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Antimisting Kerosene: Evaluation of Low Temperature Performance

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Final Report

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16. Abstract

The low temperature and freezing behavior of Jet A and AMK fuels was investigated in a 50-gallon capacity wing tank simulator. The fuel in the rectangular simulator was chilled from the top and bottom surfaces while the sides were thermally insulated. The evolution of a vertical temperature profile in the simulator was studied for Jet A and AMK fuels under nearly identical bottom wall temperature histories. A small but noticeable difference between the bulk fuel thermal response of Jet A and AMK was observed with a slower response for AMK. Holdup measurements for AMK were slightly lower than those for Jet A. Rocking of the simulated wing tank did not significantly alter the cool down and freezing behavior. The performance of two boost pumps: one for the DC-10 and the other for the Cessna 441 aircraft, was evaluated with AMK fuel. For both pumps the performance deteriorated when switching from Jet A to AMK. This performance deterioration was far more dramatic for the Cessna 441 boost pump than for the DC-10 boost pump. At low temperature (-30°C) the performance of the DC-10 pump actually improved compared to ambient temperature (20°C) performance. It deteriorated, however, for the Cessna 441 pump.

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EXECUTIVE SUMMARY

During the past several years, studies by the Federal Aviation Administration (FAA) and other government agencies have shown that the hazards from aircraft postcrash fires might be significantly decreased if an antimisting kerosene (AMK) fuel could be utilized. The addition of polymeric additives at low concentrations to jet fuels is known to suppress mist formation and ignition under circumstances often encountered in survivable aircraft crash landings.

Before implementation in commercial aircraft operations, the compatibility of AMK with the aircraft fuel system must be demonstrated. One aspect of this compatibility is the low temperature performance of AMK. During prolonged flight at altitudes, the fuel in the wing tanks is subjected to a considerable convective cooling by low temperature airflow over the wing surface. On certain polar routes, the fuel temperature may approach the freezing point of the Jet A fuel at -40^{o}C (ASTM D-1655). The behavior of AMK in the fuel tanks as well as the performance of the entire fuel system (boost pumps, ejector pumps, heat exchangers, degraders and fuel filters)at such low temperatures must be known.

Two aspects of the low temperature performance of AMK in aircraft fuel system are addressed in this report.

1) Cool down and freezing behavior in a simulated wing tank,
2) Performance of boost pumps.

The cool down and freezing behavior of Jet A and AMK was evaluated in a 50-gallon simulated wing tank. Cooling was applied to the top and bottom surfaces of the tank, while the other four sides were thermally insulated. Test fuel in the tank, initially at a uniform ambient temperature was subjected to cooling by circulation of chilled methanol through flow passages in the top and bottom walls. The cooling process was controlled such that the bottom wall temperature was maintained constant, close to a desired control temperature, throughout the run. The evolution of the vertical temperature profiles in the fuel tank, under this controlled boundary condition at the bottom wall, was compared for Jet A and AMK. At the end of a test run, the fuel tank was gravity drained and the amount of hold-up, i.e., the percentage of undrainable fuel in the tank, if any, was determined.

In the boost pump performance tests, the fuel in the simulated wing tank was chilled to the desired low temperature so that a nearly uniform fuel temperature was reached in the tank. The cold fuel was then pumped out of the wing tank by means of a DC-10 boost pump and the pump characteristics in terms of pressure drop versus flow rate were determined. A smaller test apparatus was also used to evaluate the pumpability of AMK for a smaller boost pump used on Cessna 441 aircraft.

A small but noticeable difference between the bulk fuel thermal response of Jet A and AMK was observed with a slower response for AMK. Holdup measurements for AMK were slightly lower than those for Jet A under nearly identical bottom wall cooling histories and durations of cool down. Rocking of the simulated wing tank did not significantly alter the cool down and freezing behavior.

Performance of the two boost pumps deteriorated when switching from Jet A to AMK. This performance deterioration was more dramatic for the Cessna 441 boost pump than that for the DC-10 boost pump. At low temperature (-30^{o}C) the performance of DC-10 pump actually improved over room temperature (20^{o}C) performance. It deteriorated, however, for the Cessna 441 pump.

INTRODUCTION

The fire suppression performance of antimisting kerosene (AMK) (polymer additive FM-9™ in Jet A fuel) has been demonstrated by several small and large scale tests. However, before implementation in commercial aircraft operations, the compatibility of AMK with the aircraft's fuel system must be demonstrated. One aspect of this compatibility is the low temperature performance of AMK. During prolonged flight at altitude, the fuel in the wing tanks is subjected to a considerable convective cooling of low ambient temperature airflow over the wing surface. Indeed, on certain polar routes, the bulk fuel temperature approaches the freezing point of the Jet A fuel at -40°C (ASTM D-1655) (reference 1). The behavior of AMK in the fuel tanks as well as the performance of the entire fuel system (boost pumps, ejector pumps, heat exchangers, degraders and fuel filters) at such low temperatures must be evaluated as a part of any AMK-fuel system compatibility study.

Two aspects of the low temperature performance of AMK in aircraft fuel system are addressed in this report.

1) Cool down freezing behavior in a simulated wing tank,
2) Performance of boost pumps.

The effect of low fuel temperature on the performance of an AMK degrader and fuel filters is discussed in reference 2. The performance of ejector (jet) pumps handling low temperature AMK may be found in reference 3.

The cool down and freezing behavior of Jet A and AMK was evaluated in a 50-gallon simulated wing tank. Cooling was applied to the top and bottom surfaces of the tank, while the other four sides were thermally insulated. Fuel in the tank was initially at a uniform temperature in the range 10°C to 15°C. It was then subjected to cooling by circulation of chilled methanol through flow passages in the top and bottom walls. The cooling process was controlled such that the bottom wall temperature was maintained constant, close to the desired control temperature, throughout the run. The evolution of the vertical temperature profiles in the fuel tank, under this controlled boundary condition at the bottom wall, was compared for Jet A and AMK. At the end of a test run the fuel tank was gravity drained and the amount of hold-up, i.e., the percentage of undrainable fuel in the tank, if any, was determined.

In the boost pump performance tests, the fuel in the simulated wing tank was chilled to the desired low temperature so that a nearly uniform fuel temperature was reached in the tank. The cold fuel was then pumped out of the wing tank by means of a DC-10 boost pump and the pump characteristics in terms of pressure drop versus flow rate were determined. A smaller test apparatus was also used to evaluate the pumpability of AMK for a smaller boost pump used on Cessna 441 aircraft.

The objectives of the low temperature AMK performance evaluation work discussed in this report were:

1) To measure and compare the evolution of vertical temperature profiles for Jet A and AMK in the simulated wing tank under identical imposed cooling conditions.

2) To measure and compare the hold-up (percentage of fuel undrainable from the simulated wing tank) for Jet A and AMK under identical imposed cooling conditions and duration of cooling.

3) To determine the pressure drop versus flow rate characteristics of the DC-10 and Cessna 441 boost pumps using Jet A and AMK as fuels at low temperatures.

EXPERIMENTAL APPROACH

The low temperature wing tank simulator designed and built for this investigation was generically modelled after the facility used in reference 1. It was a rectangular chamber with inside dimensions of 20 inches x 20 inches x 30 inches (50 cm x 50 cm x 75 cm) as shown in figure 1. The chamber was fabricated from 1/2 inch aluminum plates welded at corners. The top and the bottom surfaces of the chamber contained integral flow passages for circulation of chilled methanol to apply cooling to the fuel in the chamber. The side walls and the front wall contained 6-inch diameter plexiglass viewports for visual observations of the chamber interior during the cool down process. The front, back and side walls were thermally insulated by 2-inch thick open cell polyurethane foam with removable insulation panels at the viewport locations. The top and the bottom panels were also insulated on the outside.

The entire chamber was pivoted along one of the shorter bottom edges while the other short bottom edge rested on a motor driven eccentric. This arrangement allowed imparting of controlled rocking motion of the entire chamber to simulate in flight fuel tank oscillations. The amplitude of these imposed oscillations was 1.5 degrees while the frequency could be adjusted from 0 to 1 Hz. A counterweight and pulley arrangement was added to reduce the load on the eccentric when the simulator was filled with fuel. A photograph of the low temperature wing tank simulator facility is shown in figure 2.

The interior of the chamber contained Z-stringers welded to the top and bottom surfaces. A DC-10 boost pump was installed in one corner at the bottom of the chamber with output line leaving the chamber through the front cover. A set of eleven chromel-alumel thermocouples was mounted at varying distances from the bottom wall on a nylon rod and placed vertically at the center of the chamber, with a larger number placed near the bottom. The locations of the thermocouples are shown in table 1. The output of the bottom wall thermocouples was used to control the cooling applied to the top and bottom surfaces. Following the initial cooling transient, the bottom wall temperature was maintained within $\pm$ 0.3^{o}C of the desired temperature by automatic on/off control of the coolant circulation.

The bottom wall contained a drain pipe installed near one corner of the chamber. For the holdup measurements, fuel was gravity drained from this drain pipe at the end of a cooling run. The top surface also contained an outlet to top off the chamber with fuel and purge air bubbles from the system. This top outlet was connected to an overflow reservoir of 5-gallon capacity. During cool down, the density of the fuel in the chamber increased significantly, causing fuel from the overflow reservoir to be drawn into the chamber to keep the chamber filled with fuel to the top surface.

