8 1.2	Stir until dissolved Stir until dissolved Stir
Gel	30	Composition unknown and toluene diisocyanate	2.0 1.0	Stir until dissolved Stir
Gel	31	Composition unknown and water	5.0 5.0	Blend
Gel	32	Coco amide	4.0	Heat to dissolve, cool to solidify

TABLE I (Continued)

Type	No.	Description	Conc. %	Preparation
Gel	33	Methylene-bis-stearamide	5.0	Heat to dissolve, cool to solidify
Gel	34	Linoleic-oleic acids and 50% NaOH	1.8 0.6	Stir until dissolved Stir
Gel	35	Proprietary (The Western Company)	-	Proprietary
Gel	36	Cobalt oleate	0.4	Warm, stir to dissolve, cool to solidify
Gel	37	Sodium oleate Sodium stearate	0.25 0.25	Warm, stir to dissolve, cool to solidify
Gel	38	Lithium isostearate	1.0	Heat and mix with high-shear mixer, cool to solidify
Gel	39	Proprietary (The Western Company)	-	Proprietary
Gel	40		0.4	
Thick	41	Low MW polyethylene	0.5	Low-shear stirring to dissolve in warm fuel
Thick	42	Polymethacrylate	0.2	Low-shear stirring to dissolve in warm fuel
Thick	43	Polystyrene and benzene	0.2 2.8 4	Dissolve polystyrene in benzene, mix in warm fuel
Emul	44	Proprietary (The Western Company)	0.5 2.5	Mix MFE-10 in water, add fuel in small increments with high shear
Emul	45	Proprietary (The Western Company)	14.7	Proprietary
Thick	46	Polyethylene oxide	-	-

TABLE I (Continued)

Type	No.	Description	Conc. %	Preparation
Visco	47	Proprietary (The Western Company)	0.2	Proprietary
Inhib	49	Bromotrifluro methane	0.5	Stir into fuel
Inhib	50	Trichlorofluroimethane	1.0	Stir into fuel
Inhib	51	Trichlorotrifluroethane	1.0	Stir into fuel
Inhib	52		0.5	Stir into fuel
Inhib	53	Triecresylphosphate	1.0	Stir into fuel
Inhib	54	Iron pentacarbonyl	1.0	Stir into fuel
Inhib	55	Nonylphenol-ethylene oxide adduct, 1:6 mole ratio	1.0	Stir into fuel

composition of the fuel and hence its response to some elements of the testing scheme. The stock fuel was kept in cold storage. Stirring operations, where required, were performed in a minimum of time. In those cases where the application of heat was necessary, samples were sealed in a section of 2-inch diameter Pyrex pipe and heated in a thermostat. Sample pressure was monitored and kept within the safety limit prescribed for the pipe.

Difficulty was encountered in the preparation of a number of the candidate fuels. Since some of the candidates were included only on a speculative basis this is not surprising. Those agents which could not be made to produce gels were eliminated from consideration by inspection. Table II contains a list of those agents eliminated in this manner.

THE TESTING AND RATING SCHEME

The candidate materials were evaluated by the methodology developed by the Bureau of Mines. The methods and discussion (as received from the Bureau of Mines) are presented in Appendix 1.

Certain factors are basic to the suitability of a safety fuel. One of these, the formation of the modified fuel upon the incorporation of the agent, has been mentioned. Another is stability. Some of the proposed candidates were found to be unstable on short term (a few days) storage and were eliminated from consideration on this basis. Table II includes a list of those dropped because of inadequate stability. Table II also presents candidates eliminated from consideration for miscellaneous non-test reasons. The reasons are stated in the table.

Near the end of the program, fluidity was established as a criterion wherein samples possessing sufficient fluidity were those which poured, essentially completely, from a horizontally disposed, straight-sided jar within five seconds; however, during a course of the program, rigid gels were not excluded from the test scheme.

(A) Minimum Temperature for Hot Surface Ignition, (the minimum autoignition temperature (AIT) by ASTM method D2155-66). The test was postponed at the beginning of the program pending the arrival of the necessary equipment. Later, other phases of the program were allowed to take precedence over AIT due to the belief that results of the test are a function of the base fuel and not of the modified fuel itself. This belief is reasonable when it is remembered that when gels are heated to the temperatures involved (above 400°F) gel structures no longer exist, therefore the gelling agent has only a dilutative affect on the fuel.

(B) Minimum Temperature for Formation of Flammable Mixtures; (this temperature is determined by use of flash-point method ASTM D-56-64 with the procedure altered to incorporate a slower heating rate). This alteration was necessary to maintain the required temperature differential between the center of the sample and the sample container. The low thermal conductivity of the modified samples required that a low heating rate of 0.3°F per minute be used. To accomplish this, the flash-point apparatus (tag closed cup) was modified to permit circulation of the bath fluid through the bath container. In practice, an ethylene glycol solution, cooled to -30°F and kept in an insulated container, was allowed to flow by gravity through the container at the rate

TABLE II

CANDIDATES ELIMINATED FOR VARIOUS NONTEST REASONS

Type	No.	Conc. %	Remarks
Gel	13	5.0	Unavailable
Gel	14	5.0	Unavailable
Gel	15	5.0	No gel
Gel	16	1.0	Unstable
Gel	17	2.0	Unstable
Gel	18	3.0	Nonhomogenous
Gel	19	6.0	Nonhomogenous
Gel	20	13.0	Unstable
Gel	21	21.4	Unstable
Gel	22	5.0	Unstable
Gel	23	5.0	Unstable
Gel	24	5.0	Unstable
Gel	25	5.0	Precipitate formed
Gel	26	5.0	Unstable
Gel	27	4.0	Unstable
Gel	28	4.1	Unstable
Gel	31	10.0	No gel
Gel	33	5.0	No gel
Gel	34	2.4	Separates fuel
Gel	35	1.0	No gel
Gel	36	0.4	Unavailable
Gel	37	0.5	Separates fuel
Gel	38	1.0	Unstable
Gel	40	0.4	No gel

TABLE II (Continued)

Type	No.	Conc. %	Remarks
Thick	41	0.5	Unstable
Thick	42	0.2	Unavailable
Thick	43	5.0	No gel
Emul	45	14.7	Unstable
Thick	46	Var	No gel
Inhib	49	---	Boils out of fuel
Inhib	50	1.0	Boils out of fuel
Inhib	53	1.0	Not effective in liquid
Inhib	54	1.0	Toxic
Inhib	55	Var	No gel

necessary to maintain a 0.3°F per minute rise rate. One gallon of ethylene glycol was found to be sufficient for each test lasting approximately half an hour.

Flash points were found to be sensitive to the history of the sample with respect to temperatures and handling, which caused loss of volatile components. Any loss of light ends raised the flash point. Precautions were taken to keep the fuel and samples closed and to hold preparation times to a minimum. Samples which required elevated temperatures in preparation were prepared in closed containers.

Table III presents the results of flash point testing along with other pertinent data.

(C) Time for Formation of Flammable Mixtures. Combustible fuels exerting a vapor pressure of one-half pound per square inch (gage) will form combustible fuel-air mixtures in the Reid vapor pressure tester. One of the benefits of modifying a fuel is that the rate of vaporization is retarded and hence the formation of a flammable mixture is delayed. Comparisons of the times required to reach one-half psig were made using the ASTM D323-58 (Reid vapor pressure test) method with a modified procedure.

(1) Static Test. As in the flash point test, loss of volatiles causes significant changes in results obtained. To reduce this complication, samples were refrigerated to about -30°F before loading. After loading, the sample holder was securely stoppered and warmed to 32°F in an ice bath before it was attached to the air chamber.

Samples were extruded into the sample holder through a 3/8-inch tube attached to a straight-sided funnel. Care was taken to insure that the sample level was in the 1/2-inch-diameter connection between the two chambers so that the same surface area was presented to the air chamber in each determination.

It was reasoned that appreciable loss of volatile components would be reflected in the equilibrium vapor pressure of a sample. For this reason, most samples were held in a 100°F bath until equilibrium pressure was obtained. In cases where the equilibrium pressures were markedly lower, new samples were prepared and tested.

