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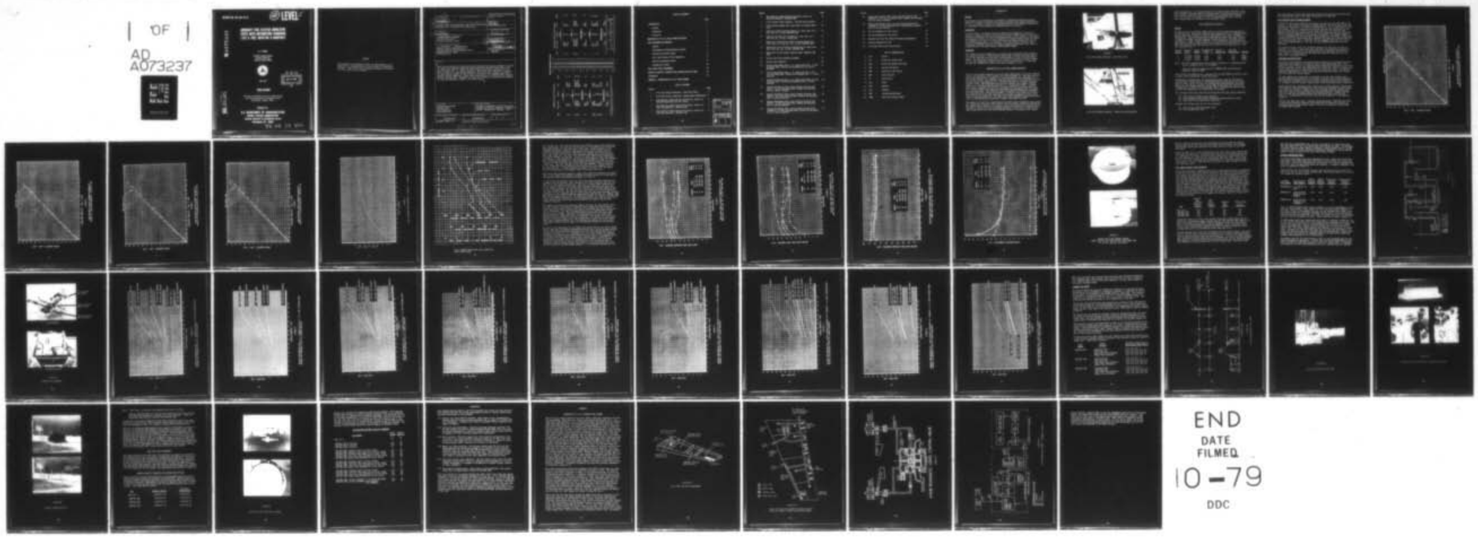

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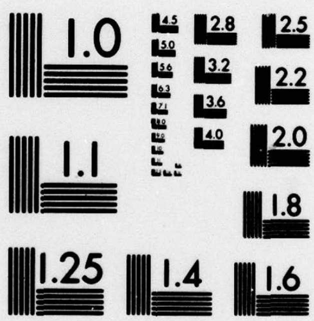
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REPORT NO. FAA-RD-79-52

AIRCRAFT FUEL SYSTEM SIMULATOR TESTS WITH ANTIMISTING KEROSENE (JET A FUEL WITH FM-9 ADDITIVE)

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MAY 1979

FINAL REPORT

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16. Abstract

Tests were conducted on a full-scale C-141 aircraft fuel system simulator to evaluate system and component operation using antimisting kerosene fuels (Jet A fuel with FM-9 additive). A typical aircraft flight profile was simulated with the tank-to-engine fuel feed system operating. Tests were also conducted to evaluate the tank quantity gaging system accuracy, tank refuel valve operation and fuel transfer ejector operation. Fuels tested included Jet A, .30% FM-9 AMK, .35% FM-9 AMK and .40% FM-9 AMK. Flammability tests were conducted on selected fuel samples to evaluate degradation caused by the above tests.

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METRIC CONVERSION FACTORS

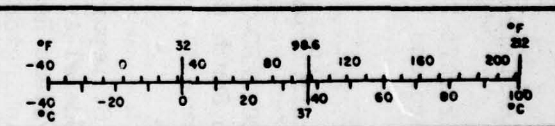
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS

1. LBS. - Pounds
2. PSI - Pounds Per Square Inch
3. PSIG - Pounds Per Square Inch Gage
4. GPM - Gallons Per Minute
5. RPM - Revolutions Per Minute
6. MPH - Miles Per Hour
7. Ml - Milliliters
8. Hrs. - Hours
9. Min. - Minutes
10. Sec. - Seconds
11. AMK - Antimisting Kerosene
12. FLCV - Fuel Level Control Valve

INTRODUCTION

PURPOSE

The purpose of this program was to evaluate a candidate antimisting kerosene (AMK) fuel relative to compatibility with an aircraft fuel system representative of those in commercial use and to determine effects of the aircraft system and/or components on the flammability characteristics of the fuel.

BACKGROUND

In recent years, the Federal Aviation Administration (FAA) has intensified research to reduce fatalities caused by post-crash aircraft fires in otherwise survivable accidents. The most promising approach to this problem at the present time appears to be the use of fuel additives or modifiers which reduce the natural tendency of the fuel to form an explosive mist when released into the air during the dynamic phase of an accident. One such additive currently being investigated is FM-9, developed by Imperial Chemical Industrial, Ltd. (ICI) in conjunction with the Royal Aircraft Establishment (RAE).

OBJECTIVE

The objective of this program was to conduct tests utilizing a C-141 aircraft fuel system simulator to define system operational problems resulting from the use of FM-9 modified fuel with FM-9 concentrations of 0.30, 0.35 and 0.40% by weight. An additional objective was to determine the effects of system operation on the flammability characteristics of the modified fuels by conducting air gun type flammability tests on one-gallon samples of fuel.

DESCRIPTION OF C-141 FUEL SYSTEM SIMULATOR

The C-141 fuel system simulator is a full-scale duplication of the left wing and center wing sections of the aircraft fuel system (Figure 1). The tanks were designed and constructed to simulate the inside dimensions and configuration of the aircraft tanks. The simulator wing was fabricated in four sections with the inboard section comprising the No. 2 inboard main and No. 2 inboard auxiliary aircraft tanks. The remaining three sections comprise the aircraft extended range, No. 1 outboard auxiliary and the No. 1 outboard main tanks. Aircraft plumbing and components are utilized throughout the fuel system including the No. 2 engine mounted fuel pump and interconnecting plumbing between the engine pump and wing tanks. The simulator tanks and internal plumbing and components were fabricated and utilized for Category I testing of the C-141A fuel system. The simulator has since been modified to the C-141B configuration which added aerial refueling capability. The tanks are rigidly mounted on supporting stands with the wing deflection simulating a normal 1.0g flight attitude.

The engine fuel feed line, engine-driven pump and related components were mounted on a supporting structural frame similar to the aircraft installation (Figure 2). The engine pump is driven by a hydraulic motor and pneumatically operated valves are used in conjunction with programmed pneumatic controllers to establish the engine pump speed, flow rate and discharge pressure in accordance with engine

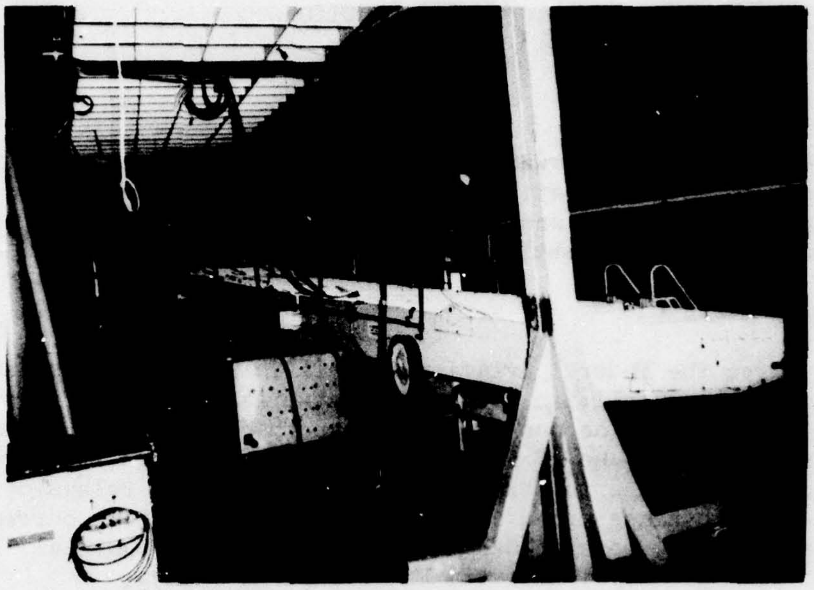
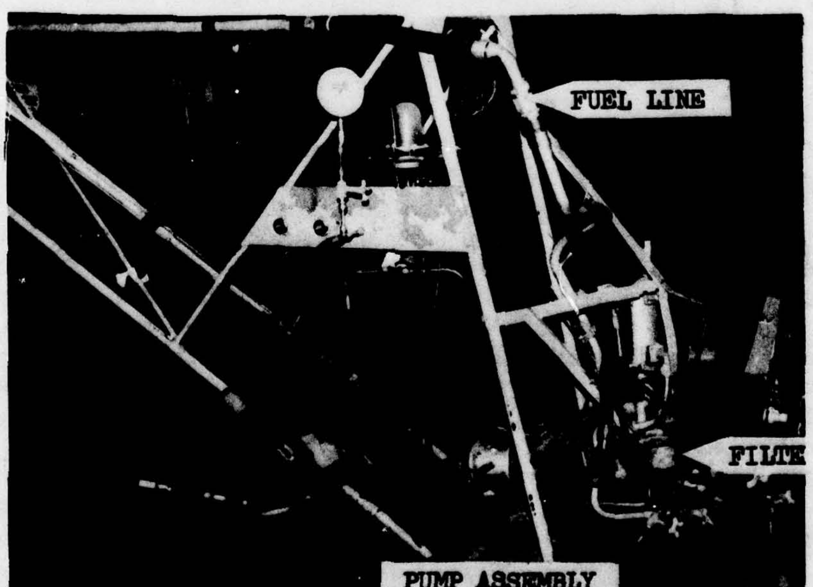


FIGURE 1

C-141 FUEL SYSTEM SIMULATOR - WING FUEL TANKS



C-141 FUEL SYSTEM SIMULATOR - ENGINE PUMP INSTALLATION power requirements. The simulator engine fuel supply system consisted of the tank-to-engine plumbing, engine driven fuel pump, fuel heater and fuel filter. Those aircraft components located downstream of the engine pump discharge (i.e. fuel control, flowmeter, oil cooler, pressurizing and dump valve and fuel nozzles) were not contained in the simulator setup.

TEST PROCEDURE AND RESULTS

GENERAL

The FM-9 antimisting kerosene (AMK) utilized in this program was prepared by ICI Americas Inc., Wilmington, Delaware and transported to the Lockheed-Georgia Company, Marietta, Georgia by Chemical Leaman Tank Lines, Inc., Dowington, Pennsylvania. Three concentrations of FM-9 AMK were tested and were received in separate shipments of approximately 3000 gallons each. The three concentrations were .30%, .35% and .40% FM-9. The concentration is defined as the percentage by weight of FM-9 powder in the total mixture of FM-9 and Jet A fuel. Data certifying the FM-9 AMK mixtures were provided by ICI Americas Inc., and are tabulated below.

Shipment Number	Shipment Date	Weight (LBS.)	Concentration (%)	Solids Content (%)	Flow Cup (Ml/30 sec.)	Clarity
1	11-18-78	20,600	0.30	.31	3.0	Clear
2	12-16-78	19,590	0.35	.311*	2.6	Clear
3	1-19-79	19,210	0.40	.31 *	3.0	Clear

Note: *All FM-9 concentrations above 0.30% are diluted to a 0.30% equivalent prior to analysis per U. K. procedure.

Base fuel used was commercial Jet A (ASTM-D-1655 specification), aromatic content 16-20%.

Additionally, ICI Americas Inc. indicated that the FM-9 AMK was produced using a carrier fluid consisting of Amine and Glycol.

The AMK was off-loaded from the transporting trailer into two 1800 gallon storage tanks. These tanks were interconnected by a manifold at the bottom and by a vent line at the top. The storage tanks were evacuated to approximately 2-3 psi negative pressure and the AMK off-load from the trailer was accomplished by suction from the storage tanks. No pumps were used in order to avoid any degradation of the AMK prior to testing.

The following tests were conducted utilizing the C-141 fuel system simulator:

(1) tank quantity gaging system evaluation
(2) tank-to-engine supply system evaluation during simulated flight
(3) tank refuel valve operational evaluation

Separate test setups were used for the following:

(1) ejector (jet pump) performance tests
(2) fuel flammability tests

The above series of tests were conducted initially with neat Jet A fuel and were then repeated with each of the three concentrations of FM-9 AMK.

TANK QUANTITY GAGING SYSTEM ACCURACY

A series of tests were conducted to determine the effects of the FM-9 AMK on the accuracy of the aircraft tank quantity gaging system. The AMK storage tanks were pressurized sufficiently to transfer the modified fuel into a weigh tank on platform scales. The No. 2 inboard main simulator tank was then evacuated and the AMK was transferred by suction from the weigh tank into the simulator tank. Beginning with an empty simulator tank, fuel was transferred from the weigh tank until an indicated quantity of 1000 pounds was obtained. The weighed quantity of fuel transferred was then recorded. This procedure was repeated in 1000 pound increments until the inboard main tank contained the quantity of AMK required for the simulated flight test. A baseline test was conducted with neat Jet A fuel prior to the AMK evaluation. The .30, .35 and .40% FM-9 AMK fuels were then evaluated.

The weighed quantity versus the indicated quantity for each fuel is shown in Figures 3, 4, 5 and 6. These data show that there is no appreciable variation or error trend introduced by the modified fuels as compared to the neat Jet A fuel. Thus, it is concluded that the AMK fuels would be compatible with the capacitance type gaging system.

SIMULATED AIRCRAFT FLIGHT

Following the tank quantity indicating system evaluation, the simulated aircraft flight test was conducted utilizing the fuel in the inboard main tank. The duration of these tests (i.e., simulated flight time) was governed by the quantity of fuel available in this tank (approximately 13,000 lbs). The No. 2 engine fuel supply system was used in conjunction with the inboard main tank. The test was therefore representative of the normal operating condition wherein the inboard main tank feeds the inboard engine.

The tank pressure was controlled in accordance with the climb schedule for a 240,000 pound aircraft from test site ambient to 40,000 feet altitude (Figure 7). The engine fuel pump RPM, fuel flow rate and discharge pressure were controlled in accordance with the aircraft engine normal rated power requirements (Figure 8).

Parameters monitored during the test included vent plenum pressure, inboard main tank pressure, tank fuel temperature, tank boost pump discharge pressure, engine boost pump inlet pressure, engine boost pump discharge pressure, engine gear pump inlet pressure and engine gear pump discharge pressure. Engine pump RPM, fuel flow rate and discharge pressure were established and controlled per Figure 8. Instrumentation data point locations are presented in the Appendix, Figure A-4.

Bourdon tube gages were used to indicate system pressures. Readings were taken at one minute intervals during the first half-hour of operation covering the transient regime between takeoff power at test site altitude and cruise power at 40,000 feet altitude.