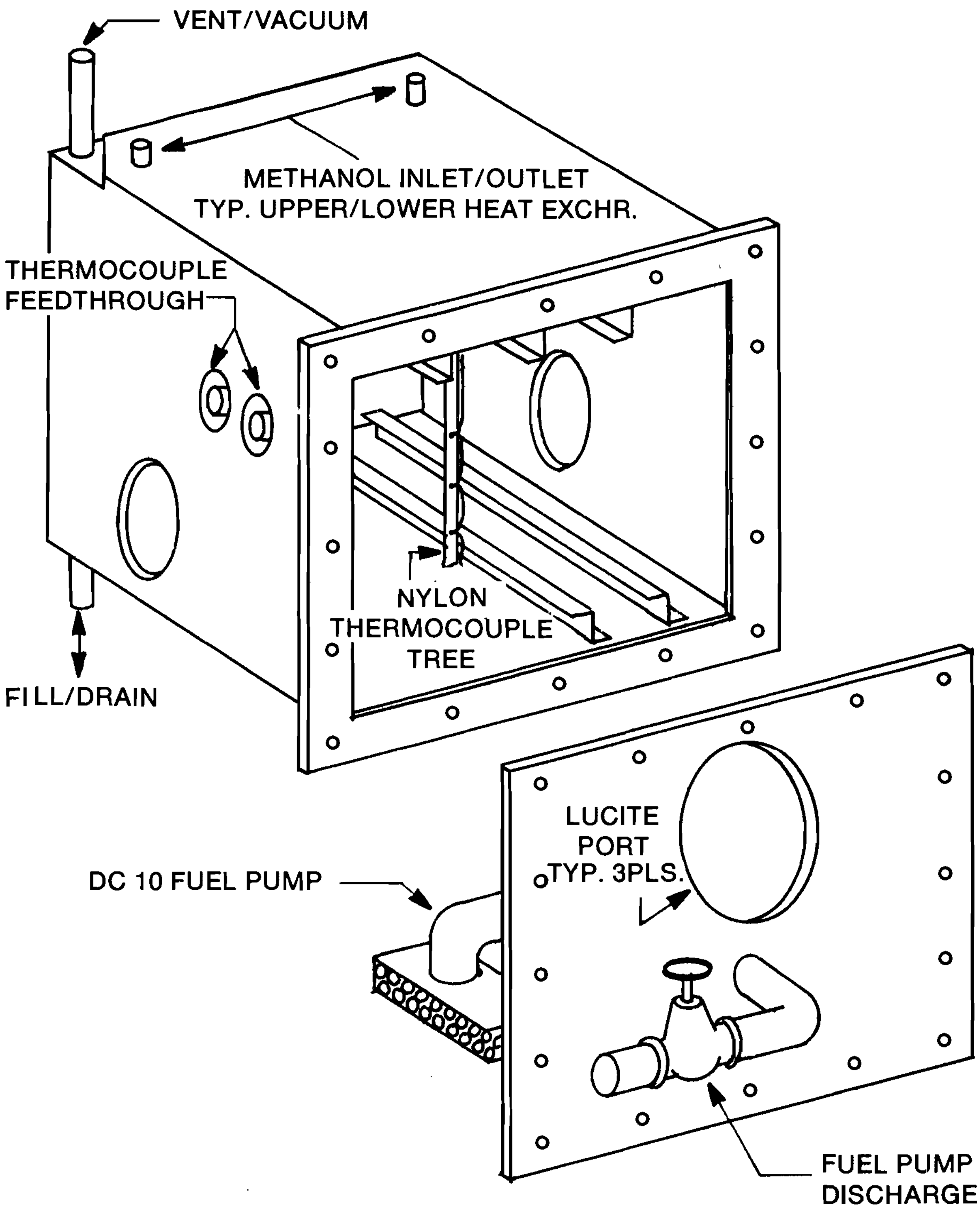

FIGURE 1. SCHEMATIC DIAGRAM OF LOW TEMPERATURE WING TANK SIMULATOR

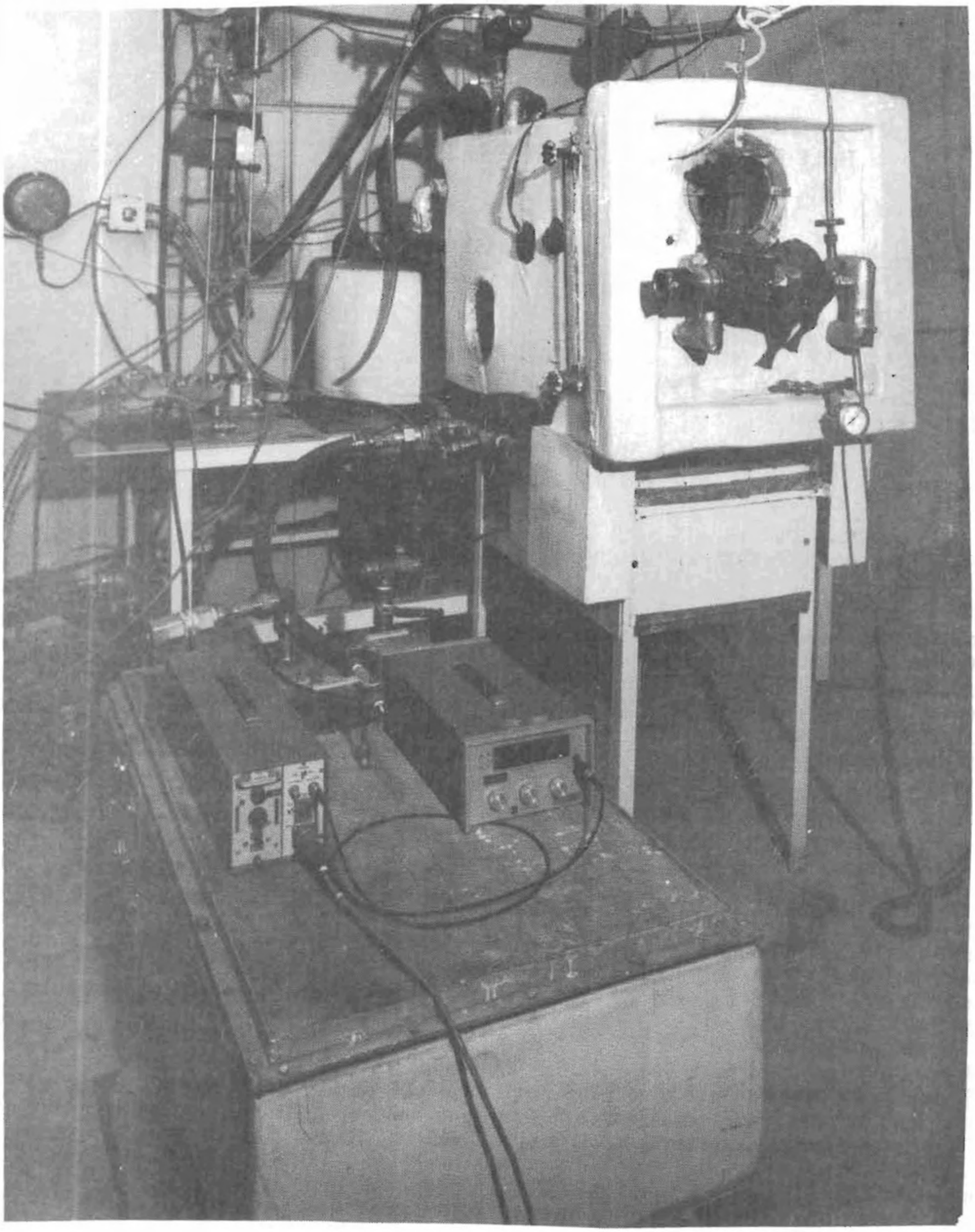

FIGURE 2. PHOTOGRAPH OF LOW TEMPERATURE WING TANK SIMULATOR

TABLE 1. THERMOCOUPLE LOCATIONS IN WING TANK SIMULATOR

T.C. No.	Distance from the Tank Bottom (in)
0 (control)	0 (Bottom Wall Skin TC)
1	0.25
2	0.50
3	1.0
4	2.0
5	4.0
6	9.0
7	14.0
8	19.0
9	19.75
10	20 (Top Wall Skin TC)

Cooling was applied to the top and bottom walls of the chamber by circulation of chilled methanol through passages in these surfaces. A schematic diagram of the methanol loop is shown in figure 3. The loop contained a methanol reservoir of 3-gallon capacity, a circulation pump, a pair of solenoid valves, a 1/2 inch copper tubing coil immersed in an acetone dry ice bath and the heat exchanger panels forming the top and bottom surfaces of the low temperature simulator. The two solenoid valves, only one of which was open at a given time, caused the methanol loop to operate in one of two modes:

(1) Include the acetone-dry ice bath in the flow loop.
(2) Exclude (bypass) the acetone-dry ice bath from the flow loop.

Thus, methanol circulated continuously through the top and bottom surfaces of the simulator and the methanol reservoir. However, the acetone-dry ice bath was included in or excluded from the methanol flow loop, depending upon the cooling requirement to maintain the bottom wall temperature nearly constant at the desired temperature.

The acetone-dry ice bath had interior dimensions of 28 inches x 18 inches x 12 inches and it contained a cooling coil made out of 1/2 inch copper tubing of 100 feet length. The cooling coil was kept submerged in the acetone-dry ice slush. The bath temperature was maintained at -78^{o}C. The rectangular bath container had a removable top and was insulated on all sides with 3-inch thick polyurethane foam. Dry ice was added to the container as needed to maintain the liquid level above the cooling coil and the bath temperature at -78^{o}C.

<u>Data Acquisition and Experiment Control</u>

The output of the thermocouples was amplified by a set of DC differential amplifiers with a gain of about 1000. The conditioned analog signal from each

