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Fire Hazards of Mixed Fuels on the Flight Deck

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An assessment was made of the increased fire hazard resulting from the spill of mixed JP-8/JP-5 fuels on a heated flight deck. The effect of the pure fuels and of various mixtures thereof on ease of ignition, flame spread and difficulty of extinguishment were examined. The results indicated that it was not until the temperature of the fuel and heated deck was more than 11°C (20°F) above the flash point of the fuel that any significant difference in flame spread occurred. Above this temperature, the flame spread increased rapidly, eventually reaching 150 cm/s (60 in/s). The fire extinghishment tests showed clear, quantifiable differences in the ability to extinguish fire involving minimum flash point JP-5 vs. Jet A (JP-8) fuels. The neat JP-5 fuel fires could always be extinguished with one hand line in less than 60 seconds whereas the 100% Jet A (JP-8) fires becomes progressively more difficult to extinguish with increasing fuel temperature. Above 71°C (160°F), the Jet A (JP-8) fires could not be extinguished in two minutes with two hand lines.

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Fire Hazards of Mixed Fuels on the Flight Deck

1.0 BACKGROUND

The Department of Defense has three principal jet fuels, namely:

JP-4 - a wide cut gasoline/kerosene fraction with an unspecified flash point in the range of -18 to -12°C (0 to 10°F) [1]. It is comparable to commercial Jet B and is currently the main jet fuel used by the Air Force.

JP-5 - a high flash kerosene with a specified minimum flash point of 60°C (140°F) [1]. It does not have a commercial counterpart. It is the main jet fuel used by the Navy. The high flash point is critical to the protection of the ship.

JP-8 - a kerosene which is a newer Air Force fuel with a specified minimum flash point of 38°C (100°F) [2]. It is very close to the widely used commercial Jet A-1 and has been used by the Air Force in Britain since 1979.

During the Persian Gulf crisis, Navy carrier-based aircraft, which normally fly on JP-5 fuel, were being refueled from Air Force tankers with JP-8 fuel. The Navy planes would then return to the carrier with a "mixed bag" of JP-5/JP-8 fuel. Since JP-8 can lower the flash point of JP-5 fuel, there was concern that in the event of a crash involving a fuel spill on the flight deck (where temperatures locally could be as high as 93°C (200°F*)), that there could be an increased fire hazard. This would be due to the fact that the mixed fuel (JP-5/JP-8) fuel on board the returning aircraft would have a flash point lower than acceptable for carrier operations. This test program was initiated to evaluate the potential fire hazard of mixed fuel on the flight deck.

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* Data supplied by the Naval Air Systems Command [3] indicated that in the summer along the Atlantic coast, daytime flight deck temperatures ranged from 60 to 90°C (140 to 190°F) and reached 93°C (200°F) in the catapult area.

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2.0 OBJECTIVES

The objectives of the study were the following:

1. To provide an assessment of the increased fire hazard resulting from the spill of mixed JP-8/JP-5 fuel on a heated flight deck; and

2. To provide guidance, if required, on fighting fires involving mixed fuels.

3.0 EXPERIMENTAL PROCEDURE

There are three questions to be resolved in assessing the possible increased fire hazard resulting from adding a more volatile fuel to a less volatile fuel: ease of ignition, flame spread, and extinguishment difficulty.

In order to resolve these questions, the following approach was taken.

1. Ease of Ignition

The effect of JP-8 fuel of the flash point of JP-5 was determined by measuring the flash points of the neat fuels and various mixtures thereof (25, 50, and 75%) using the Pensky-Martens apparatus [4]. The base fuels used in all of these tests were intentionally selected for their low flash points to produce a "worst case" scenario. Due to the extreme urgency placed on this program by operational considerations, it was not possible to locate a JP-8 fuel with a sufficiently low flash point in time to complete the program. Accordingly, a Jet A fuel was substituted for the JP-8 fuel since, from a standpoint of flammability and extinguishment, JP-8 and Jet A fuels having the same flash point would behave identically. The Jet A fuel selected had a flash point of 100°F, which is the specification minimum for both Jet A and JP-8 fuels. The flash point of the JP-5 base fuel was 146°F, just six degrees over the specification minimum.

The flash points of the pure fuels were determined as well as those of a sufficient number of JP-5/Jet A (JP-8) mixtures to prepare a curve defining the effect of the more volatile Jet A (JP-8) fuel on the ignitability of the mixture.

2. Flame Spread

The effect of the Jet A (JP-8) on the flame spread of JP-5 fuel at various concentrations of Jet A (JP-8) in JP-5 was determined over the temperature range of 27 to 82°C (80 to 180°F) using both a small scale and a large scale heated deck.

The small scale tests were conducted in a 20.3 x 152.4 cm (8 x 64 in.) stainless steel pan as shown in Fig. 1. The pan was heated by means of a water coil welded to the bottom of the pan. The fuel was heated to the same temperature as the pan before it was discharged onto the surface of the pan. The fuel was ignited by means of a propane torch, and both the ignition delay, where appropriate, and the time required for the flame to traverse the length of the pan were recorded.

Large scale flame spread tests were conducted at the Naval Research Laboratory's (NRL) Chesapeake Bay Detachment (CBD) Fire Test Facility using a 1.5 x 12.2 m (5 x 40 ft) steel deck as shown in Figs. 2 and 3. This deck was heated by circulation of hot water through chambers on the bottom side to provide temperatures from 27° to 82°C (80 to 180°F), simulating various flight deck conditions. As in the small scale tests, both the fuel and the deck were heated to the same temperature before the fuel was spilled on the deck through a "picollo"-type inlet located in the center of the deck. Ignition was provided by a propane torch located at one end (Fig. 3), and the time required for the flame to spread to the opposite end was recorded visually and on video tape.

These tests were instrumented to provide fuel temperatures in the tank and on the deck, as well as at 2.5, 7.6, and 15.2 cm (1, 3, and 6 in.) above the pan.

