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AIRCRAFT FUEL SYSTEM TESTS WITH GELLED FUEL-FLOWMETER CALIBRATION, FUEL BOOST PUMP AND JETTISON TESTS

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NOVEMBER 1973

FINAL REPORT

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16. Abstract

The feasibility of using gelled fuel (nominal 250 centipoise viscosity) with full scale aircraft fuel system components was investigated. Tests indicated that turbine-type flowmeters are suitable for measuring flow rates with accuracies of 1 percent. Jettison and fuel feed operations were conducted using a B-57 wing fuel tank. Approximately 3 percent more gelled fuel than JP-5R remained in the tank after "emptying" the tank in both boost pump and jettison tests. Flow rates and times to "empty" the tank were significantly poorer with the gelled fuel when compared to the results obtained with the JP-5R fuel. The gelled fuel tested is considered unsatisfactory because of its instability in storage, causing wide variations in viscosity.

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INTRODUCTION

PURPOSE.

The purpose of this project, as authorized by Reference (1), was to evaluate the performance of various fuel system components in a full scale aircraft, when using experimental jet fuel (nominal 250 centipoise (cP) viscosity) under simulated environmental conditions. The scope of the work covered two phases: Phase A - measurement of fuel flow rate; and Phase B - tests of a B-57 wing section to investigate dumping and fuel boost pump performance.

BACKGROUND.

In aircraft crashes, escaping fuel is subject to ignition from various sources (hot surfaces, friction sparks, electrical sparks, etc.). Conventional fuels atomize on impact and burst into flame when ignited, quickly enveloping the aircraft. Several approaches to reducing the hazard can be taken, including the modification of fuel tanks and fuel system fittings, the elimination of ignition sources, and the alteration of fuel characteristics.

The Federal Aviation Administration (FAA) and others have investigated modified fuels to evaluate their qualifications as safety fuels. The earlier modified fuels were gels and emulsions varying in consistency from a soft jelly to a vaseline-like solid. It has been shown that these thickened fuels will not flow readily from a fuel tank ruptured in a crash, will not mist readily, and have reduced rates of vaporization. The major disadvantages of these early thickened fuels were: a tendency to pick up and retain contaminants; breakdown when passing through pumps, filters, and other restrictions; and cavitation in fuel pumps. The large amounts of contaminants contained in the fuel, and the tendency of additives to separate out onto filter surfaces, caused rapid clogging of filters. The most recent trend is toward the development of modified fuels of low viscosity and high resistance to atomization. The composition of the experimental jet fuel consisted of Jet A, 1.7 percent by weight of a hydrocarbon resin and small amounts of two flow modifiers. The fuel has been rheologically profiled (Reference 2).

Tests for this report were scheduled to be run on the operation of fuel system filters and pumps under adverse weather temperatures. Work on this phase was not completed because the fuel pump was returned to the FAA for their use in an urgent test program.

METHODOLOGY

TEST CONDITIONS.

The test program is comprised of two phases:

Phase A - Measuring fuel flow rate

Phase B - Testing a B-57 aircraft wing fuel system

PHASE A. Under Phase A various methods of determining gelled fuel flow rate were investigated. The test program covered the following range of conditions as required for wing fuel system tests.

Flow Range - lb/hr	Gel Temperature - °F
2,000 to 16,000	59, 25, -16

Calibration of the flowmeter was made with JP-5R reference fuel as a basis of comparison for the gelled fuel calibration. The JP-5R is the standard jet fuel presently in use.

PHASE B. The Phase B wing fuel system test program was performed on a B-57 wing section since the B-57 wing section required little alteration to conform to space limitations in the environmental test chamber. Tests were run at the following conditions with both the gelled fuel and JP-5R reference fuel.

Test	Air Temperature °F	Altitude Pressure Inches of Mercury, Absolute	Fuel Flow Pounds per Hour
Jettison	25	17	-
Jettison	57	26.3	-
Boost Pump	Ambient to 25	Sea Level to 17	9,000 for 10 minutes 4,200 for rest of test
Boost Pump	Ambient to -16	Sea Level to 10.7	9,000 for 10 minutes 3,300 for rest of test

The jettison system tests were preceded by an 8-hour soak period at the test temperature. After start of the tests the amount of fuel emptied from the wing tank was determined at intervals from 1 to 5 minutes. Gelled fuel viscosity checks were made at intervals throughout the tests.

DESCRIPTION OF TEST EQUIPMENT.

FLOWMETERS. The turbine-type flowmeters tested under Phase A for performance when using the gelled fuel were: a Waugh Model FL-16S-2, Serial No. 8328 (1-inch size); a Cox Model AN8-4, Serial No. 7148 (1/2-inch size); and a Cox Model LF6-3, Serial No. 7143 (3/8-inch size). The turbine-type flowmeter contains a freely spinning turbine wheel which generates electrical pulses in an externally mounted coil assembly. The frequency of the pulses varies as a function of the fluid flow rate. An electronic counter (EPUT meter) was used to determine the count rate.