Static vapor pressure rise results are presented in Table III.

(2) Dynamic Test. The proposed dynamic vapor pressure buildup test is made by injecting the sample into the air chamber by means of a piston installed in the sample holder. The piston is withdrawn to its original position after the injection to keep the proper relative volumes in the apparatus. Experience with this test showed that the pressure rise to one-half psi with JP-4 base candidates was so rapid that the operator could not obtain times with a stop watch. It is believed that the test would lend itself to automation where, perhaps, sample activation and pressure records are achieved mechanically or electronically. Such a development is beyond the scope of this contract.

(D) Self Spread Rate. The most important property of a potential safety fuel is its ability to resist dynamic break up to form vapor, mist, and spray. A second important requirement is that it remain in coherent masses after dissemination, as from a ruptured fuel tank. A fuel remaining in lumps or blobs after a crash, even if ignited, would provide more escape time for passengers as compared to a rapidly spreading liquid fuel. The self-spread rate test was designed to compare the tendency of ignited candidate fuels to spread. The test was conducted in a 4-foot length of 3-inch angle iron trough inclined at an angle of two degrees from the horizontal. A 1-1/2-inch long "plug" of the candidate fuel was placed behind a removable dam at the upper end of the trough. The fuel was ignited, the dam immediately removed and the time required for the flame to advance two feet was measured.

The more fluid samples advanced by simply flowing down the trough while burning. Most of the rigid gels melted a small amount of fuel which advanced and carried the flame ahead of the body of the sample. Some rigid gels, however, did not release appreciable amounts of liquid and burned in place without moving down the trough. Results obtained in the Self-Spread Rate tests are listed in Table III.

(E) Regression or Burning Rate. Burning rates were determined by measuring the time required to burn the top one inch of fuel in an 8-inch-diameter pan initially loaded to a depth of 1-1/2 inches. In this test the candidate fuels melt almost immediately at the surface and hence throughout the test a liquid fuel surface is presented to the flame. Consequently, the modified fuels and the base liquid fuels burn at essentially the same rate in this test. Test results are given in Table III.

(F) Horizontal Flame Spread Rate Under Static Conditions. The speed at which fire will spread on a fuel which has been spilled (from a plane crash for instance) is an important characteristic of the fuel. Prevailing ambient conditions at a crash site, particularly wind, influence the spread rate. Freshness of the fuel surface is important also. The 3-inch angle iron trough was used to measure flame spread rates on the freshly stirred surfaces of candidate safety fuels. The time required for the flame to advance four feet was recorded on an electronic counter connected to two fuse wires strung across the trough. The first one started the counter and the second stopped it as the flame passed.

Half-filled trough tests were found to be unproductive because fuel vapors collected in the upper part of the trough and flashed when sample ignition was attempted.

Full trough test results are presented in Table III.

(G) Fireball Size Under Impact Conditions. The size and growth rate of a fireball produced under impact conditions depend on several factors. The basic nature of the fuel, impact speed, fuel temperature, size and proximity of ignition sources are all important to the production and ignition of vapor, mist and spray. If conditions are held constant, information about the basic nature of the fuels can be gained and comparisons of the candidates made from impact tests.

Samples were dropped onto a concrete surface from a height of 20 feet. Five-pound samples in 3-liter Pyrex Erlenmeyer flasks were dropped as near as

TABLE III
TEST RESULTS

Type	No	Conc., %	Flash Point			Vapor Pressure Rate			Self Spread Rate			Regression Rate			Flame Spread Rate			Fireball Height in 10 Sec.			Fireball Width in 10 Sec.			Fireball Width in 1/2 Sec.			Catapult Fireball Max. Dia.			Totals		
			°F, Avg.	No. Runs	Rating	Min. Avg.	No. Runs	Rating	Ft/Sec. Avg.	No. Runs	Rating	In/Min. Avg.	No. Runs	Rating	Ft/Sec. Avg.	No. Runs	Rating	Ft., Avg.	No. Runs	Rating	Ft., Avg.	No. Runs	Rating	Ft., Avg.	No. Runs	Rating	In. Avg.	No. Runs	Rating	No. Items Tested	No. Runs	Rating
-	1	-	-5	1	0	4.0	1	3.7	>5.0	2	0	-	0	-	5.3	2	0	13.0	2	0	16.0	2	2.0	15	2	2.5	17.6	5	1.2	8	17	9.4
Gel	2A	1.0	-2	1	0	17.1	2	8.5	<.03	2	15.0	-	0	-	>5.0	2	0	14.0	2	0	14.0	2	3.0	14	2	3.0	0	2	10.0	8	15	39.5
Gel	2B	1.0	-	0	-	14.5	5	8.3	.18	6	14.5	.093	5	0.7	4.3	5	1.4	12.0	4	0	13.5	4	3.2	12.5	4	3.7	9.0	5	5.5	8	38	37.3
Gel	3	0.5	-	0	-	6.5	2	6.2	<.03	2	15.0	-	0	-	5.6	2	0	10.0	1	1.7	11.0	1	4.5	11	1	4.5	1.2	1	9.4	7	10	41.3
Gel	4A	3.35	3	1	0.2	28.3	1	9.1	<.03	2	15.0	-	0	-	3.1	4	3.8	-	0	-	-	0	-	-	0	-	12.8	2	3.6	5	10	31.7
Gel	4B	3.35	-	0	-	28.0	5	9.1	<.03	6	15.0	.098	5	0.2	4.13	5	1.7	9.7	5	1.9	15.8	5	2.1	15.4	5	2.3	1.6	5	9.2	8	41	41.5
Gel	5	1.5	2	3	0.1	11.0	3	7.7	2.0	3	14.4	-	0	-	5.6	2	0	10.0	2	1.7	12.0	2	4.0	12	2	4.0	2.0	4	9.0	8	21	40.9
Gel	6	1.5	-5	1	0	23.5	1	8.9	.14	3	14.6	-	0	-	5.3	1	0	-	0	-	-	0	-	-	0	-	-	0	-	4	6	23.5
Gel	7	1.5	-3	1	0	5.5	2	4.5	.11	2	14.7	-	0	-	4.7	2	0.6	-	0	-	-	0	-	-	0	-	0.4	2	9.8	5	9	29.6
Gel	8	1.5	-1	1	0	10.0	2	7.5	.23	2	14.3	-	0	-	5.0	2	0	-	0	-	-	0	-	-	0	-	0.0	2	10.0	5	9	31.8
Gel	9	1.5	-1	1	0	13.1	3	8.1	.12	3	14.6	-	0	-	5.0	2	0	9.0	2	2.5	12.5	2	3.7	12.5	2	3.7	2.4	2	8.8	8	17	41.4
Gel	10	1.5	-1	1	0	16.2	2	8.5	.11	2	14.7	-	0	-	4.9	2	0.2	-	0	-	-	0	-	-	0	-	2.2	2	9.9	5	9	33.3
Gel	11	1.5	-	0	-	16.0	2	8.4	.13	2	14.6	-	0	-	5.0	2	0	-	0	-	-	0	-	-	0	-	6.0	1	7.0	4	7	30.0
Gel	12	1.0	2	1	0.1	4.2	2	4.0	5.5	2	0	-	0	-	4.7	3	0.6	-	0	-	-	0	-	-	0	-	-	0	-	4	8	4.7
Gel	16	1.0	1	1	0.1	3.6	1	3.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	2	2	3.1
Gel	17	2.0	-7	1	0	4.1	2	3.9	0.19	1	14.4	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3	4	18.3
Gel	18	3.0	-	0	-	6.5	2	6.1	<.03	2	15.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	1.4	4	9.3	3	8	30.4
Gel	19	6.0	-	0	-	1.6	1	0	<.03	1	15.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	2	2	15.0
Gel	20	13.0	6	1	0.3	6.5	3	6.1	2.5	3	7.6	-	0	-	5.2	2	0	-	0	-	-	0	-	-	0	-	5.0	2	7.5	5	11	21.5
Gel	21	2.0	2	2	0.1	6.4	2	6.1	3.4	2	4.9	-	0	-	4.8	4	0.4	-	0	-	-	0	-	-	0	-	18.5	1	0.7	5	11	12.2
Gel	24	3.3 1.7	12	1	0.6	7.0	1	6.4	2.0	1	9.1	-	0	-	4.4	3	1.2	-	0	-	-	0	-	-	0	-	-	0	-	4	6	13.3
Gel	25	3.5 1.5	12	1	0.6	5.0	2	5.0	5.8	2	0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3	5	5.6
Gel	26	3.3 1.7	-6	1	0	9.3	2	7.3	0.3	1	14.1	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3	4	21.4
Gel	27	2.0 2.0	-2	1	0	9.4	2	7.3	3.0	2	1.1	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3	5	8.4
Gel	28	2.8 1.3	-	0	-	7.2	1	6.5	.09	2	9.7	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	6.5	2	6.7	3	5	22.9
Gel	29	2.0 0.8 1.2	-	0	-	15.4	1	8.4	<.03	2	15.0	-	0	-	5.1	3	0	-	0	-	-	0	-	-	0	-	5.8	2	7.1	4	8	30.5
Gel	30	2.0 1.0	-3	1	0	8.4	2	7.0	<.03	2	15.0	-	0	-	5.1	3	0	8.5	1	2.9	16.0	1	2.0	16.0	1	2.0	1.2	2	9.4	8	13	38.3
Gel	31	5.0 5.0	-7	1	0	4.2	2	4.9	4.0	1	3.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0		3	4	7.9
Gel	32	4.0	-5	1	0	7.8	2	6.8	0.2	2	14.4	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	12.5	1	3.7	4	6	24.9
Gel	34	1.8 0.6	-	0	-	6.0	1	5.8	2.1	1	3.7	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	2	2	9.5
Gel	37	0.25 0.25	-7	1	0	6.1	2	5.9	2.8	2	6.7	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3	5	12.6
Gel	38	1.0	-6	1	0	12.8	1	8.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	2.8	2	8.6	3	4	16.6
Gel	39	1.6 2.7	-	0	-	8.1	2	6.9	<0.3	2	15.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3.0	2	8.5	3	6	30.4
Gel	40	0.4	-	0	-	5.1	1	5.1	4.0	1	3.0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	2	2	8.1
Thick	41	0.5	-6	1	0	4.1	2	3.9	2.9	2	6.4	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	3	5	10.3
Emul	44	0.5 2.5	-	0	-	11.1	1	7.7	<.03	2	15.0	-	0	-	-	0	-	9.8	2	1.8	13.5	2	3.2	13.0	2	3.5	-	0	-	5	9	31.2
Emul	45	14.7	-	0	-	-	0	-	.18	2	14.5	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	1	2	14.5
Visco	47	0.2	-1	2	0	3.9	2	3.6	3.2	2	5.5	-	0	-	5.4	2	0	-	0	-	-	0	-	-	0	-	-	0	-	4	8	9.1
Visco	48	0.5	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	13.5	2	0	12.0	2	4.0	12.0	2	4.0	21.2	2	0	4	8	8.0
Inhib	51	1.0	-1	1	0	3.5	2	2.9	4.0	2	3.0	-	0	-	3.93	3	2.1	-	0	-	-	0	-	-	0	-	-	0	-	4	8	8.0
Inhib	52	0.5	-1	1	0	2.8	1	1.1	-	0	-	-	0	-	4.6	2	0.8	-	0	-	-	0	-	-	0	-	-	0	-	3	4	1.9
Inhib	55		-2	1	0	2.5	1	0	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-	0	-	2	2	0

