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WING SPILLAGE TESTS OF ANTIMISTING FUELS

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INTRODUCTION

Purpose

A wing spillage test apparatus was developed to generate a broad data base on the flammability behavior of antimisting fuel.

Background

The Federal Aviation Administration has had a long term interest in modified turbine fuels which would resist formation of a flammable spray during a takeoff or approach crash. Candidate modified fuels were subjected to a variety of intermediate-scale tests which generally involved acceleration of a container of fuel and then impact at the ground or an obstacle in the presence of torches. Fuel containers were accelerated by gravity (vertical drop tests), by compressed air (air gun tests), or by mechanical means (catapult tests).

By 1972 the so-called antimisting fuels had replaced the older fuel gels and emulsions as the most promising modified fuel candidates. The antimisting fuels are solutions of high-molecular weight polymers in neat Jet A. The polymers generally are less than 1 percent of the solution by weight. The antimisting fuels were initially screened using intermediate-scale tests as a prelude to full-scale testing with surplus RB-66 aircraft. The aircraft were to be accelerated down a jet track and impacted into telephone poles for a simulated crash landing. A distribution of torches and flares would provide a rigorous ignition environment to fuel spraying from the ruptured wing tanks. The second full-scale test resulted in the ignition of the antimisting fuel (Dow Chemical XD8132) and the destruction of the aircraft by fire. Although extensive motion picture documentation of this crash test exists, no explanation of the causal factors and the growth history of the fire has been conclusive. This crash provided the motivation for the development of a realistic large-scale test that could be used for more thorough study of antimisting fuel flammability.

The resultant wing spillage test involves releasing fuel through an opening in the front of a simulated wing. The wing is placed in front of an air supply to simulate the motion of an aircraft through the air during deceleration. This wing spillage test is a steady state test in contrast to many previous transient test methods. Thus, test parameters can be specified.

2. The propane ignition torches adjacent to the airfoil would be tested.

3. The valve in the elevated tank would be closed and locked. The lock release lanyard would be laid out on the ground away from the tank. A second lanyard used to open the valve would also be laid out on the ground as was a third lanyard for removing a cover over the fuel discharge outlet.

4. The fuel would be raised to the elevated tank by fork lift and released from the 55-gallon drums.

5. A viscosity and temperature measurement would be taken of the fuel in the elevated tank.

6. The continuous ignition torches (if used) to the rear of the airfoil would be ignited.

7. The turbofan would be started, and air temperature and velocity would be established and recorded.

8. The fuel would then be released and the propane torches adjacent to the wing would be pulsed.

Test Results and Analysis

The photographic and video documentation of the tests was analyzed in an attempt to draw rational conclusions from the test series. Although 34 tests were conducted, some stringent criteria were used in judging the reliability of the data. First, a test was disregarded if no photographic coverage was used. Second, a test was disregarded if the photographic and video documentation showed no evidence of the propane ignition torch pulses. Thus, the data presented and the analysis are based on available movie and video records. Judgment decisions related to ground fires, marginal passes, and marginal failures can be confirmed by chekcing the records. A failure was noted when the fire was able to pass from the rear of the airfoil to the front and thereby engulf the entire wing in flames. A pulse that resulted in a growing fireball and a downstream pool fire was considered a pass, although the ground fire apparently has some significance as the flammability envelope is approached. Marginal passes and marginal failures are judgment evaluations. For instance, overwing fire spread that appeared to be assisted by a downstream pool fire rather than two-phase flame spread above was considered marginal failure. On the other hand, a large spray fire that did not propagate over the wing was considered a marginal pass.

When continuous torches were placed downstream of the wing, they had no effect on the test and no further discussion will be devoted to them. In the majority of the tests, a torch was pulsed under the wing. The fuel spray appeared thickest there, and these tests probably are most relevant to the fire resistant potential of antimisting fuels. Some of the earliest tests employed a torch over the wing, and these tests will be discussed separately.

Table 2 itemizes the tests with FM-4. In all tests but one, the air temperature was 103°F or greater. In all those cases, the fuel spray burned (i.e., failed). The one test where the air was at 75°F resulted in a marginal test. It is likely that the failure of the tests at the higher temperatures resulted from proximity to the flashpoint. There is not enough data here to make supportable statements on the suitability of FM-4 as an antimisting fuel.