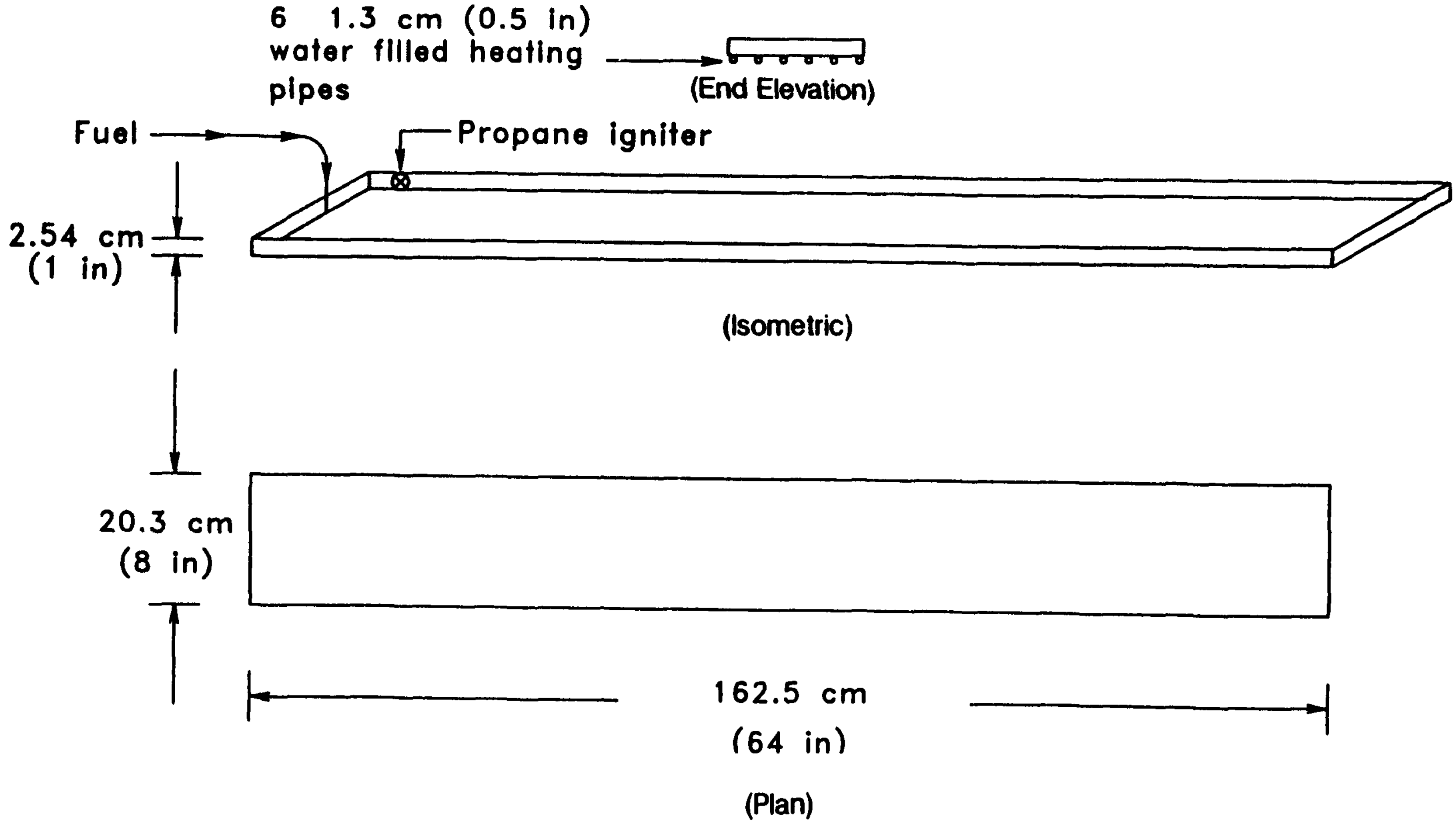

Fig. 1 - Small scale flame spread pan

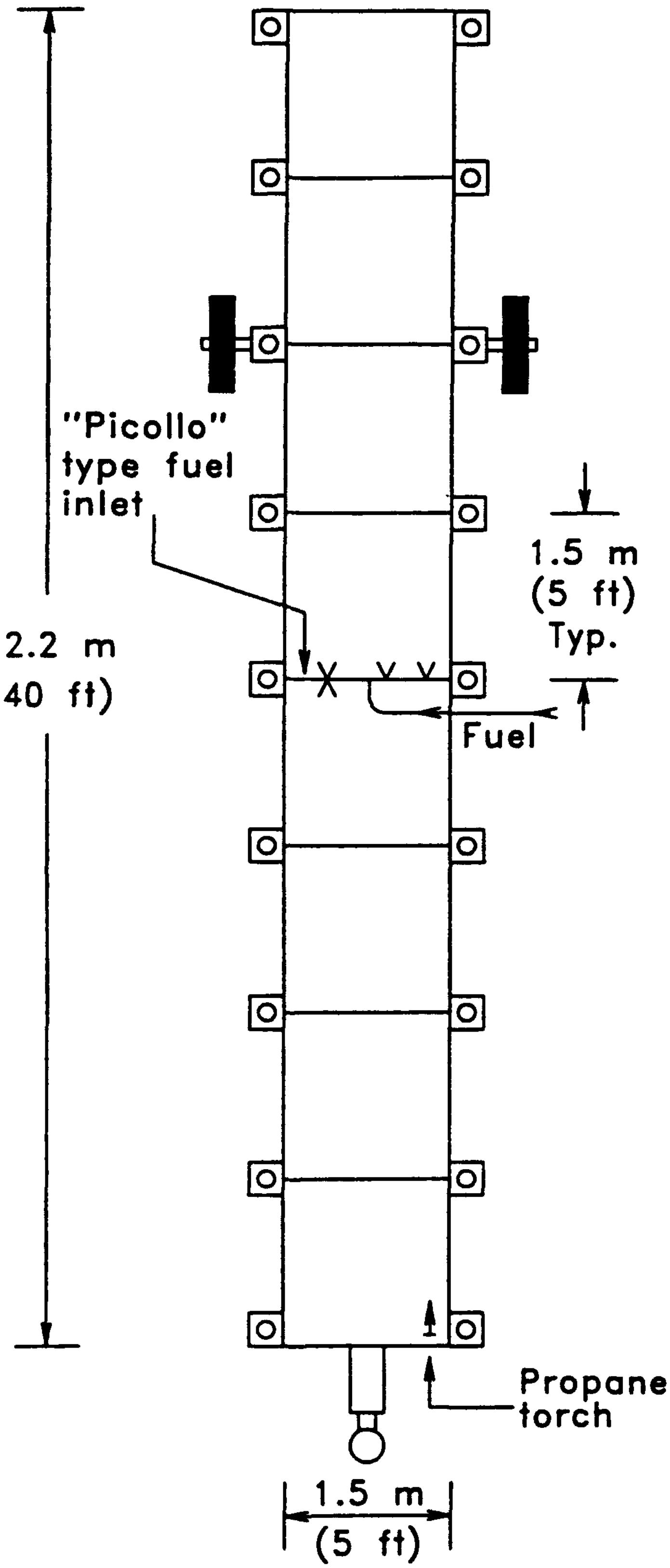

Fig. 2 - Large scale flame spread pan
(Plan)