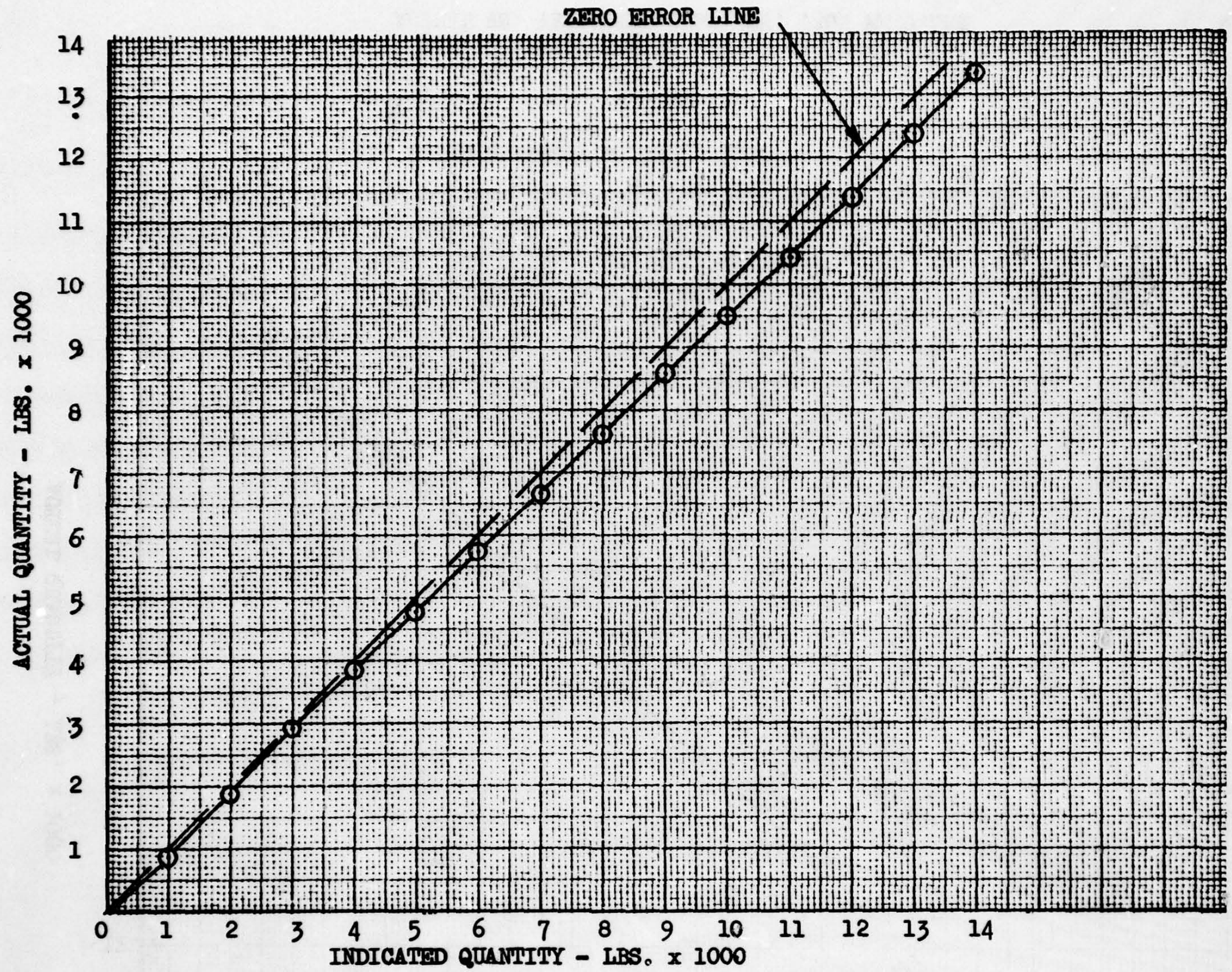


FIGURE 3

TANK QUANTITY GAGING SYSTEM CALIBRATION
ACTUAL VS. INDICATED QUANTITY, NEAT JET A FUEL

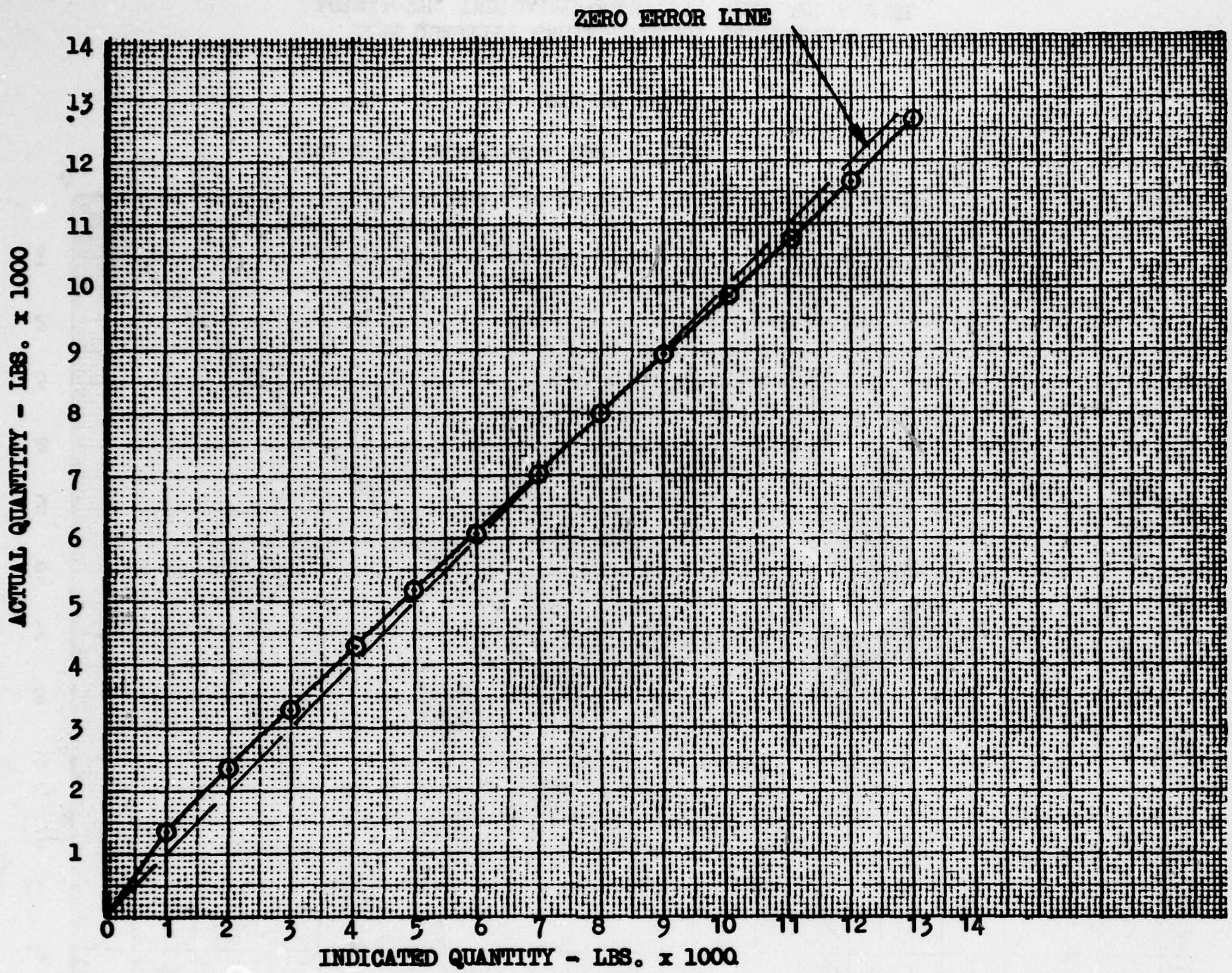


FIGURE 4

TANK QUANTITY GAGING SYSTEM CALIBRATION
ACTUAL VS. INDICATED QUANTITY, .30% FM-9 AMK

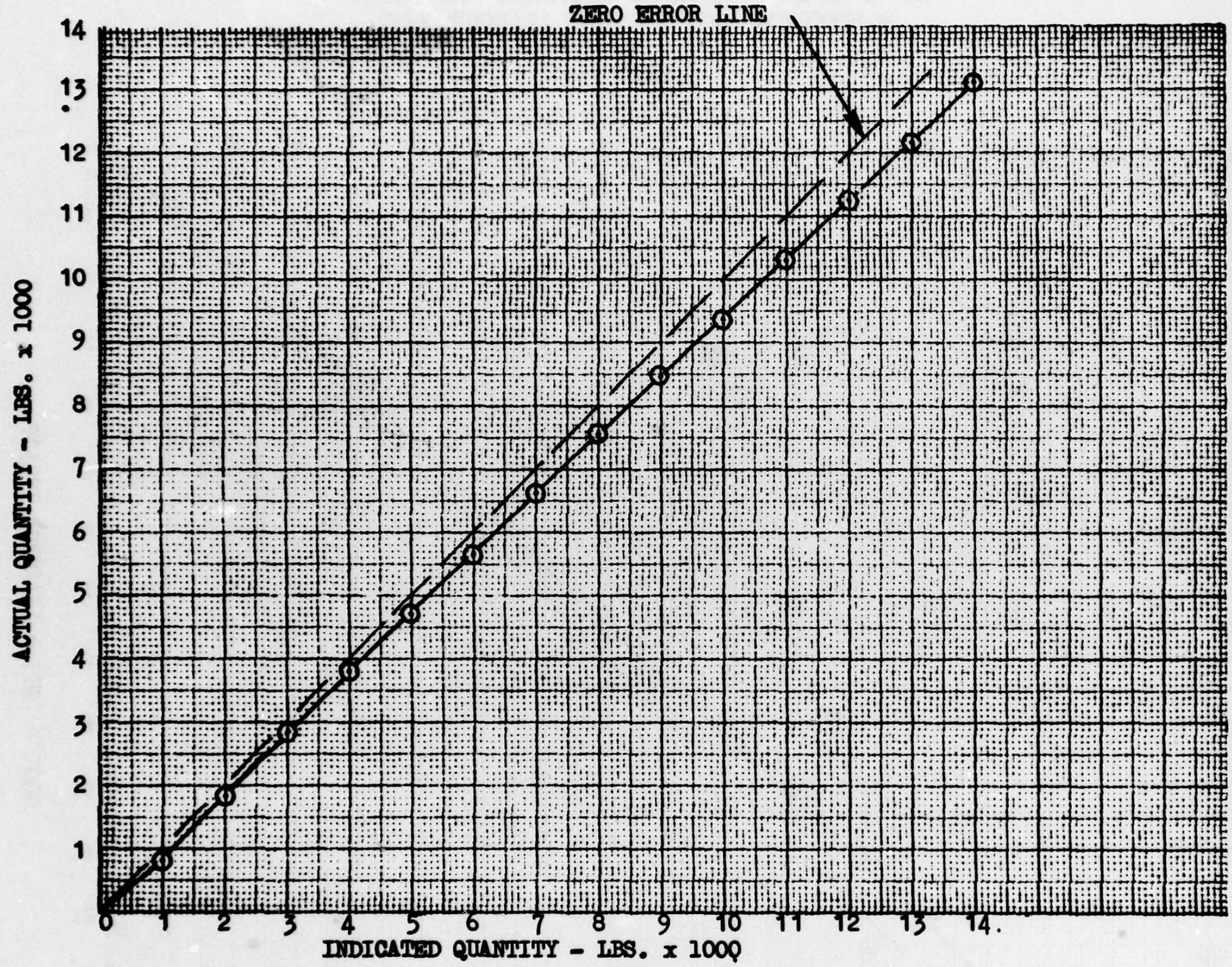


FIGURE 5

TANK QUANTITY GAGING SYSTEM CALIBRATION
ACTUAL VS. INDICATED QUANTITY, .35% FM-9 AMK

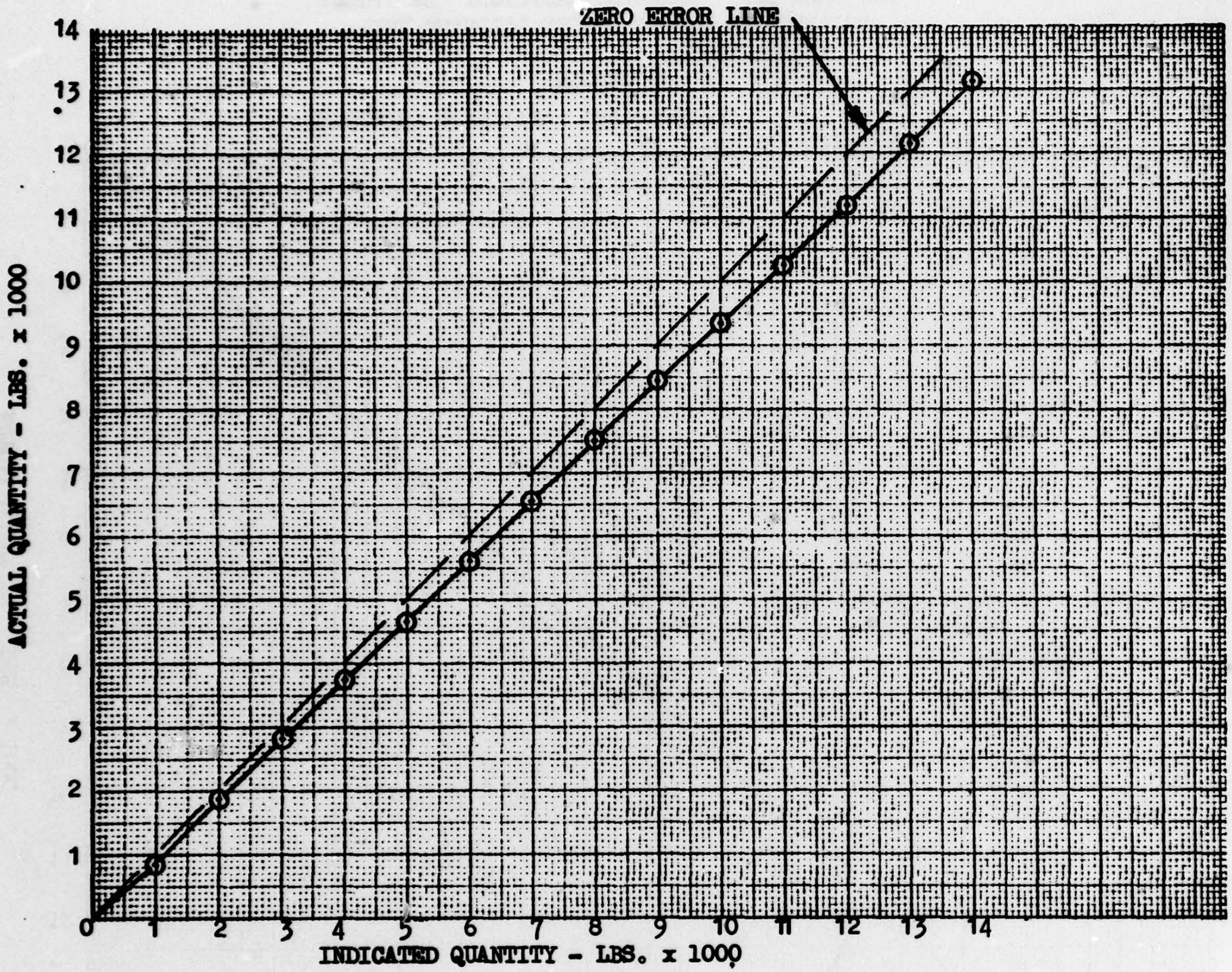


FIGURE 6

TANK QUANTITY GAGING SYSTEM CALIBRATION
ACTUAL VS. INDICATED QUANTITY, .40% FM-9 AMK

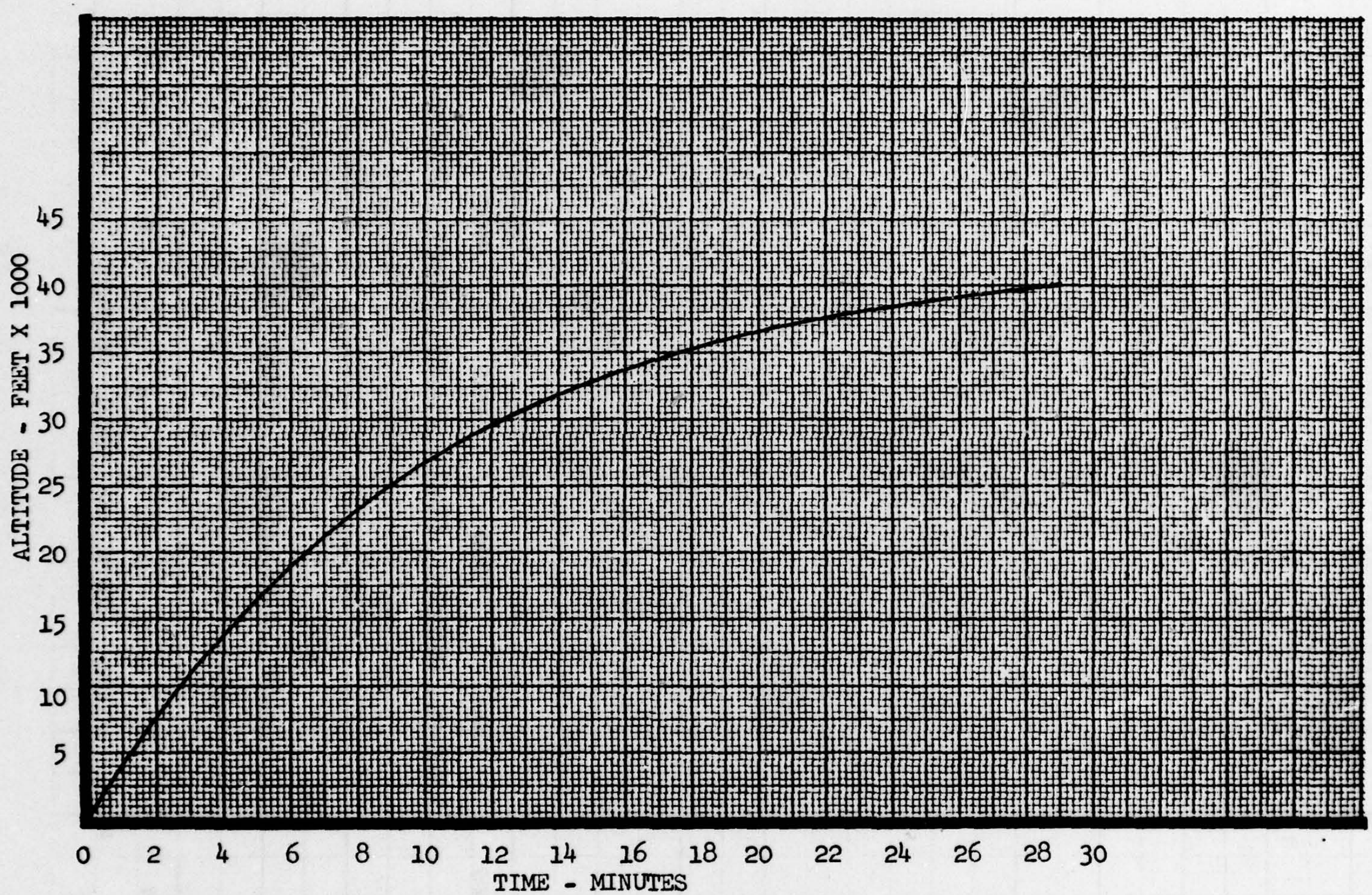
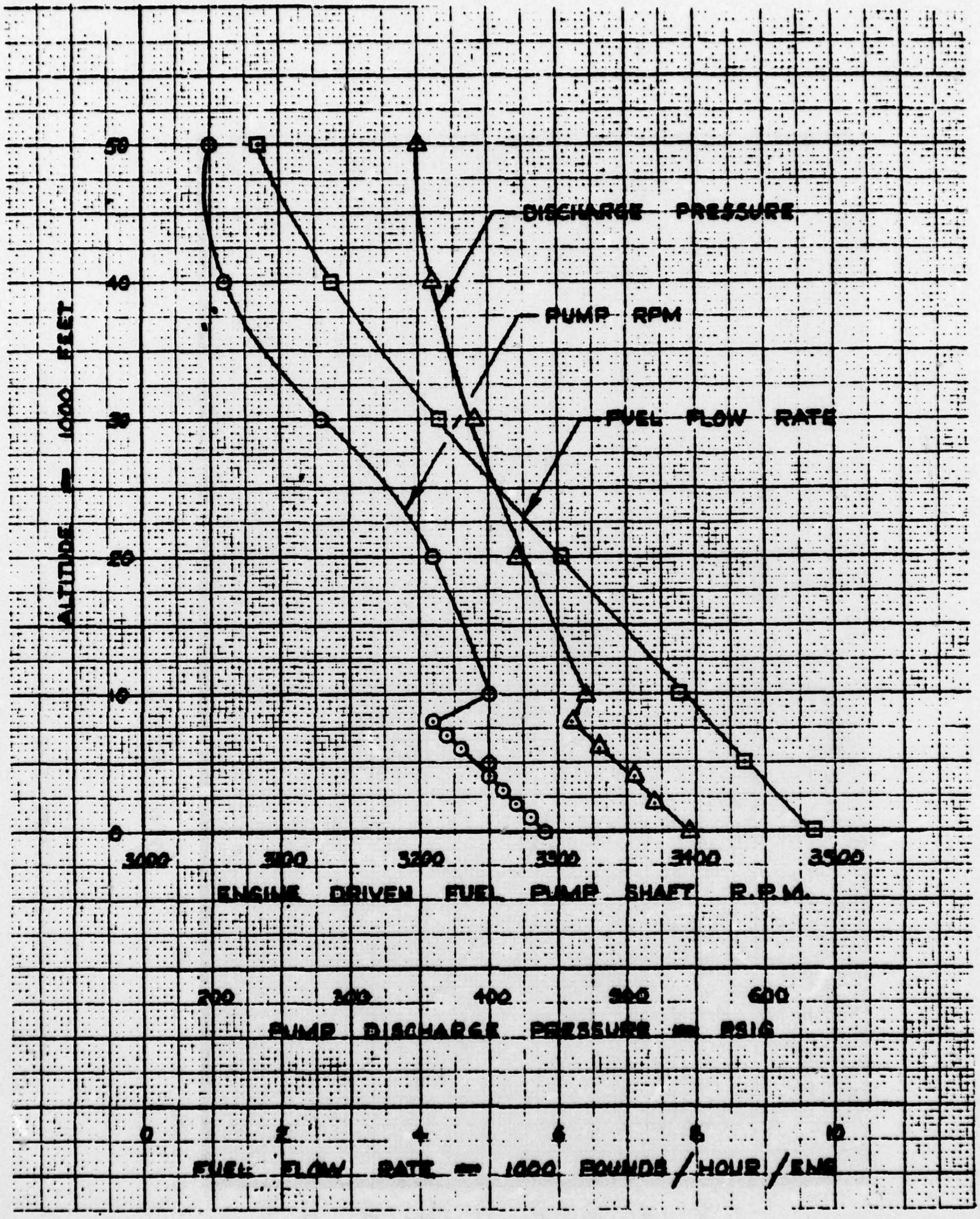


FIGURE 7

C-141 AIRCRAFT CLIMB SCHEDULE - 240,000 LB. AIRCRAFT



C-141 AIRCRAFT ENGINE FUEL PUMP OUTPUT FOR NORMAL RATED POWER

The outboard tank boost pump was turned on and takeoff engine power conditions were established. The test was then initiated by simultaneously actuating the programmed pneumatic controllers and a test timer. After one-half hour of operation and having attained a tank pressure altitude of 40,000 feet and stabilized engine cruise power conditions, fuel samples were taken from the tank, tank surge box, tank boost pump discharge and engine pump discharge for subsequent flammability testing. In order to obtain the tank and tank surge box samples, it was necessary to restore the tank pressure to test site ambient. After obtaining the sample, the tank pressure equivalent to 40,000 feet altitude was re-established and the cruise condition was maintained for one additional hour. The fuel sampling routine was then repeated. System operation at the 40,000 feet cruise condition was continued with fuel samples taken at one hour intervals. A normal descent was made at the end of the test prior to fuel depletion with fuel samples taken at the end of the run.