Table 3 provides the test parameter for overwing ignition of XD8132 at 0.5 percent and 0.7 percent. All five tests were conducted with an airspeed of 106 knots. Figure 1 shows the position of the points on a fuel temperature versus air temperature plot. The flammability line apparently lies between air temperatures of 96°F and 106°F for these tests.

Table 4 provides the test parameters for underwing torch ignition of XD8132 and XD8132.01. The differences between these two additives are not considered significant for these flammability tests. The data points are plotted in figure 2 on an airspeed versus air temperature plot. The different additive concentrations along with the points for fuel partially degraded by pumping are all included. The dotted line is an estimate of the flammability envelope. Tests above and to the right of the line fall in a failure regime while tests to the left and below are in a pass regime. The proximity of ground fire points and marginal points to this curve present a consistent picture. Far to the left of the envelope, there is no fire. As the envelope is approached, first a ground fire occurs. Then the fire will propagate back to the wing with increasing liklihood. Finally, when a data point falls to the right of the envelope, a fire can readily propagate throughout the two-phase mixture.

The flammability envelope shows two effects. As air velocity increases, the fuel is broken into finer droplets until flame propagation is possible. In addition, as the air temperature increases, the likelihood of flame propagation is enhanced. This in part would be due to the higher vapor pressure of the fuel particles as the flashpoint is approached. There is also a possibility that the polymers are less effective at the higher temperature.

Attempts to derive a flammability envelope from an airspeed versus fuel temperature plot were not successful. Thus, the two main parameters controlling these tests were airspeed and air temperature. Although few tests were conducted at high concentrations of additive, the pass point on figure 2 with 1.0 percent indicates that concentration is an important parameter.

TABLE 1

Additive Type	Concentration (% by Weight)	Number of Tests
FM-4	0.3	5
	0.4	4
XD8132	0.5	5
	0.7	3
	1.0	1
XD8132.01	0.5	1
	0.7	13
	1.0	1
Neat Jet A	--	1

TABLE 2. FM-4 TESTS

Test Number	Additive	Air Velocity (knots)	Fuel Temperature (^oF)	Air Temperature (^oF)	Ignition Results
I - 8	FM-4 (0.3%)	106	98	101	Fail, Overwing Torch
II - 1	FM-4 (0.3%)	120	95	112	Fail, Underwing Torch
II - 2	FM-4 (0.3%)	105	93	105	Fail, Underwing Torch
II - 23	FM-4 (0.3%)	100	92	75	Marginal Pass, Underwing Torch
II - 3	FM-4 (0.4%)	120	95	105	Fail, Underwing Torch
II - 4	FM-4 (0.4%)	120	96	107	Fail, Underwing Torch

TABLE 3. XD8132 (OVERWING TORCH)

Test Number	Additive	Air Velocity (knots)	Fuel Temperature (°F)	Air Temperature (°F)	Ignition Results
I-3	XD8132 (0.5%)	106	80	95	Pass
I-4	XD8132 (0.5%)	106	91	106	Fail
I-10	XD8132 (0.5%)	106	83	93	Pass
I-5	XD8132 (0.7%)	106	87	95	Pass
I-6	XD8132 (0.7%)	106	95	96	Pass

TABLE 4. XD8132 (UNDERWING TORCH)

Test Number	Additive	Air Velocity (knots)	Fuel Temperature (^{o}F)	Air Temperature (^{o}F)	Ignition Results
I-2	XD8132 (0.5%)	106	87	95	Fail
I-11	XD8132 (0.7%)	106	95	95	Fail
II-21	XD8132.01 (1.0%)	120	95	95	Pass
II-6	XD8132.01 (0.5%)	120	92	100	Fail
II-10	XD8132.01 (0.7%)	80	94	90	Pass
II-11	XD8132.01 (0.7%)	100	95	96	Pass
II-12	XD8132.01 (0.7%)	110	92	94	Pass, Ground Fire
II-13	XD8132.01 (0.7%)	120	76	85	Pass, Ground Fire
II-14	XD8132.01 0.7%	120	61	74	Pass, Ground Fire

TABLE 4. XD8132 (UNDERWING TORCH) (Continued)

Test Number	Additive	Air Velocity (knots)	Fuel Temperature (°F)	Air Temperature (°F)	Ignition Results
II-15	XD8132.01 (0.7%)	120	66	86	Marginal Failure
II-16	XD8132.01 (0.7%)	100	91	78	Pass (10% of Fuel Pumped)
II-19	XD8132.01 (0.7%)	100	95	82	Pass (30% of Fuel Pumped)
II-20	XD8132.01 (0.7%)	100	96	87	Marginal Pass (50% of Puel Pumped)
II-22	XD8132.01 (0.7%)	Variable	91	75	Failed when air speed got to 120 knots.