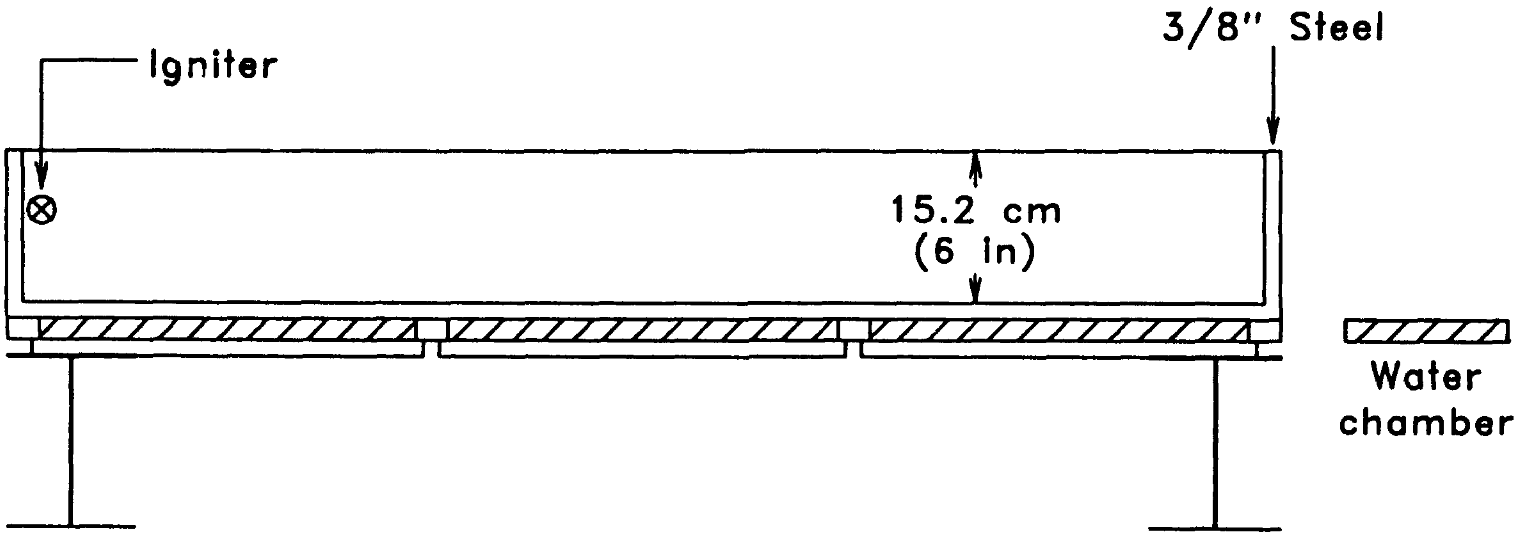

Fig. 3 - Large scale flame spread pan
(Cross Section)

After the fire spread the length of the deck, it was extinguished using a fixed nozzle AFFF system with the same application rate as used in the aircraft carrier flush deck system. These tests provided information on the effectiveness of the flush deck system in extinguishing mixed fuel fires at various temperatures.

3. Extinguishment

The extinguishment tests were performed using a "debris pile" fire which is a three-dimensional running fuel fire. The debris pile, which is a concrete block structure 2.4 x 2.4 x 3.1 m (8 x 8 x 10 ft) and having a sloping steel roof (Fig. 4), was developed during the NIMITZ fire test program [5]. It is intended to simulate the type of fire that results when an aircraft crashes into parked aircraft on the flight deck rupturing fuel tanks and producing debris, e.g., aircraft wings and damaged fuselages, which limit the access of firefighters to the running fuel fire within the pile. The inclined steel roof (Fig. 4) simulates an aircraft wing, and the slit pipe from which fuel cascades down over inclined trays (Fig. 5) represents the ruptured fuel tank spilling fuel onto wreckage. Piece of broken concrete block on the floor of the debris pile provide numerous "nooks and crannies" for the fuel to hide in, further complicating the extinguishing problem. The debris pile fire has been used extensively in previous test programs and is a reproducible and extremely challenging fire to extinguish. A variation of the debris pile fire has been installed at the Shipboard Aircraft Fire Team Training (SAFTT) facility at Millington, Tennessee (Fig. 6) as a training device for flight deck firefighting. The debris pile was selected as a trainer for SAFTT because it represents the most difficult fuel fire on the flight deck.

The debris pile fires were fought under wind conditions of 0, 15, and 30 knots using three airboat engines to generate the required wind (Figs. 7 and 8). The fires were extinguished using two 3.8 cm (1.5 in.) hand lines flowing AFFF solution at 473 lpm (125 gpm) each through standard flight deck vari-nozzles. The initial attack was made after a sixty-second preburn with one hand line (Fig. 9A). If the fire was not extinguished in 60 seconds, the second hand line was sent in from the opposite side of the debris pile (Fig. 9B). The overall attack continued for another 60 seconds or until the fire was extinguished, whichever occurred first. Experience with this fire has shown that if the fire

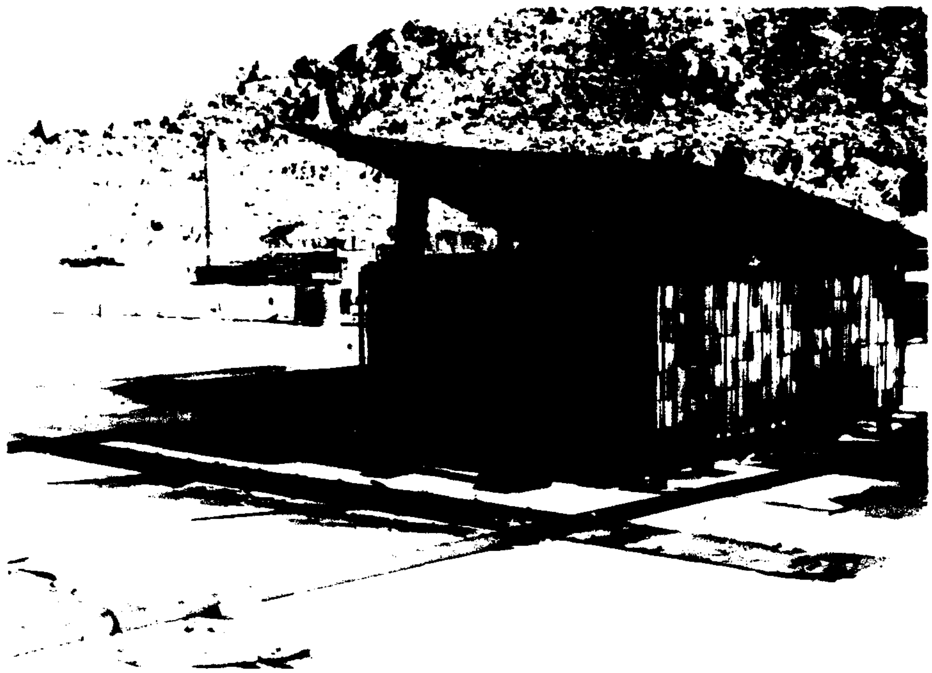

Fig. 4 - Original debris pile NWC China Lake, CA
(NIMITZ Tests 1982-83)

Fig. 5 - Inte‚ior view showing fuel cascade

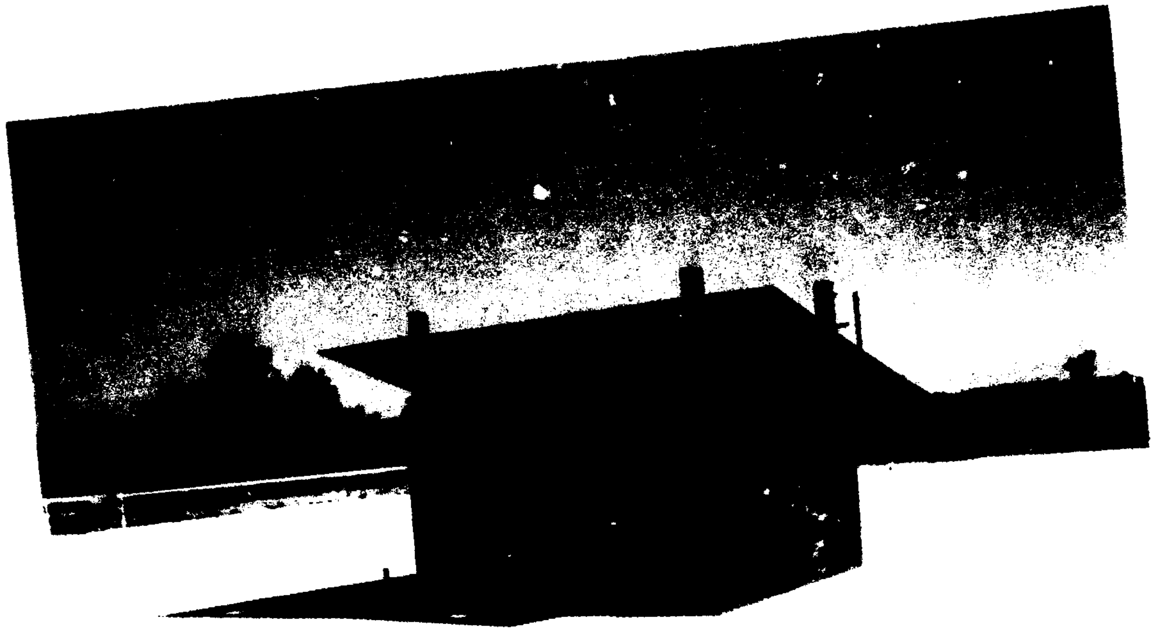

Fig. 6 - Debris pile running fuel fire at the Shipboard Aircraft Fire Team Trainer Facility, NAS Memphis