possible to an ignition source consisting of a 3-foot-diameter coil of copper tubing containing four propane burners. Immediately after sample ignition, the propane flow was turned off at the remotely located tank. Samples were packed in ice in the laboratory and then allowed to warm up to a drop temperature of 70 to 75°F.

All drop tests were photographed with a motion picture camera. By counting frames and making reference to the backgroundgrid the fireball height and width dimensions at one-half and ten seconds, as required by the method, were easily determined. Data gathered on fireball sizes are presented in Table III.

Samples of JP-4 without modification were dropped for comparison. The photograph reproduced in Figure 1 shows a typical JP-4 drop one-half second after ignition. Figure 2 shows the same drop at 10 seconds after ignition. Figures 3 and 4 show an aluminum-octoate thickened JP-4 (1%) at one-half and ten seconds respectively.

(H) Dynamic Tests, Catapult. The property of gels and emulsions which prevents break up and dispersion is difficult to measure or describe in familiar terms. The concept of viscosity as applied to liquids becomes obscure or inapplicable for semi solids. Solid properties such as yield stresses may or may not be meaningful. Many safety fuels possess rate and time dependent properties and are sensitive to their history. A further complication is that many measuring devices, such as a rotating element viscometer, "work" the sample and change its properties.

For safety evaluation purposes the dynamic integrity of candidates must be established on the basis of their performance on tests which approximate conditions of use. Drop tests furnish data of this kind. An additional laboratory test method was developed which would reflect the break-up tendencies of the candidates. A spring activated catapult was devised and built to propel samples from a container through an orifice at a predetermined and controlled rate. The subsequent break up of samples was studied in flight and on paper "catch" targets by motion picture photographs. Samples were also ignited in flight and the fireball sizes studied from motion picture records.

The catapult is shown being cocked in Figure 5. The sample holder and orifice are shown disassembled in Figure 6. To obtain a measure of the impact of the sample holder against the stop, an accelerometer was attached to the holder and the G force was measured at impact. With all four springs in operation and a 60-milliliter sample in the holder, a G reading of 500 was obtained. The sample holder was fitted with a free piston (with air relief on the back side) weighing 141 grams which forcefully expelled the sample when the holder struck the stop.

Numerous unignited tests were made in the laboratory under a fume hood. Differences between the fuels in in-flight break-up and patterns were readily observed. This can be seen in Figures 7, 8 and 9 which are photographs of JP-4, one percent aluminum octoate gel and one and one half percent FAA 1069-1 gel respectively. Samples propelled with the catapult were caught on paper targets and attempts were made to obtain quantitative data from the targets or from Polaroid photographs made immediately after impact.