FLOW CALIBRATION STAND. The turbine-type flowmeters were calibrated using the Cox Type 309X Flow Calibration Stand. This unit is a self-contained assembly which automatically times preselected weights of the fuel flowing through the flowmeter at constant flow rates. An existing fuel temperature conditioning system was modified to provide the range of temperatures required for tests under this program. Figure 1 is a schematic diagram of the flowmeter calibration installation, and Figure 2 is a photograph of the Cox Type 309X Calibration Stand.

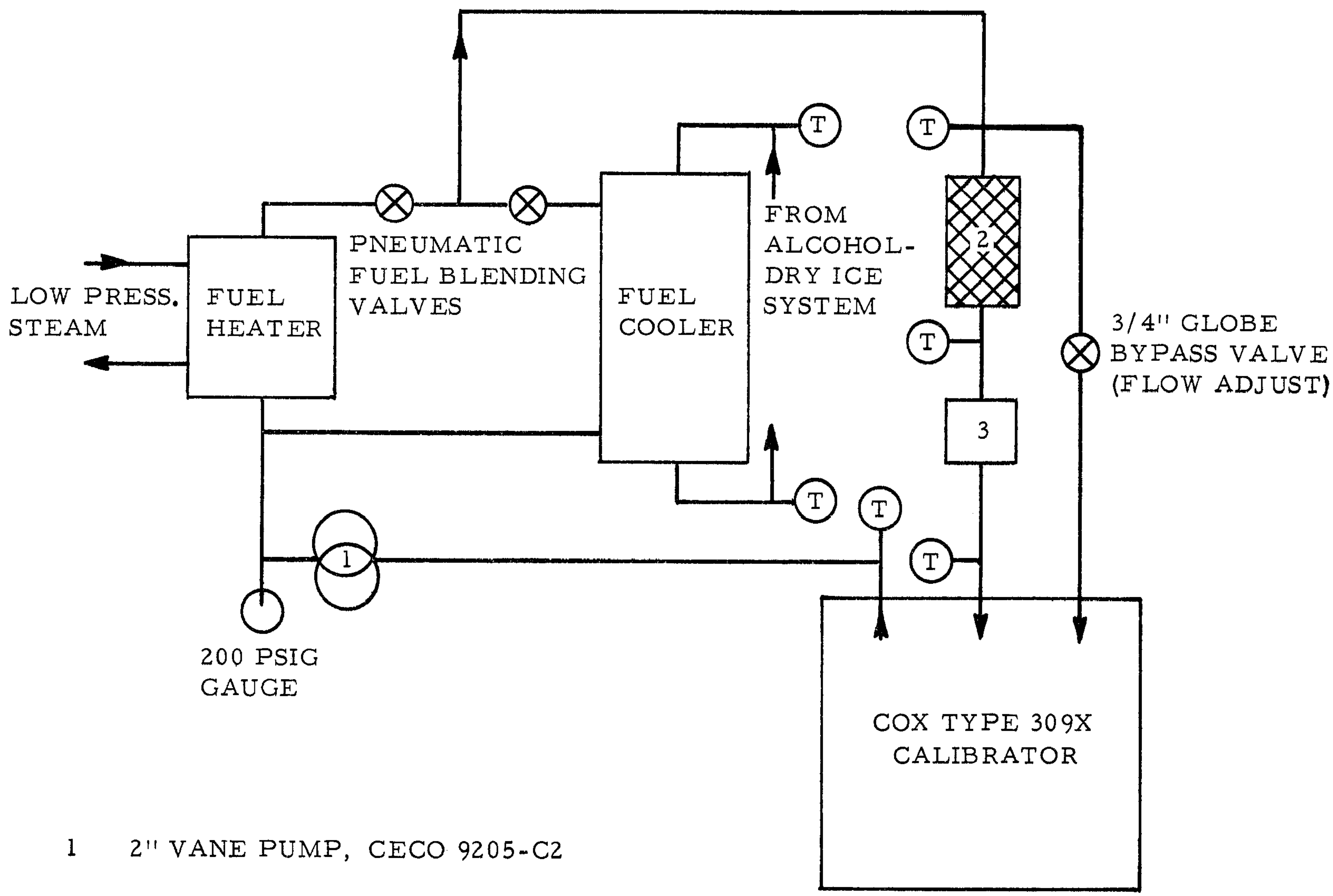
B-57 WING SECTION. Figure 3 is a schematic diagram of the installation of the B-57 wing section in an altitude chamber, as shown in Figure 4. The wing section includes a fuel tank of approximately 500-gallon capacity with an internally mounted fuel boost pump, Lear Part No. RR-1-11050-F.

Figure 5 shows the fuel connections between the wing and Weigh Tank. The 1-inch turbine type flowmeter and manual flow control valve were installed in the line from the boost pump to the weight tank. No direct connections were made to the weigh tank in order to prevent interference with the weighing system. The dump valve was a Whittaker Part No. 138091-1, electrically operated.