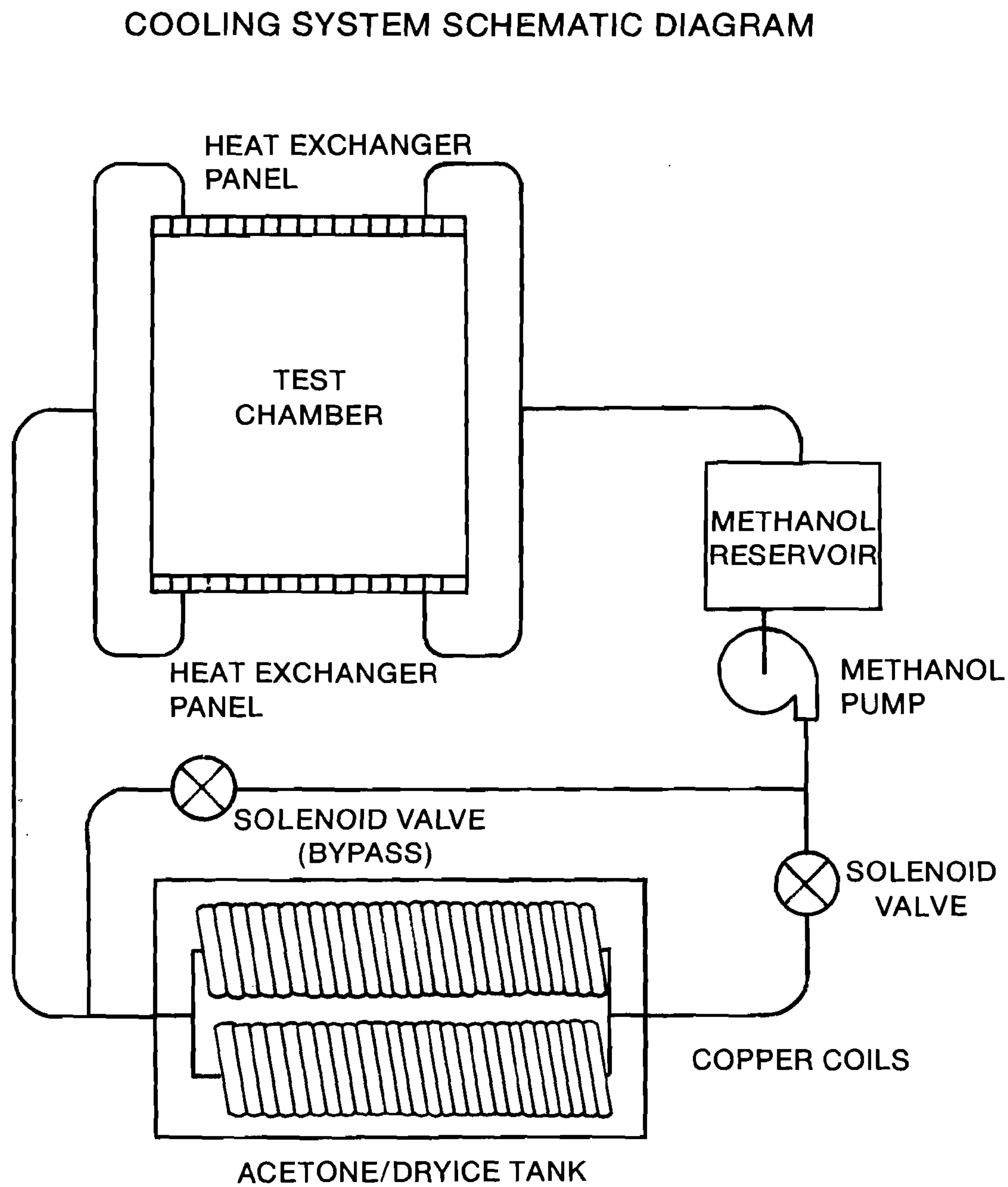

FIGURE 3. SCHEMATIC DIAGRAM OF METHANOL (COOLANT) LOOP

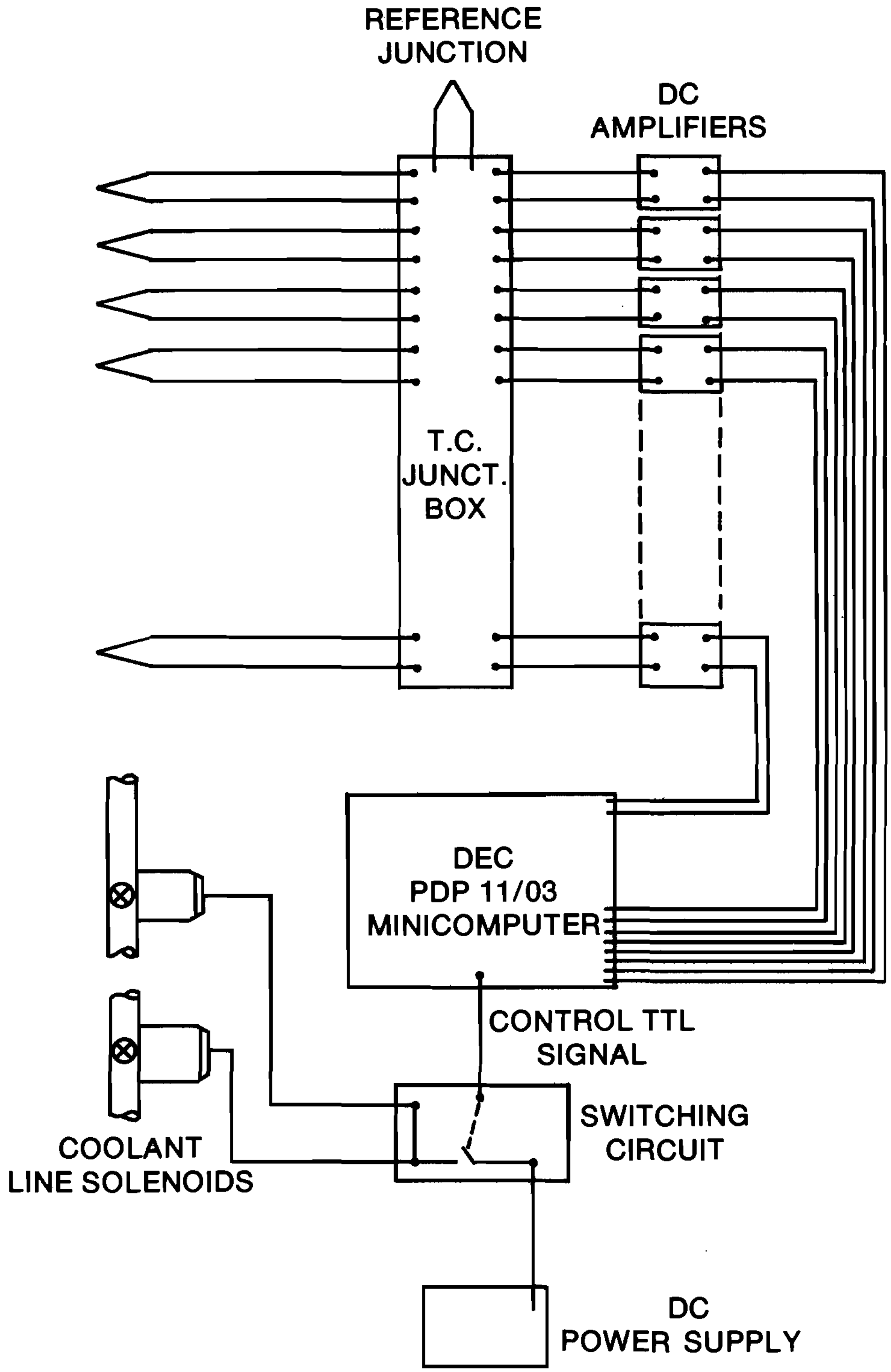

FIGURE 4. SIGNAL CONDITIONING, DATA ACQUISITION AND SOLENOID CONTROL SYSTEM

channel was transmitted to a Digital PDP 11/03 minicomputer (see figure 4). A data acquisition and control program was written to sample data from the 12 thermocouple channels and to maintain the bottom wall temperature close to the desired temperature. The thermocouple data were sampled every 10 seconds and bottom wall temperature was compared with the specified temperature. Based on the difference between the actual bottom wall temperature and the specified temperature, a decision was made to initiate or terminate methanol cooling in the acetone-dry ice bath coils. The methanol flow switching from bypass to cooling mode was accomplished by switching the two solenoids in the methanol loop. TTL-level switching signals were generated in the digital-to-analog converters of the computer. These signals in turn activated a relay to supply or cut off DC power to the solenoids.

During startup, the system was placed in a continuous cooling mode until the bottom wall temperature came down to within 2 degrees of the desired temperature. (This took about 20 minutes from startup.) At this point the system was placed in an intermittent cooling mode in which cooling was applied for 10 seconds and then kept off for 50 seconds. At the end of the 50-second waiting period, the bottom wall temperature was sampled. If it was found higher than the desired temperature, the cooling was applied for another 10 seconds, followed by a 50-second wait period. It was necessary to build in this delay between the application of cooling and making a decision on whether to continue cooling to match the delay in the system response due to thermal inertia. Without this built-in delay, the bottom wall temperature could not be controlled within a narrow band of $\pm$ 0.3^{o}C but oscillated $\pm$ 3^{o}C due to over-corrections. If, at any time, the control temperature became higher than the desired temperature by more than 2^{o}C, the system was placed in continuous cooling mode. If the control temperature fell below the desired temperature, cooling was cut off altogether.

Temperature values at the 12 thermocouple locations were plotted every 2 minutes and printed out every 10 minutes. The bottom wall temperature was continuously monitored by plotting the output of the amplifier on a strip chart recorder.

Apparatus for Boost Pump Performance

The objective of the boost pump performance tests was to determine the pressure rise versus flow rate characteristics of the pump when using Jet A and AMK at room temperature and a low temperature. Two pumps were evaluated: a DC-10 Hydro-Aire Model P/N 60-843-2 (housing)/P/N 60-874-1 (pump element) boost pump and a Cessna 441 Airborne Model Number 1012-17 boost pump. The DC-10 boost pump was mounted on the bottom wall of the low temperature simulator while the Cessna 441 boost pump was tested in a smaller facility shown in figure 5. In both cases, the high side of the pressure transducer was connected to the pump discharge line at the pump exit while the low side of the transducer was connected to the bottom of the chamber in which the pump was installed.

The discharge from the DC-10 boost pump was via a 2-inch line into a collection tank which was mounted on a load cell. The load cell was calibrated by introducing known quantities of Jet A fuel into the collection tank. A 2-inch gate valve and a 2-inch ball valve were installed in the

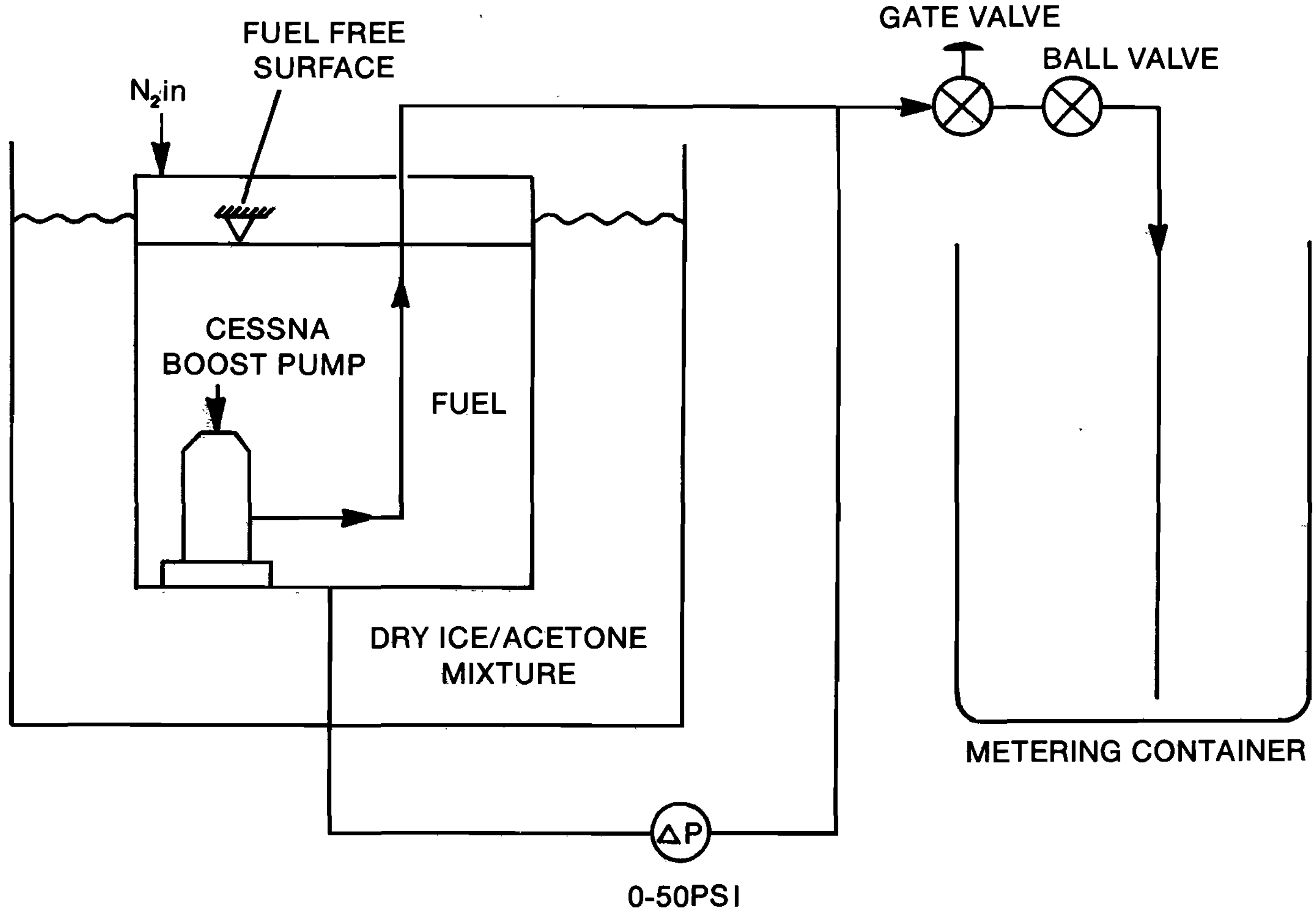

FIGURE 5. CESSNA 441 PUMPABILITY TEST APPARATUS

discharge line to control the pump outflow and to rapidly start and stop the flow. The pump power was supplied from a 220V, 400 cps generator unit.

The Cessna 441 boost pump performance test apparatus was similar in design. The pump power in this case was supplied from a DC power supply at 27 VDC. The collection tank had a depth gage in this case and the volume flow rate was determined by change in the depth gage reading over a known time interval.

Facility Test Procedure

In preparation for a cool-down run, fuel was loaded into the simulator after a sufficiently long time had elapsed from a previous run. This ensured that the initial fuel temperature was between 10°C and 15°C and was uniform throughout the simulator. The fuel was loaded into the simulator from the bottom. When charging AMK fuel into the simulator, the fuel was gravity fed from a 55-gallon barrel hoisted above the level of the simulator. This was done in preference to pumping to avoid AMK degradation. Fuel was allowed to overflow from a stand pipe at the top of the simulator and drained into an overflow reservoir via a 1/2-inch tygon tubing. The overflow reservoir was open to atmosphere. The tygon tubing remained full of fuel upon completion of fuel loading with the end submerged in the overflow reservoir. This procedure vented all the air out of the simulator and ensured that during cool-down, as the fuel in the simulator contracted, it could draw fuel from the overflow reservoir, thereby keeping the simulator full of fuel.

The acetone bath was charged with dry ice until the bath temperature dropped to -78°C with excess dry ice still left in the bath. The cool-down process was then started by switching the solenoids from bypass to cooling mode by computer control. For the same specified temperature of the bottom wall, the initial cooling transient of about 20 minutes duration was nearly the same for all fuels. Following this initial cooling transient, the bottom wall temperature was maintained within a narrow band of variation. This variation was about -1°C to +2°C for times between 20 minutes and 90 minutes and $\pm$ 0.3°C for times greater than 90 minutes.