Tank boost pump discharge pressure, engine boost pump inlet pressure and engine boost (first stage) pump discharge pressure recorded for neat Jet A and each of the modified fuels are presented in Figures 9, 10 and 11.

It can be seen from Figure 9 that the tank boost pump discharge pressures with the AMK fuels are generally lower throughout the flight envelope than with the neat Jet A, and become progressively lower with increased FM-9 concentration. At the takeoff condition, tank boost pump discharge pressure reductions were in the order of 7% with the .30% FM-9 AMK; 16% with the .35% FM-9 AMK; and 25% with the .40% FM-9 AMK. The differential between neat Jet A and the AMK fuels increased with altitude such that at 40,000 feet the tank pump discharge pressure reduction with the .30% FM-9 AMK was approximately 24%, and for the .35% and .40% FM-9 AMK was approximately 33%. The variation between the .35% and .40% FM-9 AMK fuels unexpectedly diminished with increasing altitude, such that the pump discharge pressures for these fuels were essentially the same at 40,000 feet (Figures 9 and 10).

The engine boost pump inlet pressures (Figure 10) show the same general trend as above; however, the effects of pressure drop through the tank-to-engine plumbing and the positive static fuel head at the engine pump inlet are reflected in these data. The tank-to-engine plumbing run is approximately thirty feet of 1½ inch tubing. The head differential between the tank boost pump discharge and the engine pump inlet is approximately five feet (additional static head due to tank fuel level not included). The engine boost pump inlet pressure variation between Jet A and the AMK fuels is also seen at the engine boost pump discharge (Figure 11). The pressure rise across the engine boost centrifugal element does not appear to be adversely affected by the modified fuels.

As noted in the description of the engine fuel system filter, the filter bypass valve opens when the pressure differential across the 10 micron element exceeds 12 psi. The filter pressure differential for Jet A and the modified fuels is presented in Figure 12. It is apparent that the filter element was bypassed throughout the takeoff-cruise flow regime with all three of the modified fuels. It is noted that new filter elements were installed prior to each AMK test. Examination of the AMK test filter elements after removal from the system showed no accumulation of gel or foreign matter on the filtering media to indicate element blockage (Figure 13); however, some thickened gel was found on the top end of the metal media retainer. It is therefore assumed that the