WEIGH TANK LOAD CELLS. Two Baldwin-Lima-Hamilton Model SR4 load cells, each 5,000-lb capacity, were located at each side of the weigh tank, centrally between the two ends. A tether was provided at one end to steady the tank. A Revere Part No. C-46928 digital readout was used to totalize the outputs of the load cells. The gain of the system was adjusted to indicate total weight directly.

The load cells were calibrated to correct for shifts due to temperature and altitude pressure during tests. The overall accuracy was estimated to be within ± 25 pounds when determining fuel weight. This represents an accuracy ranging from approximately ± 1 percent of the weight, with tank filled, to ± 5 percent with tank at low fuel level. This accuracy was considered adequate for the purpose of these tests since the data used was based on differences in fuel weights.

OPEN TANK. A small open tank was set below the drain of the weigh tank, with no direct connection to interfere with the function of the load cells.



1 2" VANE PUMP, CECO 9205-C2

2 COTTON WOUND FILTERS

3 TEST FLOW METER, 1" TURBINE TYPE

(T) THERMOCOUPLE

FIGURE 1. SIMPLIFIED SCHEMATIC OF FLOWMETER TEST FACILITY

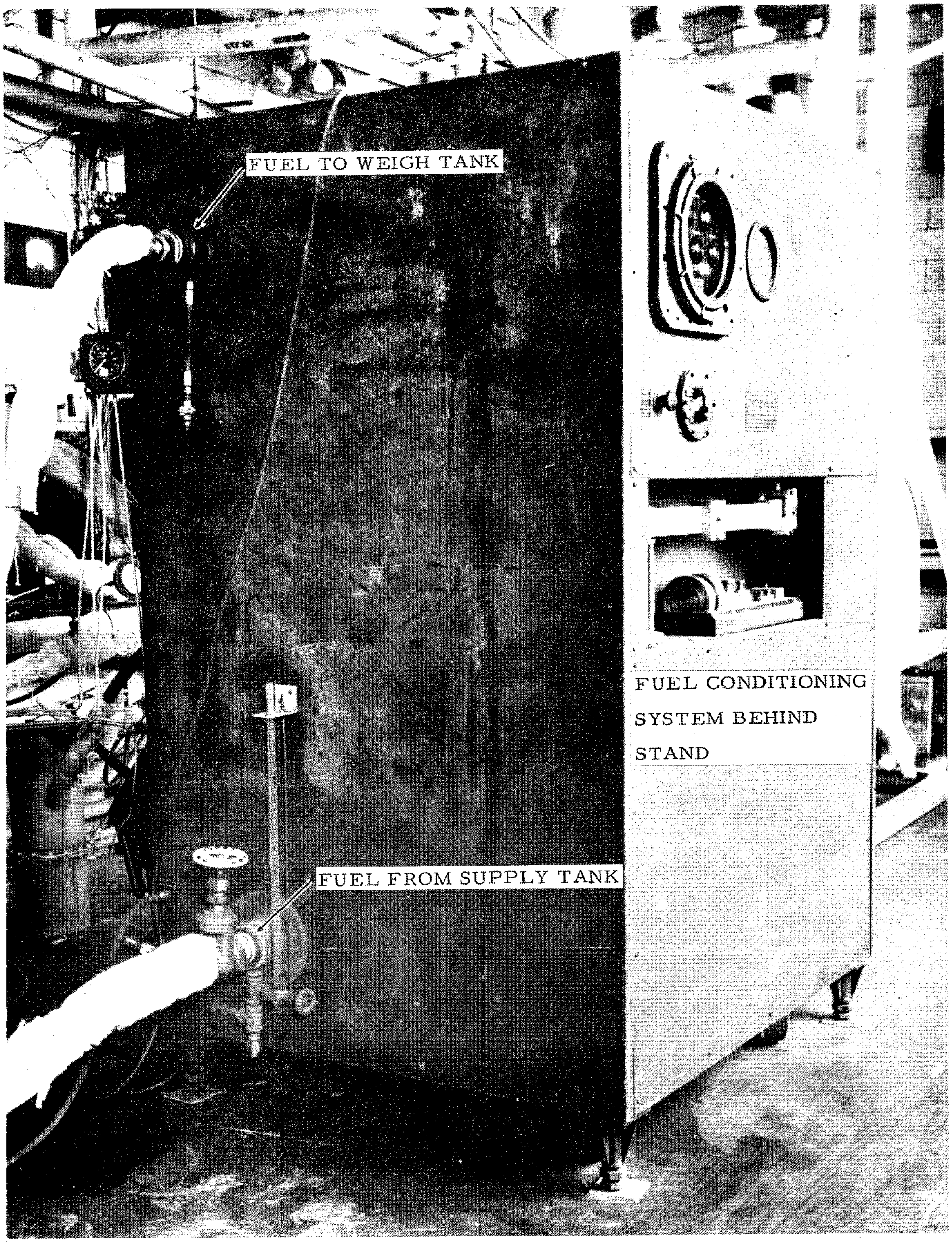
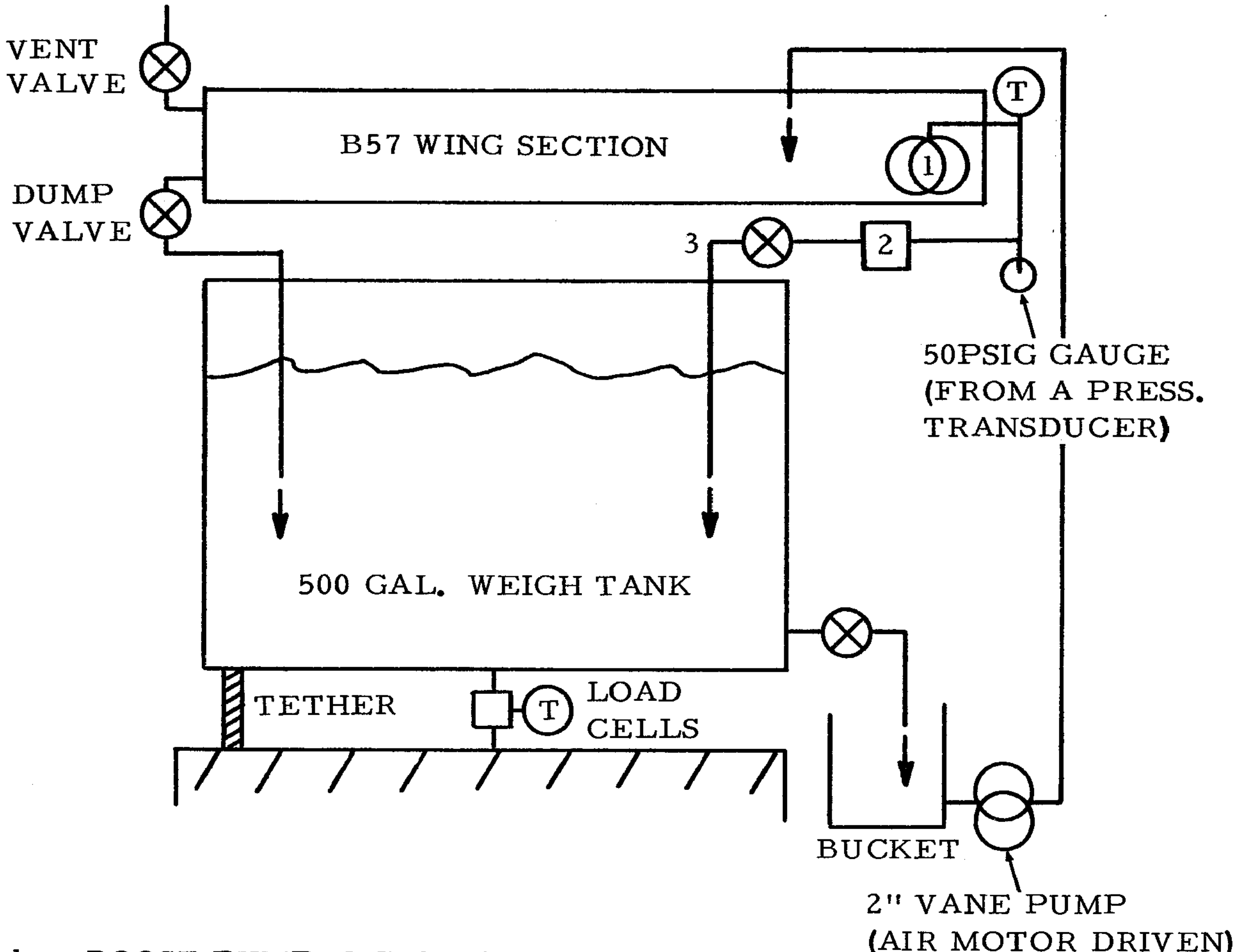