The cool-down process was continued for a period of 5 1/2 hours while maintaining the bottom wall temperature close to the desired temperature by automatic on/off control of coolant flow through the cooling coils in the acetone-dry ice bath. The 12 thermocouple channels were sampled every 10 seconds and temperature values were printed out every 10 minutes. The data provided the temperature-time history at each thermocouple location, as well as the evolution of the vertical temperature profile in the simulator.

Due to the nature of the free convection process in the enclosed simulator, with cooling applied at the top and bottom surfaces, the lowest fuel temperature was always at the bottom wall. For this reason, the bottom wall thermocouple output was chosen for control of coolant flow. This ensured that temperature anywhere in the simulator did not fall below the specified temperature anytime during the cooling process. This was especially important when the specified temperature was below the freezing point of the fuel. Had any other thermocouple location been chosen for control purposes, the fuel close to the bottom wall would have frozen even if the specified temperature was above the fuel freezing point.

At the end of a 5 1/2-hour cool-down, the difference between the maximum and minimum (bottom wall) temperatures in the simulator was about 3°C for cases where there was no significant freezing. For cases where there was significant freezing (when the specified temperature was several degrees below the fuel freezing point), the difference between the maximum and the minimum temperature in the simulator at the end of a 5 1/2-hour cool-down run increased to as much as 8°C.. The maximum fuel temperature in the simulator was at or near the center of the simulator.

The cold fuel was drained from the bottom of the simulator while supplying dry nitrogen to the simulator via the overflow tygon tubing. The automatically controlled coolant circulation was kept on during the drainage process, which lasted for 10 to 15 minutes. The bottom drain valve on the simulator was closed after ascertaining that the drainage flow had nearly stopped. The drained fuel was collected in the weigh tank and weighed. Following the completion of the drainage process, the cooling system was shut off and the simulator was allowed to warm up by letting it stand overnight. The fuel held up in the simulator had melted by this time and was drained into the weigh tank the next day and weighed. From these two weight measurements, the percent holdup was determined for the test run.

Boost Pump Performance Tests

For the DC-10 boost pump performance tests, the fuel in the simulator was chilled down to a desired temperature until the difference between the center and the bottom wall temperature was less than 3°C. The shut off head of the pump was determined by starting the pump with the ball valve in the discharge line in the closed position. It was found by displaying the output of the pressure transducer on a strip chart recorder that the pump had an excellent response time. The maximum shut off pressure head was built up in less than 0.2 seconds after the power switch was turned on. The pump was kept on for 3 to 5 seconds to ensure that a steady pressure reading was obtained on the strip chart record.

For flow rate measurements, a timed pump discharge was collected in the weigh tank. The flow rate was calculated from the difference between the initial and final weight readings together with the time interval as determined from the strip chart record. For measuring pump performance at various flow rates, the gate valve was progressively opened from its initial closed position. The ball valve was kept closed at the start of a test, the pump was turned on and after two or three seconds the ball valve was quickly opened. The pressure transducer response was less than 0.2 seconds as the flow increased from 0 to some value corresponding to the gate valve opening. The flow was kept on for 4 to 6 seconds and then the ball valve was quickly shut off. Immediately thereafter, the pump power was cut off to avoid degradation of the simulator fuel by the pump vapor removal recirculating flow. The time interval was determined from the step changes in pressure transducer trace recorded on the strip chart as the ball valve was opened and closed. The pressure rise was also determined from the strip chart record. The pump mass flow rate data were then converted to volume flow rate by use of the following density-temperature relationship for Jet A determined experimentally.

$$\rho(\text{kg/m}^3) = 821.4 - 0.7317\ t$$

where t is in ^oC in the range $-40^oC < t < 80^oC$.

Pump performance tests were run at room temperature and at a low temperature for Jet A and freshly blended AMK.

The performance test procedure for the Cessna 441 boost pump in a small test apparatus (figure 5) was similar. The chilling of the fuel in this case was achieved by introduction of dry ice-acetone mixture in the jacket surrounding the fuel tank. The fuel was gently stirred with a paddle during cool down and its free surface was kept purged with dry nitgrogen. The volume flow rate in this case was measured by timed collection in a graduated tank.

RESULTS AND DISCUSSION

Temperature profile evolution and holdup data were obtained for a total of 13 runs as shown in table 2. Three control temperatures were used: -40°C, -45°C and -50°C for cool down tests reported here. Four pairs of tests were conducted in which AMK's and base fuels from which they were blended were subjected to nearly the same bottom wall cooling histories and control temperature. The purpose was to measure differences in the cooling behavior of the bulk fuel and the holdup. One test was conducted with Jet A fuel with rocking of the simulator and compared with the case of no rocking.

Figure 6 shows the temperature-time histories for two fuels at three locations in the tank. The control temperature in this case was -40°C. The solid symbols represent AMK data while the hollow symbols represent data for the base fuel. Notice that the bottom wall temperature in both cases gets down close to -40°C rapidly within 20 minutes after startup and after 90 minutes, it remains close to the desired temperature of -40°C within ±0.2°C. Notice also that the bottom wall initial cooling transient for AMK and the base fuel are nearly the same.

With this same imposed boundary conditions at the bottom wall, the cooling responses at the top wall and at the center of the tank for AMK and the base fuel are slightly different. At both locations, the base fuel temperature drops slightly faster than the corresponding temperature for AMK. This results from a slightly lower convective heat transfer coefficient for AMK as compared to that for the base fuel. Notice that even though both the top and the bottom walls are cooled by coolant circulation in an identical fashion, the temperature response of the top wall is slower than that of the bottom wall. This is caused by the higher convective heat transfer coefficient on the fuel side at the top wall as compared to that at the bottom wall.

Data for a bottom wall control temperature of -45°C show similar behavior as shown in figure 7. In both control temperature cases of -40°C and -45°C discussed so far, no significant freezing of the fuel was encountered. Data for -50°C control temperature, where significant freezing of the fuel <u>was</u> encountered, are shown in figure 8. In this case the behavior is still generally the same, however, due to the formation of frozen fuel at the bottom and top wall, heat transfer between the fuel and the top/bottom wall is considerably reduced. Consequently, at the end of the 5 1/2-hour cool-down run, fuel temperature at the center of the tank remained as much as 8°C above the bottom wall temperature in contrast to the cases of -40°C and -45°C bottom wall control temperatures where the difference was only 2 to 3°C.

The evolutions of temperature profiles in the simulator are shown in figures 9, 10, and 11 for the cases of bottom wall control temperatures of -40, -45, and -50°C respectively. In each case the measured profiles for AMK are compared with those for the base fuel at different times from the start of the cool-down process. These data confirm the trends seen earlier: at a given time from the start of the cool-down process, the base fuel temperatures are lower than the corresponding AMK temperatures. Notice from these plots that the thermal boundary layer at the bottom wall is considerably thicker than that at the top wall, leading to a higher fuel side heat transfer coefficient at the top wall. Also notice that the temperature profiles in the core region of the simulator are fairly uniform.

TABLE 2. LISTING OF LOW TEMPERATURE SIMULATOR RUNS

Run No.	Date	Fuel	Bottom Wall Control Temp °C	Base Fuel Freezing Temp (ASTM) °C	Percent Holdup
1	2/1/84	Jet A (ICI RMH 30328)	-40	-44.5	0
2	2/2/84	Jet A (ICI RMH 30328)	-50	-44.5	33.0
3	2/7/84	AMK (ICI RMH 246)	-50	-44.5	30.0
4	2/8/84	AMK (ICI RMH 241)	-45	-44.5	5.0
5	2/9/84	Jet A (ICI RMH 20922)	-45	-	5.6
6	2/16/84	Jet A (ICI RMH 20922) (Rocking)	-50	-	32.0
7	3/14/84	AMK (Freshly Blended ICI slurry JCK 247-2 Burbank/Texaco Jet A)	-45	-49.5	0
8	3/29/84	Jet A (Burbank/Texaco)	-50	-49.5	2.5
9	5/15/84	AMK (Freshly Blended ICI slurry JCK 247-2 Burbank/Texaco Jet A)	-40	-49.5	0
10	10/4/84	Jet A (Burbank/Texaco)	-40	-49.5	0
11	10/9/84	Jet A (Burbank/Texaco)	-45	-49.5	0
12	10/12/84	AMK (Freshly Blended ICI slurry JCK 16-95-2 Burbank/Texaco Jet A)	-40	-49.5	0
13	10/15/84	AMK (Freshly Blended ICI slurry JCK 16-95-2 Burbank/Texaco Jet A)	-45	-49.5	0

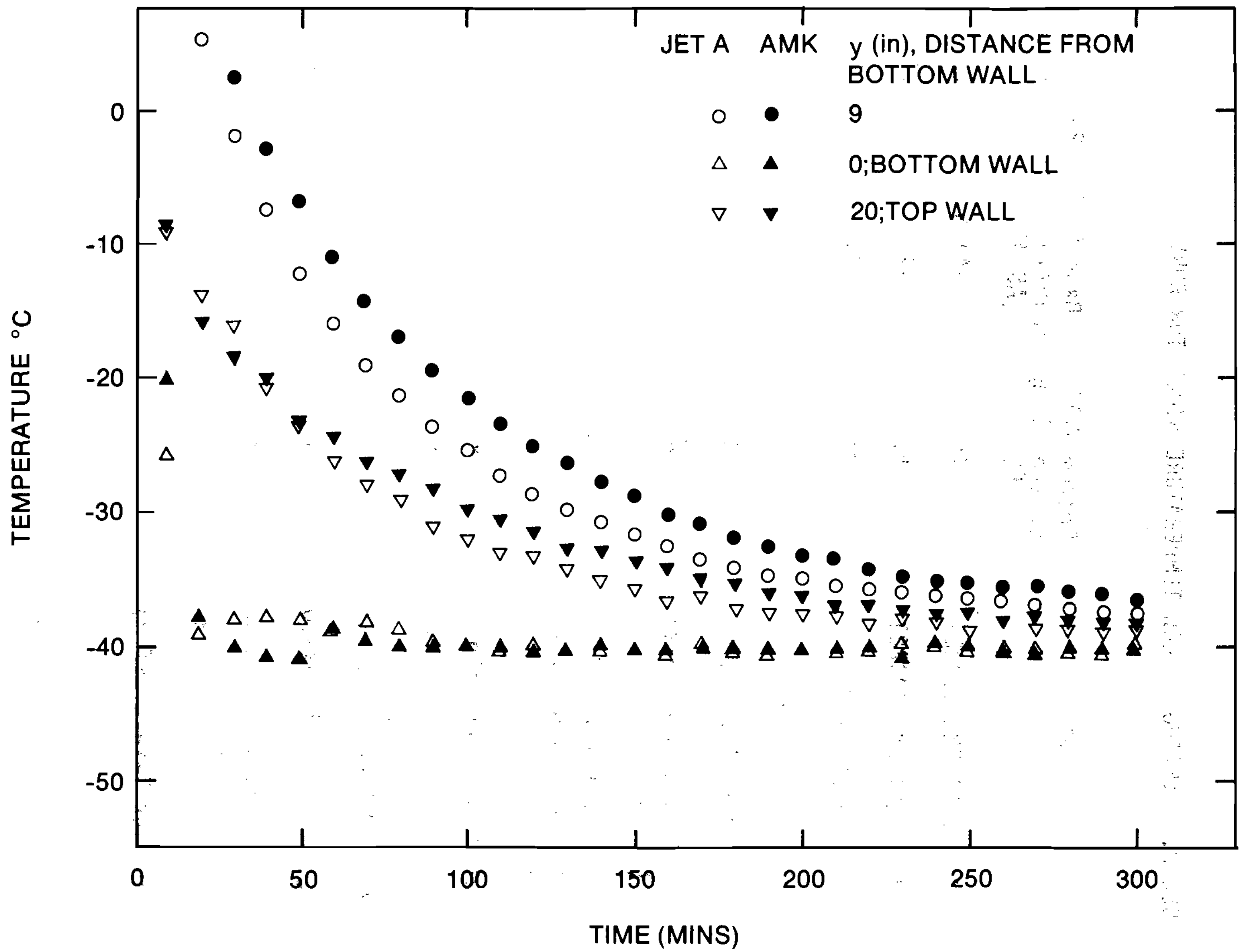

FIGURE 6. TEMPERATURE - TIME HISTORY AT THREE LOCATIONS INSIDE SIMULATOR - COMPARISON OF JET A AND AMK BEHAVIOR FOR A CONTROL TEMPERATURE OF -40°C