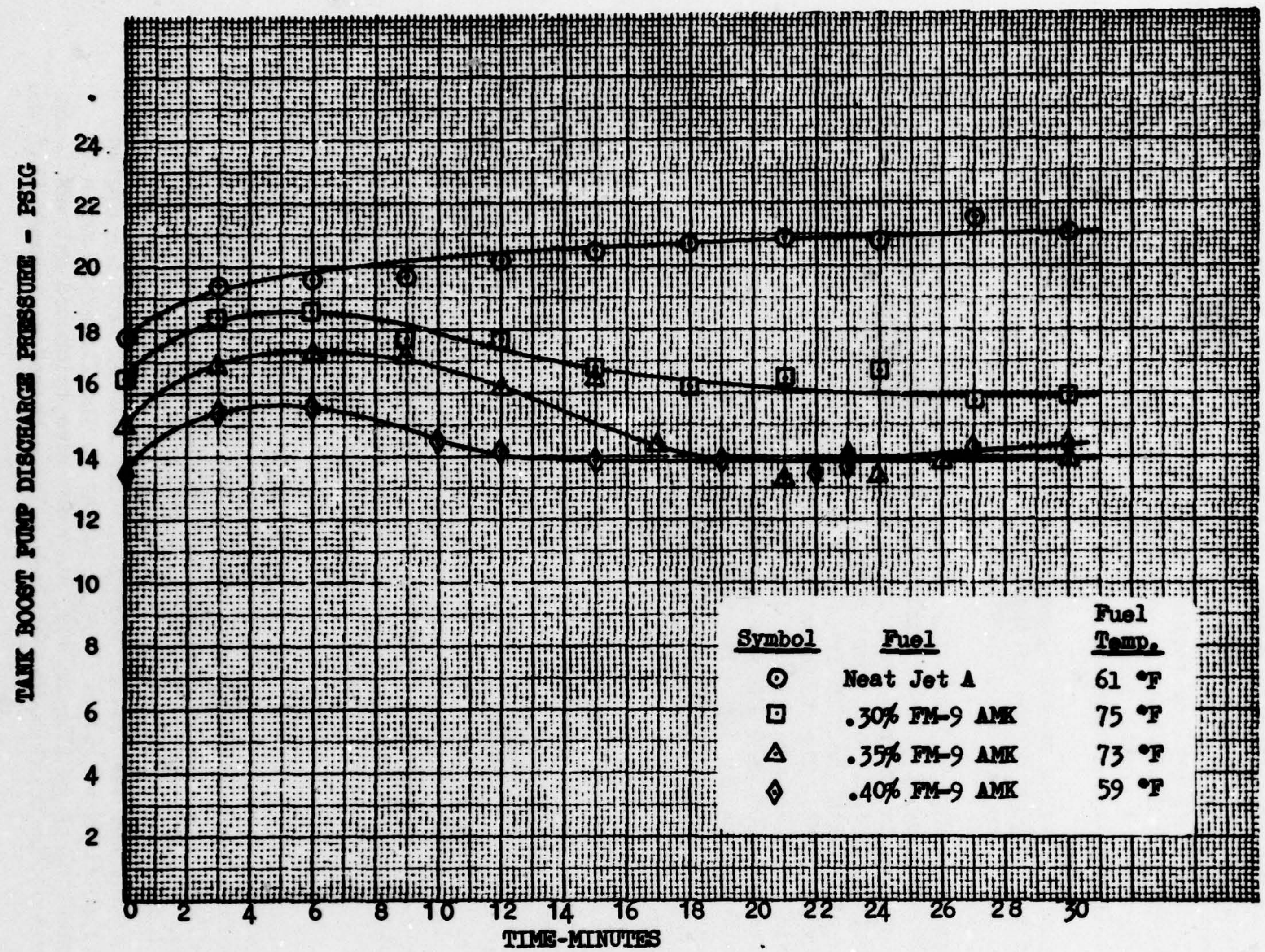


FIGURE 9

TANK BOOST PUMP DISCHARGE PRESSURE VS. TIME
NEAT JET A FUEL AND .30, .35 AND .40% FM-9 AMK

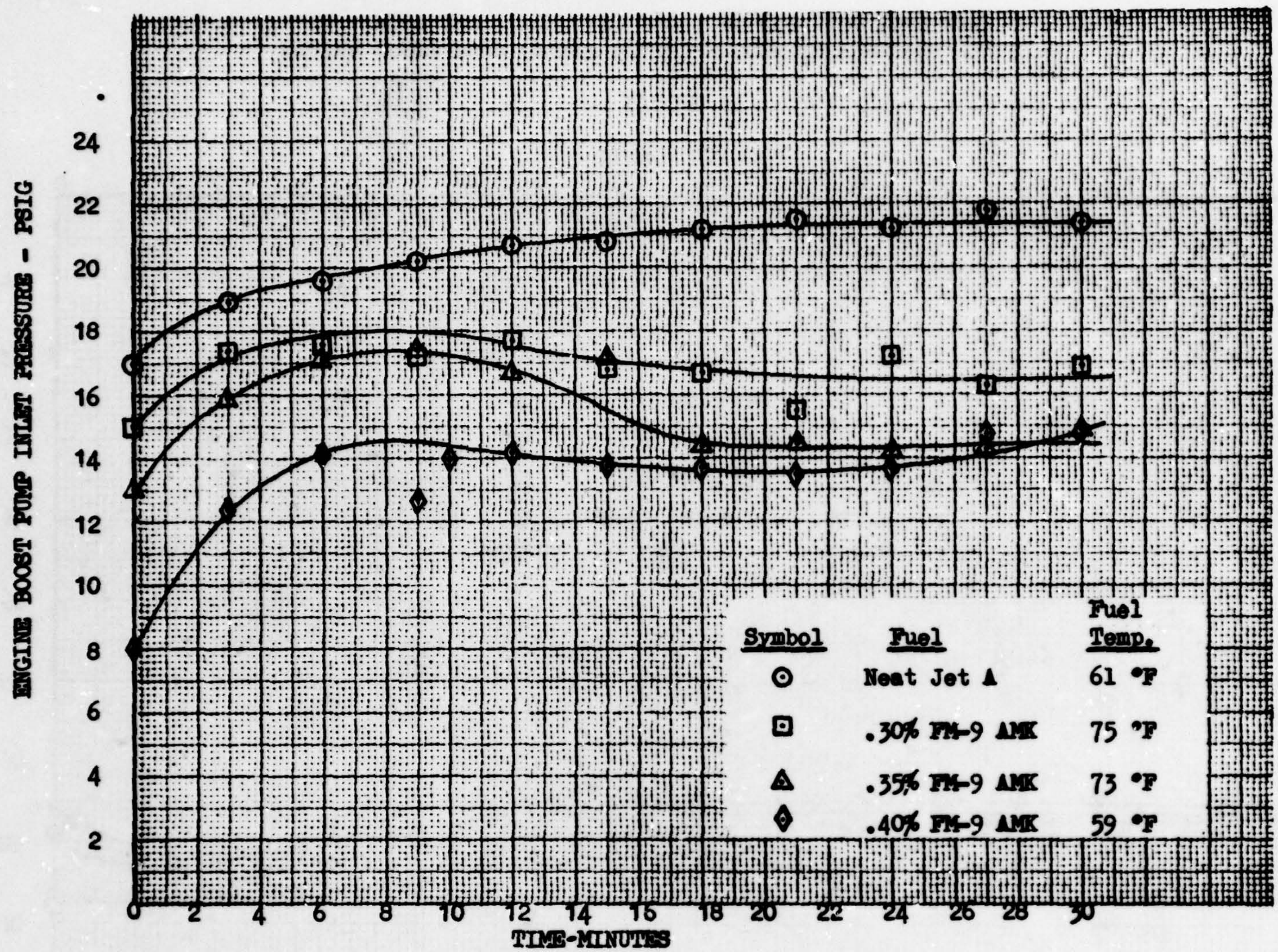


FIGURE 10

ENGINE BOOST PUMP INLET PRESSURE VS. TIME
NEAT JET A FUEL AND .30, .35 AND .40% FM-9 AMK

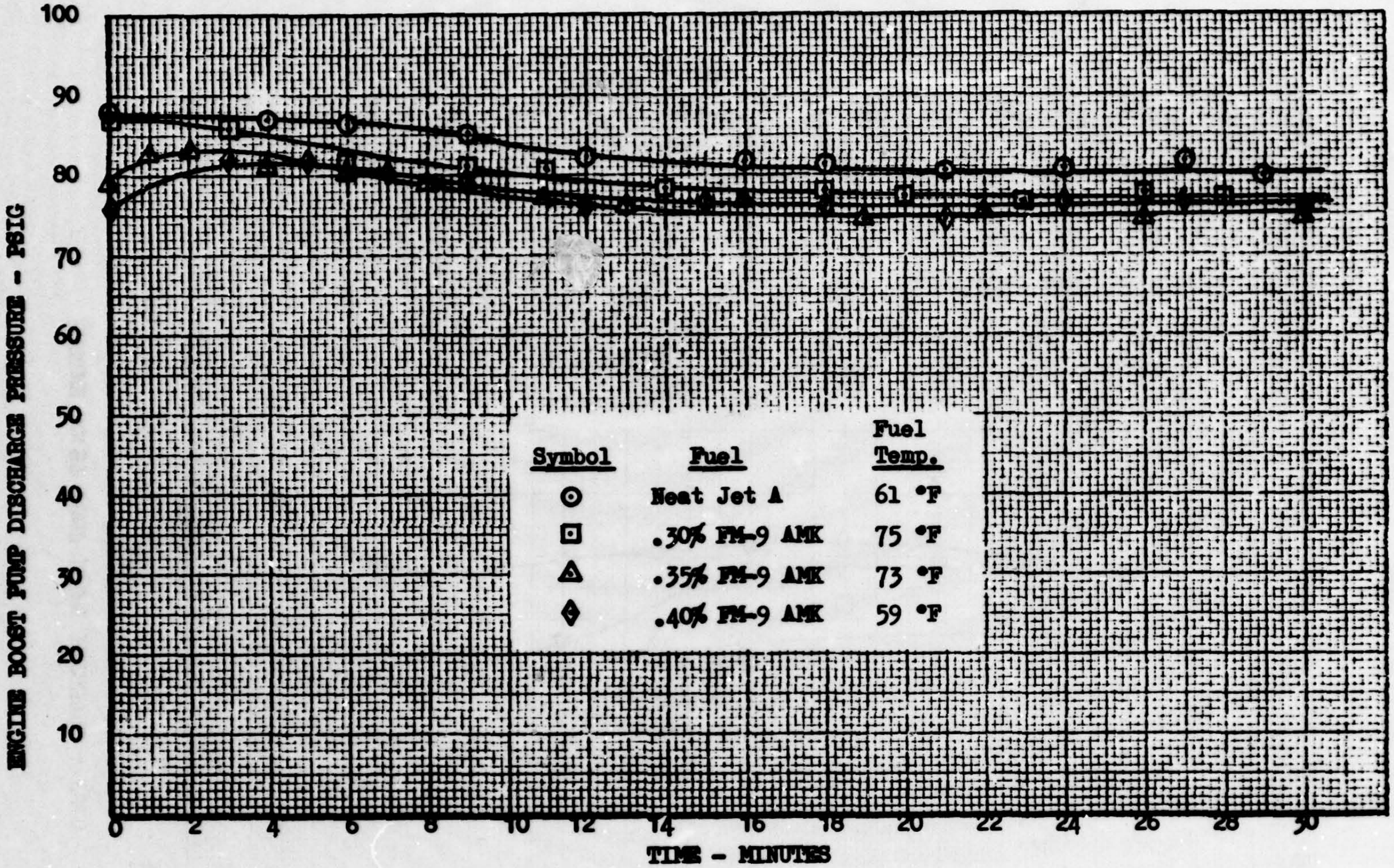


FIGURE 11

ENGINE BOOST PUMP (FIRST STAGE) DISCHARGE PRESSURE VS. TIME
NEAT JET A FUEL AND .30, .35 AND .40% FM-9 AMK

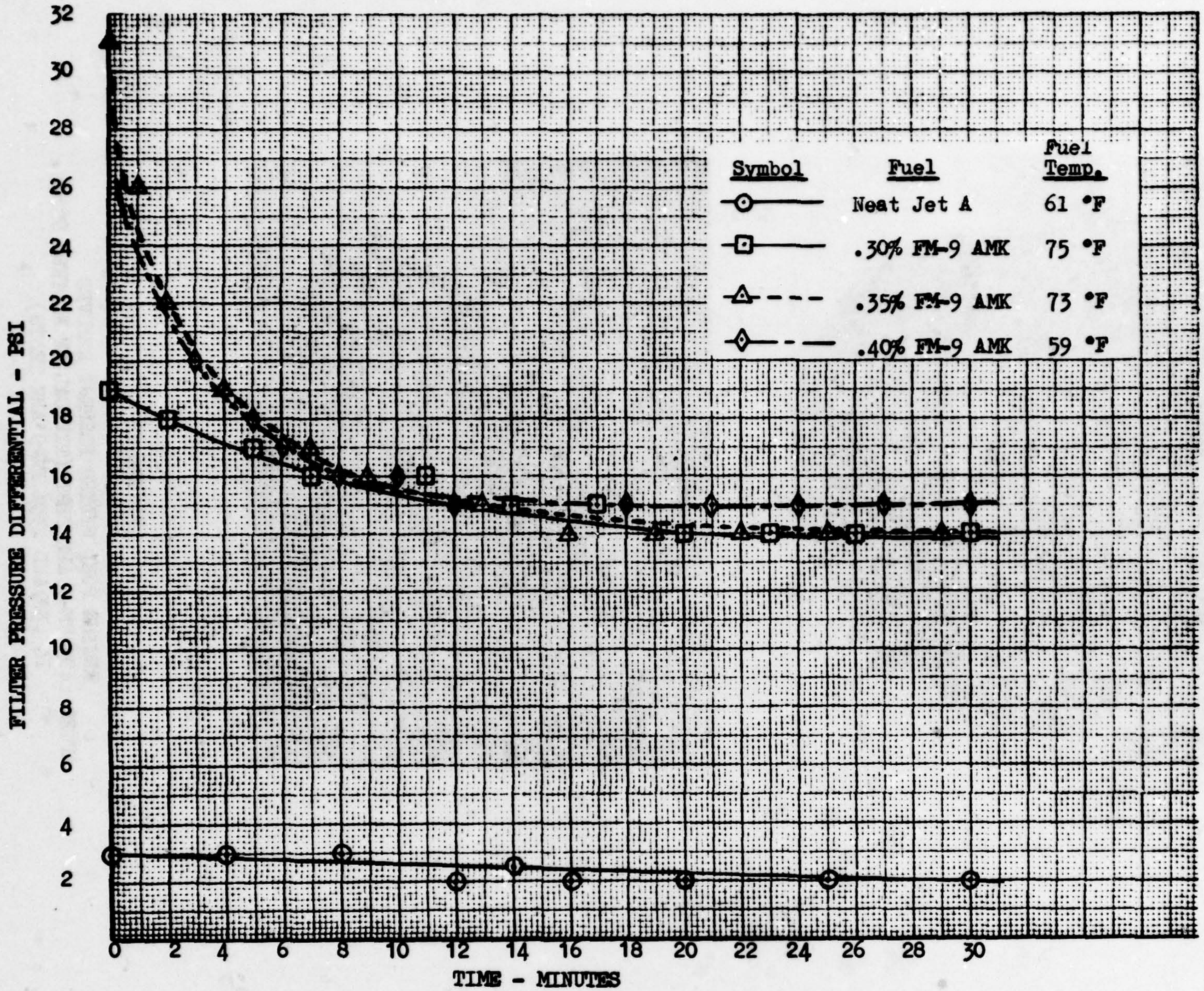


FIGURE 12

ENGINE FUEL FILTER PRESSURE DIFFERENTIAL VS. TIME
NEAT JET A FUEL AND .30, .35 AND .40% FM-9 AMK

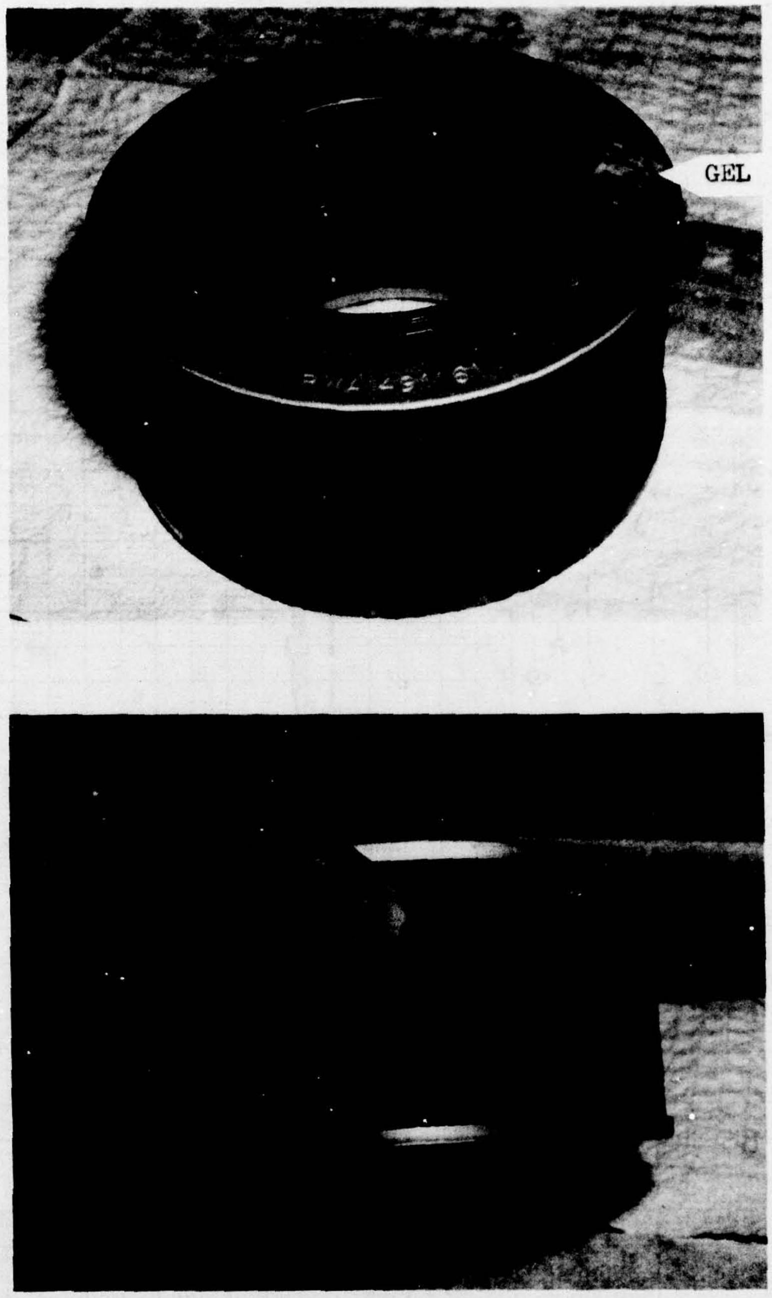


FIGURE 13

ENGINE FUEL FILTER ELEMENT REMOVED
AFTER .40% FM-9 AMK TEST (TYPICAL OF FILTERS USED
IN .30 AND .35% FM-9 AMK TESTS)

AMK fuel passing through the filter housing was flowing through the spring-loaded bypass valve, since the required engine flow and engine pump discharge pressure were maintained throughout the flight profile for each of the modified fuels.

During the AMK tests, visual observations of the fuel level in the inboard main tank surge box were made. Indications were that the fuel transfer ejector was not transferring fuel from the tank into the surge box at a sufficient rate to cause an increase in surge box fuel level above tank fuel level. In the case of neat Jet A fuel, the surge box was maintained full during the cruise condition; however, with all three AMK fuels the surge box level decreased directly with tank fuel level.

FUEL LEVEL CONTROL VALVE OPERATION

Tests were conducted to determine the effects of FM-9 modified fuels on operation of the C-141 tank fuel level control valve, and the effect of valve operation on the flammability characteristics of the fuels. The inboard main C-141 fuel system simulator tank was evacuated such that fuel could be transferred by suction from the AMK storage tanks into the simulator tank without degrading the fuel. The fuel was then transferred into the inboard auxiliary tank through the auxiliary tank fuel level control valve (FLCV) using the main tank boost pump. During the transfer operation, the FLCV was cycled from the open to closed position several times to check operation and closing time. The transfer rate was determined by recording incremental tank quantity gage readings versus time. The transfer pump discharge pressure and FLCV inlet pressure were recorded. Fuel samples were also taken at the FLCV inlet and from the auxiliary tank fuel which had passed through the valve for flammability testing. Results of these tests are tabulated below.

Fuel	Transfer Pump Discharge Pressure (PSIG)	FLCV Inlet Pressure (PSIG)	Transfer Rate (GPM)	FLCV Closing Time (Seconds)
Neat Jet A	11.0	3.4	54.	10.
.30% FM-9 AMK	10.7	2.0	42.	57.
.35% FM-9 AMK	11.4	2.3	36.	70.
.40% FM-9 AMK	11.2	2.0	36.	136.

Operational tests of the fuel level control valve while transferring fuel resulted in a considerably longer closing time with the modified fuels than Jet A. This is attributed to the small orifices through which the fuel must pass in order to fill and pressurize the actuator chambers. After the initial valve closure (times shown above), repeated actuations resulted in generally faster closing rates but still considerably slower than neat Jet A.

Reduced transfer rates were also encountered with the modified fuels. One objective of this test was to evaluate the effects of this valve on AMK degradation, such as during a normal ground refueling operation. It should be noted, however, that the main tank boost pump used for the transfer test did not provide adequate flow capacity to simulate normal ground refueling rates (in most cases above 50 GPM, depending on refueling pressure and tank combinations). During the .40%

FM-9 AMK fuel transfer/FLCV test, the fuel collected in the inboard auxiliary tank was pumped back into the inboard main tank through its FLCV. The auxiliary tank pump, having a higher capacity, produced a return transfer rate of 90 GPM. A sample of this fuel was retained for subsequent flammability testing (having passed through two pumps and two fuel level control valves).

EJECTOR PERFORMANCE TESTS

The ejector performance test setup consisted of a fuel supply tank containing a centrifugal boost pump (Hydro-Aire P/N 60-371B) which provided the ejector primary flow, a second tank containing the test ejectors, an ejector discharge fuel collection tank, and associated valves and plumbing. A schematic diagram of this setup is presented in Figure 14.

Three ejectors with nozzle sizes of 0.07, 0.15 and 0.25 inch were tested with neat Jet A and the .30, .35 and .40% FM-9 AMK. Particulars relative to the ejector designs are tabulated below.

Lockheed Part Number	Manufacturer's Part Number	Nozzle Diameter (Inches)	Throat Diameter (Inches)	Suction Port Diameter (Inches)	Discharge Port Diameter (Inches)
4P940021-103	J.C. Carter Co. 60312	0.07	0.23	0.72	0.58
3P90012-101	Allen Aircraft Products, Inc. 816E101	0.15	0.55	1.24	1.24
3P90011-103	Allen Aircraft Products, Inc. 1224E500-1	0.25	1.04	2.37	1.88

The J. C. Carter Company 60312 ejector assembly is a cluster arrangement of five ejectors, each having a nozzle diameter of 0.07 inch and a throat diameter of 0.23 inch. There is one primary flow port and one discharge port common to all five ejectors and five individual secondary suction ports. The Allen Aircraft Products ejectors are individual units with one primary flow port, one secondary flow port and one discharge flow port. These ejectors are shown in Figure 15.

The AMK storage tanks were pressurized sufficiently to transfer the AMK fuel into the ejector test setup so as to avoid any pre-test degrading of the fuel. The ejector test tank was filled to a pre-determined level to provide the desired ejector discharge head. Primary flow was provided by the boost pump in the supply tank. The nozzle supply pressure was regulated by a valve at the nozzle inlet. By-pass flow from the supply tank into the test tank maintained a constant test tank level and thus a constant ejector discharge head. Ejector performance data were obtained at discharge heads of 25, 32.5 and 40 inches and primary nozzle pressures of 15, 25 and 30 psig.

Performance data for the three ejectors at each of the discharge heads are presented in Figures 16 through 24. In each case, the reduced performance of the three ejectors with AMK fuels relative to neat Jet A can be seen. A considerable reduction in the secondary/primary flow ratio occurred with the .35% FM-9

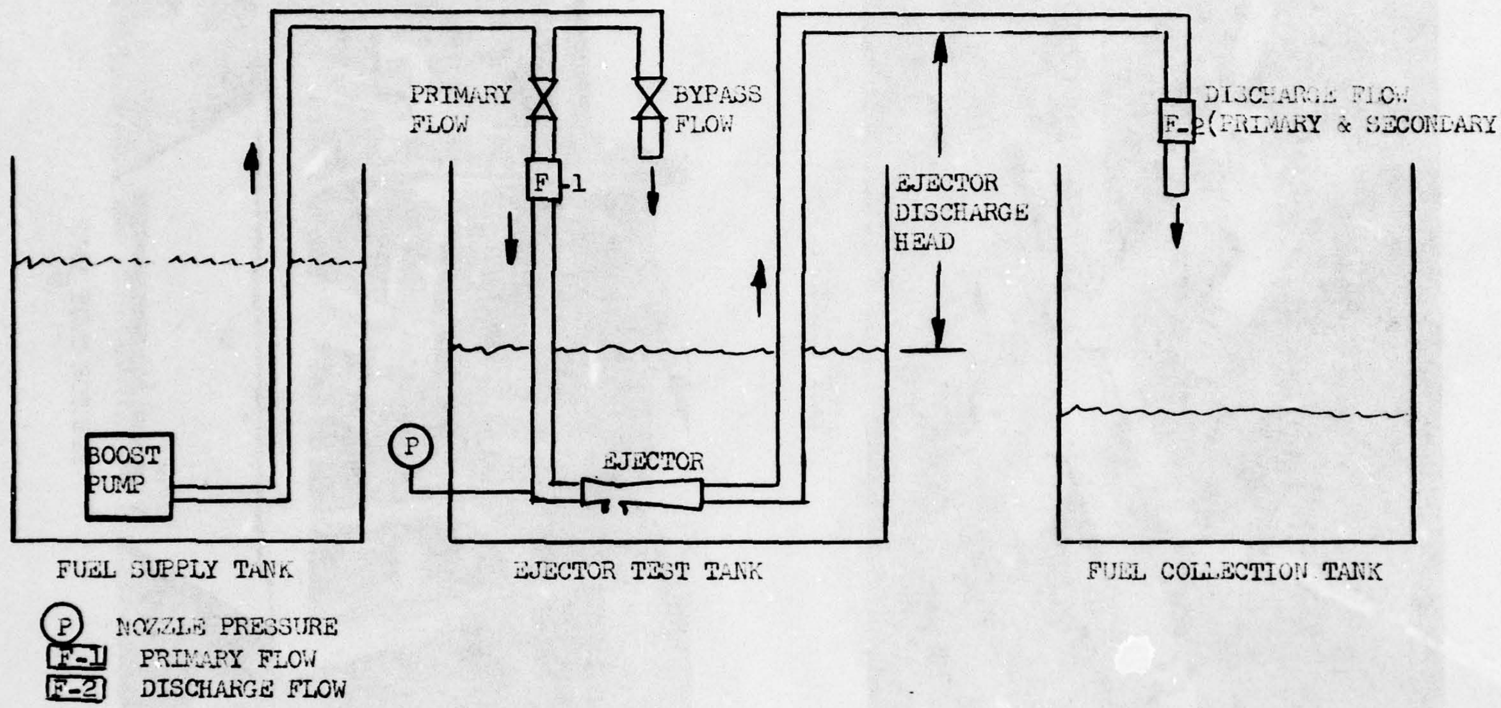
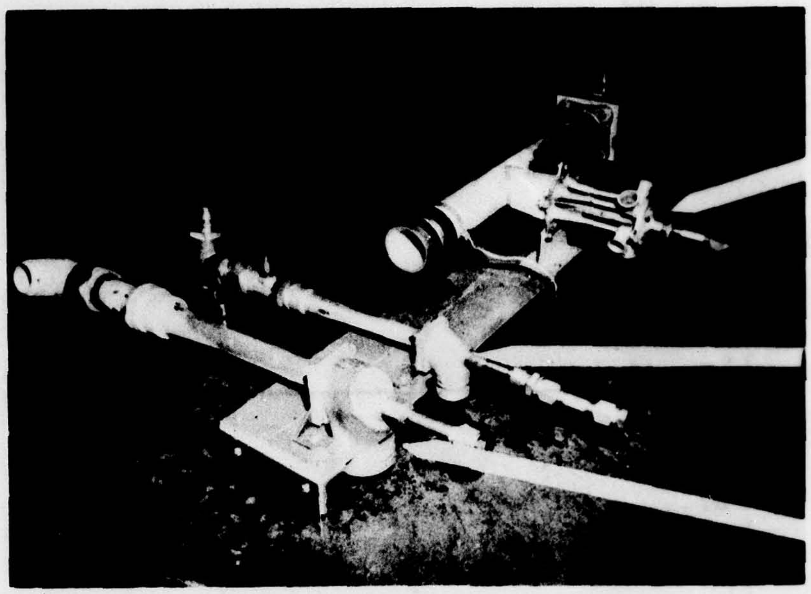


FIGURE 14

EJECTOR TEST SETUP
SCHEMATIC DIAGRAM

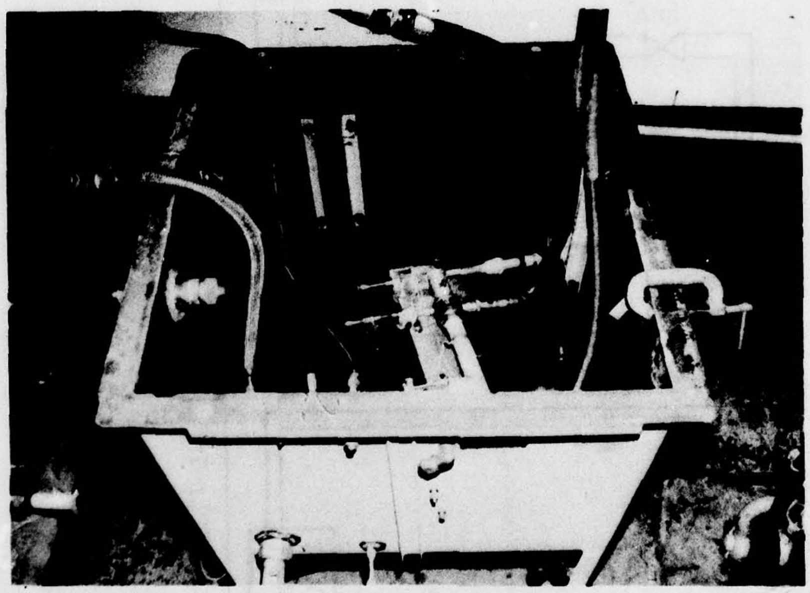


J. C. CARTER
P/N 60312

ALLEN AIRCRAFT
P/N 816E101

ALLEN AIRCRAFT
P/N 1224E500-1

TEST EJECTORS



EJECTOR TEST TANK

FIGURE 15

EJECTOR TEST APPARATUS

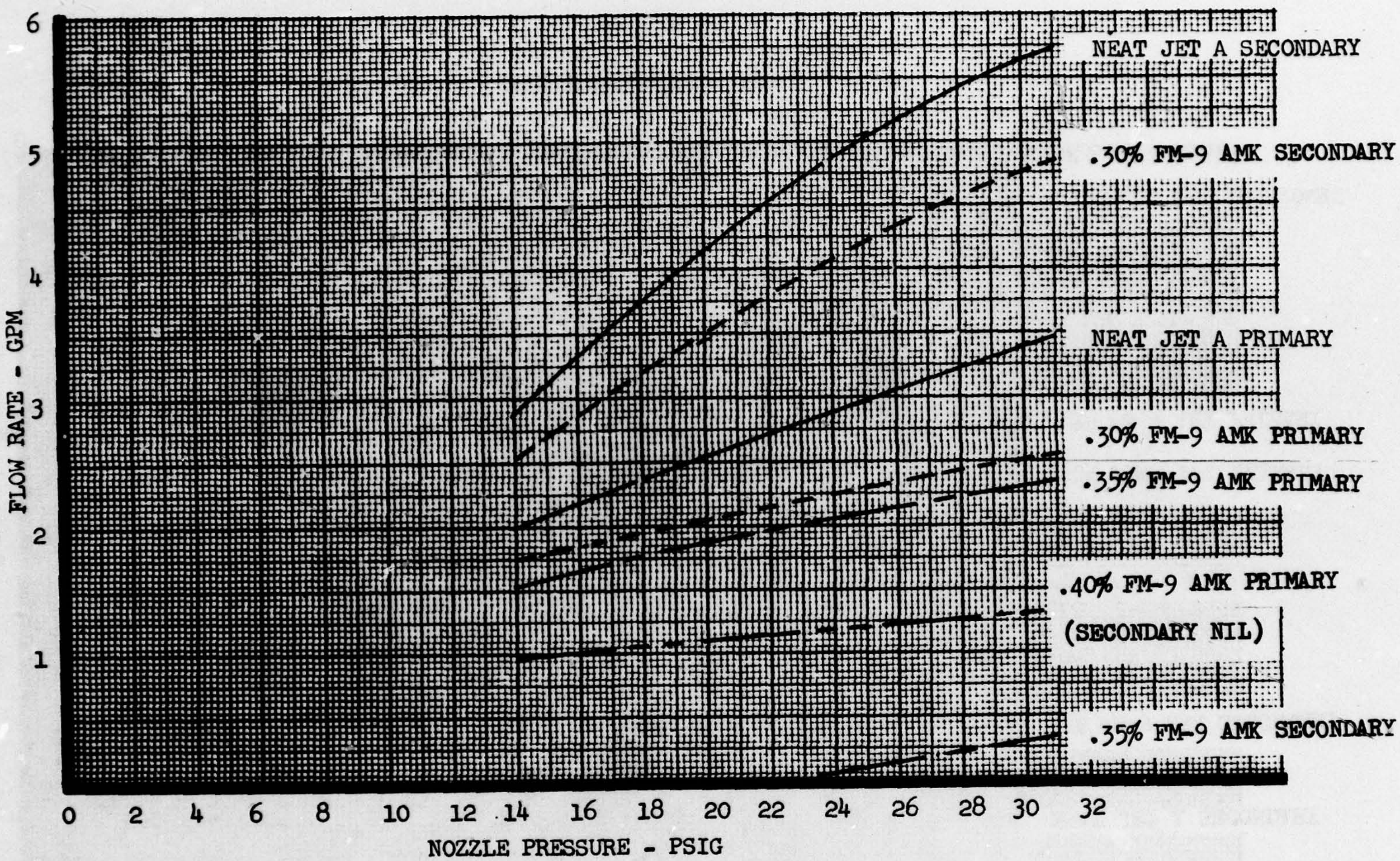


FIGURE 16

EJECTOR PERFORMANCE DATA, J. C. CARTER P/N 60312, 25 INCH DISCHARGE HEAD
PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

