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Antimisting Kerosene Flammability Tests Using the Wing-Fuel Spillage Facility

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November 1986

DOT/FAA/CT-TN86/51

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16. Abstract

A comprehensive data base was developed representing the flammability characteristics of Antimisting Kerosene (AMK) fuel as tested on a Wing-Fuel Spillage Facility. Presented herin are the results of wing-fuel spillage tests examining FM-9™ antimisting fuel, FM-9 variants, alternate additives, inline blended fuels, and degraded fuels.

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EXECUTIVE SUMMARY

This report represents the observations, test data, and conclusions obtained during the course of 187 wing-fuel spillage tests conducted at the Federal Aviation Administration Technical Center. During the accomplishment of this effort, a comprehensive data base was developed representing the flammability characteristics of FM-9™ antimisting kerosene (AMK) as well as several alternate additives. The performance of fuels produced by batch and inline blending, as well as intentionally degraded fuels, was evaluated.

TEST RESULTS AND CONCLUSIONS.

1. As a result of this and other corroborating testing, the FM-9 designated "SD" was selected for use in the full-scale validation phase of the Federal Aviation Administration AMK Program.

2. Degrading FM-9 AMK or mixing the AMK with highly volatile contaminants reduces the effectiveness of the additive in suppressing mist fires.

3. External contaminations consisting of a high local concentration of volatile misted liquids reduces the effectiveness of AMK in suppressing mist fires.

4. Two of the three alternate additives tested showed a significant amount of fire suppression.

5. Inline blending produced AMK fuel of equal or superior flammability characteristics compared to batch blended AMK fuel.

6. Improved quality control of FM-9 and better on-site conditioning of the FM-9 slurry increased the mist-fire suppression of the inline blended fuel.

INTRODUCTION

The Federal Aviation Administration (FAA) initiated a program in July 1978, to evaluate the performance of an antimisting fuel in preventing post-crash fireballs in otherwise impact-survivable crashes. The Wing-Fuel Spillage Facility was constructed to be a primary means of evaluating the mist suppression characteristics of antimisting kerosene additives. This document reports the results of 187 tests conducted from December 1, 1980 to November 6, 1984. Facility construction and prior testing are reported in reference 1.

DISCUSSION

THEORY.

Jet A fuel, due to its low vapor pressure, does not readily ignite in bulk form. However, when released into a high relative velocity airstream, it forms a fine mist which is highly ignitable and explosive. This resulting fireball can be lethal in an otherwise survivable aircraft impact.

The introduction of small amounts (0.3 percent by weight) of FM-9™ polymer, manufactured by Imperial Chemical Industries (ICI Americas and ICI Limited), into Jet A kerosene enables the fuel to resist this mist formation. Evaluation of the effectiveness of antimisting additives by crashing aircraft is desirable but not economically feasible. The Wing-Fuel Spillage Facility was designed to simulate the fuel spillage that would occur from a ruptured aircraft wing. Release of fuel into the counterflow air discharging from the facility, causes the fuel to breakup into a mist. Testing has shown the facility to be accurate in predicting the performance of the antimisting agent in large-scale crash situations.

FACILITY DESCRIPTION.

The facility is designed to simulate a ruptured wing fuel tank moving through a high relative air velocity. This is accomplished by a fixed simulated wing section positioned behind an open air 6-foot square wind tunnel, as pictured in figure 1.

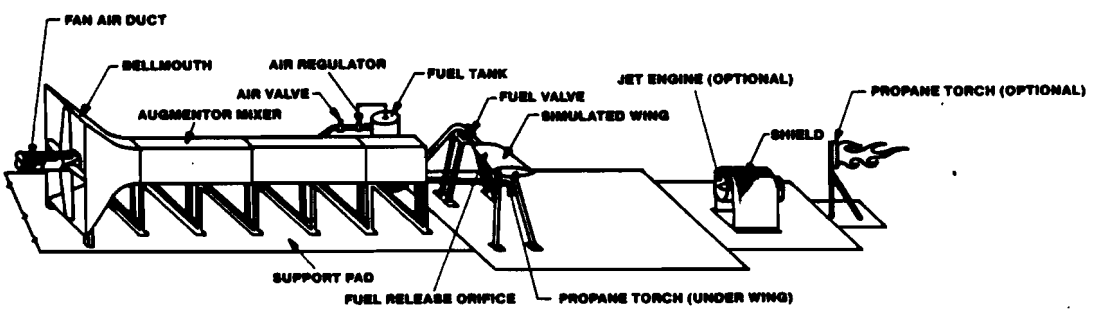

FIGURE 1. WING-FUEL SPILLAGE TEST FACILITY

The wing section is fitted with a 12-inch supply pipe and an orifice in the leading edge. This orifice size and shape can be changed to permit openings up to the 12 inches in diameter. Fuel is supplied to the wing through this 12-inch pipe from a pressurized 1000-gallon vessel, as depicted in figure 2. The vessel is insulated and provided with a means of heating the fuel. Flow rate through the wing opening is controlled by the size of the orifice and the driving pressure in the tank. Flow duration is controlled by an air-operated butterfly valve.