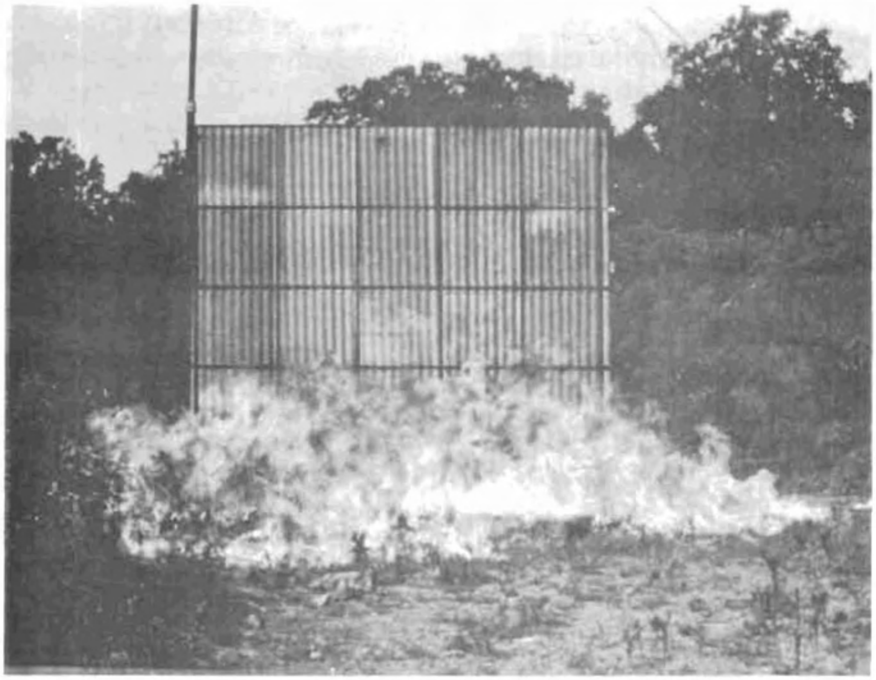

FIGURE 1 - DROP TEST FIREBALL, 1/2 SECOND AFTER IGNITION, JP-4

FIGURE 2 - DROP TEST FIREBALL, 10 SECONDS AFTER IGNITION, JP-4

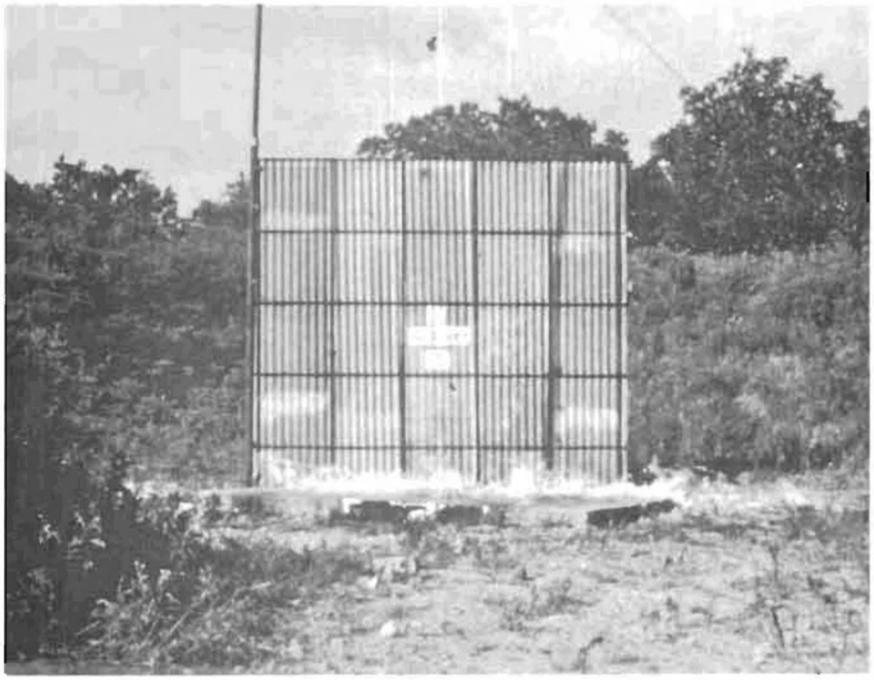

FIGURE 3 - DROP TEST FIREBALL, 1/2 SECOND AFTER IGNITION
1% ALUMINUM OCTOATE IN JP-4

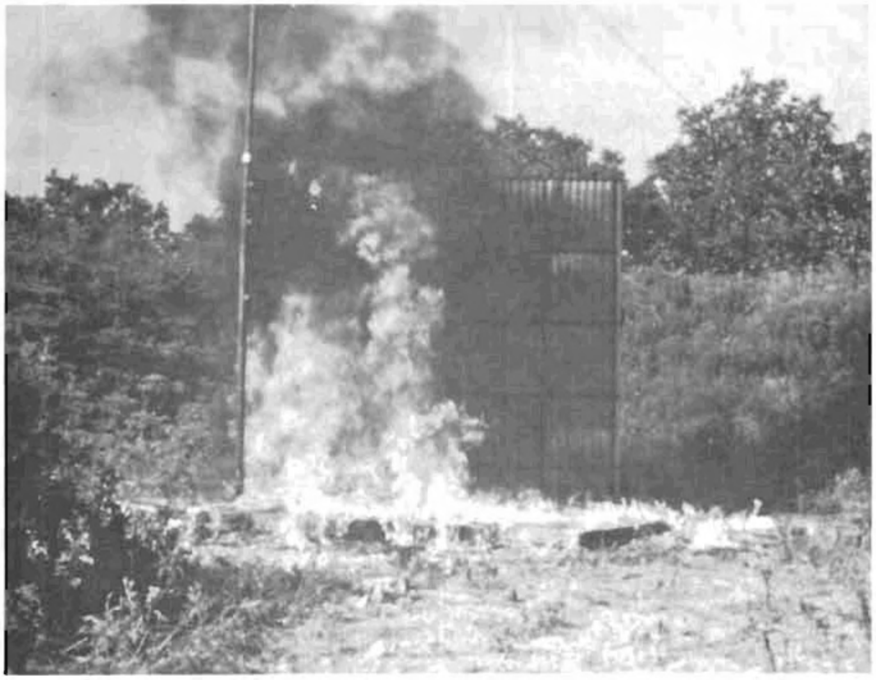

FIGURE 4 - DROP TEST FIREBALL, 10 SECONDS AFTER IGNITION,
1% ALUMINUM OCTOATE IN JP-4

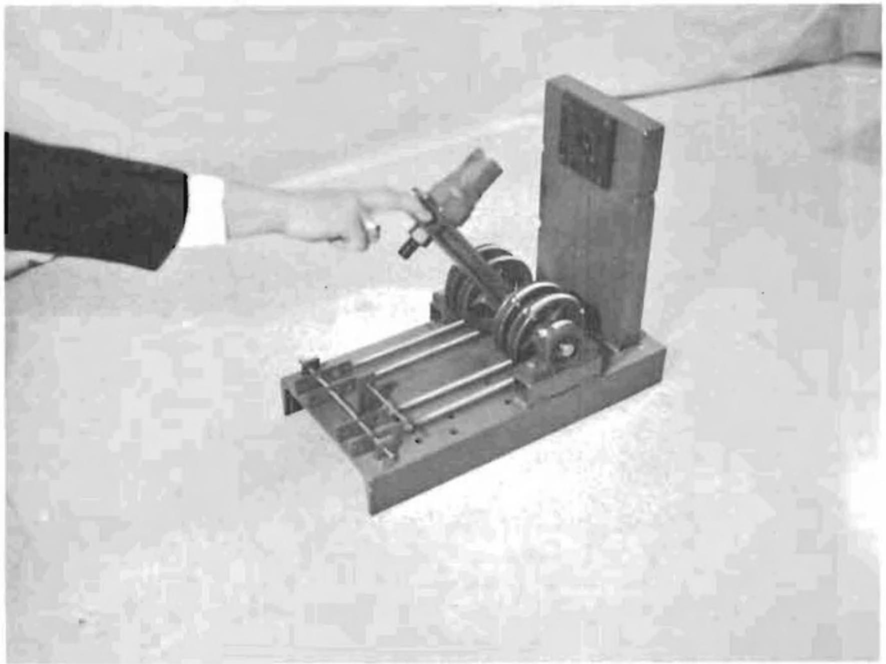

FIGURE 5 - CATAPULT BEING COCKED

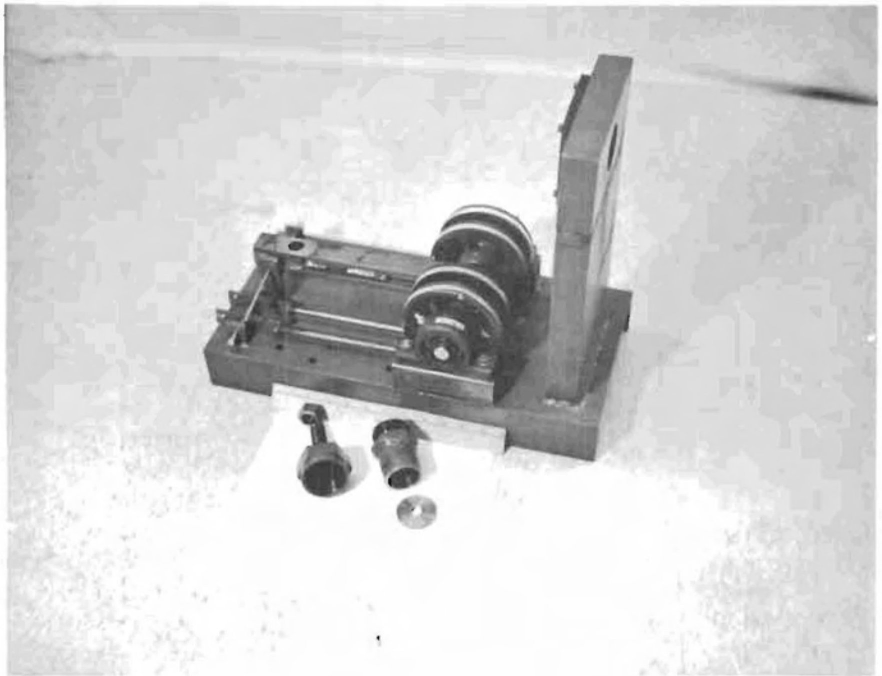

FIGURE 6 - CATAPULT WITH SAMPLE HOLDER DISASSEMBLED

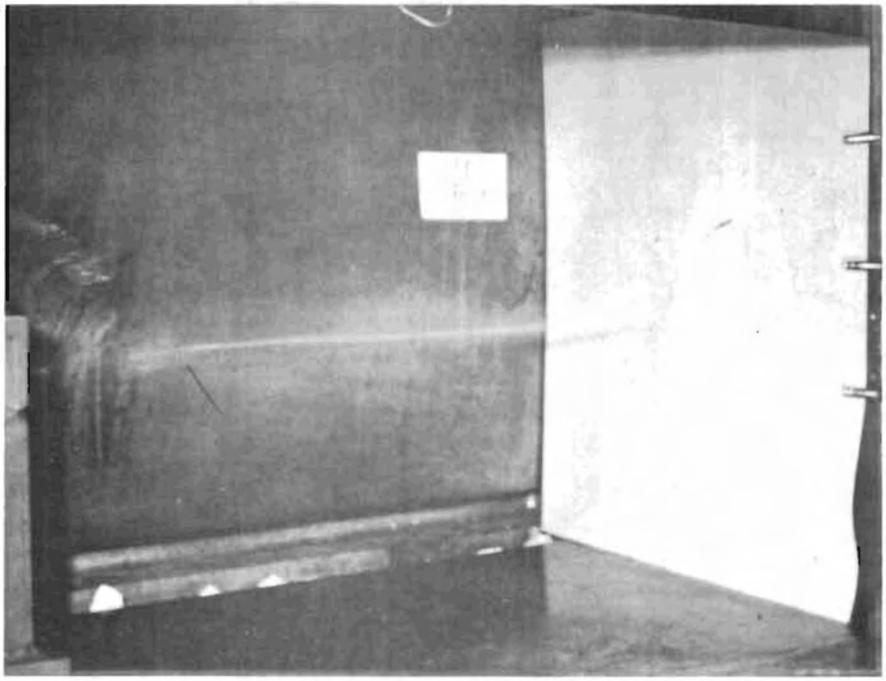

FIGURE 7 - IN-FLIGHT BREAKUP, CATAPULT TEST, UNIGNITED JP-4

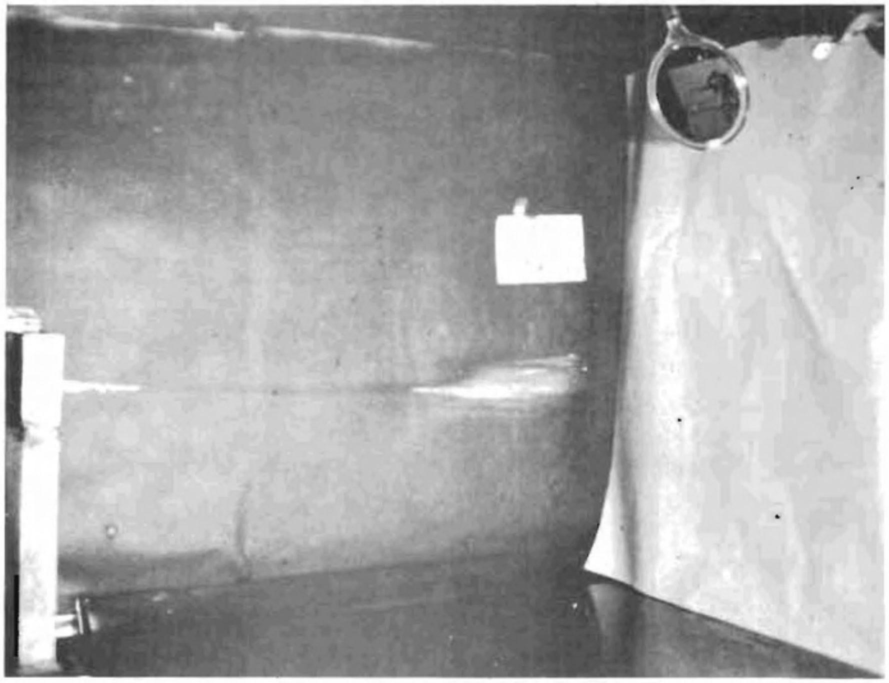

FIGURE 8 - IN-FLIGHT BREAKUP, CATAPULT TEST, UNIGNITED, 1% ALUMINUM OCTOATE IN JP-4

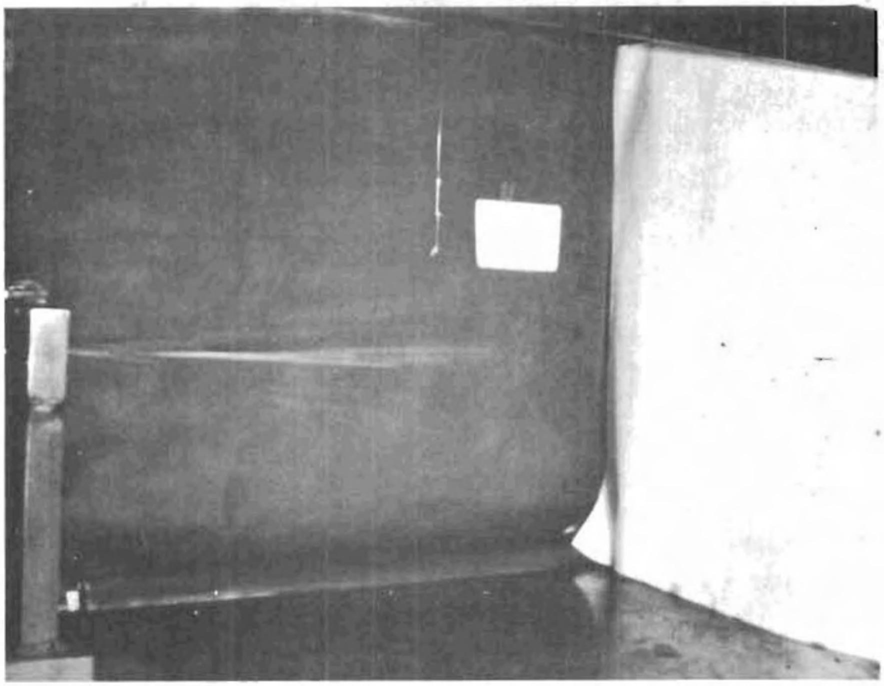

FIGURE 9 - In-Flight Breakup, Catapult Test, Unignited, FAA 1069-1 Gel.

However, neither the in flight behavior or the catch targets yielded significant quantitative information. Photographs of JP-4 and one percent aluminum octoate targets are shown in Figures 10 and 11.

Significant data were obtained from ignited catapult tests. These tests were made by propelling samples through a 10-inch-diameter ring containing 10 propane burners each pointed toward the center of the ring. The ring was located 12 inches from the catapult so that the entire sample was forced to pass through the flames. The resulting fireball size was taken as a measure of the amount of vapor and mist produced by sample break up under the stresses produced in the orifice and in flight. Figure 12 is a photograph of a JP-4 catapult fireball at its maximum size. Figure 13 shows a similar view of the fireball made by a one percent aluminum octoate gel.