FIGURE 2. COX TYPE 309X CALIBRATION STAND



1 BOOST PUMP, WING TANK MOUNTED

2 FLOW METER, 1" TURBINE TYPE

3 1" GATE VALVE (FLOW ADJUST)

(T)– THERMOCOUPLE

FIGURE 3. SCHEMATIC OF B-57 WING SECTION TEST INSTALLATION

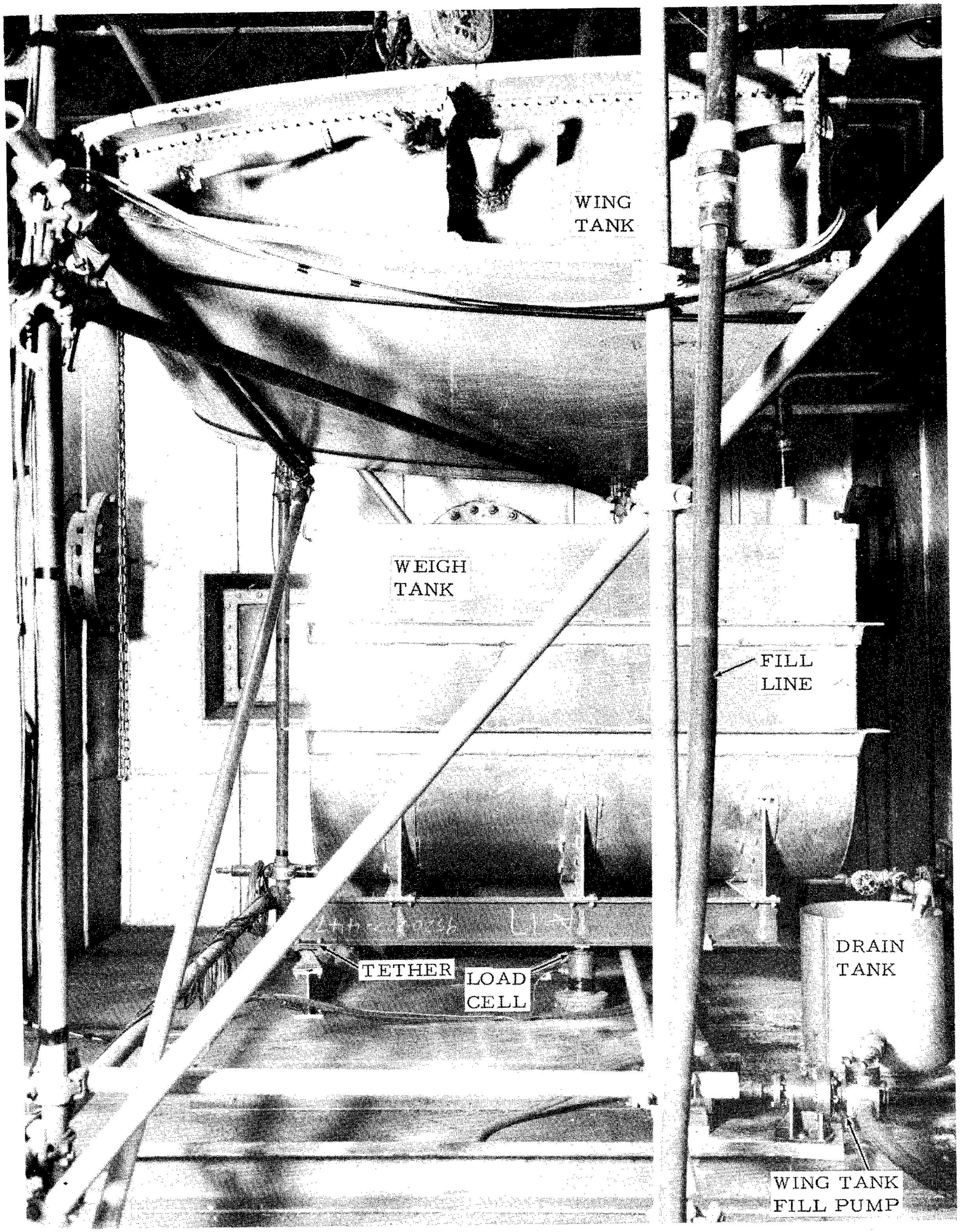


FIGURE 4. B-57 WING FUEL TANK TEST INSTALLATION IN ALTITUDE CHAMBER

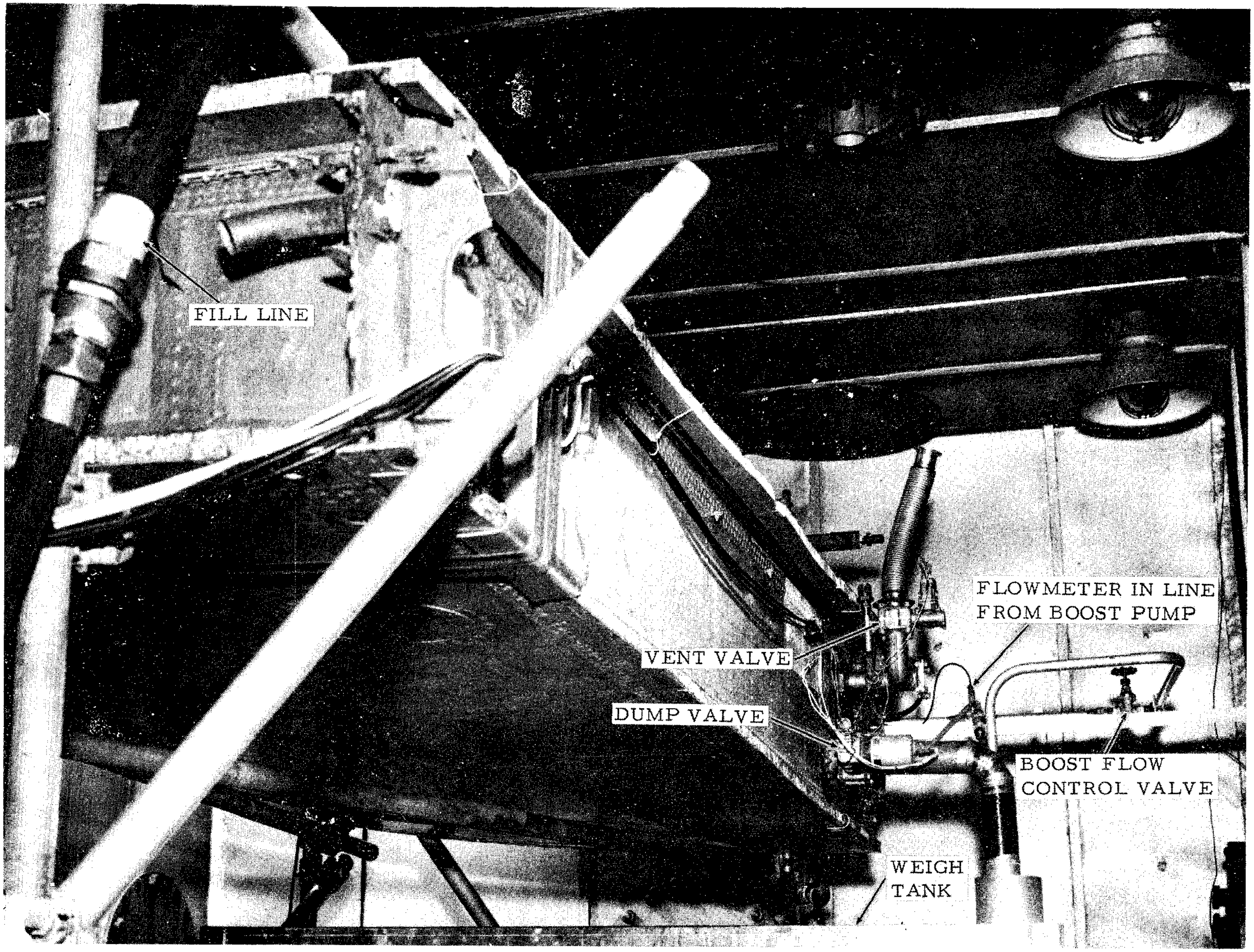


FIGURE 5. CONNECTIONS TO B-57 WING TANK

Recycling Test Fluid. After each test the weigh tank drain valve was opened, and the test fluid was pumped from the drain tank to the wing tank. The complete system (except load and flow indicators and controls) was installed in an altitude chamber capable of providing the temperature and altitude conditions to simulate operation to 35,000-feet altitude.

RESULTS AND DISCUSSION

PHASE A - FLOW RATE MEASUREMENT.

The turbine-type flowmeter was selected for investigation since it is the most convenient to use and appeared to offer the best probability for an acceptable calibration. Figure 6 shows the calibration curves for the 1-inch Waugh Model FL-16S flowmeter using gelled fuel at temperatures of -16, 25 and 59°F. The curves are essentially linear, the largest deviation being approximately 3 percent at 400 Hz with -16°F gel and 4 percent at 100 Hz with 59°F gel. The 59°F JP-5R reference fuel calibration is shown as a dashed line. The corresponding gelled fuel curve has a slope 13.5 percent less than that of the reference fuel because of the viscosity effect which caused drag on the impeller.

The gel calibration curves in Figure 6 were plotted from the averages of the flow rate values at times of gradual flow increase and decrease. Figure 7 indicates the maximum percentage of error in the gel calibration data from the median line. The increasing rate of flow direction was usually greater than the corresponding flow in the decreasing rate of flow direction. Occasionally, however, this flow pattern was reversed and the decreasing flows would be greater than the increasing flows. This reversal is arbitrarily indicated in Figure 7 as negative errors. The random scattering of the data was probably due in a greater degree to nonhomogeneity of the gelled fuel than to change in visocity.

The operating time for a calibration at any one fluid temperature was short, and the change in the gelled fuel viscosity small. Viscosity measurements before and after each calibration indicated a maximum decrease of 15 cP during a calibration at any one temperature. It was not known whether this relatively small viscosity change was sufficient to have caused the lower readings in the decreasing flow direction than in the increasing flow direction.

Figure 7 indicates that the 1-inch flowmeter is satisfactory for use with the particular gelled fuel tested when accuracy of approximately ±1.0 percent from 7,000 to 16,000 lb/hr is sufficient. At 2,000 lb/hr accuracy decreases to about 3.5 percent. For greater accuracy at the low flows, smaller size flowmeters are required.