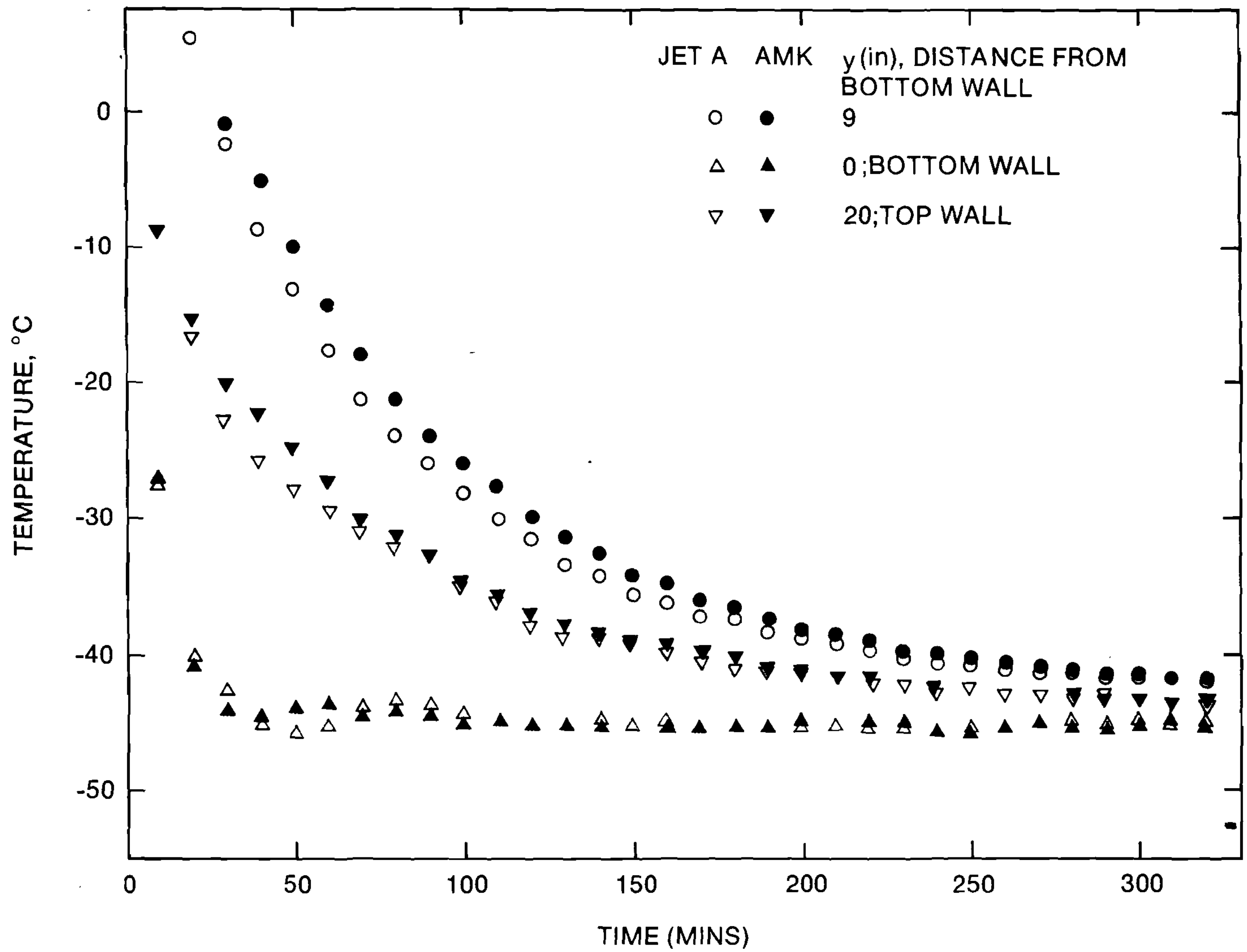

FIGURE 7. TEMPERATURE - TIME HISTORY AT THREE LOCATIONS INSIDE SIMULATOR - COMPARISON OF JET A AND AMK BEHAVIOR FOR A CONTROL TEMPERATURE OF -45°C

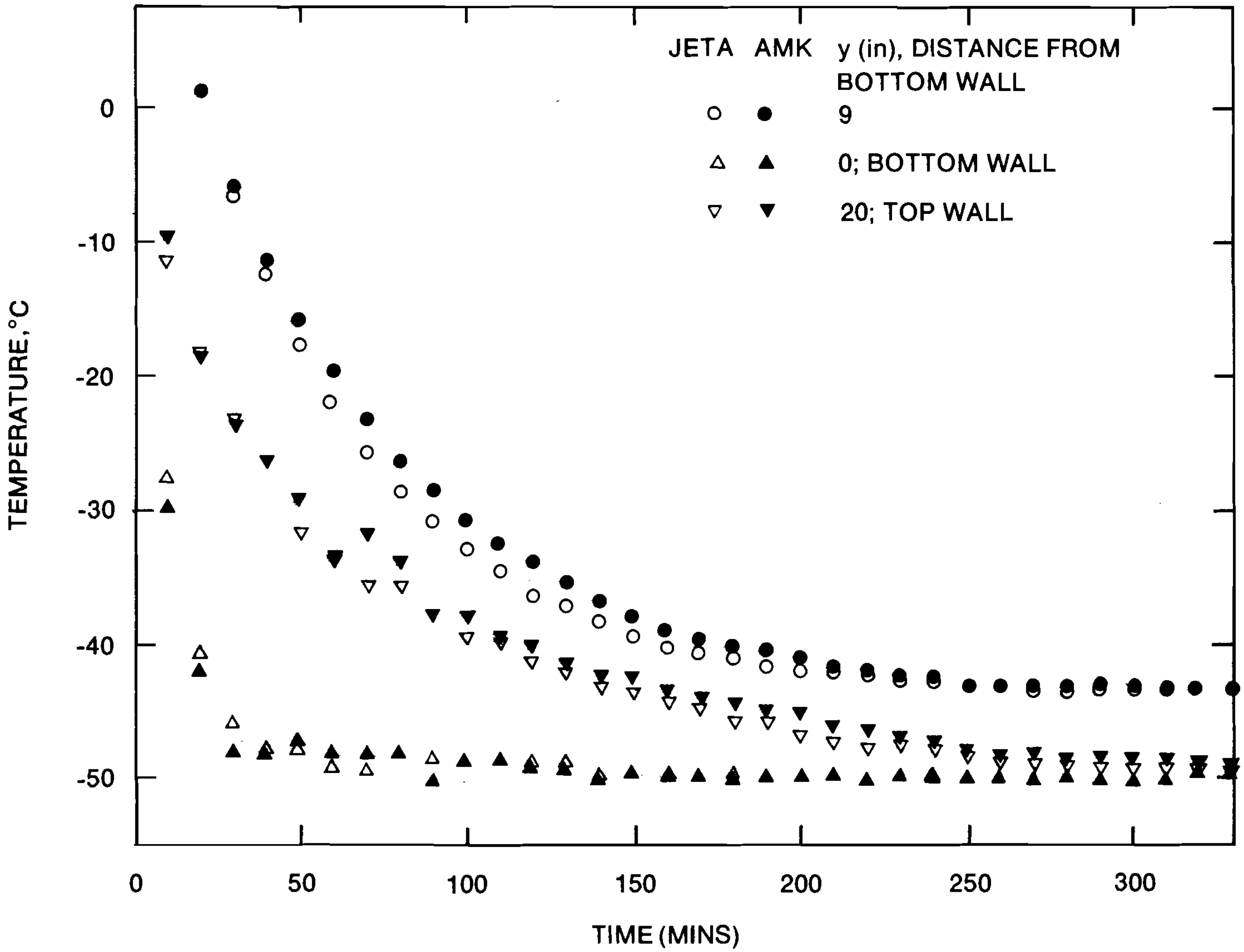

FIGURE 8. TEMPERATURE - TIME HISTORY AT THREE LOCATIONS INSIDE SIMULATOR - COMPARISON OF JET A AND AMK BEHAVIOR FOR A CONTROL TEMPERATURE OF -50°C