Fig. 7 - Debris pile fire test CBD

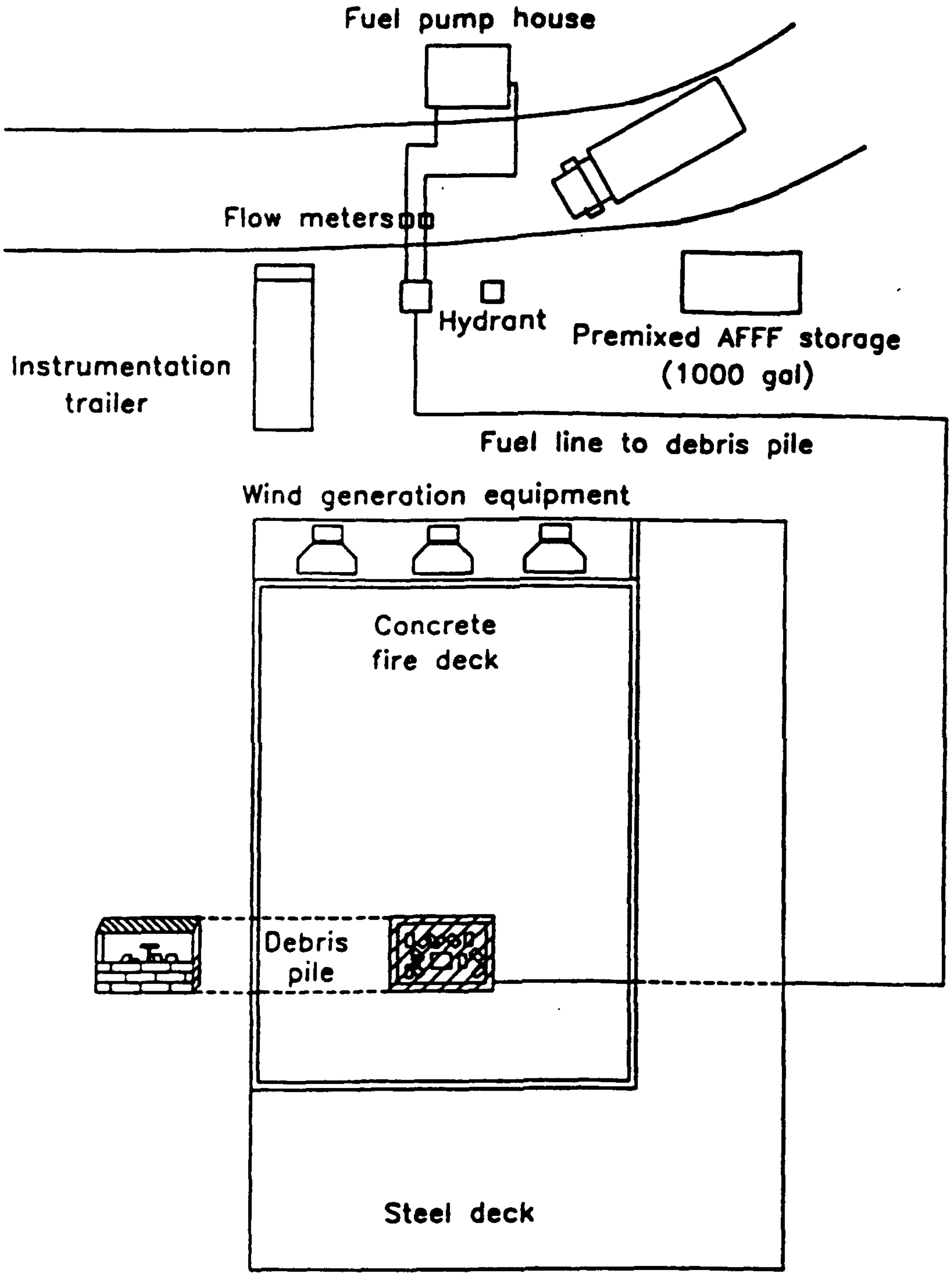

Fig. 8 - Debris pile test deck

Fig. 9A - DEBRIS PILE - ONE HANDLINE ATTACK

Fig. 9B - DEBRIS PILE - TWO HANDLINE ATTACK was not extinguished within two minutes, it could not be extinguished with that particular equipment and technique. The temperature of the AFFF solution and the fuel, both at the fuel cart and at the debris pile, were recorded during each test.

4.0 RESULTS AND DISCUSSION

4.1 Flash Point Tests

The flash points of pure JP-5 and Jet A (JP-8) along with various mixtures of the two fuels are shown in Fig. 10. The curve is virtually a straight line indicating that the lowering of the flash point of JP-5 is nearly directly proportional to the amount of Jet A (JP-8) added. Previous work with JP-4/JP-5 mixtures [6] showed a much greater drop in the flash point of JP-5 fuel with small additions of JP-4 (Fig. 11); but, of course, the much greater volatility of the JP-4 fuel vis-a-vis the JP-5 was responsible for this drop. To the extent that the flash point is lowered, the ignition hazard is increased. This could be crucial in terms of whether or not a fire occurs, particularly inside of the ship where compartment temperatures could exceed 49°C (120°F). The spill of a 38°C (100°F) flash point fuel in a compartment where the temperature was 49°C (120°F) could lead to an ignition if the fuel vapors encountered even a weak ignition source, e.g., a static spark, whereas no fire would ensue under the same circumstances if the flash point of the fuel were 60°C (140°F).

It is recognized that, in practice, the <u>difference</u> in the flash points of individual samples of JP-5 and JP-8 fuels may be anywhere between 0 and 31°C (0 and 56°F). Consequently, it is not possible to make generalizations about the fuels per se; one can only compare individual samples of these fuels on the basis of their flash points.