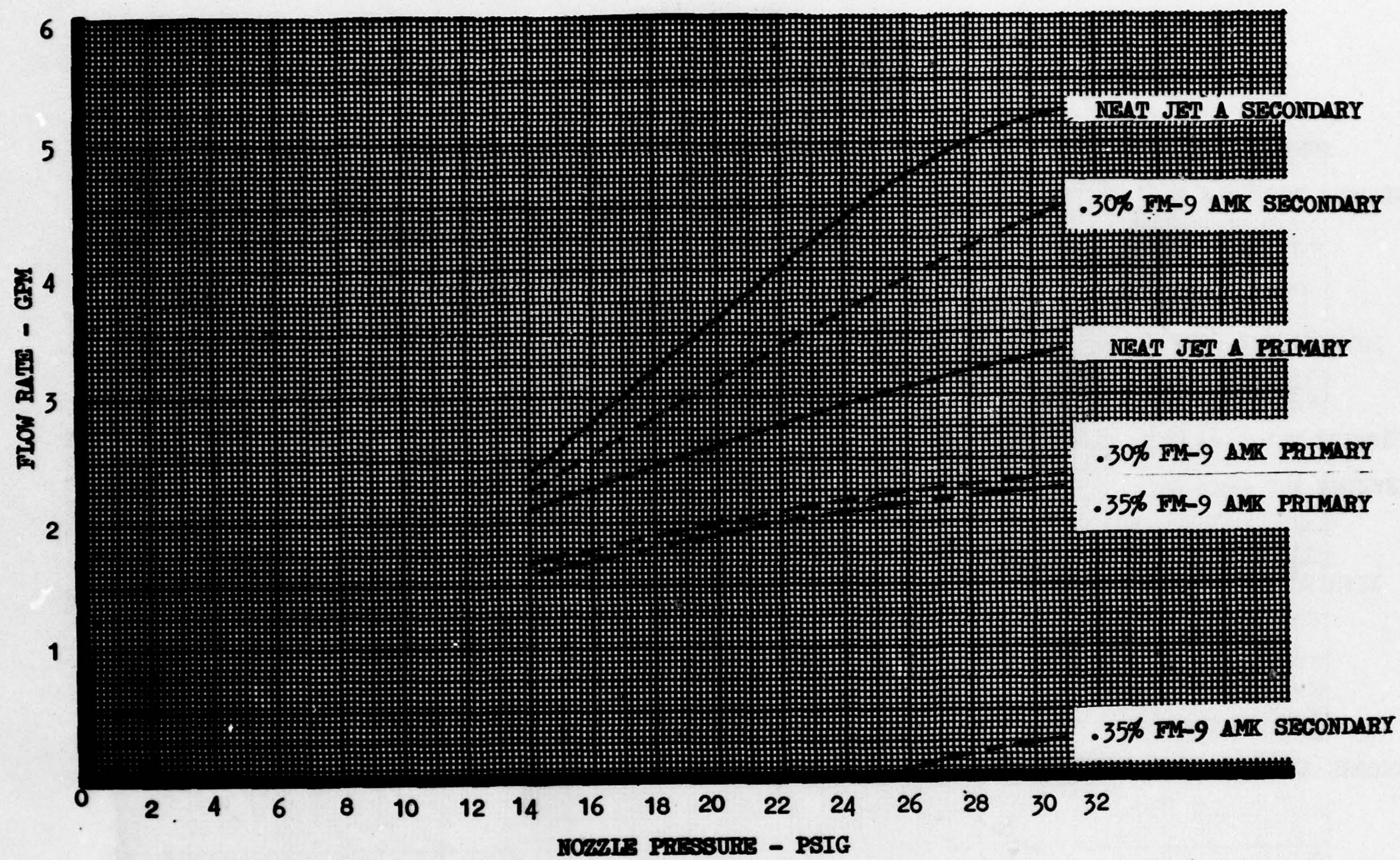


FIGURE 17

EJECTOR PERFORMANCE DATA, J. C. CARTER P/N 60312, 32.5 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

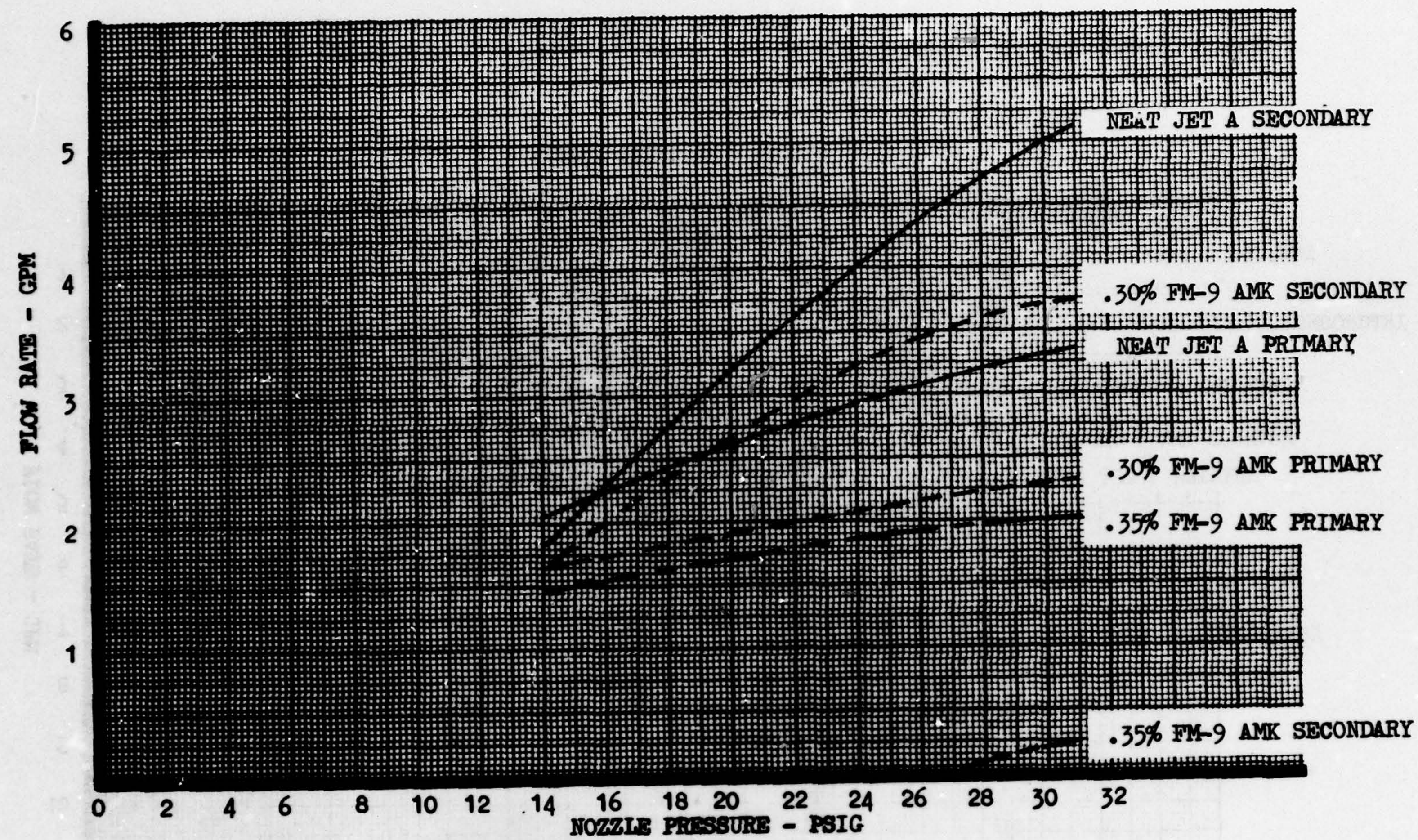


FIGURE 18

EJECTOR PERFORMANCE DATA, J. C. CARTER P/N 60312, 40 INCH DISCHARGE HEAD
PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

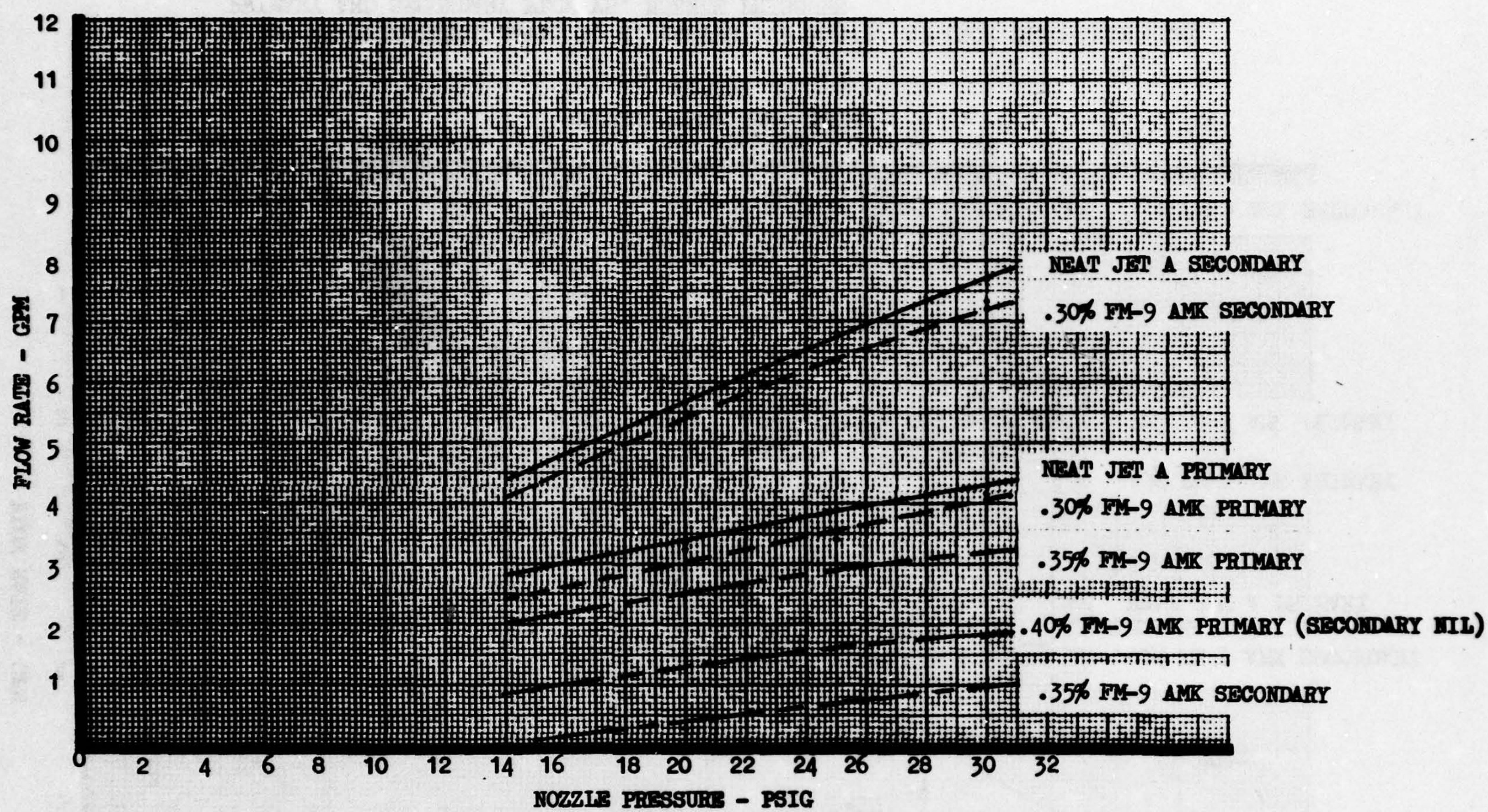


FIGURE 19

EJECTOR PERFORMANCE DATA, ALLEN AIRCRAFT PRODUCTS P/N 816E101, 25 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

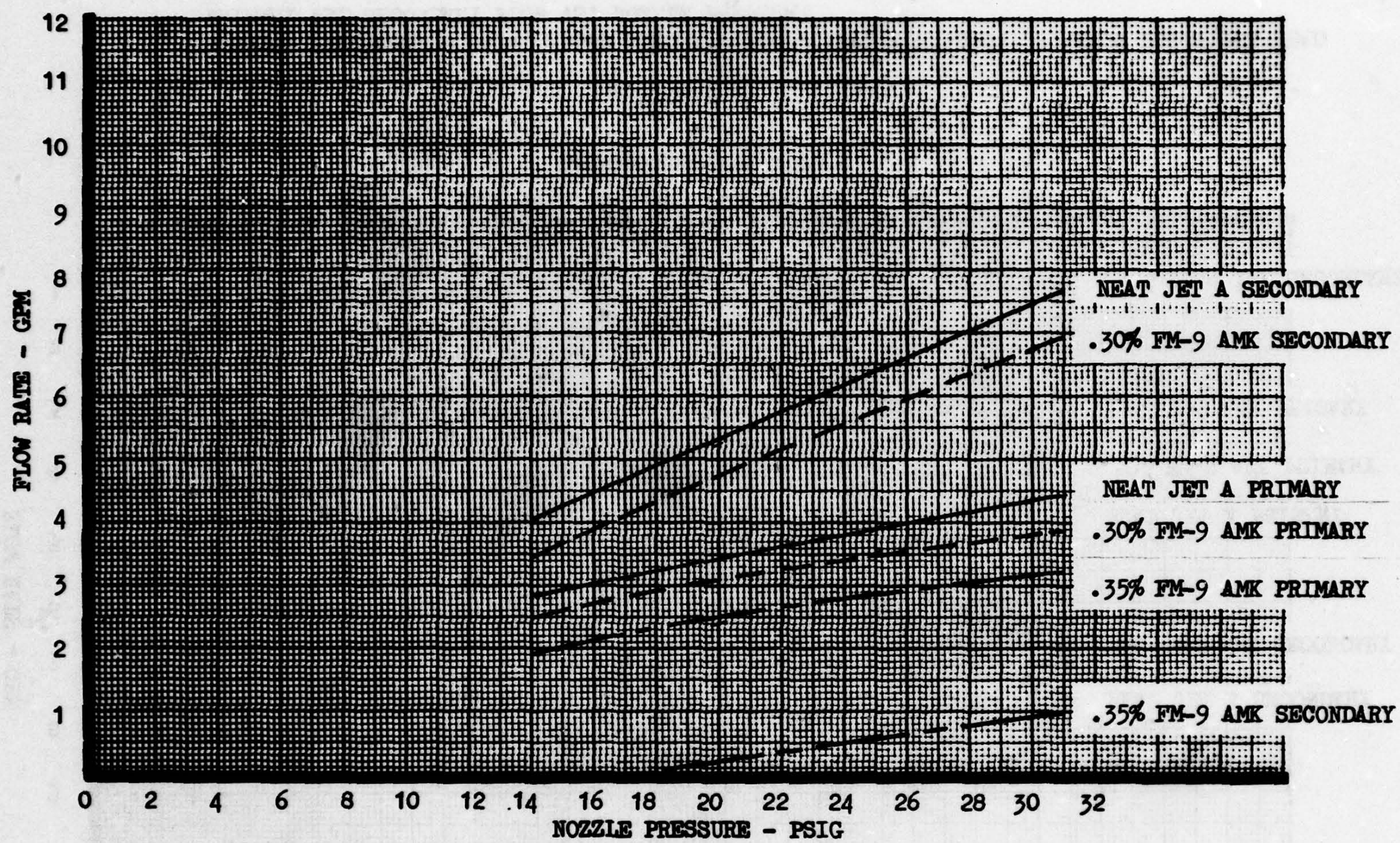


FIGURE 20

EJECTOR PERFORMANCE DATA, ALLEN AIRCRAFT PRODUCTS P/N 816E101, 32.5 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