Quantitative data was taken from motion picture films of the ignited catapult shots by estimating an average maximum fireball diameter. In assigning ratings based on these estimated diameters it was intended that the numbers be proportionate to the importance of the test in comparison with other tests in the rating scheme. In keeping with the other formulas used, a base diameter of 20 inches was selected. Ratings were calculated according to the formula

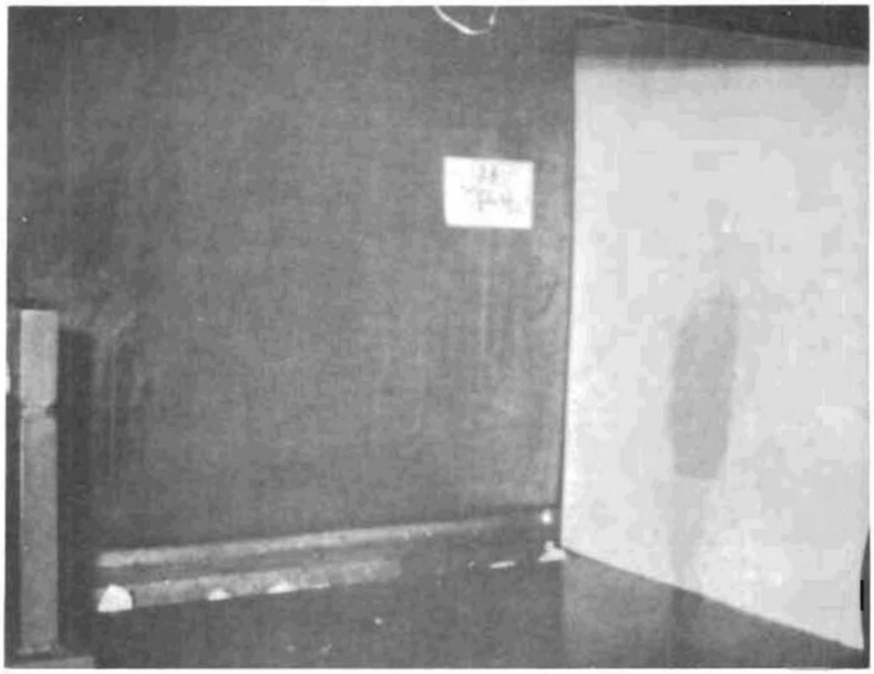

FIGURE 10 - TARGET PATTERN, CATAPULT TEST, UNIGNITED, JP-4

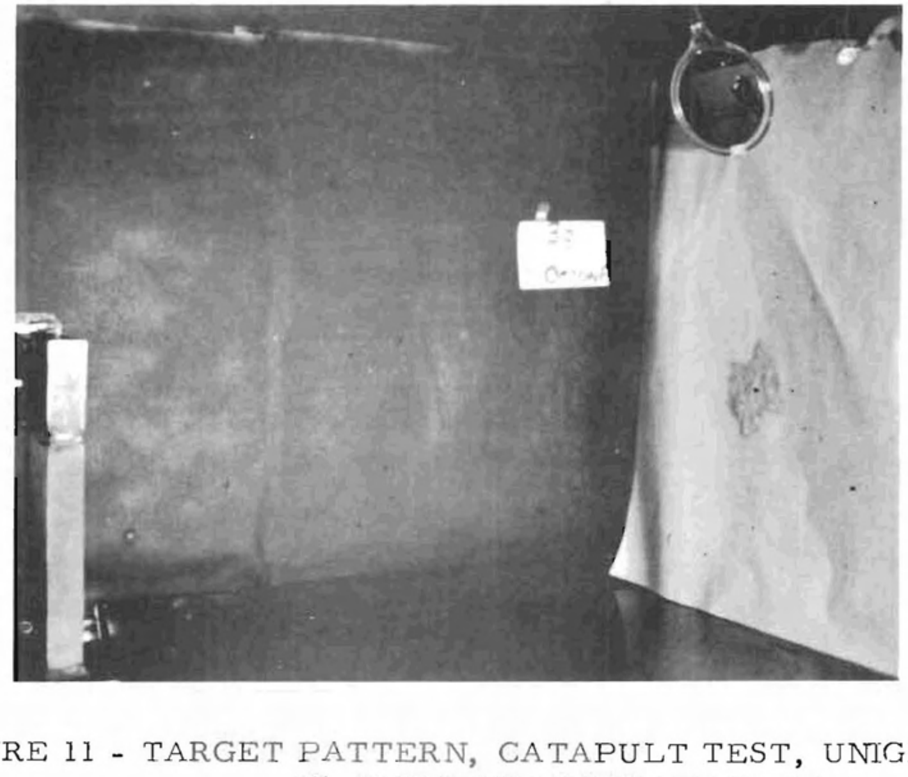

FIGURE 11 - TARGET PATTERN, CATAPULT TEST, UNIGNITED, 1% ALUMINUM OCTOATE IN JP-4

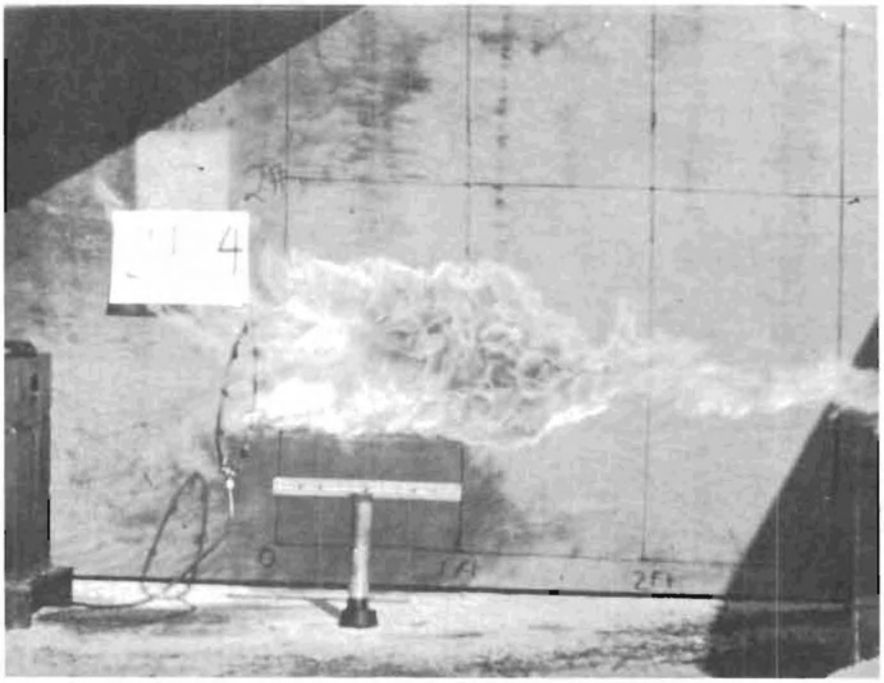

FIGURE 12 - FIREBALL, CATAPULT TEST, JP-4

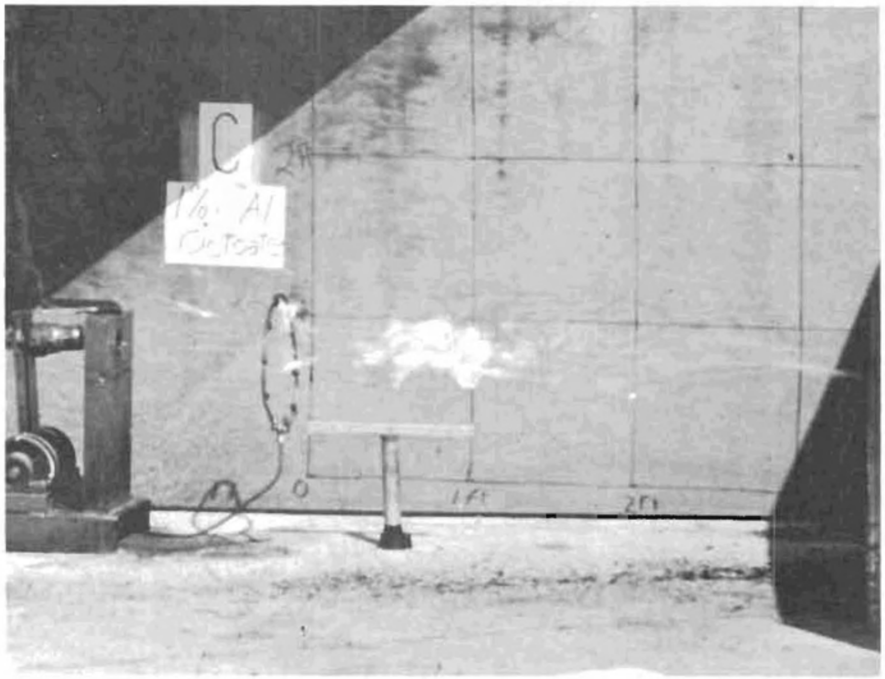

FIGURE 13 - FIREBALL, CATAPULT TEST, 1% ALUMINUM OCTOATE IN JP-4

$$R = 10\left(1 - \frac{\text{Dia., In.}}{20}\right),$$

where the diameter is less than 20 inches.