4.2 Small Scale Flame Spread Tests

The results of the small scale flame spread tests for the neat JP-5 and Jet A (JP-8) fuels are shown in Fig. 12 and are listed in Table 1. The data points for the JP-5/Jet A

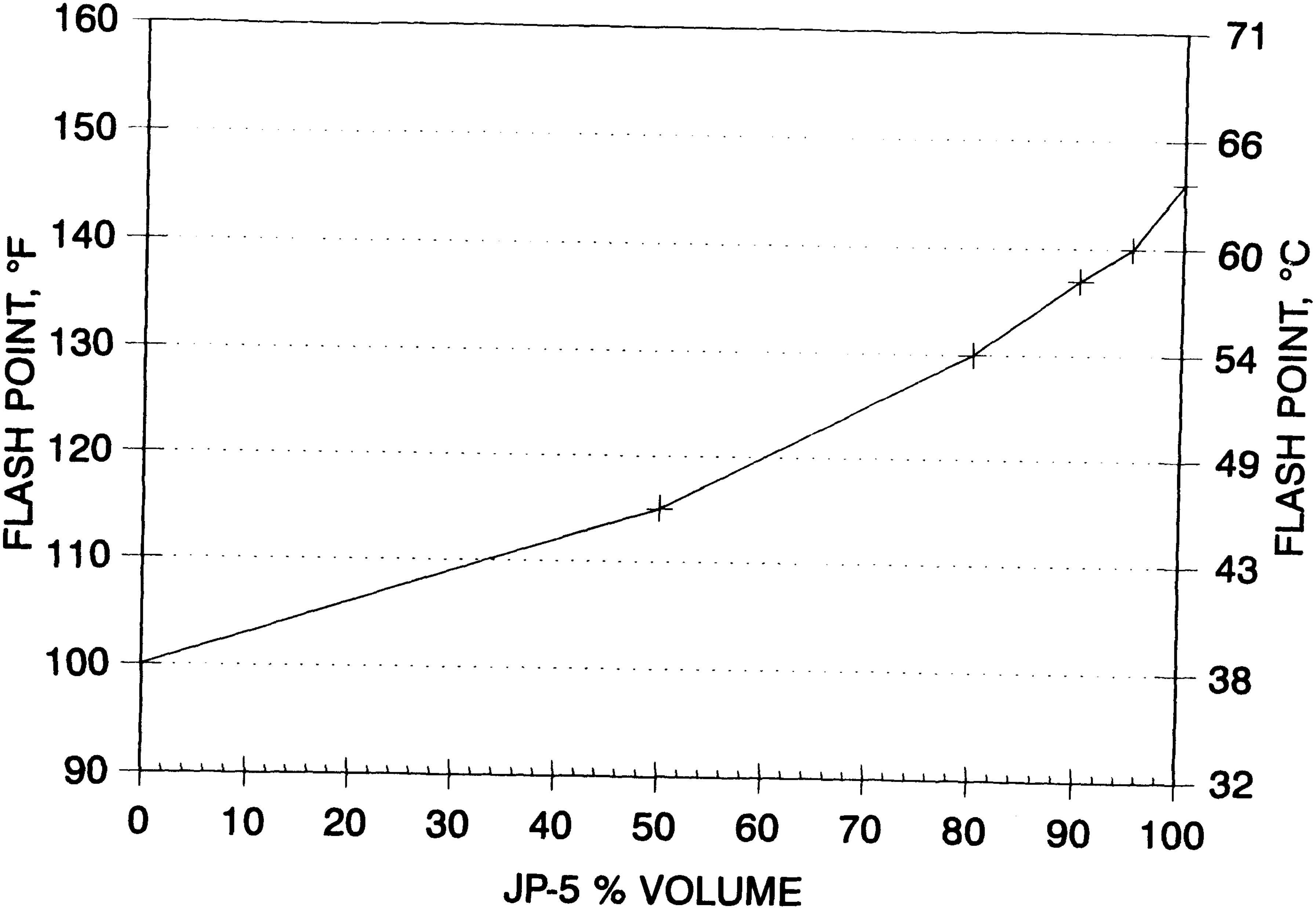

Fig. 10 - Flash point of JP-5/Jet A mixtures

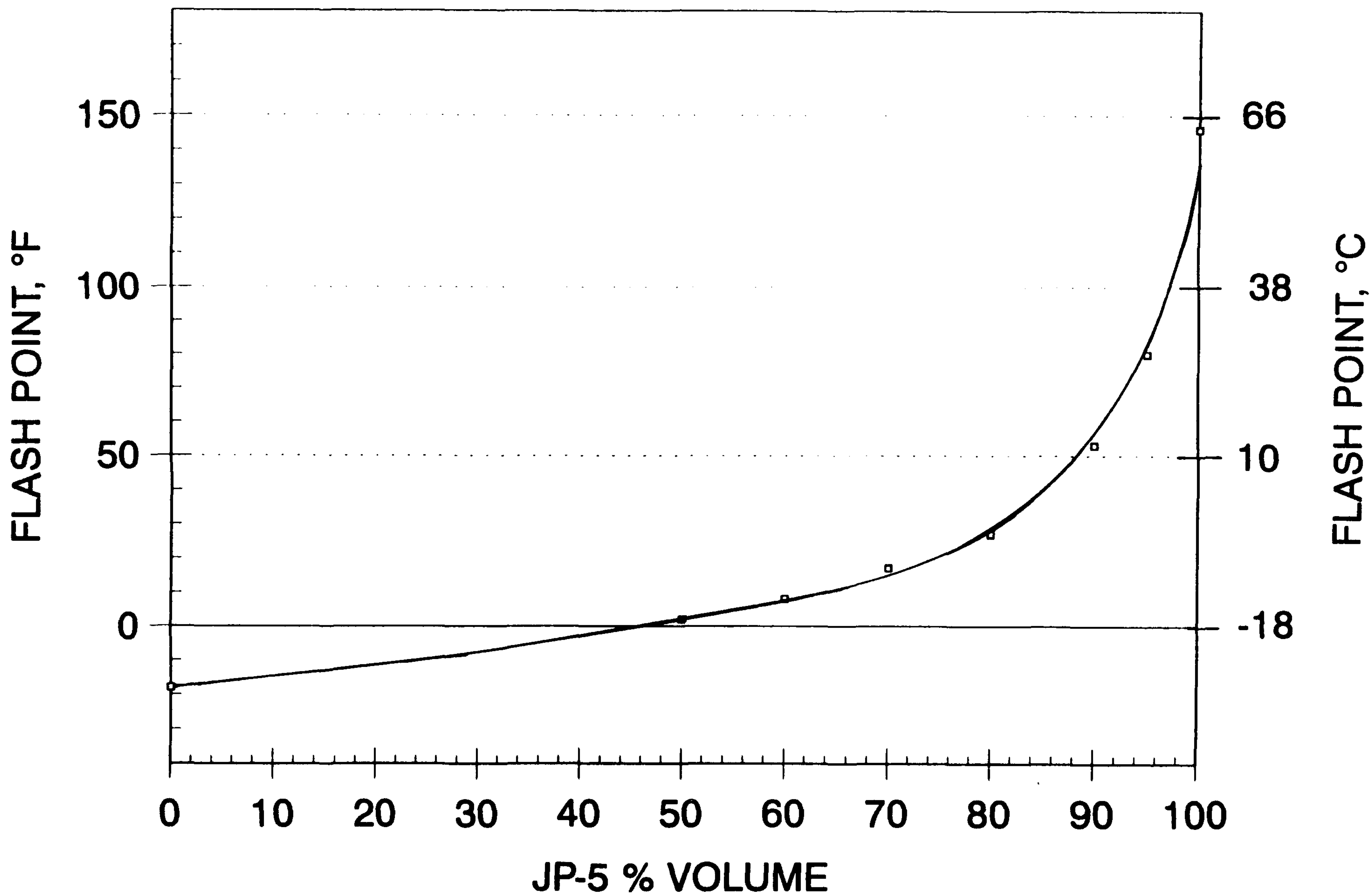

Fig. 11 - Effect of JP-4 on flash point of JP-5

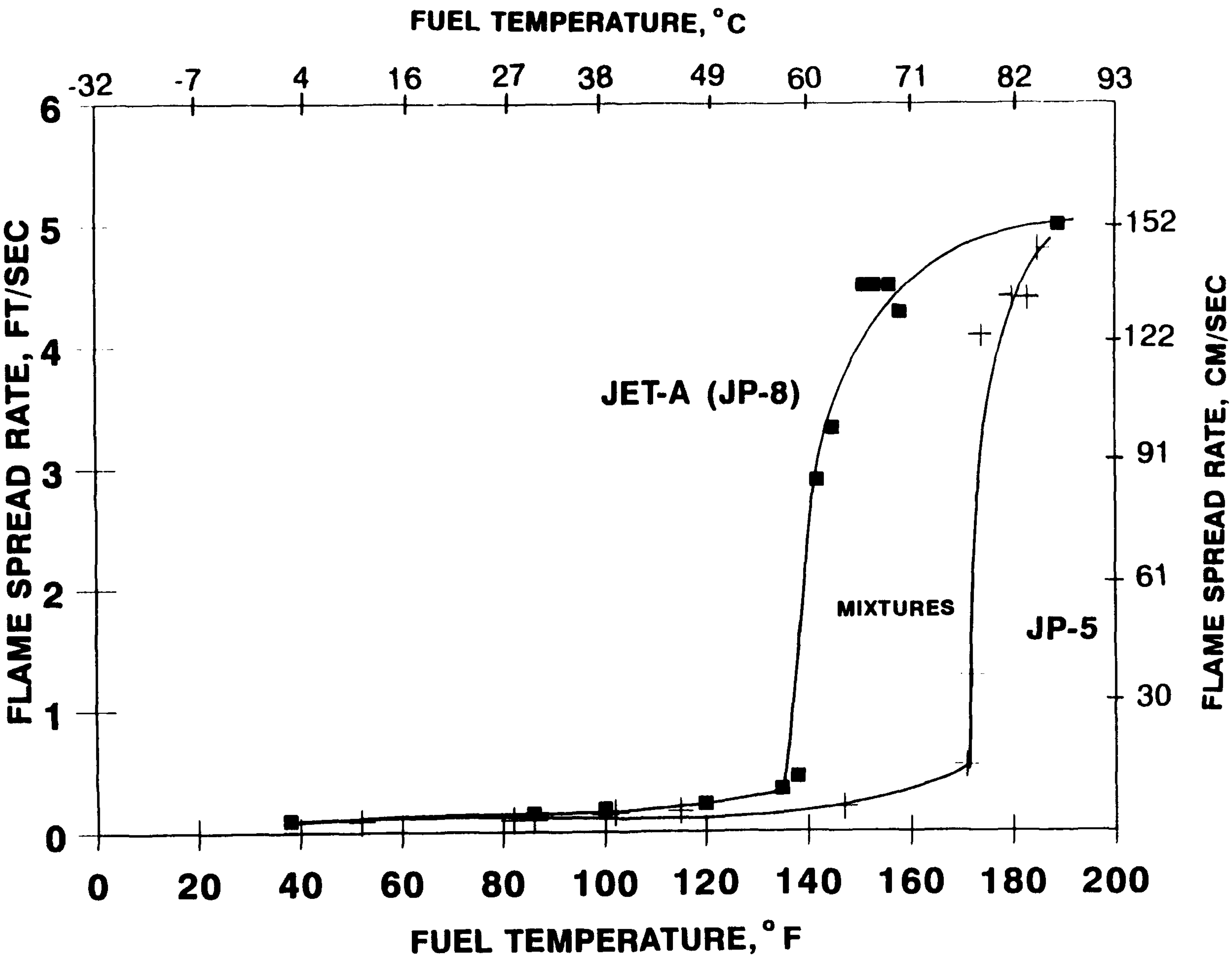

Fig. 12 - Small scale flame spread data on JP-5/Jet A (JP-8) fuels

Table 1. Small Scale Flame Spread Rates

Fuel JP-5	Fuel JP-8		Temperature of Fuel and Pan: 27°C (80°F)	38°C (100°F)	49°C (120°F)	60°C (140°F)	71°C (160°F)	82°C (180°F)
			Flame Spread Rate					
100%	0%	cm/s	3.2	4.6	4.8	6.0	6.4	70.6
		(in./s)	(1.3)	(1.8)	(1.9)	(2.4)	(2.5)	(27.8)
75%	25%	cm/s	4.2	4.6	5.7	6.1	42.7	128.3
		(in./s)	(1.7)	(1.8)	(2.2)	(2.4)	(16.8)	(50.5)
50%	50%	cm/s	3.8	4.6	6.1	9.5	62.2	136.5
		(in./s)	(1.5)	(1.8)	(2.4)	(3.7)	(24.5)	(53.7)
25%	75%	cm/s	4.6	5.1	6.3	34.3	64.8	110.5
		(in./s)	(1.8)	(2.0)	(2.5)	(13.5)	(25.5)	(43.5)
0%	100%	cm/s	4.6	5.8	6.9	24.0	137.2	152.4
		(in./s)	(1.8)	(2.3)	(2.7)	(9.5)	(54.0)	(60.0)

Additional Tests to Define High Temperature End of Curves*

Fuel JP-5	Fuel JP-8							
			77°C (171°F)	**79°C (174°F)**	**82°C (180°F)**	**84°C (183°F)**	**85°C (185°F)**	**90°C (194°F)**
100%	0%	cm/s	16.5	124.7	135.2	133.9	146.8	166.3
		(in./s)	(6.5)	(49.1)	(53.2)	(52.7)	(57.8)	(65.5)
			61°C (142°F)	**63°C (145°F)**	**66°C (151°F)**	**69°C (156°F)**	**70°C (158°F)**	**87°C (189°F)**
0%	100%	cm/s	88.4	101.6	137.2	137.2	130.6	152.4
		(in./s)	(34.8)	(40.0)	(54.0)	(54.0)	(51.4)	(60.0)

* The flame spread rates above 100 cm/s are not very accurate due to the short flame spread times involved, i.e., 1-2 seconds on the 162 cm pan.