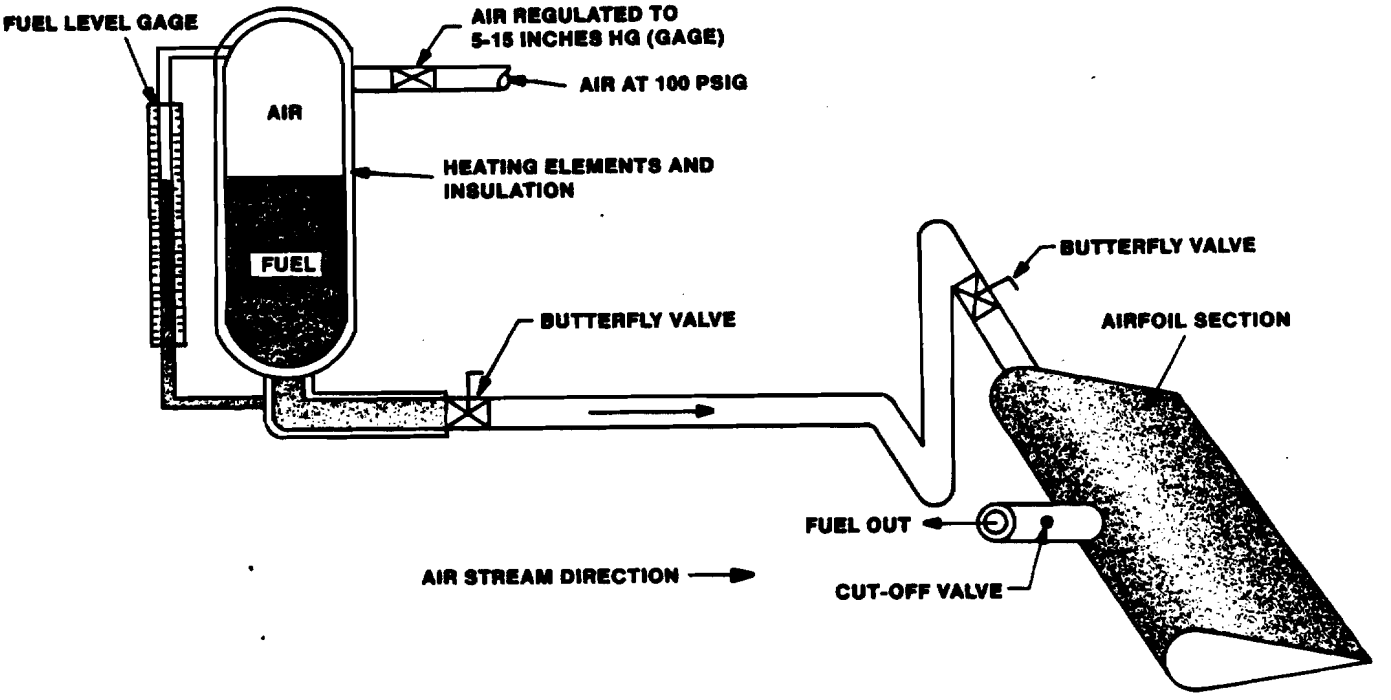

FIGURE 2. FUEL SPILLAGE SYSTEM SCHEMATIC

The open air wind tunnel consists of a high velocity primary section and an augmenter section. High velocity air, up to 200 pounds/second at 550 knots, from the fan section of a TF-33 turbofan engine, is ducted to the throat of the augmenter bellmouth. This induces an additional 400 pounds/second (maximum) of air into a 50-foot augmentor mixing duct. A fairly flat profile controllable air velocity, measured 21 inches from the exit, is produced over the range of 55 to 180 knots, depending on the TF-33 drive engine power condition.

Ignition is normally provided by a propane torch located 3 feet under the wing and 4 1/2 feet aft of the release point. This location was selected as the most severe during calibration testing. Additional ignition sources and location have been used for special test configurations. A capability also exsists to mount and operate turbine engines in the region of released fuel.

The tunnel airspeed is manually set by the drive turbofan engine power level. An automatic sequencer controls the ignition, fuel release, and high-speed cameras to record the results. The duration of a normal test, from fuel valve open to close, is approximately seven seconds.

INSTRUMENTATION.

Air velocity and temperature are measured at the augmenter exit. Ambient air temperature, humidity, fuel temperature, respective time of valve opening and closing, and ignition temperature are parameters recorded on a data acquisition system. Additional parameters, as desired, are recorded manually as the test dictates.

The primary source of data is by means of high-speed photography. A minimum of two views at 200 frames per second provide a high-speed film record of the fuel dump and any resulting fireballs.

To assess differences between test sequences, the rate at which a resultant fireball would grow was determined from the film by measurement of the 2-dimensional area of the fireball at discrete time increments. This area is converted into an equivalent circular area and the rate of change of the radius of this resultant area is used as a term to define severity of the fire. Experience has shown that effective radius growth rates of 0-11 feet per second indicate a PASS (P), 11-20 feet per second a MARGINAL (M), and above 20 feet per second a FAIL (F). This assumed breakdown refers to the propensity for ignition to propagate through the misted fuel, or to self extinguish.

A more complete description of the facility, instrumentation, and data analysis methods can be found in reference 1.

TEST DESIGN.

The Wing-Fuel Spillage Facility was used to evaluate the flammability characteristics of AMK candidates throughout the program, provided small-scale bench testing indicated it was warranted. The tests examined various effects such as use of inline blended fuel, FM-9 slurry variations, degraded fuel, alternate candidates, and base fuel quality.

BATCH-BLENDED FUEL. Testing of the FM-9 additive prior to 1983 was almost exclusively conducted with AMK fuel which was prepared by batch blending the polymer, glycol, and amine with Jet A at ICI processing facilities. The batch-blended FM-9 AMK continued to be used as a baseline fuel for comparing AMK fuels produced from FM-9 polymer variants, by other blending processes, and from slurry variations. The batch-blended FM-9 was periodically tested on the Wing-Fuel Spillage Facility as a check on the facility calibration.

INLINE-BLENDED FUEL. Inline blenders were developed at the Jet Propulsion Laboratory (JPL) and the Technical Center to disperse the FM-9 slurry into Jet A (reference 2). The requirement was to mix the slurry/Jet A in an acceptable fashion while retaining the flammability characteristics. Concurrent with the inline blender development, Imperial Chemical Industries (ICI) was developing improved slurries with better viscosity and dispersion properties. The fuels made from each of these variants were evaluated both in terms of blending quality and flammability protection.

DEGRADED FUEL. The FM-9 AMK is subject to a certain amount of unwanted degradation through handling, pumping, and exposure to sunlight. Wing-fuel spillage tests were conducted to determine the effect of the level of degradation.

ALTERNATE CANDIDATES. Throughout the program, the FAA has encouraged the development of AMK additives by industry. The FM-9 additive was selected as the most promising candidate for the initial feasibility phase of the FAA antimisting fuel program. Changes to the FM-9 formulation were prohibited during the feasibility phase to provide a common data base for use in evaluating the antimisting concept. The program plan included a candidate fuels evaluation phase which was intended to encourage and support industry development of alternate fuels. As a result of a reduction in funds, the "seed money" was not made available and contracts were not awarded for the development of alternate AMK fuels. Independent development of candidates by industry was encouraged with an understanding that such fuels would be examined by the FAA. The Wing-Fuel Spillage Facility has been made available to test alternate additives that had performed acceptably in laboratory- and bench-scale tests (reference 3).

FUEL QUALITY. Wing spillage tests were performed to evaluate the effect of large-scale fuel blends on flammability characteristics, i.e., blends prepared for large-scale impact tests at the Navy Air Engineering Center; the flight testing of AMK using a CV880 aircraft; and FAA Technical Center engine test cell tests of AMK. These tests also served to evaluate the performance of inline blenders in producing a consistent, quality product.

TEST RESULTS

Appendix A includes a tabulation of all the wing-fuel spillage tests discussed in this report.

BATCH-BLENDED FUEL.

The baseline batch-blended 0.30 percent FM-9 fuel consistently provided fire protection with pass velocities of 130 knots and lower.