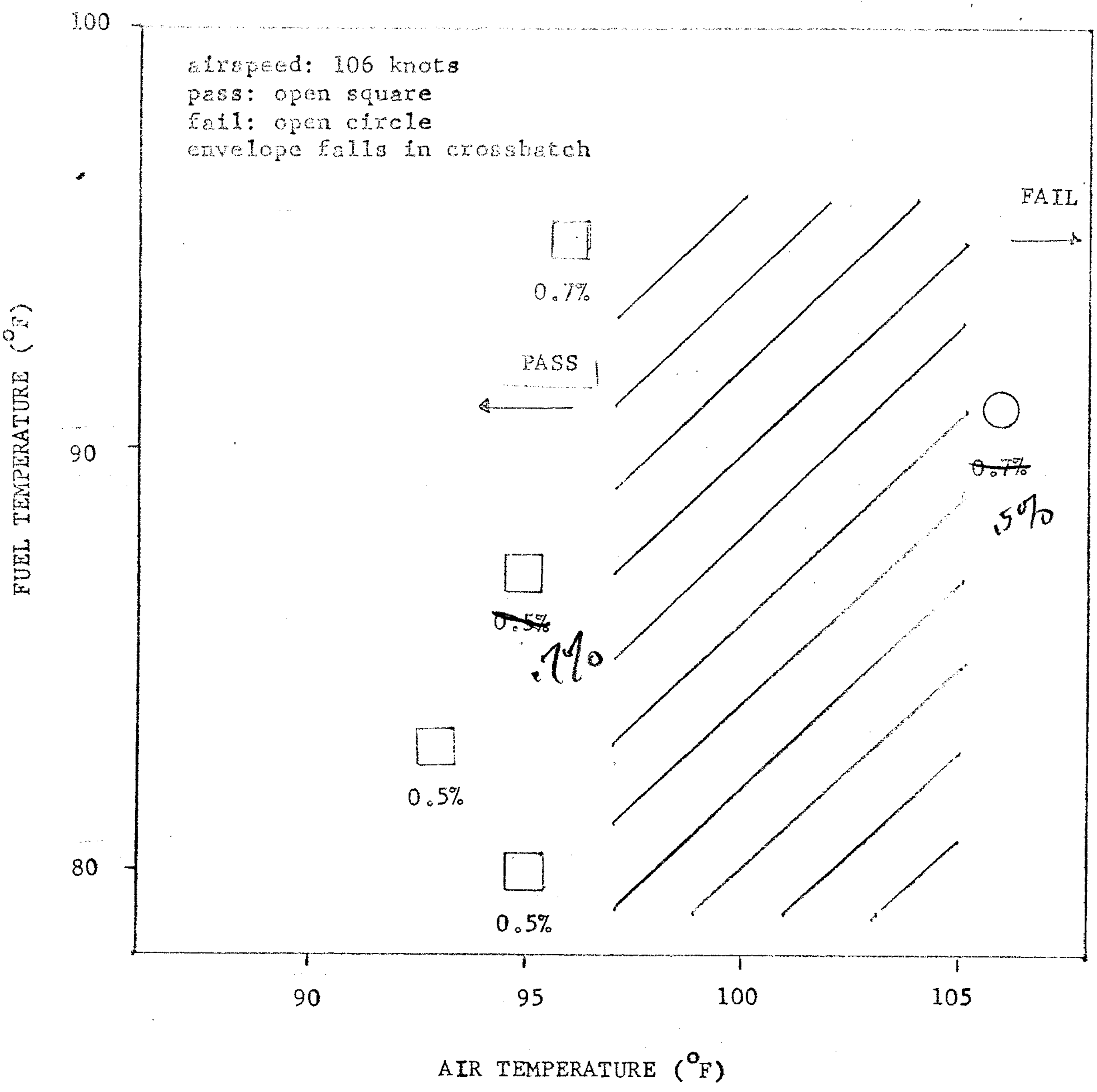

FIGURE 1. OVERWING TORCH IGNITION (XD8132)