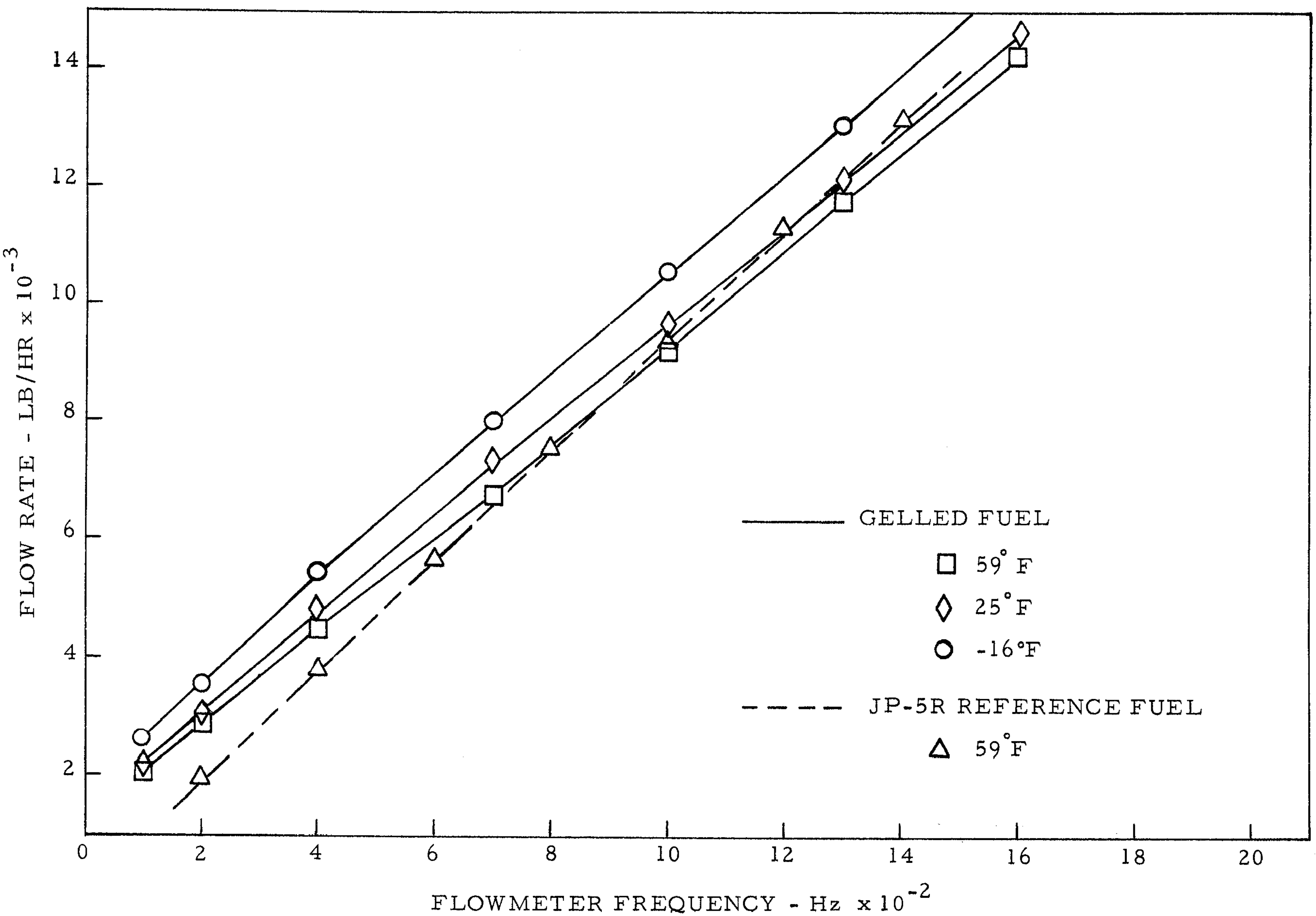


FIGURE 6. CALIBRATION OF WAUGH MODEL FL-16S-2 FLOWMETER

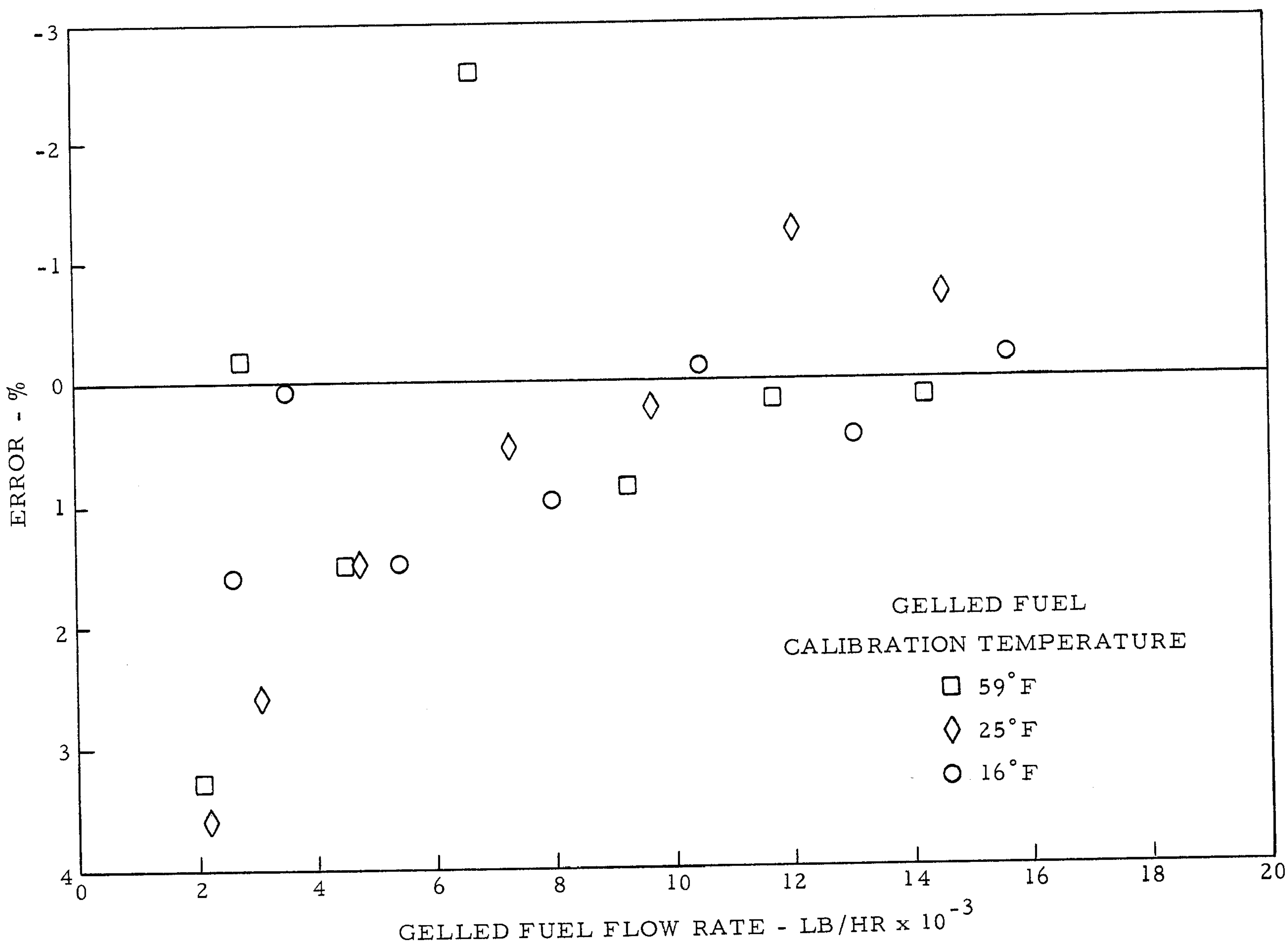


FIGURE 7. GELLED FUEL CALIBRATION ERROR- WAUGH FL-16S-2 FLOWMETER

Figure 8 shows the results of the calibration of 3/8- and 1/2-inch size flowmeters which were performed jointly in a parallel Navy gelled fuel program. The effect of viscosity was shown for each size flowmeter. When the gelled fuel viscosity changed from 120 to 40 cP the calibration curve for the 1/2-inch flowmeter shifted 18 lb/hr in the decreased flow direction. It shifted approximately 1.9 percent less at 950 lb/hr and it shifted to 4.5 percent less at 400 lb/hr. The effect of viscosity in the 3/8-inch flowmeter was greater, varying from approximately 4.3 percent less at 550 lb/hr, to 14 percent less at 150 lb/hr, for a change in viscosity from 120 to 60 cP. When the gelled fuel viscosity was constant the accuracy of the flowmeters was within 0.5 percent for gelled fuel temperatures down to at least 0°F.

PHASE B - TEST OF B-57 WING TANK FUEL SYSTEM.

PUMPDOWN TESTS. Pumpdown tests of the 500-gallon B-57 wing fuel tank using the fuel boost pump were made under test conditions simulating 10-minute climbs to 25,000 feet, 0.8 Mach number, standard day (25 ±3°F, 17.0 ±0.2 inches of mercury, absolute (in HgA)); and to 35,000 feet, 0.8 Mach number, standard day conditions (-16 ±3°F, 10.7 ±0.2 in HgA). Table 1 lists results of the tests. The tests to the 25,000-feet simulated conditions were made at two different temperature ranges.