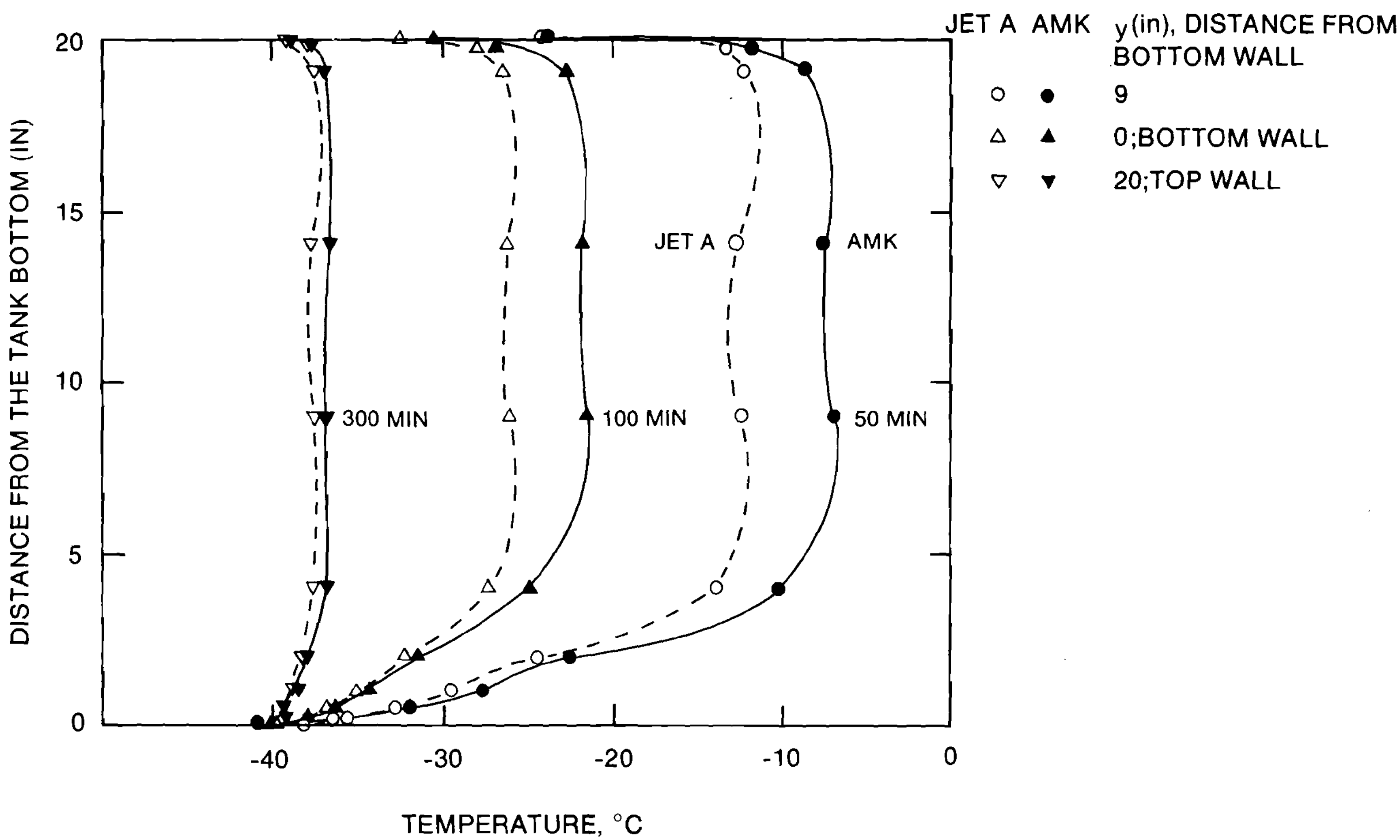

FIGURE 9. EVOLUTION OF TEMPERATURE PROFILES - COMPARISON OF JET A AND AMK BEHAVIOR FOR A CONTROL TEMPERATURE OF -40°C

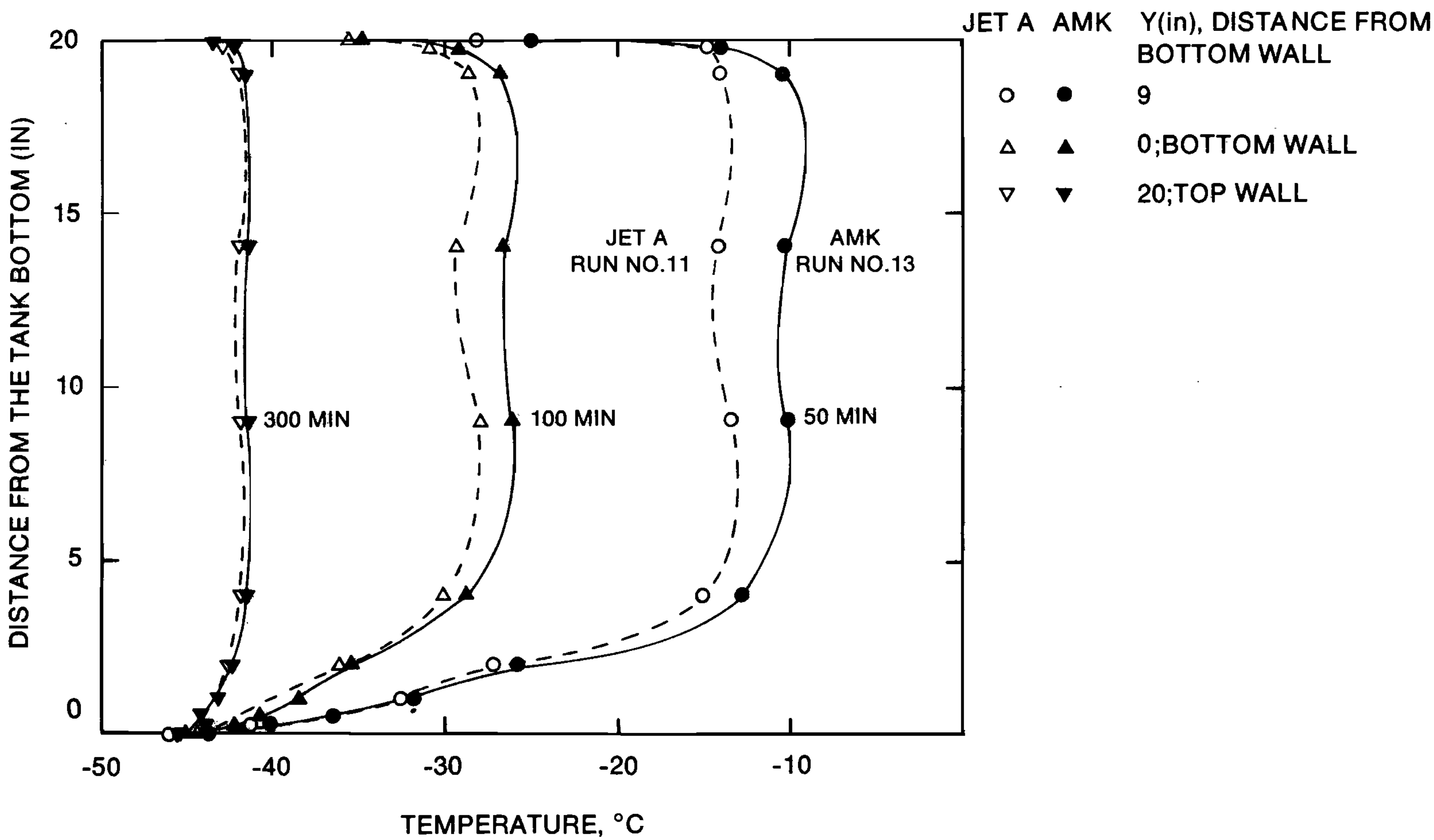

FIGURE 10. EVOLUTION OF TEMPERATURE PROFILES - COMPARISON OF JET A AND AMK BEHAVIOR FOR A CONTROL TEMPERATURE OF -45°C

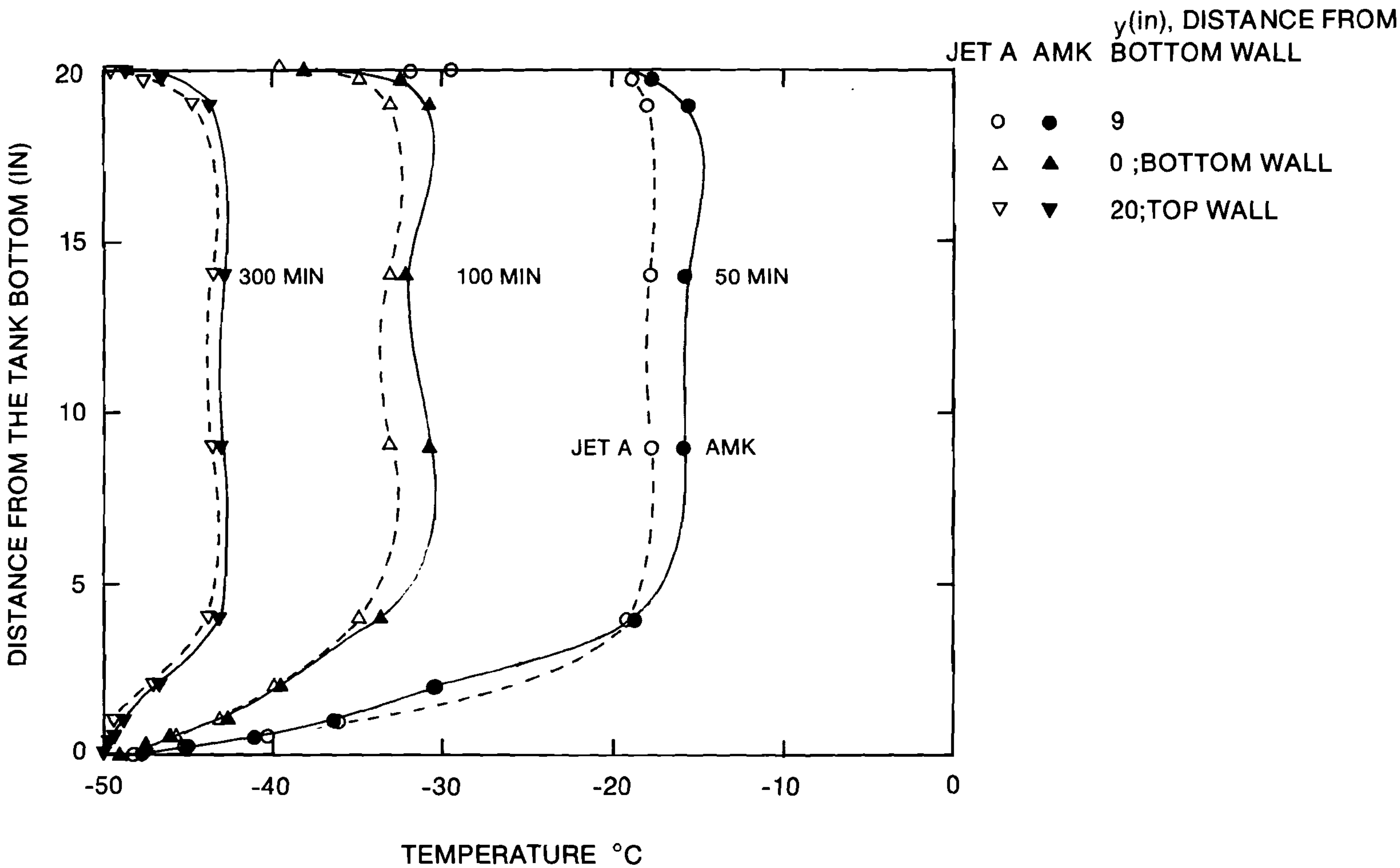

FIGURE 11. EVOLUTION OF TEMPERATURE PROFILES - COMPARISON OF JET A AND AMK BEHAVIOR FOR A CONTROL TEMPERATURE OF -50°C

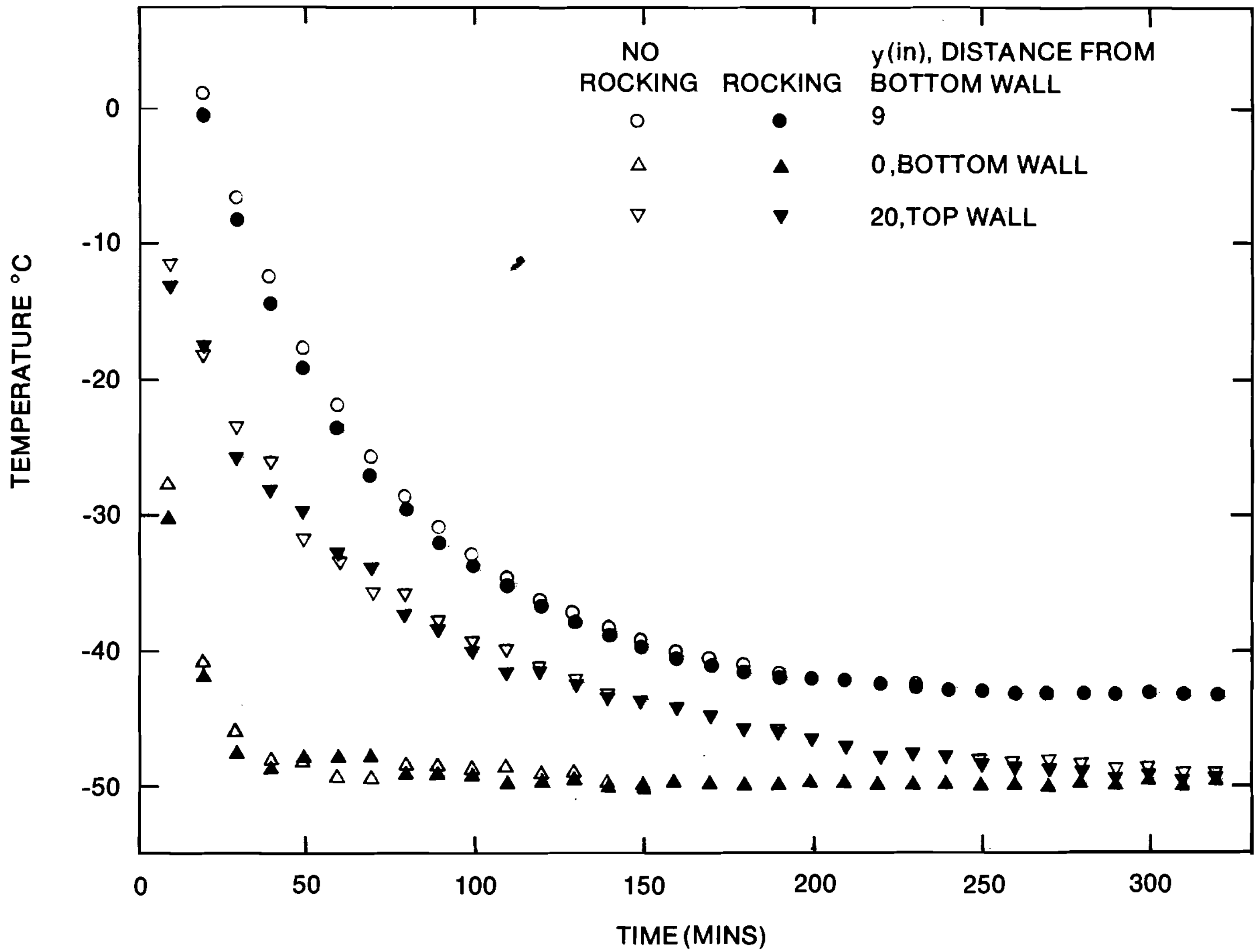

FIGURE 12. TEMPERATURE - TIME HISTORY AT THREE LOCATIONS INSIDE SIMULATOR - COMPARISON OF ROCKING AND NO ROCKING TESTS FOR JET A. CONTROL TEMPERATURE: -50°C