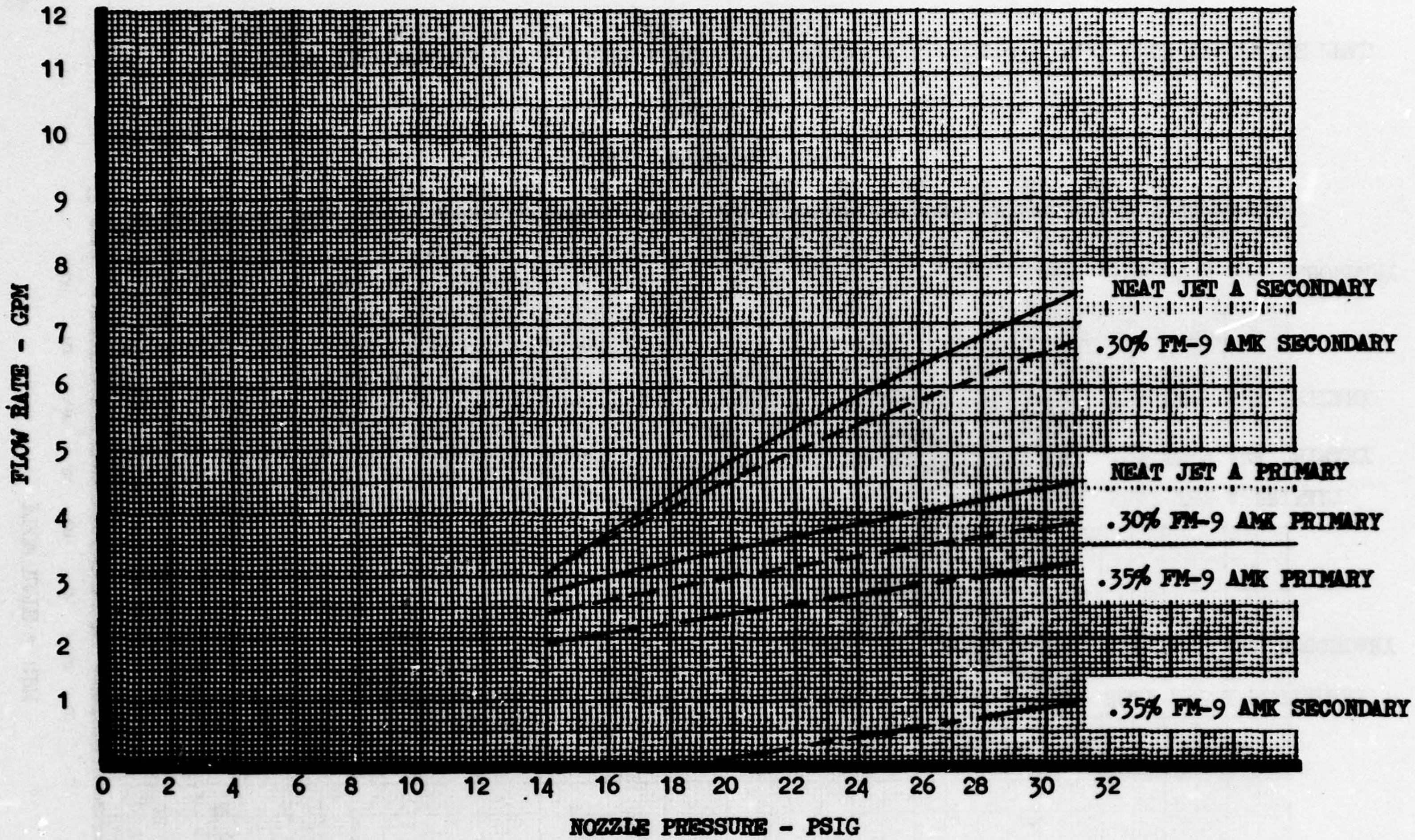


FIGURE 21

EJECTOR PERFORMANCE DATA, ALLEN AIRCRAFT PRODUCTS P/N 816E101, 40 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

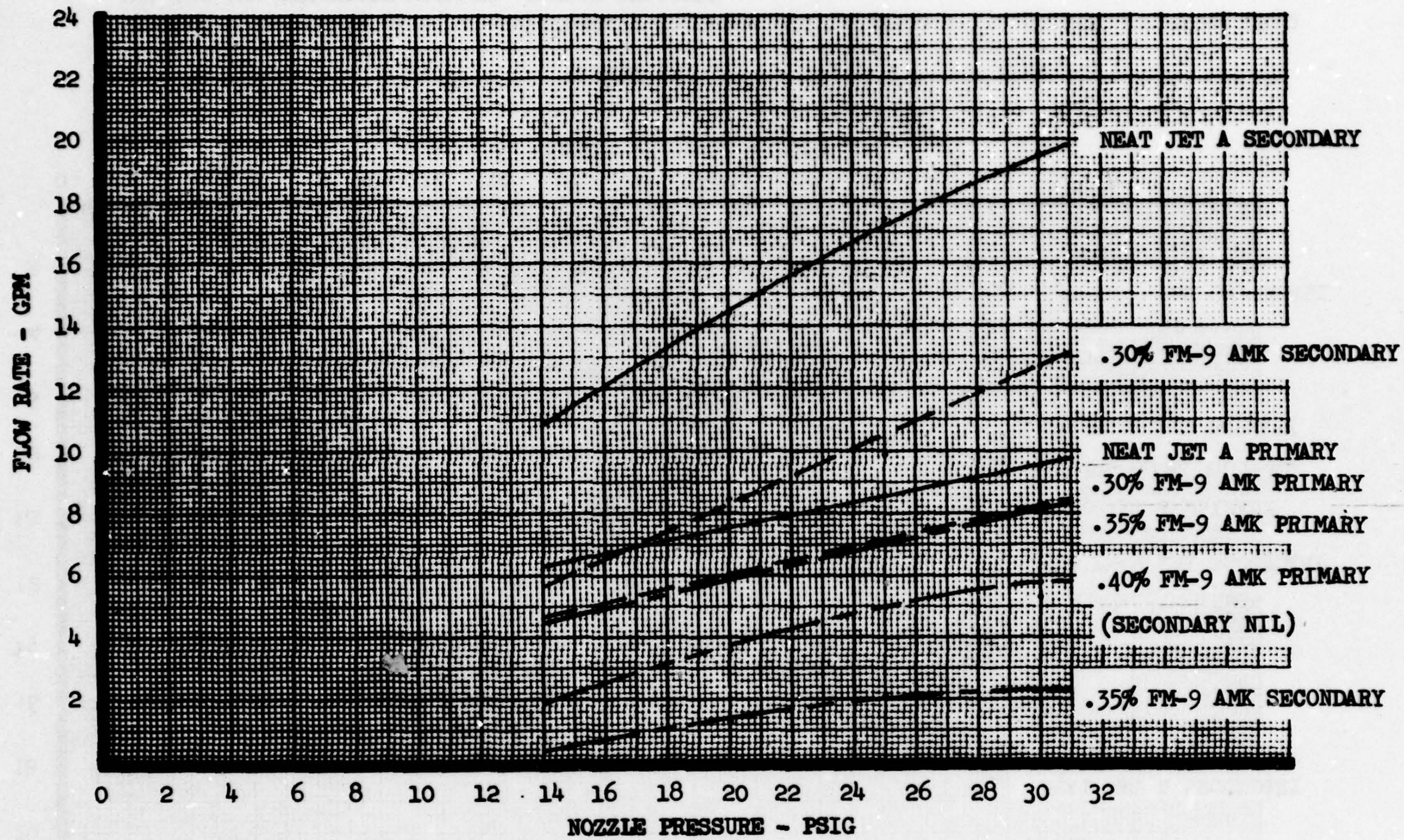


FIGURE 22

EJECTOR PERFORMANCE DATA, ALLEN AIRCRAFT PRODUCTS P/N 1224E500-1, 25 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

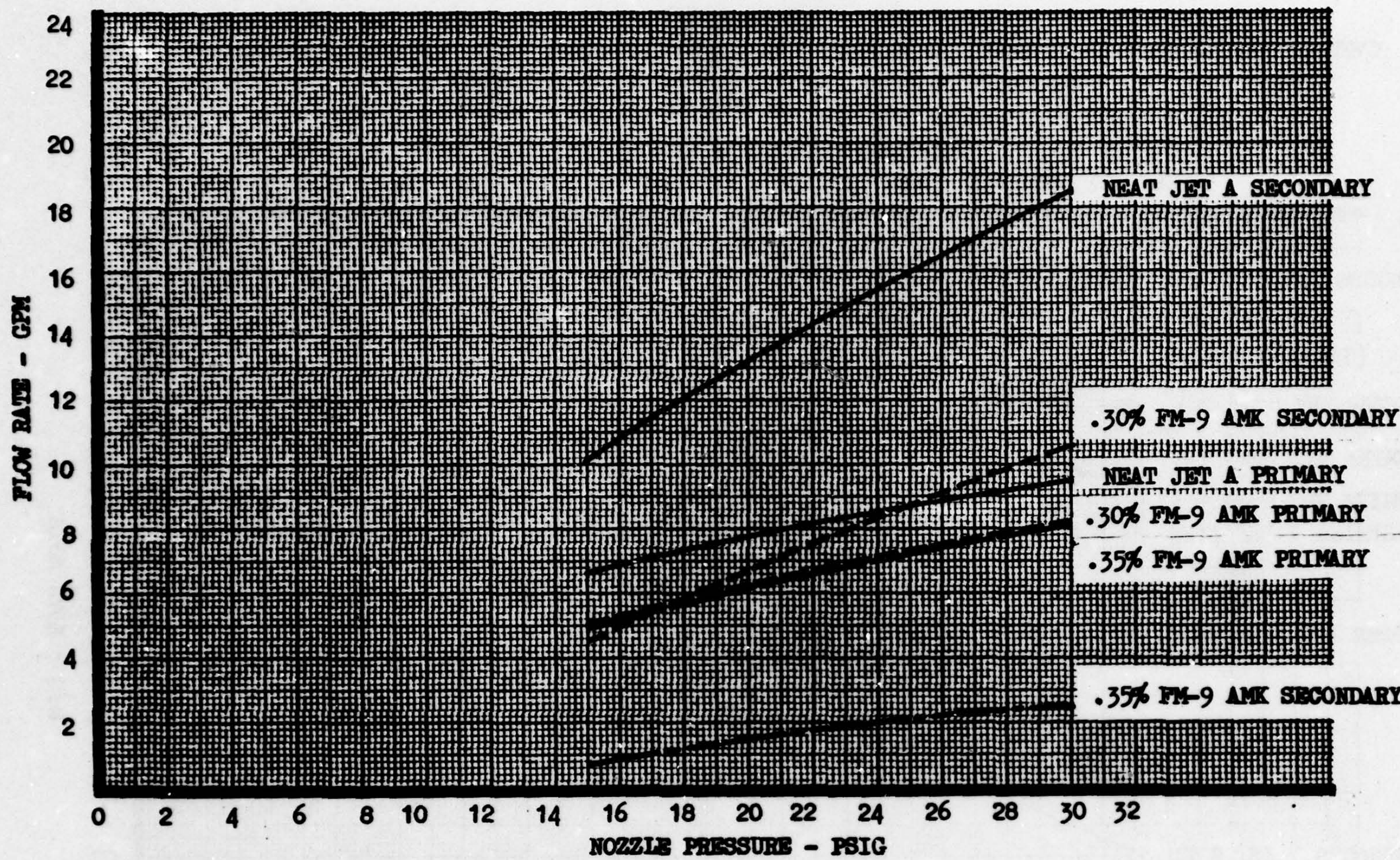


FIGURE 23

EJECTOR PERFORMANCE DATA, ALLEN AIRCRAFT PRODUCTS P/N 1224E500-1, 32.5 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

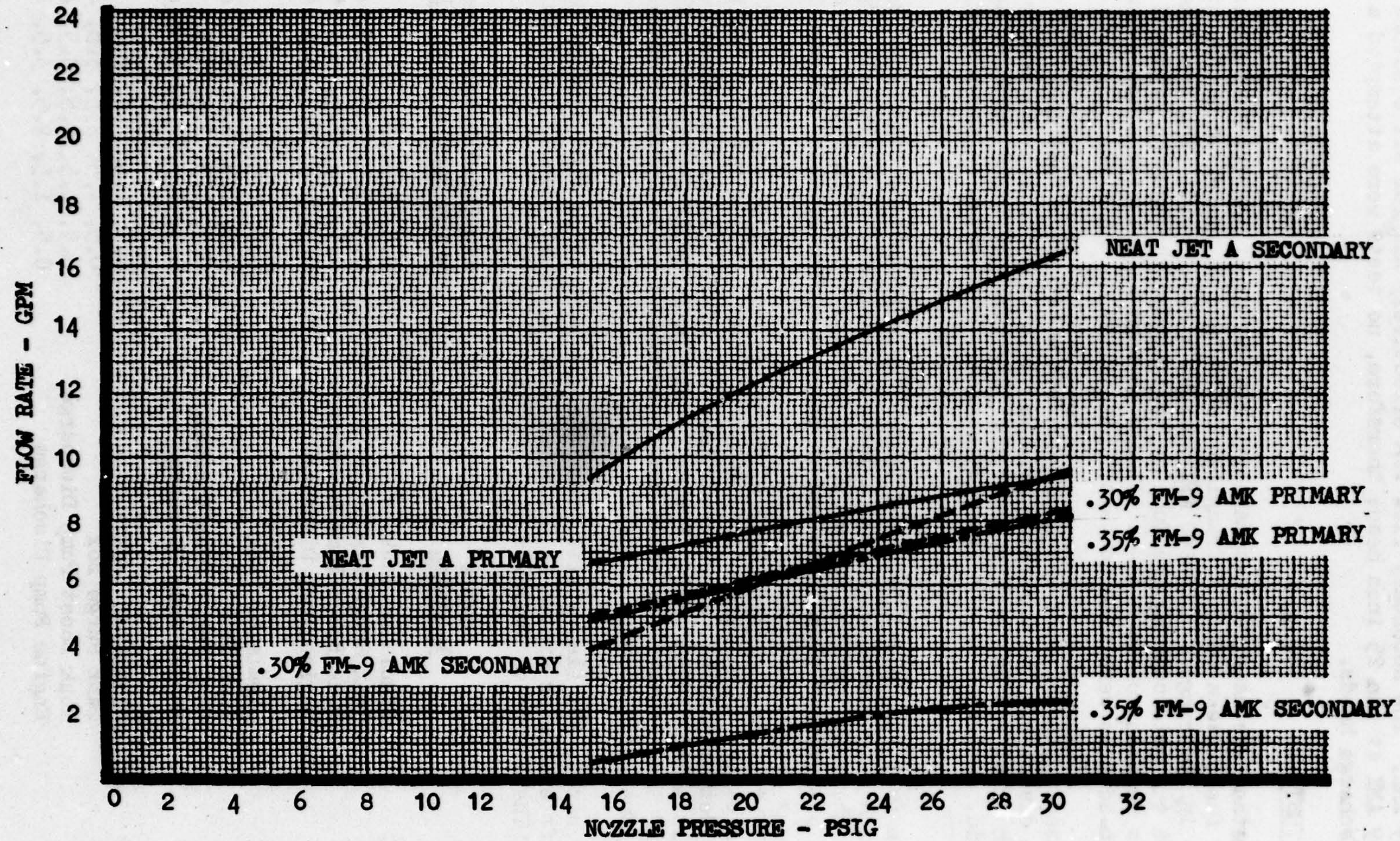


FIGURE 24

EJECTOR PERFORMANCE DATA, ALLEN AIRCRAFT PRODUCTS P/N 1224E500-1, 40 INCH DISCHARGE HEAD PRIMARY AND SECONDARY FLOW VS. NOZZLE PRESSURE

AMK (ratio less than one), and all three ejectors were considered inoperative with .40% FM-9 AMK. The secondary flow was effectively nil for all ejectors with .40% FM-9 AMK at the 25 inch head; therefore, no tests were attempted at the higher discharge heads.

FLAMMABILITY TESTS

The air gun method was used for flammability evaluation of the modified fuels. One gallon of fuel, packaged in a frangible container, is propelled by the air gun at speeds in the range of 120-140 MPH against a steel grid. The container is arrested at the grid causing the fuel to be extruded through the grid and sheared by its interaction with the still air to form a fuel-mist cloud. Open flame ignition sources were used to test flammability of the mist.

The air gun used in these tests was equipped with a barrel 20 feet long and 5.0 inches inside diameter. The arresting grid was 3 ft. x 2 ft. and was constructed of 1/4 inch steel rod on two-inch centers. Six kerosene-fired torches, spaced behind the grid, were used as the ignition source. This setup is shown in Figures 25 and 26.

The one-gallon fuel sample was packaged inside two polyethylene bags, one inside the other, which were contained inside a cardboard cylinder approximately 17½ inches long. The test specimen was propelled through the gun barrel by the air charge behind a styrofoam plug installed in the end of the cylinder (Figure 27).

The projectile velocity was determined by means of two photocells mounted at the end of the gun barrel which were connected to a timer. During pre-test calibrations, it was determined that a reservoir pressure of 27 psig would produce consistent velocities of 130 ± 5 MPH. Typical tests in progress are shown in Figure 28. Results of the flammability tests were recorded by color motion pictures made at 300 frames per second.

As previously noted, AMK flammability test samples were taken from various points in the aircraft simulator system at different time intervals during the simulated flight test. These were as follows:

Fuel Sample	Sample Location	Simulated Flight Time At Which Sample Taken (Hrs.)
.30% FM-9 AMK	Simulator Tank	0.5, 1.5, 2.5 *
	Tank Surge Box	0.5, 1.5, 2.5, 3.5, 4.0
	Tank Boost Pump Discharge	0.5, 1.5, 2.5, 3.5 **
	Engine Pump Discharge	0.5, 1.5, 2.5, 3.5 **
.35% FM-9 AMK	Simulator Tank	0.5, 1.5, 2.5 *
	Tank Surge Box	0.5, 1.5, 2.5, 3.5, 4.2
	Tank Boost Pump Discharge	0.5, 1.5, 2.5, 3.5, 4.2
	Engine Pump Discharge	0.5, 1.5, 2.5, 3.5, 4.2
.40% FM-9 AMK	Simulator Tank	0.5, 1.5, 2.5 *
	Tank Surge Box	0.5, 1.5, 2.5, 3.5, 4.0
	Tank Boost Pump Discharge	0.5, 1.5, 2.5, 3.5, 4.0
	Engine Pump Discharge	0.5, 1.5, 2.5, 3.5, 4.0