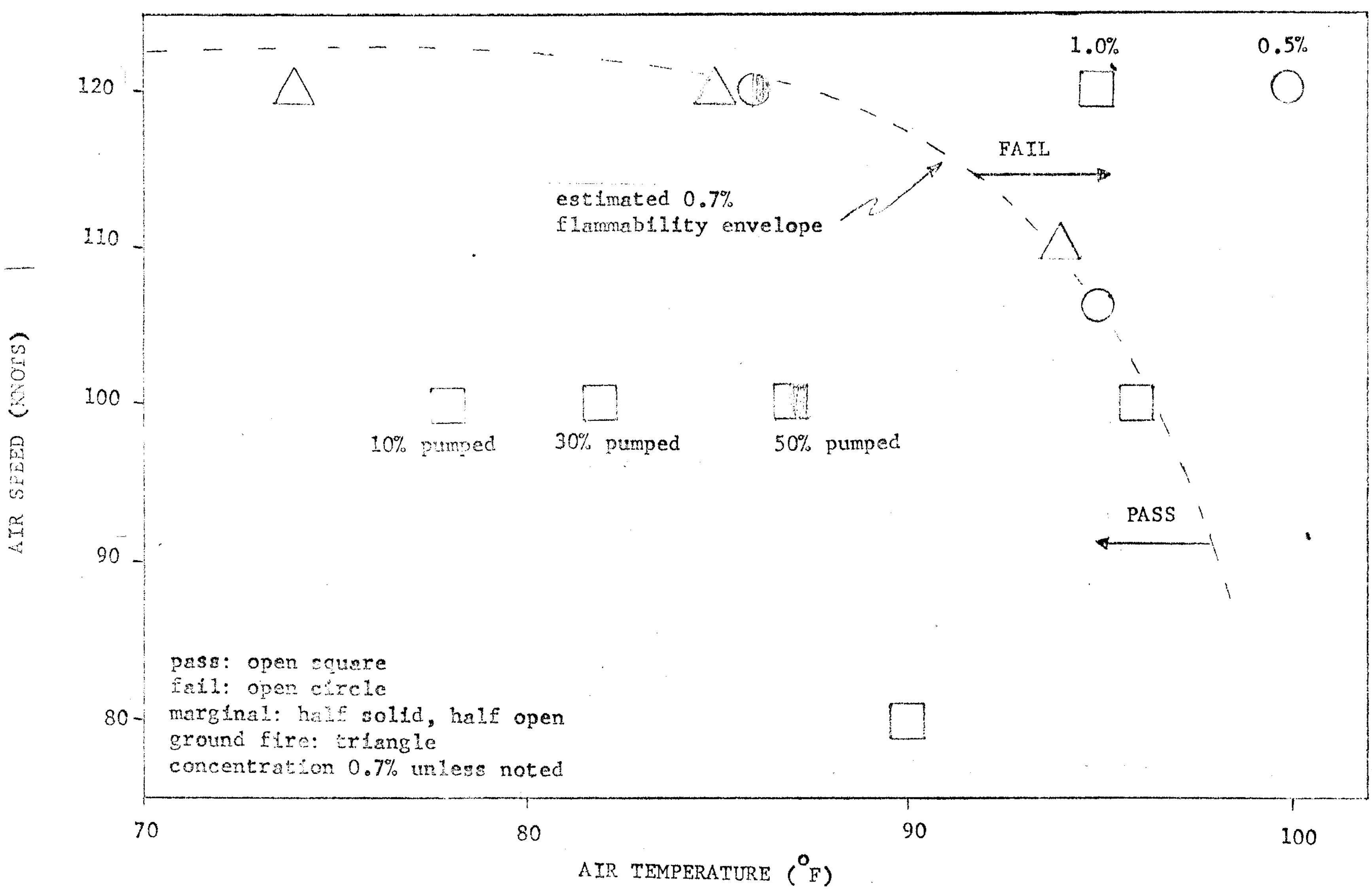

FIGURE 2. UNDERWING TORCH IGNITION (XD8132)