Effect of Rocking

The effect of rocking the wing tank simulator during the cool-down process is shown in figure 12. Temperature - time history at three locations in the simulator are shown for Jet A fuel with a bottom wall control temperature of -50°C. Due to the slightly lower initial bulk temperature of the fuel in the rocking case, the fuel temperature near the tank center appears lower than the corresponding temperature for the no rocking case. However, with increasing time of cool-down these differences become negligibly small, indicating that rocking has little effect on the cool-down process of the bulk fuel in the simulator. This conclusion is valid for a completely full tank with no airspace at the top.

Holdup Results

The holdup results are presented for various runs in tables 2 and 3. The data in table 3 show that the holdup is strongly dependent on the base fuel's freezing pint temperature in relation to the bottom wall control temperature. The differences between holdup measurements for AMK and the base Jet A fuel under identical cooling histories were small, with AMK showing slightly less holdup than the base fuel. This is in agreement with the cooling trends discussed earlier and it results from a slightly lower convective heat transfer coefficient for AMK compared to that for the base fuel. The base fuel freezing point temperature is far more significant in holdup determination at a given bottom wall set point temperature.

TABLE 3. COMPARISON OF HOLDUP FOR DIFFERENT JET A SAMPLES

Run No.	Date	Fuel	Control Temp °C	Freezing Point Temp-(ASTM) °C	Percent Holdup
2	2/2/84	ICI Jet A RMH 30328	-50	-44.5	33
6	2/16/84	ICI Jet A RMH 20922	-50	-	32
8	3/29/84	Burbank/Texaco Jet A	-50	-49.5	2.5

Boost Pump Performance Results

Two sets of boost pump performance test results were acquired. One for the DC-10 boost pump in the low temperature simulation facility and the other for the Airborne Model 1012-17 boost pump for the Cessna 441 aircraft, taken in a smaller facility shown in figure 5.