(JP-8) mixtures are not shown on this figure to avoid clutter, but the mixtures all fall between the two extremes on the figure. The data for the mixtures as well as data for a number of pure hydrocarbons in the same flash point range are the subject of a separate report [7].

As indicated in Fig. 12, the flame spread rates for both JP-5 and Jet A (JP-8) are quite similar (Jet A (JP-8) is slightly faster), increasing gradually from ca. 4 to 7 cm/s (2 to 3 in./s) up to around 15-20°C (27-36°F) above the flash point. Above this temperature, the flame spread rates increase rapidly, reaching a maximum of ca 150 cm/s (60 in./s) for both fuels. These results are quite consistent with the data obtained for pure hydrocarbons having flash points in the same range as the JP-5/Jet A (JP-8) [7].

4.3 Large Scale Flame Spread Tests

The results of the large scale flame spread tests are listed in Table 2 and are plotted in Fig. 13. Again, the data points for the mixtures are not included in the figure to avoid clutter, but they are fall between the two extremes.

The data show a more gradual increase in flame spread with temperature than was found in the small scale, no-wind conditions starting about 11°C (20°F) above the flash point. The flame spread rates for Jet A (JP-8) eventually reached about 150 cm/s (60 in./s), just as in the small scale tests. The maximum flame spread rate attained for the JP-5 fuel was about 75 cm/s (30 in./s); although, as shown in Fig. 13, JP-5 was clearly headed for a flame spread rate of about 150 cm/s (60 in./s). However, it was not possible to heat the flight deck above 82°C (180°F) in order to attain this flame spread rate for JP-5 fuel.