Batch blended FM-9 variants were developed by ICI and evaluated on the Wing-Fuel Spillage Facility following the feasibility phase of the AMK Program. The flammability resistance of the first FM-9 variant (FM-9X without amine) to be tested was significantly lower than the baseline AMK fuel, with fail velocities as low as 110 knots at 0.30 percent polymer concentrations. When amine was added to this variant during the batch processing, the flammability protection was restored, passing the 130-knot wing-fuel spillage test at 0.30 percent concentration.

Another batch-blended FM-9 variant (0.30 percent FM-9SF) also passed the wing-fuel spillage test at a velocity of 130 knots.

INLINE-BLENDED FUEL.

An inline blended FM-9 variant (FM-9X with amine) produced limited flammability protection with marginal and fail classifications for 0.30 percent polylmer concentrations at 100 and 130 knots, respectively. This AMK fuel required a special two-stage blending procedure consisting of a FM-9X/glycol slurry being blended at a high concentration with Jet A fuel, and the resulting blend being mixed to the required concentration with Jet A containing the amine. The resulting AMK fuel proved to be very fragile, subject to a high degree of unintentional degradation. This problem, together with high slurry viscosities and the lower fire protection, was serious enough to eliminate it as a viable AMK candidate for the full-scale validation phase of the AMK program.

The viscosity of FM-9SF slurry was also high, approximately the same as the FM-9X slurry. The polylmer went into solution but produced an AMK fuel that was cloudy with small gel-like particles. The AMK fuel and all the other FM-9 variant fuels tested, except for the FM-9X and fuels prepared from a 1-percent concentration of polymer in Jet A, were produced by inline blending slurries containing polymer, glycol, and amine with Jet A in a single-stage procedure. Several slurries also contained water or a cosolvent.

The FM-9SF fuel exhibited good flammability protection with pass velocities as high as 130 knots. FM-9SF, prepared as a concentrate in Jet A and then inline blended, provided a lower degree of fire protection than 0.30 percent batch blended FM-9 and FM-9SF at 0.26 and 0.31 percent concentrations and approximately the same protection at 0.35 and 0.38 percent concentrations.

The high viscosity and blending problems associated with the FM-9SF slurry and the logistic problems of handling large quantities of FM-9SF concentrate were considered serious, and this variant was also eliminated as a candidate for future development.

Another FM-9 variant slurry (FM-9SDJ) was very thick and parctically unpourable. Mechanical premixing of the slurry reduced the viscosity, but the blending euipment had to be modified to pressure feed the slurry to the metering pump. Once dispersed into the Jet A, the polymer exhibited good dissolution properties. The AMK fuel produced showed better fire protection than batch-blended FM-9 at 0.30 percent and lower concentrations. However, fire protection at concentrations above 0.30 percent was lower than batch-blended FM-9. When the FM-9SDJ AMK was tested at low temperatures, the polymer tended to precipitate out of the solution. This, combined with the unacceptable high viscosity of the slurry, resulted in this variant also being eliminated.

The FM-9SFE slurry was quite thin and easily pourable, but readily separated. The slurry consistency was not homogeneous and contained heavy grit particles. When blended with Jet A, these particles would not go into solution and served as a nucleus about which gel would form. As a result of the gel formation, the solid content of the AMK fuel was low (0.21 and 0.25 percent) and the fire protection was lower than the baseline 0.30 percent FM-9.

Another FM-9 variant slurry (FM-9SDE) was very thin, homogeneous, and pourable. The slurry went into solution easily and quickly. The resulting AMK exhibited superior fire protection with a pass velocity of 140 knots at 0.30 percent concentration. Development work on this slurry, therefore, continued in parallel with polymer refinements.

The refinements to the FM-9 polymer and changes in the polymer loading resulted in a slurry (FM-9SD) that was nearly as thin and workable as the FM-9SDE slurry. The FM-9SD slurry went into solution quickly and produced an AMK fuel which exhibited excellent fire protection with pass velocities of 130 knots as 97° Fahrenheit (F) and 160 knots at 44° F fuel temperatures. The FM-9SD slurry with a 25 percent polymer loading was, therefore, selected for use in the full-scale validation phase of the AMK program. This decision was based on flammability and blendability performance, as well as the fact that chemically, the AMK was identical to the standard baseline batch-blended fuel.

Fire protection also increased as the polymer manufacturer improved the quality of the slurry and as the slurry conditioning and blending techniques were improved. The pass velocity on the Wing-Fuel Spillage Facility for 0.30 percent FM-9SD increased to as high as 170 knots, surpassing the original batch-blended AMK fuel by 40 knots.

The FM-9SD slurry did show some sensitivity to scale-up in the polymer production process. As the ICI polymer production lost size was increased, the pass velocity for the resultant AMK blends dropped from 170 knots to 140 knots. The inline blended FM-9SD showed good equilibration characteristics, developing full fire protection within the first hour after completing the blend. The AMK produced from high quality FM-9SD slurry passed the wing-fuel spillage test at 160 and 170 knots within the first hour. The FM-9SD slurry produced from the scaled-up process, resulted in an AMK fuel which passed at 140 knots 1/2 hour after completing the blend.

The AMK produced from FM-9SD slurry was tested on the Wing-Fuel Spillage Facility over a range of polymer concentration from 0.24 to 0.37 percent. Over this range, fire protection increased at a rate of approximately 50 knots per 0.10 percent increase in concentration, with 0.24 percent passing at 130 knots, 40 minutes after blending.

The sensitivity of AMK produced from FM-9SD slurry to fuel temperature was also examined in the Wing-Fuel Spillage Facility. While 71° F and 83° F AMK fuel passed the 170-knot velocity test, 97° F fuel passed at 130 knots and failed at 150 knots (marginal at 140 knots).

Experimental ICI sodium-free FM-9 slurries were also inline blended and tested on the Wing-Fuel Spillage Facility. During the initial blend, problems were noted with the slurry consistency and dissolution when mixed with Jet A. A second blend was made using a new lot of the experimental sodium-free slurry. The consistency of this second slurry was much improved, and no significant problems were noted while inline blending. Both blends exhibited good fire protection with pass velocities of 140 knots.

An experimental FM-9SD slurry with a monomer processing change was also inline blended and tested on the Wing-Fuel Spillage Facility. The fire protection provided by this fuel was considered nearly equivalent to the standard FM-9SD AMK with 0.29 percent fuel passing at 150 knots, 44 minutes after blending.

The effect of different base Jet A fuels on the performance of the resulting AMK fuel was also examined in the Wing-Fuel Spillage Facility. Three sources of Jet A were used in this study (Edwards Air Force Base, Federal Aviation Administration Technical Center, and Kern County Airport, Mojave, California). The flammability protection provided by inline blended FM-9SD slurry with Mojave Jet A was approximately 10 and 20 knots lower than that provided by AMK produced with Edwards and Technical Center base Jet A fuels, respectively. However, the level of protection was still considered to be high with 0.29 percent polymer in Mojave Jet A passing at 150 knots.