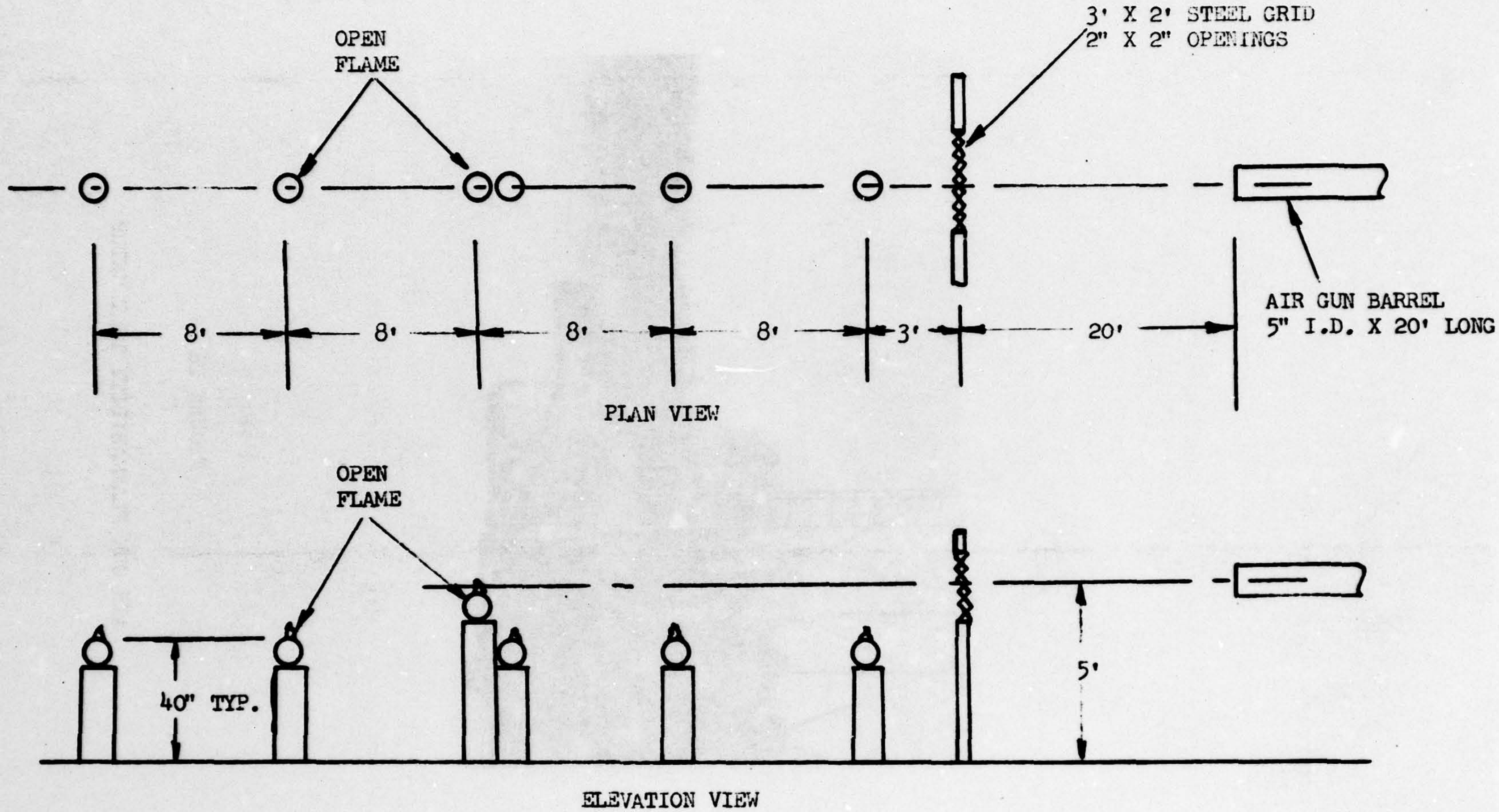


FIGURE 25

AIR GUN FLAMMABILITY TEST LAYOUT

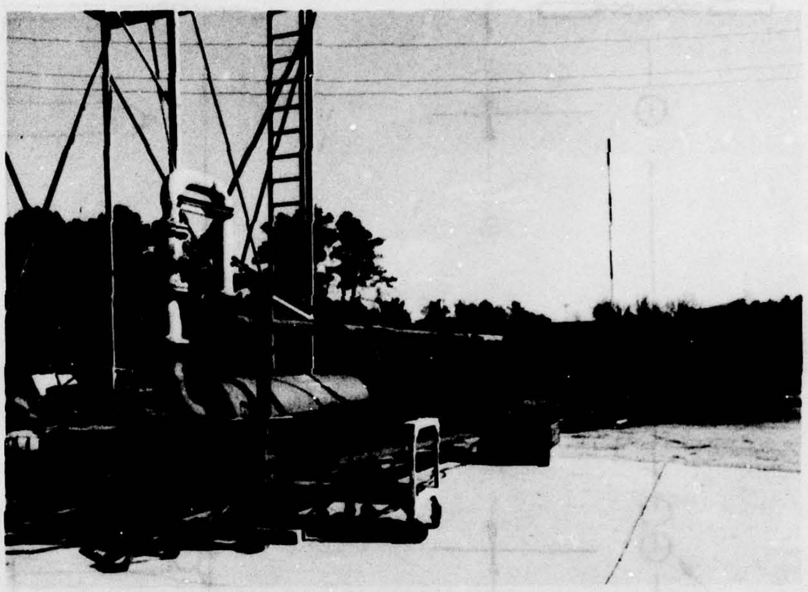


FIGURE 26

AIR GUN FLAMMABILITY TEST SETUP

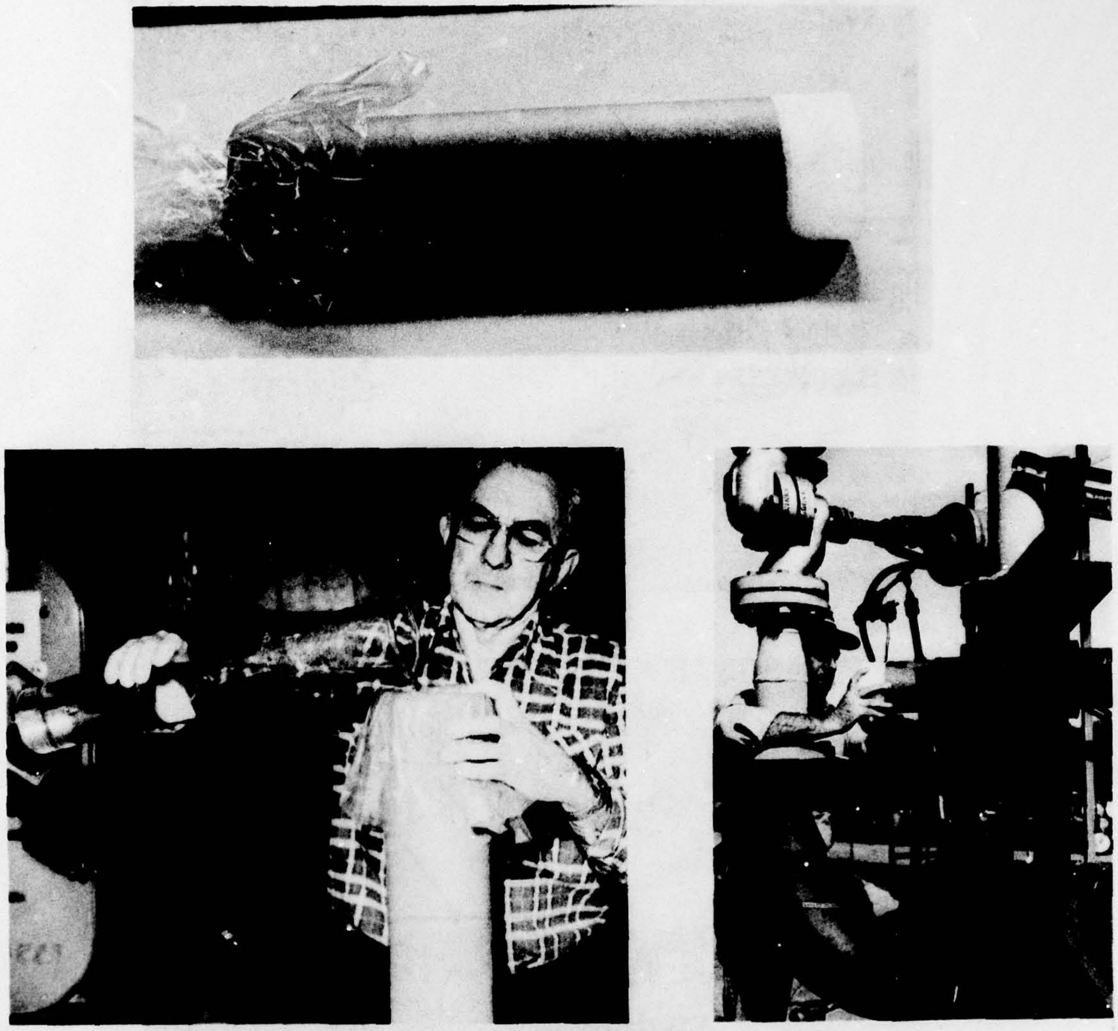


FIGURE 27

FLAMMABILITY TEST FUEL SAMPLE PACKAGING ARRANGEMENT

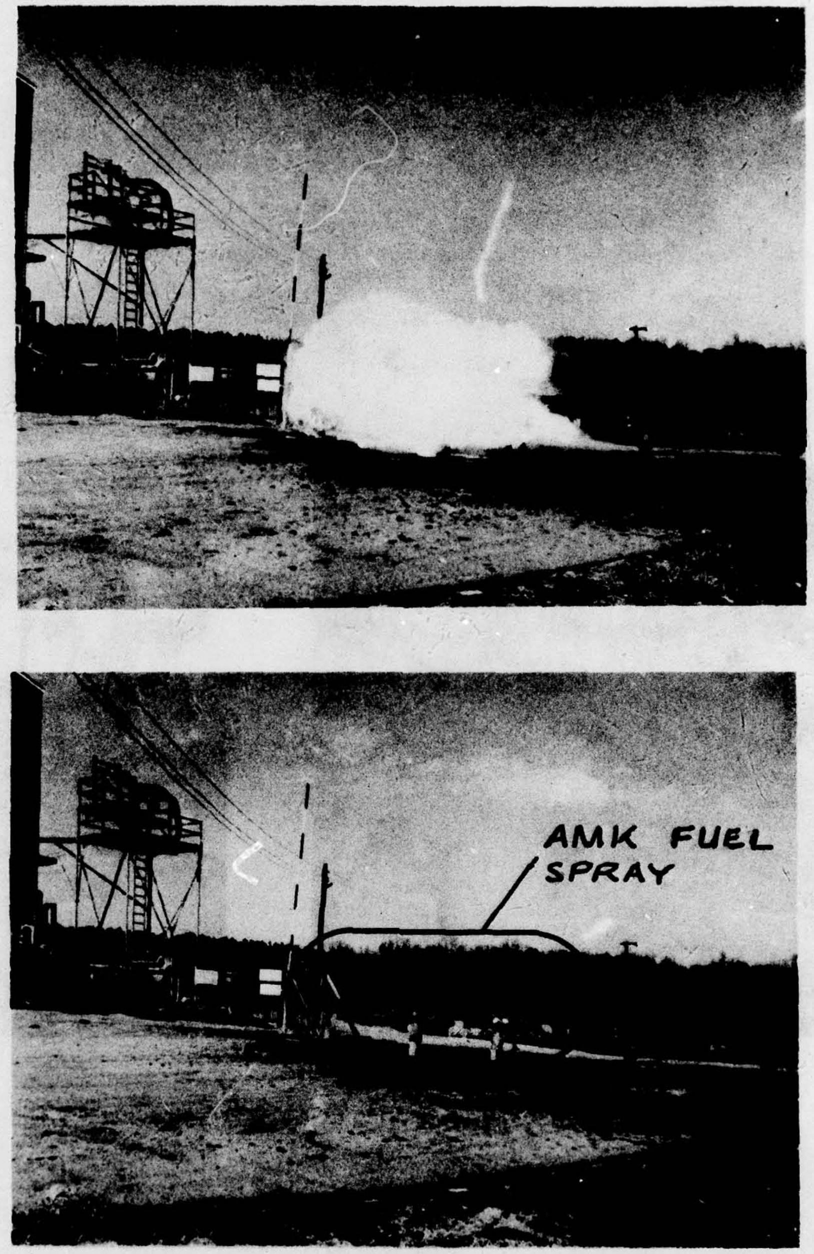


FIGURE 28

TYPICAL FLAMMABILITY TEST

Note: *Fuel level in tank was below sampling point after 2.5 hours.

**During .30% FM-9 AMK test, tank fuel was depleted at 4.0 hours with tank and engine pump beginning to cavitate due to fuel depletion. Surge box sample was obtained after shutdown from residual fuel.

In addition to the above, flammability tests were conducted on neat Jet A, each modified fuel "as received", and on samples taken at the fuel level control valve inlet and discharge for each fuel during the transfer/FLCV operational test.

There was no significant AMK degradation (as compared to FM-9 AMK as received) of the .30, .35 or .40% FM-9 AMK samples collected from the simulator tank, tank surge box or tank boost pump discharge as evidenced by flame propagation during the previously described air gun flammability test. There was some flare-up or flaming around the ignition sources in some cases, but not to the point or propagating beyond the immediate area of the ignition source. All of the engine pump discharge samples, however, were very flammable, appearing similar to neat Jet A during the air gun tests. The FLCV test samples showed no significant degradation as a result of passing through this valve. Further analysis and observations relative to the degree of AMK degradation and/or flammability can be made by viewing the test motion picture film, a copy of which is on file with the FAA.

TANK BOOST PUMP DISASSEMBLY

Following completion of all AMK tests, the tank boost pump which was utilized in the simulated flight tests was removed, disassembled and examined for evidence of gel accumulation or other abnormalties resulting from the AMK tests. There was no gel accumulation inside the impeller or motor housing and no other indication of pump deterioration as a result of these tests. It should be noted however, that the inboard main simulator tank was flushed following each AMK test by pumping approximately 500 gallons of JP-5 fuel into the tank and pumping this quantity out of the tank with the boost pump. The disassembled pump is shown in Figure 29.

SPECIFIC GRAVITY, VISCOSITY AND ORIFICE FLOW CUP DATA

Specific gravity, viscosity and orifice flow cup measurements were made on selected fuel samples during the previously described tests. Specific gravity was determined using a laboratory hydrometer and viscosity data were obtained using a Ubbelohde Viscometer. Measurements were made on samples of neat Jet A fuel and on each of the three modified fuels in the "as received" condition prior to any testing. These data were as follows:

Fuel	Specific Gravity	Viscosity (Centistokes)
Neat Jet A	0.807 @ 74 °F	1.98 @ 74°F
.30% FM-9 AMK	0.800 @ 78 °F	2.89 @ 78 °F
.35% FM-9 AMK	0.807 @ 68 °F	3.66 @ 68 °F
.40% FM-9 AMK	0.808 @ 73 °F	3.81 @ 73 °F

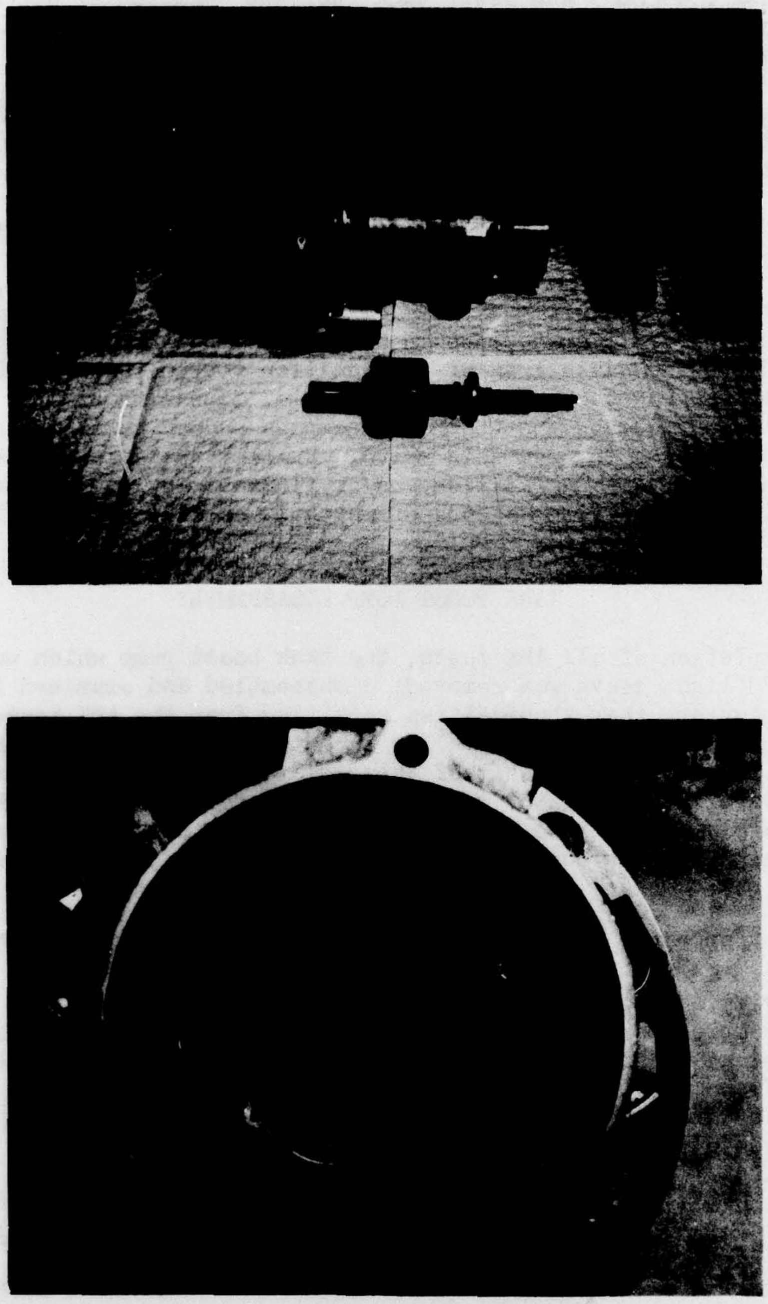


FIGURE 29

C-141 MAIN TANK BOOST PUMP ASSEMBLY

Orifice flow cup data were obtained on selected fuel samples. This type measurement was developed by Imperial Chemical Industries, Ltd. as an indication of the degree of degradation of antimisting kerosenes. The particular flow cup utilized was manufactured by ICI and had a 0.026 inch orifice in the bottom of the cup. The cup is filled to overflow and the fuel is then allowed to flow through the orifice for a 30 second period. During the next 30 second period the fuel flowing through the orifice is collected in a graduated cylinder. The quantity collected (milliliters) for various samples is tabulated below.

ORIFICE FLOW CUP DATA (.026 IN. ORIFICE)

Fuel Sample	Milli-liters	Sample Temp. °F
Neat Jet A	7.9	68
.30% FM-9 AMK as received	3.3	76
.35% FM-9 AMK as received	2.5	68
.40% FM-9 AMK as received	2.2	73
.30% FM-9 AMK, simulator tank at 2.5 Hr. cruise	2.9	64
.30% FM-9 AMK, simulator tank surge box at 3.5 Hr. cruise	5.6	68
.30% FM-9 AMK, simulator tank surge box at 4.0 Hr. cruise	6.2	68
.30% FM-9 AMK, tank boost pump discharge at 3.5 Hr. cruise	5.9	68
.30% FM-9 AMK, engine pump discharge at 3.5 Hr. cruise	6.5	68
.35% FM-9 AMK, simulator tank at 2.5 Hr. cruise	2.9	64
.35% FM-9 AMK, simulator tank surge box at 4.2 Hr. cruise	6.0	64
.35% FM-9 AMK, tank boost pump discharge at 4.2 Hr. cruise	5.3	64
.35% FM-9 AMK, engine pump discharge at 4.2 Hr. cruise	7.0	64
.40% FM-9 AMK, simulator tank at 2.5 Hr. cruise	2.6	68
.40% FM-9 AMK, simulator tank surge box at 4.0 Hr. cruise	4.2	68
.40% FM-9 AMK, tank boost pump discharge at 4.0 Hr. cruise	4.9	68
.40% FM-9 AMK, engine pump discharge at 4.0 Hr. cruise	7.0	68
.30% FM-9 AMK, ejector discharge, J. C. Carter P/N 60312	4.8	76
.30% FM-9 AMK, ejector discharge, Allen Aircraft P/N 1224E500-1	4.0	76

CONCLUSION

Fuel system simulator tests on the C-141 aircraft fuel system with FM-9 modified fuel revealed the need for further development activity to resolve certain problem areas encountered in this program.

(1) Ejector (jet pump) transfer systems - Other means of fuel scavenging and transfer must be utilized unless performance can be improved by further AMK fuel development. Unuseable fuel would be increased without improved scavenging techniques.

(2) Tank boost pump performance - Reduced boost pump discharge pressures with the AMK indicate the need for pump performance/development tests and possibly design improvements to ensure an adequate engine system supply pressure throughout all flight operating regimes and environments.

(3) AMK filtration - The C-141 engine fuel filter pressure differentials were in excess of the bypass pressure during all phases of the AMK tests, indicating fuel flow around the filter instead of through it. Means of accomplishing adequate AMK filtration must therefore be developed.