Since the flame spread curves in Fig. 13 are for minimum flash point fuels, they represent a worst case scenario. What they show is that at a temperature of 82°C (180°F), which, as indicated above, is within the range of temperatures observed on a flight deck during summer daytime operations, the flame spread rate for a minimum flash point Jet A (JP-8) fuel would be twice that of a minimum flash point JP-5. As indicated

Table 2. Large Scale Flame Spread Rates

Fuel: JP-5	JP-8	units	Fuel Temperature: 27°C (80°F)	38°C (100°F)	49°C (120°F)	60°C (140°F)	71°C (160°F)	82°F (180°F)
			Flame Spread Rate					
0%	100%	cm/s	10.0	11.6	26.9	76.0	100.6	152.4
		(in./s)	(4.0)	(4.8)	(10.6)	(30.0)	(40.0)	(60.0)
25%	75%	cm/s	9.1	13.2	28.4	38.0	55.2	152.4
		(in./s)	(3.6)	(5.2)	(11.2)	(15.0)	(21.7)	(60.0)
50%	50%	cm/s	9.1	10.7	23.4	33.5	48.1	152.4
		(in./s)	(3.6)	(4.2)	(9.2)	(12.0)	(18.9)	(60.0)
100%	0%	cm/s	8.2	10.0	24.4	33.5	40.2	73.2
		(in./s)	(3.2)	(4.0)	(9.6)	(12.0)	(16.0)	(29.0)

Fuel		units	16°C (60°F)	32°C (90°F)
JP-4	100%	cm/s	190.5	190.5
		(in./s)	(75.0)	(75.0)

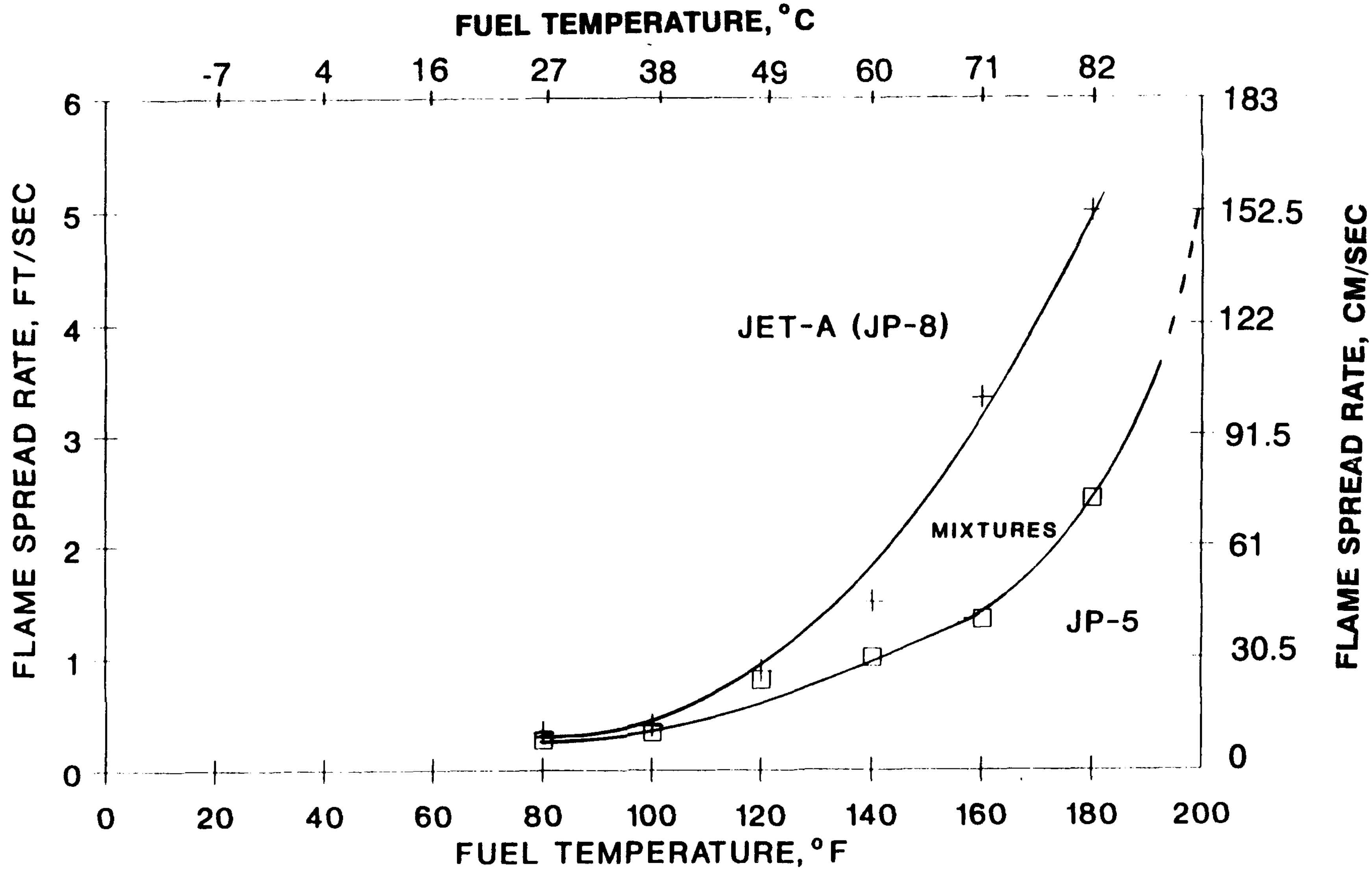

Fig. 13 - Large scale flame spread data for JP-5/Jet A (JP-8) fuels

JP-5 8 Seconds after ignition at 170°F

Jet A/JP-8 8 Seconds After Ignition at 170°F

Fig. 14 - Extent of flame spread on large scale heated deck for Jet A (JP-8) and JP-5 fuels at 76.6°C (170°F) eight seconds after ignition

in the time sequence photos in Fig. 14, this means that by the time the Jet A (JP-8) had traversed the entire 12.2 m (40 ft) deck, the JP-5 fuel had only travelled 6.1 m (20 ft). In other words, flight deck personnel would have up to twice as long to react to an advancing fire if the fuel were JP-5 instead of Jet A (JP-8). Granted, the difference may be in seconds, but seconds could be crucial in deploying firefighting equipment or in saving lives.

The results of the debris pile extinguishment tests are shown in Fig. 15. The data show that the extinguishment times for all fuels increase with increasing temperature of the fuel. However, the 100% JP-5 fuel fires could always be extinguished with one hand line in less than 60 seconds. In fact, it was not until there was 60% Jet A (JP-8) in the mixture that it was necessary to employ a second hand line to extinguish this fire.

At 90% Jet A (JP-8), the debris pile fires could not be extinguished in two minutes with two AFFF hand lines if the fuel temperature was above 77°C (170°F). For 100% Jet A (JP-8), the debris pile fires could not be extinguished above 71°C (160°F).

These results clearly show that in certain flight deck firefighting scenarios, fires involving minimum flash point Jet A (JP-8) fuels could be more difficult to extinguish than JP-5 fires. However, for these scenarios to occur, the fuel tanks would have to be exposed to a fire for a sufficiently long time to heat the fuel to about 35°C (60°F) above its flash point. These temperatures would not occur in the fuel tanks of an aircraft parked on the flight deck in normal operations, even in tropical climates, since the fuel is a poor conductor of heat. In any event, the resultant fires could be extinguished using standard flight deck fire fighting procedures.