DEGRADED FUEL.

The AMK fuel is subjected to unintentional degradation as a result of pumping, temperature cycling, exposure to ultraviolet light, sloshing in a fuel tank, and chemical interaction. Wing-fuel spillage tests were conducted to determine the effect of degradation on the mist-fire suppressant characteristics of the FM-9 AMK. The level of degradation was measured by a filter ratio device (reference 4) which determines the ratio of AMK filtration time to the time required to filter the Jet A fuel.

Eleven wing-fuel spillage tests were performed with batch blended FM-9 AMK degraded to various degrees. The fuel was degraded by single and multiple passes through a fuel tank boost pump. The resulting filter ratios ranges from 6 to 32, as compared to 39 for the undegraded AMK.

The degraded fuel with a filter ratio of 32 showed a 10-knot decline from the undegraded fuel, 120-knot versus 130-knot pass. At a filter ratio of 16 and a velocity of 100 knots, 80° F fuel failed and 67° F fuel passed the wing-fuel spillage test. The 67° F fuel also passed at 107 knots with a filter ratio of 13. At filter ratios of 8 and less, the AMK fuel failed at all air velocities tested, including a test at 80 knots.

A second analytical method used to quantify the level of degradation was the orifice flow test (reference 4), which measures the volume of AMK fuel passing through a small diameter orifice at a specified temperature and time interval. Undegraded AMK passed at an air velocity of 130 knots at a orifice flow of 2.8 cc/30 seconds. Degraded AMK with orifice flow of 6.6 cc/30 seconds and greater were unable to pass in the Wing-Fuel Spillage Facility at velocities as low as 80 knots.

The effective propagation rate in the marginal-fail area also increased with decreasing filter ratios and the corresponding increasing levels of degradation (figure 3). The width of the propagation rate band is primarily due to test air velocities differences, with higher velocities causing higher propagation rates for the same filter ratio fuel.

ALTERNATE CANDIDATES.

The FAA screened several alternate additives from different manufacturers using small flammability test rigs such as the Flammability Comparison Test Apparatus (FCTA) (reference 5). Three of these candidate exhibited sufficient fire protection to warrant testing on the Wing-Fuel Spillage Facility.

The first candidate additive was mixed as per the manufacturer's (Dow) instructions to 0.2 percent concentration by weight with polymer number 192-C001-13. This concentration was determined by FCTA testing to exhibit the best fire protection. Tests were conducted at 130 knots and 110 knots. The fuel did not exhibit any noticeable fire protection at these speeds.

A second manufacturer (Conoco) submitted several potential additives to the FAA for evaluation. After preliminary testing on the FCTA, it was decided to test the most promising, AM-110-3, on the wing-fuel spillage rig. Three different concentrations by weight were tested: 0.100 percent, 0.125 percent, and 0.150 percent. The 0.1 percent demonstrated insufficient fire protection. However, the 0.125 and 0.150 percent, showed good fire protection (140-knot pass for 0.150 percent).

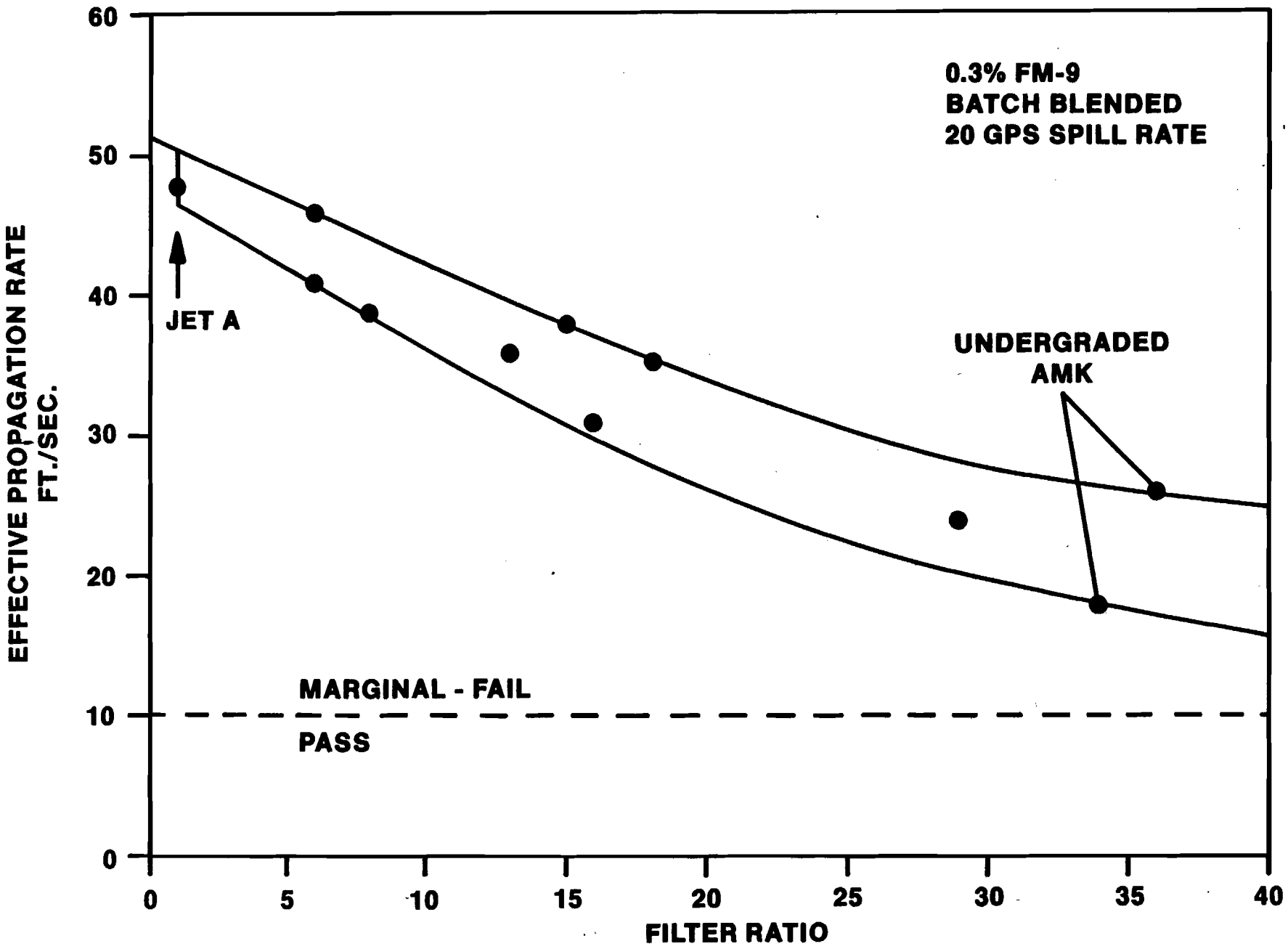

FIGURE 3. FLAME PROPAGATION DURING BREAKUP OF ANTIMISTING FUELS

A third manufacturer (Arco) submitted an additive designated AMF-1. This additive exhibited very good fire protection in concentrations by weight of 0.15 and 0.30 percent when tested on the FCTA. This additive showed good fire protection when tested at 0.1 percent on the wing-fuel spillage rig (120-knot pass).