(4) Engine fuel pump operation - The required engine pump fuel flow and discharge pressure was maintained throughout the simulated flight envelope (0-40,000 feet) for all three FM-9 AMK concentrations tested, however the tank boost pump was operating during each test. Future evaluations should include suction feed tests with tank boost pumps off (simulating a failed boost pump) to determine suction feed capability with modified fuels.

(5) Fuel level control valve operation - The fuel level control valve and other components having small orifices or pressure sensing passages will require further development, or changes to the AMK fuel to enhance dynamic response of these components.

(6) Tank quantity gaging system - The accuracy of the capacitance type gaging system was not significantly altered by the FM-9 AMK.

With the exception of the engine mounted fuel pump, none of the C-141 fuel system components caused any significant degradation of the .30, .35 or .40% FM-9 AMK as evidenced by the air gun flammability tests described herein. All of the FM-9 AMK fuels passed through the engine fuel pump, however, were very flammable, appearing similar to neat Jet A during the air gun tests. Thus, results of this test indicate that the FM-9 AMK effectively reduces the flammability of the wing tank fuel which would be released into the surrounding air during the dynamic phase of an accident. The AMK entering the engine is apparently degraded significantly by the engine mounted fuel pump which should aid in restoring normal misting properties to the fuel.

APPENDIX

DESCRIPTION OF C-141 AIRCRAFT FUEL SYSTEM

The C-141 fuel system consists of ten fuel tanks, functional components and associated plumbing. There are five tanks in each wing which include a No. 1 outboard main (1230 gallons), a No. 1 outboard auxiliary (2510 gallons), an extended range (4060 gallons), a No. 2 inboard auxiliary (1650 gallons), and a No. 2 inboard main (2090 gallons). The aircraft tank arrangement is shown in Figure A-1. The system plumbing consists of engine feed lines, crossfeed lines, a wing fuel manifold connecting the tank fill valves with refueling adapters, a tank scavenge ejector system and a tank vent system. There are two electrically driven centrifugal booster pumps in each tank for fuel transfer and engine feed. The pumps are plug-in type, totally submerged, and are operated by 200 volt AC, 400 cycle, 3 phase power. In normal operations only one pump in each tank is used, with the second pump serving as a backup unit. The main tank pumps, Pesco P/N 124470-021-01, have a rated capacity of 23,700 PPH at 6 PSIG (22 PSIG at 0 flow), while the extended range and auxiliary tank pumps, PESCO P/N 124471-031-01, have a rated capacity of 40,000 PPH at 8 PSIG (40 PSIG at 0 flow). The extended range and auxiliary tank pumps, having a higher discharge pressure, override the main tank pumps until the extended range and auxiliary tank fuel is depleted. The main tank pumps are enclosed in smaller compartments extending from the upper surface to the lower surface called surge boxes. One-way flapper valves permit gravity flow of tank fuel into the surge box, and ejectors (jet pumps) scavenge tank fuel which is pumped into the surge box. This insures a constant supply of fuel to the main tank pumps. The outboard main tank surge box capacity is approximately 37 gallons while the inboard main tank surge box capacity is approximately 120 gallons. Capacitance type fuel quantity probes are located in each tank for fuel quantity indication. A schematic diagram of the wing tank plumbing arrangement is presented in Figure A-2.

Each tank contains one refuel valve (Rogerson P/N 32900) located near the upper surface which governs the level to which the tank may be filled. The valve is opened by electrical actuation of either of two solenoids and may be closed by de-energizing these solenoids. A schematic diagram of the refuel valve is presented in Figure A-3. The valve consists of a valve body, dual piston-operated control mechanisms, dual floats and solenoids. This arrangement makes up a primary and secondary actuation circuit, each independent of the other. With the primary solenoid energized as shown in Figure A-3, incoming fuel pressure unseats the inlet poppet and fuel flows into the tank. Fuel also flows through the primary and secondary piston chamber passages and out of the chambers through the open pilot outlet. When the solenoid is de-energized as shown by the secondary pilot, pressure builds up in the two chambers causing the chamber piston to seat the inlet poppet and thereby closing the valve.

Fuel flows from the wing tanks through the engine feed line in the pylon to the engine fuel system. The engine system consists of a two-stage engine-driven pump (Ceco Model 9466), fuel heater, filter, shutoff actuator, fuel control, flowmeter, pressurizing and dump valve, fuel nozzles and related controls (Figure A-4). The first stage of the engine-driven pump is an impeller assembly which boosts the pressure approximately 60 PSI. Fuel is then ported through the fuel heater and filter and into the second stage of the pump. The filter element contains a 10 micron disposable element, a differential pressure switch and a spring loaded bypass valve. Should the pressure differential reach 8 PSI, the pressure

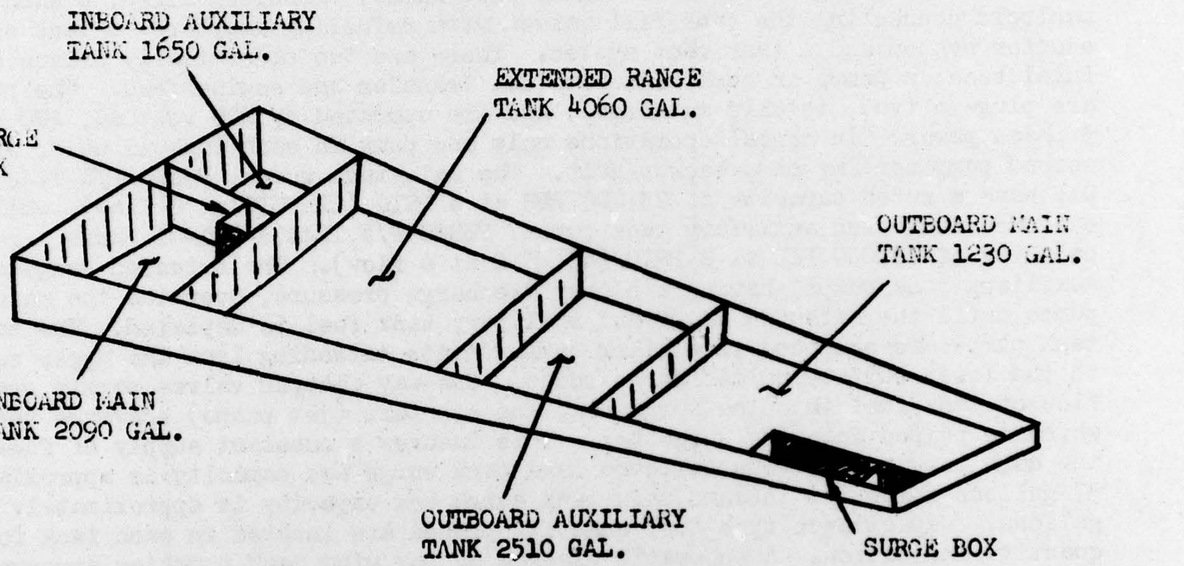


FIGURE A-1

C-141 WING FUEL TANK ARRANGEMENT

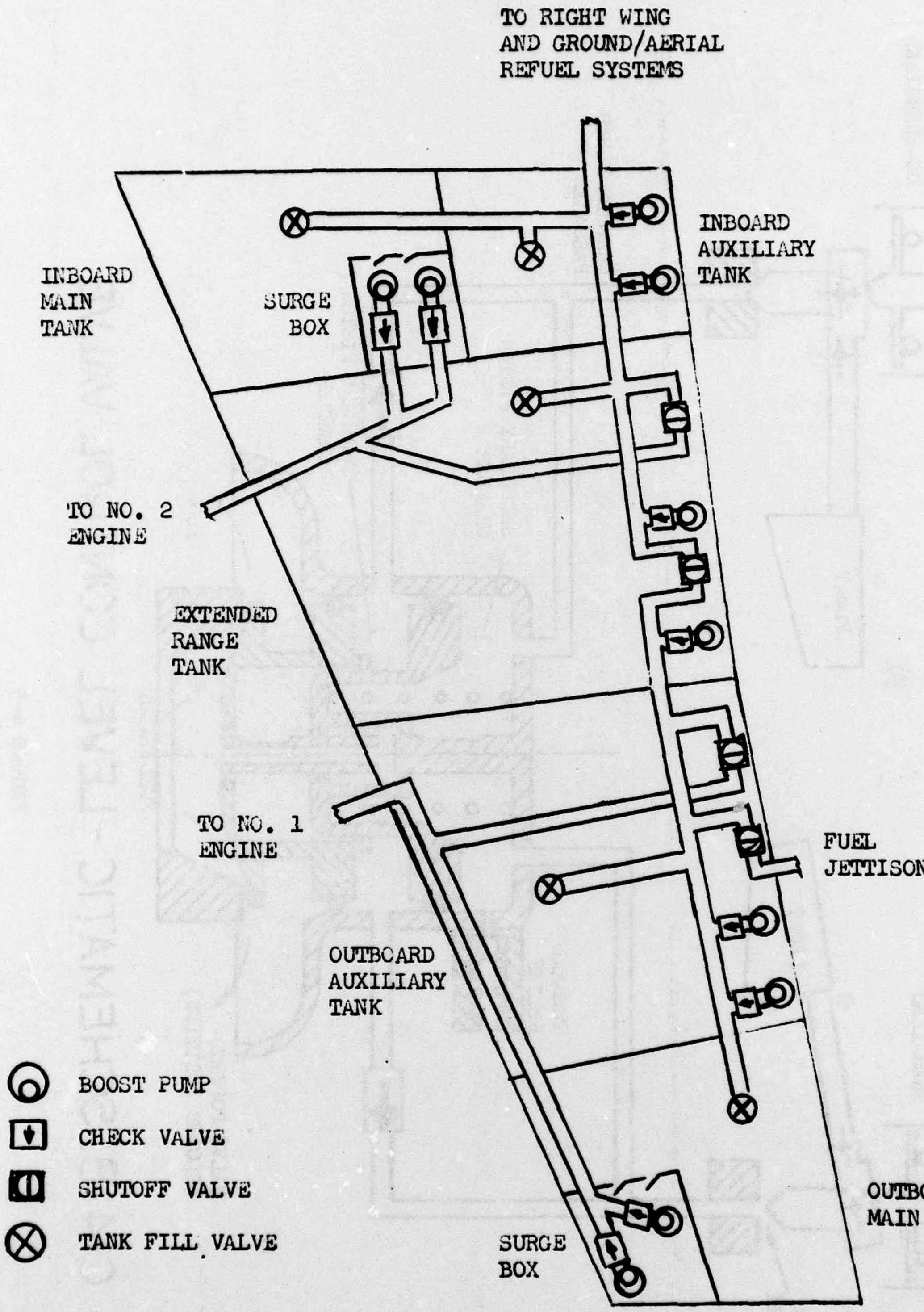
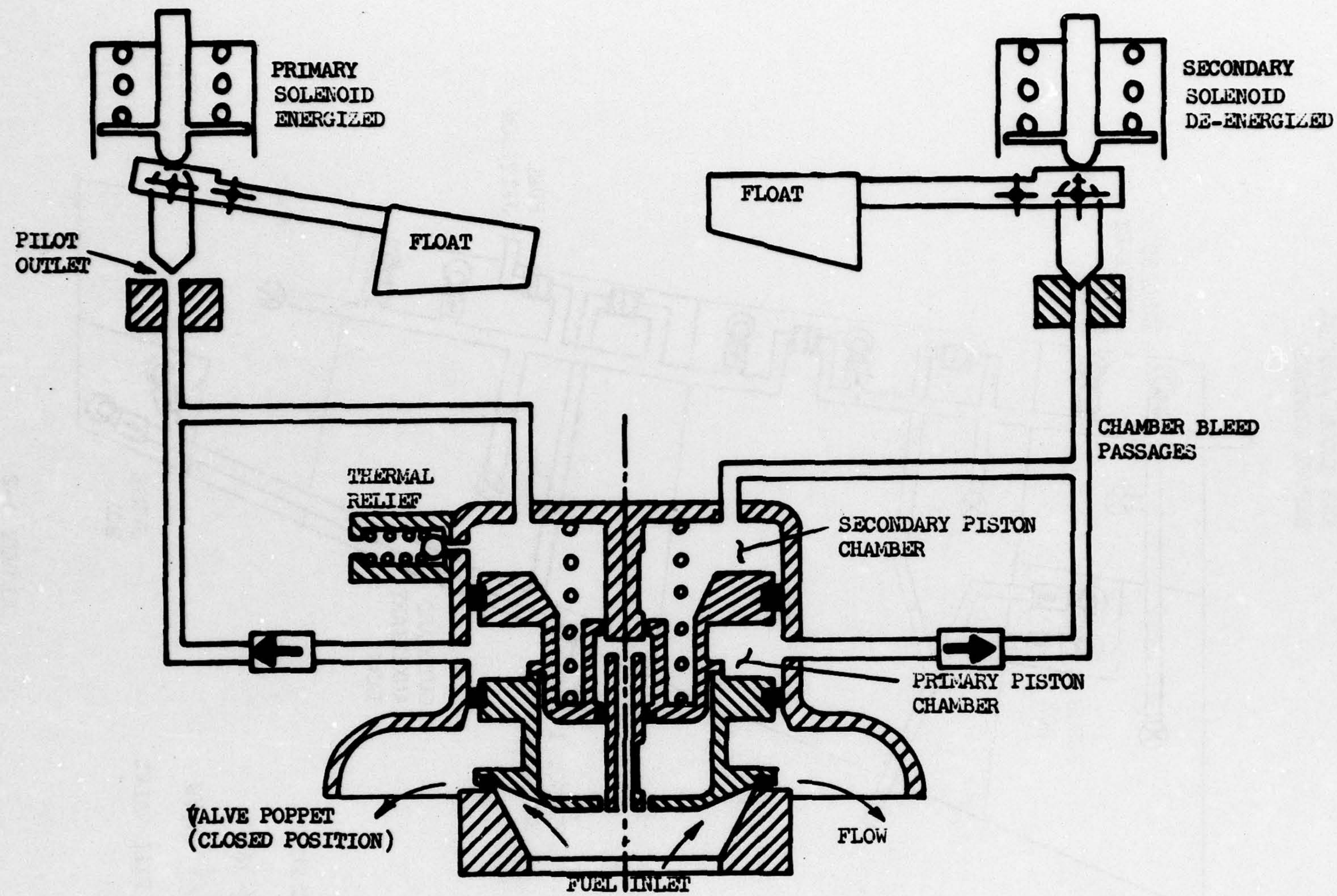


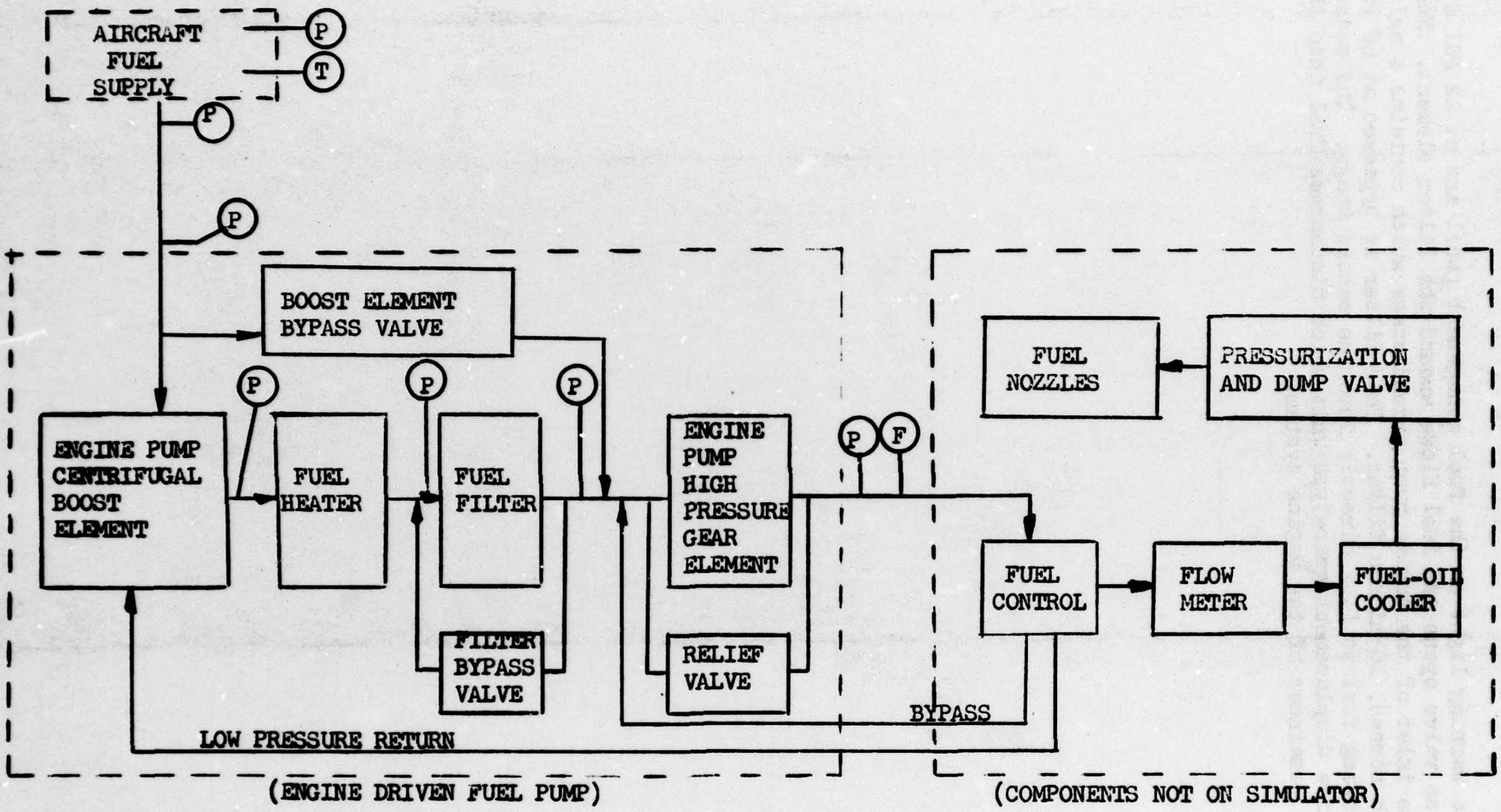
FIGURE A-2

C-141 WING FUEL TANK PLUMBING SCHEMATIC DIAGRAM
(VENT AND EJECTOR SYSTEMS PLUMBING NOT SHOWN)



C141B. SCHEMATIC - LEVEL CONTROL VALVE

FIGURE A-3



INSTRUMENTATION DATA POINT

(P) PRESSURE

(F) FLOW

(T) TEMPERATURE

FIGURE A-4

C-141 ENGINE FUEL SYSTEM - SCHEMATIC DIAGRAM switch actuates a warning light on the fuel management panel and at 12 PSI differential, the bypass valve opens and fuel flows around the filter element. Fuel then flows to the inlet of the engine pump second stage which contains a self-relieving 40 mesh screen, 10 micron filter. This filter is bypassed at 60 PSI differential allowing fuel to flow directly into the second stage. The second stage is a positive displacement gear-type unit which discharges fuel into the fuel control and remainder of the engine system.