5.0 CONCLUSIONS

The following conclusions were drawn from this study:

1. Flash Point - For the fuels selected, the lowering of the flash point of the JP-5 was nearly directly proportional to the amount of Jet A (JP-8) added. To

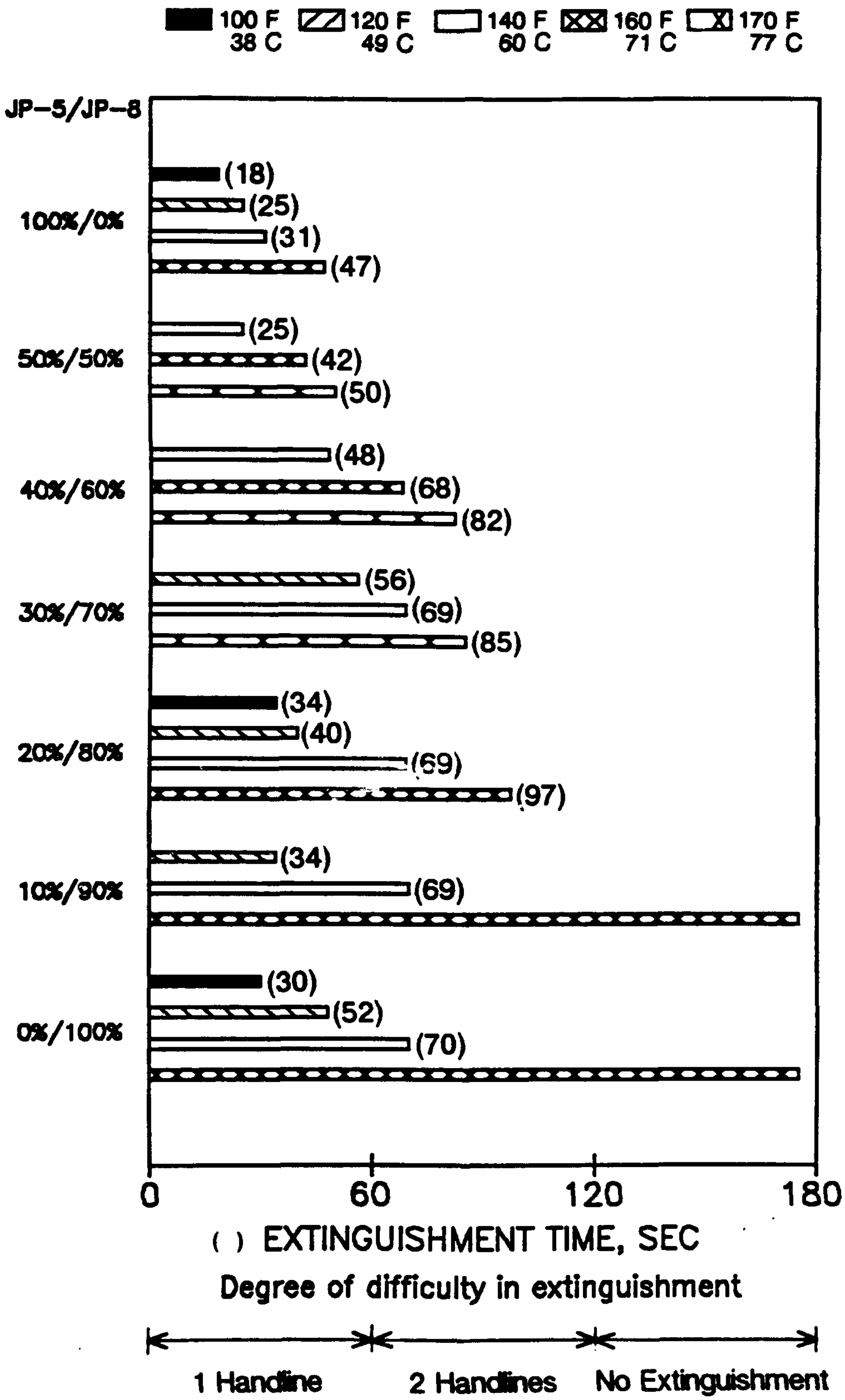

Fig. 15 - Extinguishment times for JP-5/Jet A (JP-8) fuels

the extent that the flash point is lowered, the ignition hazard is increased. This could be crucial in terms of whether or not fire occurs, particularly inside of the ship where compartment temperatures could exceed 49°C (120°F). However, it is recognized that in the field, the difference in the flash points of individual samples of JP-5 and Jet A (JP-8) may be anywhere between 0 and 31°C (0 and 56°F). Consequently, it is not possible to generalize about the fuels themselves; one can only compare individual fuels on the basis of their flash points.

2. Small Scale Flame Spread Tests - Up to about 17°C (30°F) above the flash point, the flame spread rates for all fuels were quite similar, increasing gradually from ca 4-7 cm/s (2-3 in./s) up to around 15-20°C (27-36°F) above the flash point. Above this temperature, the flame spread rates increased rapidly, reaching a maximum of ca 150 cm/s (60 in./s) for all fuels.

3. Large Scale Flame Spread Tests - Up to about 11°C (20°F) above the flash point, the flame spread rates for all fuels were similar, increasing gradually with temperature, just as in the small scale tests. Above this temperature, the flame spread rates increased with temperature, but not as rapidly as in the small scale tests. The flame spread rate for Jet A (JP-8) eventually reached about 150 cm/s (60 in./s), just as in the small scale tests. The maximum flame spread rate attained for the JP-5 fuel was about 75 cm/s (30 in./s) although it clearly would have reached about 150 cm/s (60 in./s) if the deck could have been heated further.

In a worst case scenario, the flame spread rate for Jet A (JP-8) was twice as fast as JP-5, indicating the flight deck personnel would have up to twice as long to react to an advancing fire if the fuel were JP-5 instead of Jet A (JP-8). Granted, the difference may be in seconds, but seconds could be crucial in deploying firefighting equipment or in saving lives.

4. Fire Extinguishment - The debris pile fire extinguishment tests showed clear, quantifiable differences in the ability to extinguish fires involving minimum flash point JP-5 vs. Jet A (JP-8) fuels. The neat JP-5 fuel fires could always be extinguished with one hand line in less than 60 seconds whereas the 100% Jet A (JP-8) fires became progressively more difficult to extinguish with increasing fuel temperature. Above 71°C (160°F), the Jet A (JP-8) fires could not be extinguished in two minutes with two hand lines. These results show that in certain flight deck firefighting scenarios, fires involving minimum flash point Jet A (JP-8) fuels would be more difficult, but not impossible, to extinguish.

6.0 REFERENCES

1. Military Specification, "Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8 ST," MIL-T-5624N, 10 February 1989.

2. Military Specification, "Turbine Fuel, Aviation, Kerosene Type, Grade JP-8," MIL-T-83133B, 25 March 1988.

3. CDR J.J. Breslin, Naval Air Systems Command, private communication, January 1990.

4. American Society of Testing and Materials, "Standard Test Methods for Flash Point by Pensky-Martens Closed Tester," D93-85.

5. H.W. Carhart, *et al.*, "Aircraft Carrier Flight Deck Fire Fighting Tactics and Equipment Evaluation Tests," NRL Memorandum Report 5952, February 26, 1987.

6. H.W. Carhart, "Test Plan–JP-4/JP-5 Mixture Firefighting," NRL Letter 6180-567:HWC:mls.

7. J.T. Leonard, *et al.*, "Flame Spread on Aviation Fuels," NRL Memorandum Report (in preparation).