FUEL QUALITY.

Fuel quality flammability tests were conducted to verify the characteristics of certain blends. These tests were performed to check:

1. Blender operation
2. Batch size effects
3. Fuel intended for engine, flight and crash tests

These tests made up most of the remaining wing-fuel spillage tests. The operation of each blender was verified and the fuel produced generally was shown to have the same degree of fire protection.

FUEL CONCENTRATION.

Concern was expressed regarding possible contamination of the AMK with small amounts of volatile liquids. This could occur internally in the wing tank or externally during a crash situation; i.e., broken degrader line. To examine the problem of internal contamination, a 95-percent AMK/5-percent JP4 fuel mixture was tested. The wing spillage tests were conducted at 20 gallons/second dump rate using the underwing propane torch ignition source.

The 5-percent JP4 reduced the pass threshold velocity 20 knots from 130 knots to 110 knots. The marginal zone was also reduced with repeated failure at 120 knots. To explore the possibility of external contamination, the Wing-Fuel Spillage Facility was modified to spray a small amount of the contaminant into the primary discharge. The contaminant tank was loaded with highly degraded AMK and discharged under pressure through a 1-inch nozzle in the same direction as the main fuel dump. The two discharges mixed and were sheared by the same airflow prior to exposure to the ignition source.

These tests indicated that external contamination may be a more serious problem than internal contamination, with a 150-knot fail and 130-knot margin (compared to a 160-knot pass for the uncontaminated AMK). The high local concentration of the highly flammable contaminant ignited quite readily, providing a high intensity ignition source for the AMK, reducing its effectiveness. The key factor is the volume of the contaminant. When the contaminant is exhausted, the AMK again showed good mist-fire suppression.

CONCLUSIONS

1. Degrading FM-9 AMK or mixing the AMK with highly volatile contaminants reduces the effectiveness of the additive in supressing mist-fires.

2. External contaminations consisting of a high local concentration of volatile misted liquids reduces the effectiveness of AMK in suppressing mist-fires.

3. Two of three alternate additives showed a significant amount of fire suppression.

4. Inline blending produced AMK fuel of equal or superior flammability characteristics compared to batch-blended AMK fuel.

5 Improved quality control of FM-9 and better on-site conditioning of the slurry increased the mist fire suppression capability of the inline blended fuel.

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APPENDIX A

WING-FUEL SPILLAGE TEST TABULATION

This section includes a tabulation of all Wing-Fuel Spillage tests included in this report. All tests, unless otherwise noted, were performed in the standard configuration. This included:

1. Ignition source consisting of a continuous propane torch located under the wing section.

2. Fuel spillage rate of 20 gallons per second (nominal) for 5 seconds.

3. Driving air pressure in the supply tank of 14-inch Hg above ambient.

4. Fuel temperature set a 80° F.

5. Round orifice in wing leading edge of 4 1/4 inches diameter.

6. Airspeed manually set, ranging from 80 to 170 knots.

WING SPILLAGE TABULATION

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
149	FUEL CONTAMINATION	.3% FM-9	120	F-29	79	---	---	BATCH	--	5% JP4 ADDED
150	FUEL CONTAMINATION	.3% FM-9	110	P-6	79	---	---	BATCH	--	5% JP4 ADDED
151	FUEL CONTAMINATION	.3% FM-9	120	F-27	79	---	---	BATCH	--	5% JP4 ADDED
152	GROUND PLANE	.3% FM-9	140	M-16	81	---	---	BATCH	--	60 GPS DUMP RATE; 4-FT SPLASH PAN
153	GROUND PLANE	.3% FM-9	150	F-23	81	---	---	BATCH	--	60 GPS DUMP RATE; 4-FT SPLASH PAN
154 - 170	EXPERIMENTAL LOW VOLUME FUEL SPILLAGE INVESTIGATION									
171	PARTIALLY DEGRADED	.3% FM-9	130	F-24	88	---	25	BATCH	--	CONTAMINATED DOUGLAS FUEL
172	PARTIALLY DEGRADED	.3% FM-9	120	F-26	88	---	25	BATCH	--	CONTAMINATED DOUGLAS FUEL
173	PARTIALLY DEGRADED	.3% FM-9	100	F-22	88	---	25	BATCH	--	CONTAMINATED DOUGLAS FUEL
174	PARTIALLY DEGRADED	.3% FM-9	120	F-24	48	---	25	BATCH	--	CONTAMINATED DOUGLAS FUEL
175	PARTIALLY DEGRADED	.3% FM-9	100	M-18	48	---	25	BATCH	--	CONTAMINATED DOUGLAS FUEL