Ignited catapult test results are given in Table III.

(I) Base Fuel. JP-4 turbine fuel meeting military specification MIL-T-5624G was used throughout the program. Analysis of the fuel used during the program is given in Appendix 2. Lot 1 was used during the main part of the program. Lot 2 fuel was used in the final series of confirming tests.

DISCUSSION OF RESULTS

Many of the candidate fuels eliminated for various reasons were subjected to one or more of the rating-scheme tests along with the other contenders. This testing was done to gain experience with the tests and to avoid overlooking an effective candidate. The data from these tests are included in Table III.

Candidate modified fuels scoring high total scores were those having relatively strong structural integrity. Integrity under static conditions was measured by the selfspread-rate tests and under dynamic conditions, by the catapult (ignited) tests and the fireball drop tests. The other elements of the testing scheme give results within a narrow range, depending more upon the properties of the base fuel and its history than the fuel as modified. Flash points and flame spread rates in particular are sensitive to the loss of light ends. Regression rate results did not vary appreciably from those reported by the Bureau of Mines for fuel alone. Vapor-pressure rise rates (static) reflect the ease with which flammable vapors will evolve from a fuel under quiescent conditions at 100^{0}F. As expected, immobilized fuels released vapor more slowly than liquid fuels. No positive correlation was found, however, between vapor pressure rise scores and the dynamic catapult scores.

Those candidates not eliminated for other reasons (Table II) were considered to be under "active" consideration; however, this is not strictly true since valid non-test reasons existed for ruling out most of the active candidates. The criterion which most of the high-scoreing materials failed to meet was that of "pourability." The rigid gels, particularly the alkyl-hydroxybutyramides and amine diisocyanates, performed well in both static and dynamic tests, but would not pour. Other reasons for candidate elimination included (1) high sodium content, (2) relatively high concentrations, and (3) separation of fuel in storage.

Only five pourable fuels were "active" candidates. (Their scores and remarks are given in Table IV.)

TABLE IV

SCORES AND REMARKS, ACTIVE CANDIDATES

Type	No.	Conc. %	Total Score	No. Items Tested	Remarks
-	1	-	9.4	8	For comparison
Gel	2A	1.0	39.5	8	(Chosen as top candidate on basis of test scores, pourability, stability, easy preparation, non-corrosiveness)
Gel	2B	1.0	37.3	8	
Gel	3	0.5	41.3	7	
Gel	4A	3.35	31.7	5	High sodium content, high concentration
Gel	4B	3.35	41.5	8	High sodium content, high concentration
Gel	5	1.5	40.9	8	Not pourable, separates fuel slightly
Gel	6	1.5	23.5	4	Not pourable, separates fuel slightly
Gel	7	1.5	29.6	5	Not pourable, separates fuel slightly
Gel	8	1.5	31.8	5	Not pourable, separates fuel slightly
Gel	9	1.5	41.4	8	Not pourable, very stable
Gel	10	1.5	33.3	5	Not pourable, very stable
Gel	11	1.5	30.0	4	Not pourable, separates fuel
Gel	12	1.0	4.7	4	Not pourable, low scores, separates fuel
Gel	28	4.1	22.9	3	Not pourable, high concentration, separates fuel
Gel	29	3.8	30.5	4	Not pourable, high concentration, inhomogeneous
Gel	30	3.0	38.3	8	Not pourable, very stable
Gel	32	4.0	24.9	6	High concentration, fragile structure
Gel	39	4.3	16.6	3	Not pourable, high concentration, high sodium
Gel	44	3.0	31.2	5	Not pourable
Visco	47	0.2	9.1	4	Low test scores
Visco	48	0.5	8.0	4	Low test scores
Inhib	51	1.0	8.0	4	Low test scores, corrosive combustion product
Inhib	52	0.5	1.9	3	Low test scores, corrosive combustion product

Aluminum octoate gel
Gel - 4B
Visco - 47 viscoelastic gel
Fuels inhibited with Inhibitor - 51
Fuels inhibited with Inhibitor - 52

The inhibited fuels performed poorly on the tests and were ruled out on that basis. Fuels containing Visco - 47 scored low on the tests also and, significantly, two samples containing 0.5 percent Visco - 47 scored zero on the catapult (ignited) tests.

A comparison of the two remaining candidates (aluminum octoate and Gel - 4B) showed that Gel - 4B had a higher total score.

Drawbacks to the use of Gel-4B gels were (1) it contained harmful sodium, (2) a relatively high concentration of agent is required in JP-4, and (3) the presence of a de-icer in JP-4 prevents proper gel formation.

Aluminum octoate gels, on the other hand, were easily prepared, stable, completely combustible and noncorrosive. For these reasons, 1-percent aluminum octoate gel was selected as the best overall candidate considered.

Aluminum octoate dissolved completely in JP-4 so that no particulate matter was added to the fuel. It is believed that, when an aluminum octoate gel is burned in a turbine engine, the small amount of aluminum contained in the octoate will be burned to the oxide, Al_2O_3.

The ash content of aluminum octoate as given by the manufacturer is 15.7 percent expressed as Al_2O_3. Thus, a 1-percent gel would contain an added ash content of 0.157 percent. This content is above the limit of 0.10 percent specified in ASTM D396-66 for No. 4 and No. 5 fuel oils; however, the 0.10 percent specified includes troublesome, low-melting, slag-producing alkali sulfates and vanadium pentoxide. Al_2O_3 alone is nonslagging. If Aluminum octoate gel is atomized and burned in a trubine engine the ash produced is expected to be very finely divided and should pass readily from the engine.

CONCLUSIONS

Information developed in the course of this investigation substantiated the following conclusions.

1. The testing and rating system developed by the Bureau of Mines can be used to compare the relative effectiveness of candidate safety fuels in reducing crash-fire hazards.

2. Vapor-pressure rise rate, selfspread-rate and catapult fireball tests

provide significant data relative to the crash-fire characteristics of safety fuels.

3. Most of the candidate safety fuels currently available can be eliminated from consideration by the nontest requirements of gel formation, stability and pourability.

4. Aluminum octoate gels provide greater safety benefits, consistent with nontest requirements, than any other available candidate.

5. Rigid gels, such as the alkyl-hydroxybutyramides and amine diisocyonates, provide safety benefits but fail to meet other requirements.

6. A pourable gel prepared from a styrene type polymer (Gel-4B) has good safety properties but (1) contains sodium which could be harmful to a turbine engine, (2) requires a relatively high concentration, and (3) is not compatible with the de-icer contained in JP-4.

RECOMMENDATIONS

Based on the conclusions stated above, the following actions are recommended.

1. Research and development should be continued for the purpose of improving the equipment and expanding the methods necessary for testing and comparing safety fuels.

2. Aluminum octoate fuel gel should be tested further to determine its operational characteristics and provide information necessary to solve fuel-aircraft incompatibilities.

3. The conflicting·fuel requirements of fluidity for aircraft use and high consistency for crash-safety should be resolved by conducting: (1) a fuel systems program to develop the requirements for using safety fuels such as aluminum octoate gel (2) a laboratory program to develop liquifying treatment for fuels, such as aluminum octoate gel, at the engine.

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APPENDIX 1

PROPOSED CRASH FIRE HAZARD RATING FOR GELLED AND EMULSIFIED FUELS WITH RECOMMENDED TEST PROCEDURES

This rating system and the required testing apparatus and procedures were developed by the Bureau of Mines, U.S. Department of the Interior.