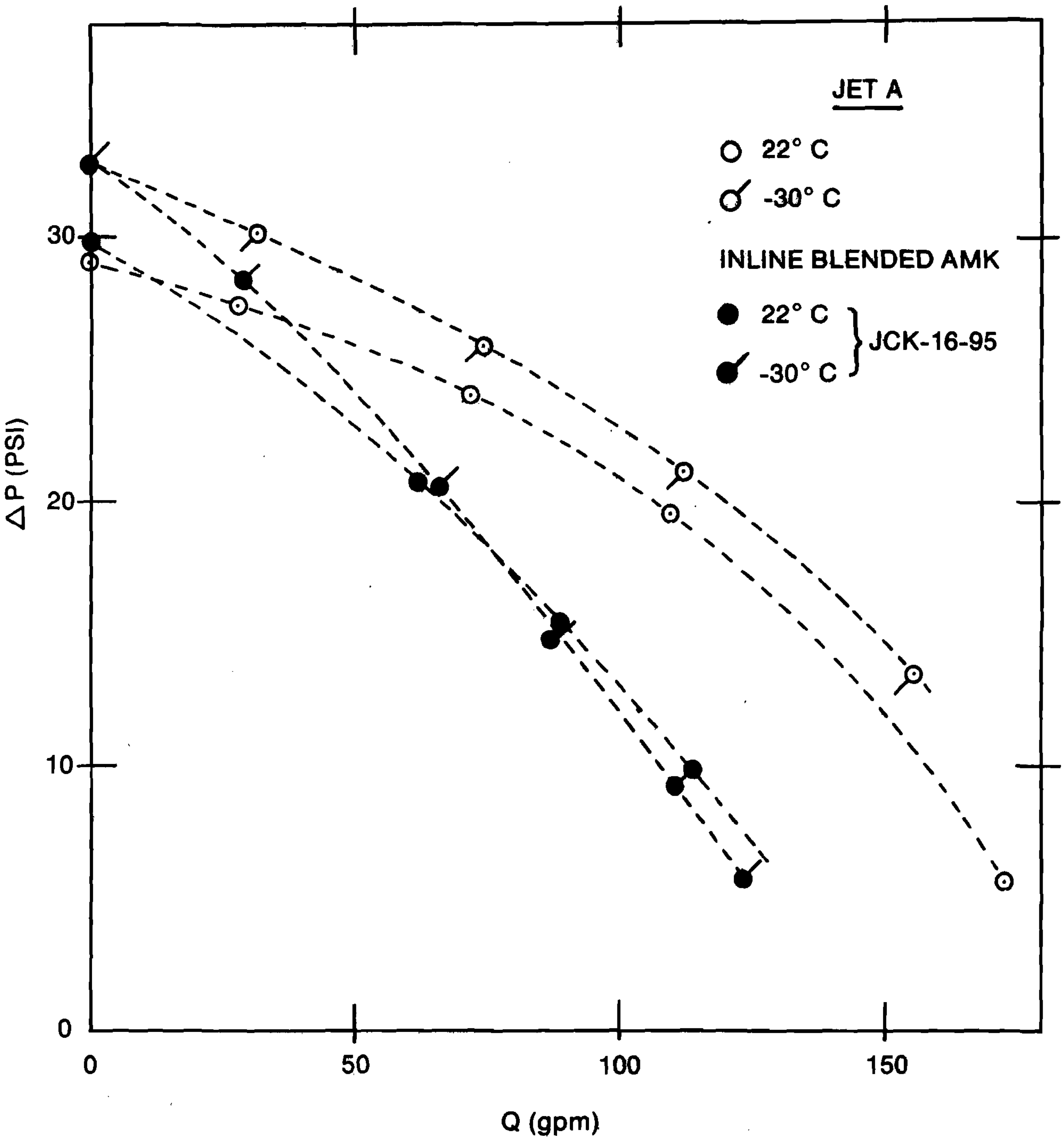

FIGURE 13. DC-10 BOOST PUMP PERFORMANCE: COMPARISON OF JET A AND AMK AT AMBIENT AND LOW TEMPERATURES

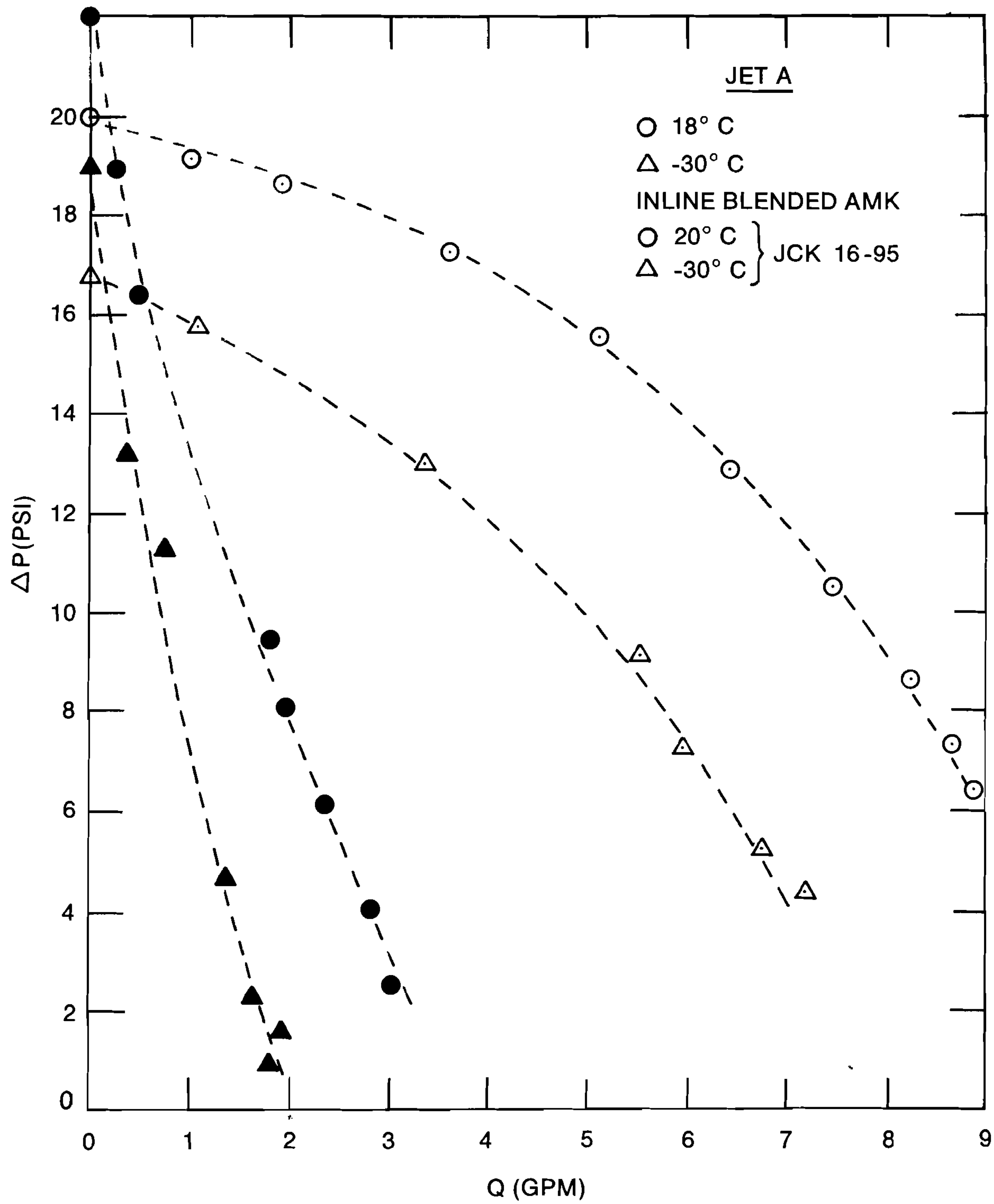

FIGURE 14. CESSNA 441 (AIRBORNE) BOOST PUMP PERFORMANCE: COMPARISON OF JET A AND AMK AMBIENT AND LOW TEMPERATURES

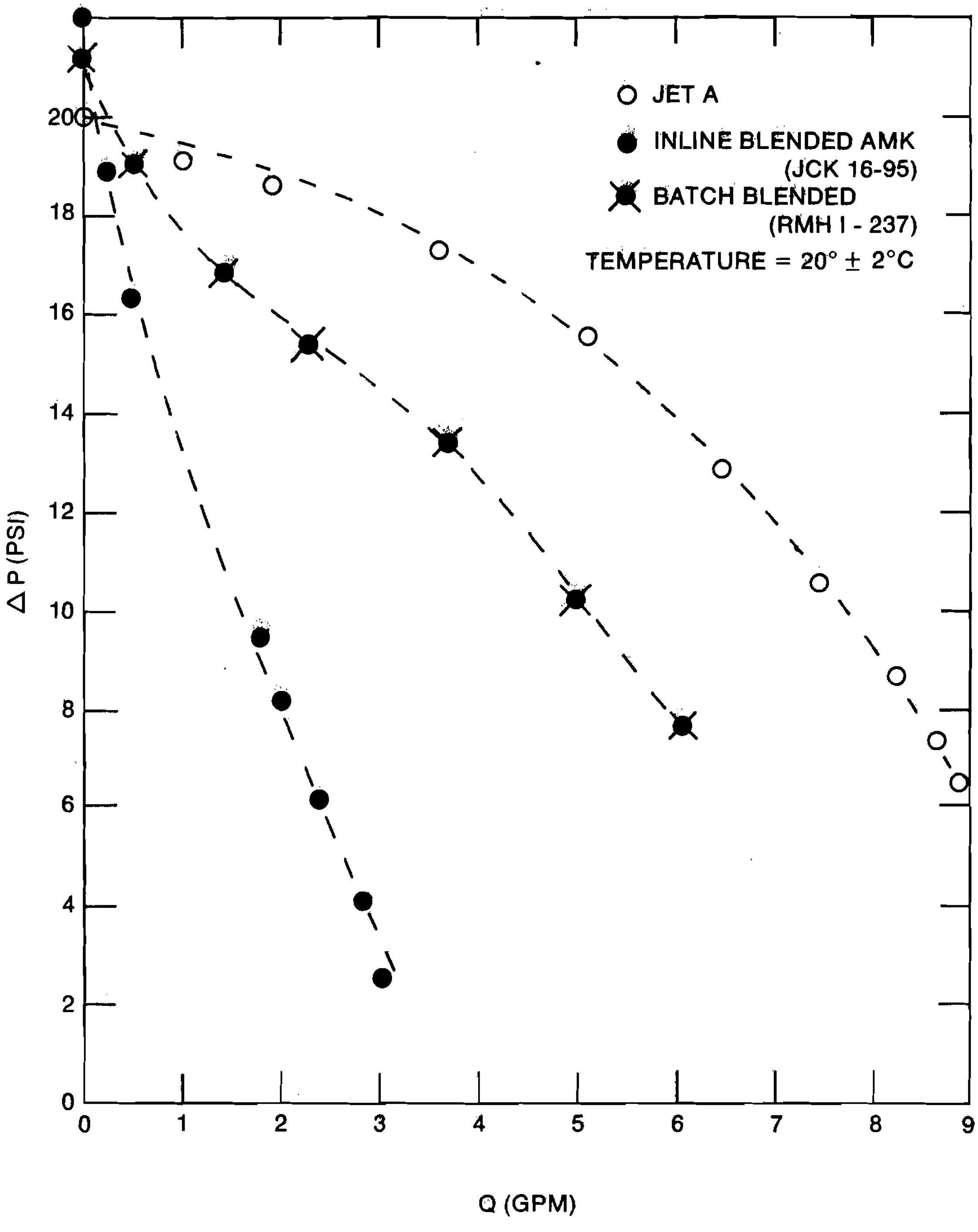

FIGURE 15. COMPARISON OF PUMPABILITY OF TWO AMKs USING CESSNA 441 BOOST PUMP

The DC-10 boost pump performance data are plotted in figure 13. The pump performance is shown for fuel temperatures of 22° and -30°C for inline blended AMK and the base Jet A fuel. The ICI slurry No. JCK 16-95 was used in the JPL 10 gpm inline blender together with Texaco/Burbank Jet A to blend the AMK used for the pumpability tests. At a given fuel temperature, the pump performance deteriorates when switching from the base fuel to AMK. For example, at 22°C, and 20 psi pressure rise, the flow rate decreases from 106 gpm to 66 gpm when switching from Jet A to AMK, i.e., a 38 percent decrease in flow rate. At the lower fuel temperature (-30°C), the Jet A pumping performance improves, both in terms of shutoff (Q = 0) head and the flow rate at lower pressure rise. For low temperature AMK, the shutoff head is higher than that at room temperature. However, the drop in pressure rise with increasing flow rate is sharper compared to room temperature AMK. Therefore, at low temperature and higher flow rates, the pumping pressure drops below its value for the room temperature test.

The Cessna 441 boost pump performance results are shown in figure 14. The AMK used in these tests was again inline blended using ICI slurry No. JCK 16-95 and Texaco/Burbank Jet A. The data show that at a given fuel temperature there is a considerable performance deterioration when switching from Jet A to AMK. For example, at room temperature (18°C) and pressure rise of 10 psi, the volume flow rate is decreased from 7.8 gpm to 1.5 gpm when switching from Jet A to AMK, i.e., an 81 percent decrease. This performance loss is much more significant compared to the loss observed with DC-10 boost pump operation. At low temperature (-30°C), pumping performance deteriorates even further both for AMK and Jet A. This was in contrast to the behavior of DC-10 boost pump, whose performance improved with low temperature Jet A and even with AMK over a lower range of flow rates. Earlier tests with Cessna 441 boost pump using ICI batch blended AMK did not show as dramatic a performance loss as seen with the inline blended AMK using the JCK 16-95 slurry. The data from an earlier ICI batch blended AMK (RMH 1-237) are shown in figure 15 and compared with the inline blended AMK data. Notice that the pumping loss at 10 psi for AMK RMH 1-237 is only about 36 percent as compared to the 81 percent loss for the inline blended AMK. The reason for this is unknown.

A comparison of AMK pumpability data using DC-10 and Cessna boost pumps shows that the performance loss when pumping AMK is strongly dependent on the pump design. The performance loss on the DC-10 boost pump was much less severe compared to that on the Cessna 441 pump.

CONCLUSIONS

1. Under identical externally applied cooling conditions, the rate of cooling of the bulk fuel may be expected to be slightly smaller for AMK than for Jet A. Also, the percentage holdup for AMK would be expected to be slighly smaller than for Jet A.

2. The holdup measurement is much more sensitive to the freezing point of the base fuel than it is to the rheological property differences between a given Jet A and AMK prepared from the same Jet A.

3. The pumpability performance deterioration (or improvement) when switching from Jet A to AMK and from ambient temperature to low temperature fuel is strongly dependent on the pump design. Conclusions drawn from performance tests on one pump may not be valid for a pump of different design.

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2. Parkih, P. G., A. Yavrouian and V. Sarohia: Antimisting Kerosene: Low Temperature Degradation and Blending. FAA Report No. DOT/FAA/CT-86/3.

3. Bernal, L. P. and V. Sarohia: Effect of Non-Newtonian Antimisting Kerosene on Jet Pump Performance. FAA Report No. DOT/FAA/CT-85/30, May 1986.

APPENDIX A

DEC FORTRAN PROGRAM FOR DATA AQUISITION AND EXPERIMENT CONTROL OF LOW TEMPERATURE WING TANK SIMULATOR

```
      INTEGER*2 IBUFF(24)
      REAL*4 TEMP(12),GAIN(12)
      DATA IERR,ICLK,IRATE,IBL,IADC,IPRINT/0,0,1,0,1,0/
C     TDEL IN SECONDS
      DATA NCH,TDEL,C1,C2/12,10.,25.28,-.58/
      DATA TIME/0./
C     READ INPUT GAINS
      READ(3)(GAIN(I),I=1,NCH)
      TYPE 100,(GAIN(I),I=1,NCH)
100   FORMAT(' ADC CHANNEL GAINS (/MV): ',/,(8F10.2))
      TYPE 102
102   FORMAT(//)
C     REQUEST CONTROL TEMPERATURE
      TYPE 104
104   FORMAT('$ENTER DESIRED FUEL TEMP (C): ')
      ACCEPT 105, TREF
105   FORMAT (F12.3)
      TWALL=AMAX1(-45.,(TREF-5.))
      TWALL=TREF
      TYPE 106
106   FORMAT(////)
      TYPE 110
110   FORMAT(T4,'-50',T24,'-40',T44,'-30',T64,'-20')
      DO 10 I=1,NCH
10    TEMP(I)=TREF
      CALL TGRAPH(0,TREF,TEMP,NCH)
C     SET UP ADC - DOUBLE BUFFER & CLOCK OVERFLOW DRIVEN
      REWIND 2
      NPTS=2*NCH
      CALL RTS(IBUFF,NPTS,2,-1,,NCH,,2,IERR,IBEF,IADC)
C     START CLOCK - NO INTERRUPT OVERFLOW
      IDEL=INT(120./TDEL+0.5)
      PRESET=TDEL*100.
      IDLY=0
      CALL SETR(5,9,PRESET,ICLK)
C     WAIT FOR BUFFER EVENT
50    CALL LWAIT(IBEF,2)
      IDLY=IDLY+1
      TIME=TIME+TDEL/60.
C     CONVERT TO TEMPS & WRITE TO DATA FILE
      NO=MOD(IBL,2)*NCH
      IBL=IBL+1
      DO 60 I=1,NCH
      E=(IBUFF(NO+I)-2048)/GAIN(I)
60    TEMP(I)=E*(C1+C2*E)
C     PRINTOUT @ 2 MIN INTERVALS
      IF(MOD(IBL,IDEL).NE.0)GOTO70
      IPRINT=IPRINT+1
      CALL TGRAPH(IPRINT,TREF,TEMP,NCH)
```

```
C       DECISION - TO BYPASS OR NOT TO BYPASS
70      IF(MOD(IBL, 60).NE.0)GOTO72
        TYPE 152,(TEMP(I),I=1,NCH)
152     FORMAT((10F7.1))
72      IF((TEMP(7)-TREF).LT.(2.))TWALL=TREF
        ERR=TEMP(1)-TWALL
        IFF=IDIR(1,"170440,-1,1)
        IFLAG=INT(IFF/4096.+0.5)
        IF(IBEF.LE.0)STOP 'TOO FAST'
        IBEF=IBEF+1
        IF((ERR.LT.2.0).AND.(IFLAG.EQ.1).AND.(IDLY.EQ.1))GOTO74
        IF((ERR.LT.2.0).AND.(IDLY.LT.6))GOTO50
        IF((ERR.GT.2.).AND.(IFLAG.EQ.1))GOTO50
        IF((ERR.LT.0.).AND.(IFLAG.EQ.0))GOTO50
        IF((ERR.LT.2.0).AND.(IFLAG.EQ.0))IDLY=0
74      IFLAG=MOD((IFLAG+1),2)
        IFF=IFLAG*4095
        CALL IDOR(1,"170440,-1,IFF)
        GO TO 50
        END
        SUBROUTINE TGRAPH(IC,TREF,TT,NN)
        REAL*4 TT(1)
        LOGICAL*1 SYM(80),TSYM(12),BLANK,TIC,DOT
        DATA TSYM/'B','2','3','4','5','6','7','8','9',
     *  '0','T','C'/
        DATA BLANK/' '/,TIC/'+'/,DOT/'.'/
        DO 10 I=1,80
10      SYM(I)=BLANK
        I=MIN0(80,MAX0(1,INT(2*TREF+105.5)))
        SYM(I)=DOT
        IF(MOD(IC,15).NE.0)GOTO50
        DO 15 I=1,80,2
15      SYM(I)=DOT
        DO 20 I=5,80,10
20      SYM(I)=TIC
50      CONTINUE
        DO 80 I=1,NN
        ITEMP=INT(2*TT(I)+105.5)
        ITEMP=MIN0(80,MAX0(1,ITEMP))
80      SYM(ITEMP)=TSYM(I)
        SYM(1)=BLANK
        TYPE 200,(SYM(I),I=1,80)
200     FORMAT(80A1)
        RETURN
        END
```

APPENDIX B

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