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
176	PARTIALLY DEGRADED	.3% FM-9	90	P-6	48	---	25	BATCH	--	CONTAMINATED DOUGLAS FUEL
177	PARTIALLY DEGRADED	.3% FM-9	130	F-24	68	3.4	29	BATCH	--	
178	PARTIALLY DEGRADED	.3% FM-9	120	P-5	70	3.5	32	BATCH	--	
179	PARTIALLY DEGRADED	.3% FM-9	120	F-35	80	6.0	18	BATCH	--	
180	PARTIALLY DEGRADED	.3% FM-9	110	F-38	79	6.0	15	BATCH	--	
181	PARTIALLY DEGRADED	.3% FM-9	100	P-3	67	6.4	16	BATCH	--	
182	PARTIALLY DEGRADED	.3% FM-9	107	P-0	67	6.0	13	BATCH	--	
183	PARTIALLY DEGRADED	.3% FM-9	110	F-36	80	6.6	13	BATCH	--	
184	PARTIALLY DEGRADED	.3% FM-9	100	F-31	80	6.6	16	BATCH	--	
185	PARTIALLY DEGRADED	.3% FM-9	110	F-46	72	7.1	6	BATCH	--	
186	PARTIALLY DEGRADED	.3% FM-9	90	F-39	73	7.1	8	BATCH	--	
187	PARTIALLY DEGRADED	.3% FM-9	80	F-41	73	7.1	6	BATCH	--	
188	BASELINE	.3% FM-9	130	F-0	83	2.8	39	BATCH	--	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
189	BASELINE	.3% FM-9	150	F-26	83	2.6	36	BATCH	--	
190	BASELINE	.3% FM-9	140	M-18	83	2.6	34	BATCH	--	
191	MODIFIED POLYMER	.2% FM-9X JCK 10-95	140	F-28	78	2.9	44	BATCH	--	
192	MODIFIED POLYMER	.2% FM-9X JCK 10-95	120	F-25	83	3.3	44	BATCH	--	
193	MODIFIED POLYMER	.2% FM-9X JCK 10-95	100	M-18	84	3.5	41	BATCH	--	
194	MODIFIED POLYMER	.15% FM-9X JCK 10-80	100	F-26	79	4.8	28	BATCH	--	
195	MODIFIED POLYMER	.15% FM-9X JCK 10-80	90	F-23	78	4.1	32	BATCH	--	
196	MODIFIED POLYMER	.3% FM-9X JCK 10-135	140	F-30	81	3.3	68	BATCH	--	
197	MODIFIED POLYMER	.3% FM-9X JCK 10-135	120	F-21	82	3.5	57	BATCH	--	
198	MODIFIED POLYMER	.3% FM-9X JCK 10-135	110	F-22	82	2.8	55	BATCH	--	
199	MODIFIED POLYMER	.3% FM-9X w/AMINE	150	F-24	81	1.6	79	BATCH	--	
200	MODIFIED POLYMER	.3% FM-9X w/AMINE	150	F-24	83	1.4	92	BATCH	--	
201	MODIFIED POLYMER	.3% FM-9X w/AMINE	140	M-17	85	1.5	110	BATCH	--	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
202	BLUFF BODY	.3% FM-9	150	F-28	74	---	11	BATCH	--	FLAME HOLDER;CONTAMINATED DOUGLAS FUEL
203	BLUFF BODY	.3% FM-9	120	23	80	---	11	BATCH	--	FLAME HOLDER;CONTAMINATED DOUGLAS FUEL
204	BLUFF BODY	.3% FM-9	100	F-21	50	---	11	BATCH	--	FLAME HOLDER;CONTAMINATED DOUGLAS FUEL
205	MODIFIED POLYMER	.3% FM-9SF JCK 11-20	130	M-17	72	---	---	BATCH	--	FLAME HOLDER
206	MODIFIED POLYMER	.3% FM-9SF JCK 11-20	130	P-6	76	---	---	BATCH	--	WITHOUT FLAME HOLDER
207	MODIFIED POLYMER	.3% FM-9SF JCK 11-20	140	F-25	76	---	---	BATCH	--	WITHOUT FLAME HOLDER
208	MODIFIED POLYMER	.3% FM-9SF JCK 11-20	135	F-26	81	---	---	BATCH	--	WITHOUT FLAME HOLDER; SHORT DUMP
209	SLURRY	.3%FM-9X w/AMINE JCK 11-39	130	F-33	74	---	---	JPL	--	
210	SLURRY	.3% FM-9X w/AMINE JCK 11-39	110	M-16	75	---	---	JPL	--	
211	SLURRY	.3% FM-9X w/AMINE JCK 11-39	100	P-0	75	---	---	JPL	--	
212	SLURRY	.3% FM-9X w/AMINE JCK 11-39	110	M-19	75	---	---	JPL	--	
213	SLURRY	.3% FM-9SF JCK 11-35	130	F-22	68	---	---	JPL	--	
214	SLURRY	.3% FM-9SF JCK 11-35	120	P-0	69	---	---	JPL	--	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
215	SLURRY	.3% FM-9SF JCK 11-35	140	F-23	61	---	---	JPL	--	
216	SLURRY	.3% FM-9SF JCK 11-35	130	P-9	61	---	---	JPL	--	
217	ALT. ADD.	AMF-1 0.1%	130	M-15	61	---	---	BATCH	--	ARCO ADDITIVE
218	ALT. ADD.	AMF-1 0.1%	140	F-21	62	---	---	BATCH	--	ARCO ADDITIVE
219	ALT. ADD.	AMF-1 0.1%	120	P-0	62	---	---	BATCH	--	ARCO ADDITIVE
220	ALT. ADD.	AMF-1 0.1%	150	M-19	58	---	---	BATCH	--	ARCO ADDITIVE
221	SLURRY	.34% FM-9X w/AMINE JCK 11-170	130	M-17	75	1.6	90	JPL	10	
222	SLURRY	.34% FM-9X w/AMINE JCK 11-170	120	P-3	75	1.6	90	JPL	10	
223	SLURRY	.34% FM-9SDJ JCK 11-206	120	P-5	68	2.8	34	JPL	10	
224	SLURRY	.34% FM-9SDJ JCK 11-206	140	F-23	68	2.8	34	JPL	10	
225	SLURRY	.25% FM-9SFE JCK 11-179	130	M-18	74	3.0	29	JPL	10	
226	SLURRY	.25% FM-9SFE JCK 11-179	140	F-25	74	3.0	29	JPL	10	
227	SLURRY	.25% FM-9SFE JCK 11-179	120	P-5	74	3.0	29	JPL	10	
228	SLURRY	.29% FM-9SDJ JCK 11-221	120	P-0	76	3.3	31	JPL	10	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
229	SLURRY	.29% FM-9SDJ JCK 11-221	130	P-8	76	3.3	31	JPL	10	
230	CONCENTRATE	.31% FM-9SF JCK 11-219	130	F-24	68	2.6	32	INLINE	--	
231	CONCENTRATE	.31% FM-9SF JCK 11-219	110	P-8	68	2.6	32	INLINE	--	
232	CONCENTRATE	.31% FM-9SF JCK 11-219	120	F-32	68	2.6	32	INLINE	--	
233	CONCENTRATE	.26% FM-9SF JCK 11-219	120	M-16	65	---	---	INLINE	--	
234	CONCENTRATE	.26% FM-9SF JCK 11-219	115	P-0	65	---	---	INLINE	--	
235	SLURRY	.21% FM-9SFE JCK 11-222	130	F-25	65	6.3	---	JPL	10	DISSOLUTION PROBLEM
236	SLURRY	.21% FM-9SFE JCK 11-222	120	F-23	65	6.3	---	JPL	10	DISSOLUTION PROBLEM
237	SLURRY	.21% FM-9SFE JCK 11-222	110	M-19	65	6.3	---	JPL	10	DISSOLUTION PROBLEM
238	SLURRY	.29% FM-9SDE JCK 13-29	130	M-17	62	3.4	29	JPL	10	
239	SLURRY	.29% FM-9SDE JCK 13-29	140	F-23	62	3.4	39	JPL	10	
240	SLURRY	.29% FM-9SDE JCK 13-29	125	P-8	68	3.4	29	JPL	10	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
241	SLURRY	.33% FM-9SDJ JCK 13-30	130	P-73	68	3.2	34	JPL	10	
242	SLURRY	.33% FM-9SDJ JCK 13-30	150	F-36	68	3.2	34	JPL	10	
243	SLURRY	.33% FM-9SDJ JCK 13-30	140	F-21	68	3.2	34	JPL	10	
244-246	FUEL CONTAMINATION INVALIDATES TESTS									
247	CONCENTRATE	.38% FM-9SF JCK 11-238	130	P-0	65	2.0	57	INLINE	11	
248	CONCENTRATE	.38% FM-9SF JCK 11-238	150	P-9	65	2.0	57	INLINE	11	
249	CONCENTRATE	.38% FM-9SF JCK 11-238	170	M-13	65	2.0	57	INLINE	11	
250	CONCENTRATE	.35% FM-9SF JCK 11-239	150	M-19	51	2.2	47	INLINE	--	
251	CONCENTRATE	.35% FM-9SF JCK 11-239	140	P-5	51	2.2	47	INLINE	--	
252	CONCENTRATE	.35% FM-9SF JCK 11-239	160	M-15	51	2.2	47	INLINE	--	
253	BASELINE	.30% FM-9 RMH 1-242	130	P-4	71	2.9	35	BATCH	--	
254	BASELINE	.30% FM-9 RMH 1-242	140	M-12	71	2.9	35	BATCH	--	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
255	BASELINE	.30% FM-9 RMH 1-242	150	F-22	71	2.9	35	BATCH	--	
256	SLURRY	.31% FM-9SDJ JCK 13-30	130	F-24	57	3.2	30	JPL	10	
257	SLURRY	.31% FM-9SDJ JCK 13-30	120	P-5	57	3.2	30	JPL	10	
258	ALT. ADD.	.2% DOW 197-004-13	130	F-44	84	---	---	---	--	DOW ADDITIVE
259	ALT. ADD.	.3% DOW 197-0004-13	110	F-40	84	---	---	---	--	DOW ADDITIVE
260	FUEL QUALITY	.35% FM-9SDJ JCK 13-30	150	F-25	85	---	---	JPL	--	LAKEHURST BACKUP FUEL; 2 MONTHS OLD
261	FUEL QUALITY	.35% FM-9SDJ JCK 13-30	140	F-30	85	---	---	JPL	--	LAKEHURST BACKUP FUEL; 2 MONTHS OLD
262	FUEL QUALITY	.35% FM-9SDJ JCK 13-30	120	M-17	84	---	---	JPL	--	LAKEHURST BACKUP FUEL; 2 MONTHS OLD
263	SLURRY	.30% FM-9SDE JCK 13-142	140	P-9	82	1.6	---	BOEING	9	
264	SLURRY	.30% FM-9SDE JCK 13-142	150	P-7	82	1.6	---	BOEING	9	
265	SLURRY	.30% FM-9SDE JCK 13-142	150	M-19	82	1.6	---	BOEING	9	
266	SLURRY	.28% FM-9SDE JCK 14-40	130	P-4	74	1.4	---	BOEING	24	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
267	SLURRY	.28% FM-9SDE JCK 14-40	150	P-9	74	1.4	---	BOEING	24	
268	SLURRY	.28% FM-9SDE JCK 14-40	160	F-21	74	1.4	---	BOEING	24	
269	SLURRY	.30% FM-9SDE JCK 14-40	140	P-3	80	1.6	60	BOEING	5	
270	SLURRY	.30% FM-9SDE JCK 14-40	150	M-18	80	1.6	60	BOEING	5	
271	SLURRY	.30% FM-9SDE JCK 14-40	145	M-17	80	1.6	60	BOEING	5	
272	SLURRY	.30% FM-9SDE JCK 14-40	140	P-5	80	1.6	60	BOEING	5	
273	SLURRY	.3% FM-9SDJ	130	P-0	82	---	---	JPL	--	
274	SLURRY	.3% FM-9SDJ	150	P-5	82	---	---	JPL	--	
275	SLURRY	.3% FM-9SDJ	160	F-26	82	---	---	JPL	--	
276	SLURRY	.30% FM-9SD JCK 14-184	130	P-0	97	1.8	40	JPL	10	
277	SLURRY	.30% FM-9SD JCK 14-184	150	F-27	97	1.8	40	JPL	10	
278	SLURRY	.30% FM-9SD JCK 14-184	140	M-16	97	1.8	40	JPL	10	
279	SLURRY	.30% FM-9SD JCK 14-184	130	M-14	97	1.8	40	JPL	10	