(1) Minimum Temperature for Hot Surface Ignition. Minimum AIT by ASTM D2155-66 method

$$\text{Rating Value} = 10 \left(\frac{\text{AIT} - 100}{1000}\right)$$

Minimum autoignition temperatures of the fuels are determined in air by the standard ASTM D-2155-66 method with two minor modifications.

(a) The thickened fuels are passed through a wire screen of approximately 10 mesh prior to use and

(b) They are injected into the test flask (200 cc Pyrex Erlenmeyer) with the "needle" of the hypodermic syringe removed. These modifications are recommended to facilitate fuel injection and they should have little or no affect on the minimum AIT's expected for the fuels of interest.

(2) Minimum Temperature for Formation of Flammable Mixtures. Flash point by ASTM D-56-64 method with modified procedure.

$$\text{Rating Value} = 10 \left(\frac{\text{F.Pt.}}{200}\right)$$

Flash points of the fuels are determined by the ASTM D-56-64 method (Tag Closed Cup) with certain modifications in procedure. The thickened fuels have relatively low thermal conductivity and fluidity and,therefore, considerable thermal lag can exist between the fuel sample and the sample container or bath in a flash-point tester. A low heating rate of approximately 0.3^{0}F per minute is required to overcome this difficulty and to obtain a given uniform sample temperature. For this purpose, the Tag Closed Cup apparatus must be modified to permit circulation of low-temperature fluids. This can be done by adding an inlet port opposite to the outlet port and near the bottom of the bath container; also, the sides of the bath container are covered with insulation to reduce heat leaks. In a determination, the sample is cooled to 20^{0}F below the expected flash point. A bath temperature of 5^0 to 8^{0}F below the sample temperature is necessary to achieve the optimum heating rate of 0.3^{0}F per minute. The thickened fuels should be passed through a No. 3 wire mesh before use.

(3) Time for Formation of Flammable Mixtures. Time to attain one-half psig at 100^{0}F in Reid Vapor Pressure Apparatus, ASTM D323-58, with modifications.

$$\text{Rating Value} = 10\,(1 - 2.5/t)$$

Modifications of the ASTM Reid Vapor Pressure Test Method (ASTM D323-58) are made to compare the relative rates at which the fuels form flammable vapor-air mixtures at 100°F. The time required for a fuel to attain a vapor pressure of one-half psig was selected since the corresponding fuel concentration will fall well within the flammable range for the fuels of interest. The data under static conditions are obtained in the standard apparatus utilizing the ASTM recommended procedure with one exception; the bomb and the fuel container are not shaken during a determination and precautions are taken not to let any liquid spill from the fuel container into the air chamber (bomb). The thickened fuels should be passed through a No. 3 wire mesh before use.

(4) Self Spread Rate. Time for fuel to spread two feet after ignition in proposed "Slope Test."

$$\text{Rating Value} = 15\,(1 - R/5)$$

A "Slope Test" was designed to measure the relative ease with which a thickened fuel, once ignited, can melt and flow and, thus, increase the potential size of the fire. In this test, a 4-foot-long metal trough is used and is sloped at a 2-degree angle; 3-inch aluminum angle is recommended for the trough. A 1-1/2-inch fuel segment is placed at the upper end of the trough and the top surface of the segment is ignited with a torch. For fuels that do not hold in place, these should be held in place (e.g., by plastic plates) until they are ignited. The time required for the fuel to melt and travel two feet down the trough is then measured from the time of ignition. Ambient temperature should be $70^0 \pm 5^0$F and the thickened fuels should be passed through a No. 3 wire mesh before use.

(5) Regression or Burning Rate. Regression rate of fuel ignited in 8-inch-diameter burning tray.

$$\text{Rating Value} = 10\,\left(1 - \frac{R}{0.1}\right)$$

The regression or burning rates of the fuels are determined in 8-inch-diameter metal trays with a fuel depth of at least one inch. Aluminum or steel trays are recommended and they should be filled to a height equal to or less than one-half from the top. The average regression rate is determined by measuring the burning time for a fuel depth of one inch; to minimize tray effects at low fuel depths, the total fuel depth should be slightly greater than one inch, e.g., 1-1/4 inches. The rates can be measured by visual observation by pressure-load transducers, or by other devices whose output can provide a change of fuel weight and fuel depth with time. Ambient temperature should be $70^0 \pm 10^0$F.

(6) Horizontal Flame Spread Rate Under Static Conditions. Horizontal flame spread rate of fuel ignited in 3-inch angle trough.

$$\text{Rating Value} = 10\ (1 - R/5)$$

The flame spread rates should be determined in a metal trough of at least 4-1/2 feet in length; 3-inch aluminum angle is recommended for this test. The fuel is ignited with a torch at one end of the trough and flame propagation is measured over a 4-foot distance. Flame propagation can be measured by the use of fuse wires (1/2 amp) and a suitable timer or recorder; the first fuse wire should be about six inches from the point of ignition. Ambient temperature should be $70^0 \pm 5^0$F and the thickened fuels should be passed through a No. 3 wire mesh before use.

(7) Fire Ball Size Under Impact Conditions. Height and width of fire ball im proposed "Fuel Drop Fire Test" with five pounds of fuel at a drop height of 20 feet.

(a) Maximum Height Within 10 Seconds After Ignition.

$$\text{Rating Value} = 10\ (1 - H_2/12)$$

(b) Maximum Width Within 10 Seconds After Ignition.

$$\text{Rating Value} = 10\ (1 - W_2/20)$$

(c) Maximum Width Within One Second After Ignition.

$$\text{Rating Value} = 10\ (1 - W_1/20)$$

A "Fuel Drop Fire Test" was designed for comparing the relative fire hazard which may be associated with the fuels in ignitions under impact conditions. For this purpose, five pounds of fuel contained in a Pyrex Erlenmeyer flask is dropped from a height of 20 feet onto a concrete or asphalt surface. A torch is positioned near the point of impact to effect immediate ignition and is removed after ignition. The flame spread and size of fire ball produced is recorded by a motion picture camera; a metal frame grid is mounted in the background to facilitate the film measurements. The maximum height and width of the "fire ball" attained within 10 seconds is measured since the size of the "fire ball" does not appear to increase much beyond this time for the type of fuels considered here. The maximum width attained within one-half second is also measured to observe flame spread differences which can be attributed to increased vapor formation, mist formation, or fuel spread under impact conditions. Ambient temperature should be $70^0 \pm 10^0$F and the thickened fuels should be passed through a No. 3 wire mesh before use.

APPENDIX 2

FUEL ANALYSIS, JP-4

	Lot 1	Lot 2
Distillation		
Initial boiling point	146^0F	162^0F
Fuel evaporated, 10% at	168^0F	225^0F
20% at	194^0F	275^0F
50% at	280^0F	318^0F
90% at	460^0F	380^0F
End point	490^0F	450^0F
Percent evaporated at 400^0F (204.4^0C)		93.0
Residue, volume percent	1.0	1.0
Distillation loss, volume percent	1.0	1.0
Gravity ^{0}API (sp. gr.)	54.0	53.8(0.764)
Existent gum, mg./100 ml.	1.0	0.5
Potential gum, mg/100 ml.	2.0	0.9
Sulfur, total, wt. percent	0.06	0.04
Mercaptan sulfur, wt. percent	0.0005	0.0005
Reid Vapor Pressure, 100^0F, psi	2.7	2.7
Freezing Point	below -76^0F	-76^0F
Heating Value		
Net heat of combustion Btu/eb	---	18,750
Aniline gravity product	7,128	7,000
Aromatics, volume percent	10.0	11.0
Olefin, volume percent	1.0	1.0
Smoke point, mm. min.	25.0	29.0
Smoke volatility index	57.3	68.1
Copper strip corrosion, ASTM classification	1A	No. 1
Water separometer index	75	98
Water reaction, interface rating	1	1
Thermal Stability		
Change in pressure drop in 5 hours, in. of Hg	0.01	0.2
Pre heater deposit	2	below No. 2

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