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
280 - 281	O M I T T E D									
282	ALT. ADD.	.125% AM-1	130	M-12	84	---	---	---	--	CONOCO ADDITIVE
283	ALT. ADD.	.125% AM-1	120	P-8	84	---	---	---	--	CONOCO ADDITIVE
284	ALT. ADD.	.125% AM-1	140	F-22	84	---	---	---	--	CONOCO ADDITIVE
285	ALT. ADD.	.1% AM-1	120	M-13	73	---	---	---	--	CONOCO ADDITIVE
286	ALT. ADD.	.1% AM-1	110	P-5	73	---	---	---	--	CONOCO ADDITIVE
287	ALT. ADD.	.1% AM-1	130	F-26	73	---	---	---	--	CONOCO ADDITIVE
288	ALT. ADD.	.15% AM-1	130	P-0	75	---	---	---	--	CONOCO ADDITIVE
289	ALT. ADD.	.15% AM-1	140	M-19	75	---	---	---	--	CONOCO ADDITIVE
290	ALT. ADD.	.15% AM-1	140	P-6	75	---	---	---	--	CONOCO ADDITIVE
291	FUEL QUALITY	.3% FM-9SD JCK 14-162	130	M-12	76	---	---	BOEING	9	QUALITY OF AMK QUESTIONABLE
292	SLURRY	.31% FM-9SD JCK 14-254	140	P-0	44	2.1	53	FAA	--	34-MINUTE FUEL
293	SLURRY	.31% FM-9SD JCK 14-254	150	P-4	44	---	---	FAA	--	40-MINUTE FUEL
294	SLURRY	.31% FM-9SD JCK 14-254	160	P-3	44	2.1	---	FAA	--	48-MINUTE FUEL
295	SLURRY	.24% FM-9SD JCK 14-254	140	F-26	46	3.0	---	FAA	--	33-MINUTE FUEL

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
296	SLURRY	.24% FM-9SD JCK 14-254	130	P-7	46	2.7	44	FAA	--	40-MINUTE FUEL
297	SLURRY	.24% FM-9SD JCK 14-254	140	F-24	46	---	---	FAA	--	49-MINUTE FUEL
298	SLURRY	.21% FM-9EXP 3694-230	140	M-14	46	2.3	40	FAA	--	33-MINUTE FUEL; SODIUM-FREE
299	SLURRY	.21% FM-9EXP 3694-230	130	P-5	46	---	---	FAA	--	40-MINUTE FUEL; SODIUM-FREE
300	SLURRY	.21% FM-9EXP 3694-230	140	P-4	46	---	---	FAA	--	46-MINUTE FUEL; SODIUM-FREE
301	SLURRY	.21% FM-9EXP 3694-230	150	F-24	46	2.1	---	FAA	--	53-MINUTE FUEL; SODIUM-FREE
302	FUEL QUALITY	.29% FM-9SD JCK 14-264	140	P-6	48	---	---	FAA	--	35-MINUTE FUEL; NEW MONOMER
303	FUEL QUALITY	.29% FM-9SD JCK 14-264	150	F-24	48	---	---	FAA	--	40-MINUTE FUEL; NEW MONOMER
304	FUEL QUALITY	.29% FM-9SD JCK 14-264	150	P-7	48	---	---	FAA	--	44-MINUTE FUEL; NEW MONOMER
305	FUEL QUALITY	.29% FM-9SD JCK 14-264	160	F-27	48	---	---	FAA	--	49-MINUTE FUEL; NEW MONOMER
306	FUEL QUALITY	.31% FM-9SD JCK 16-95	120	F-34	80	6.9	8	JPL	--	CV880 FUEL FLOWN ACROSS COUNTRY
307	SLURRY	.33% FM-9SD JCK 16-98***	140	P-0	70	---	---	FAA	54	37-MINUTE FUEL

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
308	SLURRY	.33% FM-9SD JCK 16-98	150	P-0	70	---	---	FAA	54	45-MINUTE FUEL
309	SLURRY	.33% FM-9SD JCK 16-98	160	P-3	70	2.8	34	FAA	54	55-MINUTE FUEL
310	SLURRY	.33% FM-9SD JCK 16-98	150	P-2	80	2.7	39	FAA	54	21-HOUR FUEL
311	SLURRY	.33% FM-9SD JCK 16-98	170	M-12	80	2.7	39	FAA	54	21-HOUR FUEL
312	SLURRY	.37% FM-9SD JCK 16-95	150	P-0	72	2.1	68	FAA	60	1/2-HOUR FUEL
313	SLURRY	.37% FM-9SD JCK 16-95	170	P-4	72	2.1	68	FAA	60	1/2-HOUR FUEL
314	RUN NUMBER SKIPPED									
315	SLURRY	.30% FM-9SD JCK 16-98	140	P-5	70	2.8	34	FAA	50	1/2-HOUR FUEL
316	SLURRY	.30% FM-9SD JCK 16-98	150	M-17	70	2.8	34	FAA	50	1/2-HOUR FUEL
317	SLURRY	.30% FM-9SD JCK 16-98	140	P-7	78	2.6	36	FAA	50	20-HOUR FUEL
318	SLURRY	.30% FM-9SD JCK 16-98	150	F-21	80	2.6	36	FAA	50	20-HOUR FUEL
319	SLURRY	.30% FM-9SD JCK 16-98	140	P-0	90	2.6	36	FAA	50	24-HOUR FUEL
320	SLURRY	.30% FM-9SD JCK 16-98	150	F-24	90	2.6	36	FAA	50	24-HOUR FUEL

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
321	SLURRY	.30% FM-9EXP JCK 16-106	140	P-6	74	3.0	31	FAA	56	1-HOUR FUEL; SODIUM-FREE
322	SLURRY	.30% FM-9EXP JCK 16-106	150	F-21	74	3.0	31	FAA	56	1-HOUR FUEL; SODIUM-FREE
323	SLURRY	.30% FM-9EXP JCK 16-106	140	F-20	83	3.4	23	FAA	56	19-HOUR FUEL; SODIUM-FREE
324	SLURRY	.30% FM-9EXP JCK 16-106	130	P-5	83	3.4	23	FAA	56	19-HOUR FUEL; SODIUM-FREE
325	SLURRY	.30% FM-9SD JCK 16-95	150	P-4	71	2.1	52	FAA	--	1-HOUR FUEL
326	SLURRY	.30% FM-9SD JCK 16-95	170	P-6	71	2.1	52	FAA	--	1-HOUR FUEL
327	SLURRY	.30% FM-9SD JCK 16-95	170	P-9	83	1.9	78	FAA	--	23-HOUR FUEL
328	SLURRY	.30% FM-9SD JCK 16-95	160	P-3	83	1.9	78	FAA	--	23-HOUR FUEL
329	SLURRY	.20% FM-9SD JCK 16-95	150	F-25	80	5.4	84	FAA	--	DILUTED FROM .3% FM-9; 24-HOUR FUEL
330	SLURRY	.29% FM-9SD JCK 16-95	140	P-5	80	2.3	76	FAA	--	MOJAVE JET A; 27-HOUR FUEL
331	SLURRY	.29% FM-9SD JCK 16-95	150	P-4	80	2.3	76	FAA	--	MOJAVE JET A; 27-HOUR FUEL
332	SLURRY	.29% FM-9SD JCK 16-95	160	M-11	80	2.3	76	FAA	--	MOJAVE JET A; 27-HOUR FUEL

TEST NO.	TEST TYPE	FUEL TYPE	AIR VELOCITY (KNOTS)	FLAME PROP RATE* (FT/SEC)	FUEL TEMP (°F)	LAB RESULTS CUP	LAB RESULTS F/R	BLENDER TYPE	BLENDER RATE (GPM)	REMARKS
333	SLURRY	.31% FM-9SD JCK 16-95	150	P-7	82	2.0	75	FAA	10	EDWARDS JET A; 51-HOUR FUEL
334	SLURRY	.31% FM-9SD JCK 16-95	160	P-5	82	2.0	75	FAA	10	EDWARDS JET A; 51-HOUR FUEL
335	FUEL CONTAMINATION**	.31% FM-9SD JCK 16-95	130	P-9	80	2.0	75	FAA	10	EDWARDS JET A; 72-HOUR FUEL
336	FUEL CONTAMINATION**	.31% FM-9SD JCK 16-95	150	M-12	80	2.0	75	FAA	10	EDWARDS JET A; 72-HOUR FUEL

* P - PASS (LESS THAN 11 FT/SEC)
M - MARGINAL (11 TO 20 FT/SEC)
F - FAIL (GREATER THAN 20 FT/SEC)

** DEGRADED AMK RELEASED WITH UNDEGRADED FUEL AT 0.5 GPM

*** FM-9SD, LOT JCK 16-98, PRODUCED FROM SCALED-UP POLYMER PRODUCTION PROCESS