The amount of residual fuel left in the tank after the 36°F to 38°F gelled fuel test was higher (by roughly 10 percent) than the amount of fuel left after the two tests with gel at 50°F to 74°F; this indicated a greater tendency of the gel fuel to cling to the interior of the tank surface at low temperatures because of the increased viscosity.

The amount of residual gelled fuel was approximately twice that of the JP-5R reference fuel over the range of test conditions. The JP-5R fuel remaining was roughly 3 percent of the 500-gallon tank capacity, and the gel 6 percent of tank capacity. Assuming that the lowest value of JP-5R remaining after pumpdown (109 pounds or 16 gallons) is the tare weight which could not be removed by pumping, the additional quantity of gel remaining (in excess of tare) was 14 gallons at 73°F, and 17 gallons at 37°F.

The fuel temperature column in Table 1 indicated a change in temperature during each test. This variation occurred because the fuel temperature did not reach the ambient temperature during the 8-hour presoak and continued to change during the scheduled test periods. The temperature change was consistently greater for the JP-5R fuel even though the test times were 30 to 40 percent shorter than those for the gelled fuel because of the lower heat transfer capability of the gelled fuel. The reduced heat sink capability of the gelled fuel will, for example, require larger oil coolers.

The above discussion presents a qualitative observation of heat transfer effects; a formal evaluation of oil cooler performance was to have been made under one of the phases of the program established by reference (2) which has been deferred until a decision is made on the use of a new fuel.

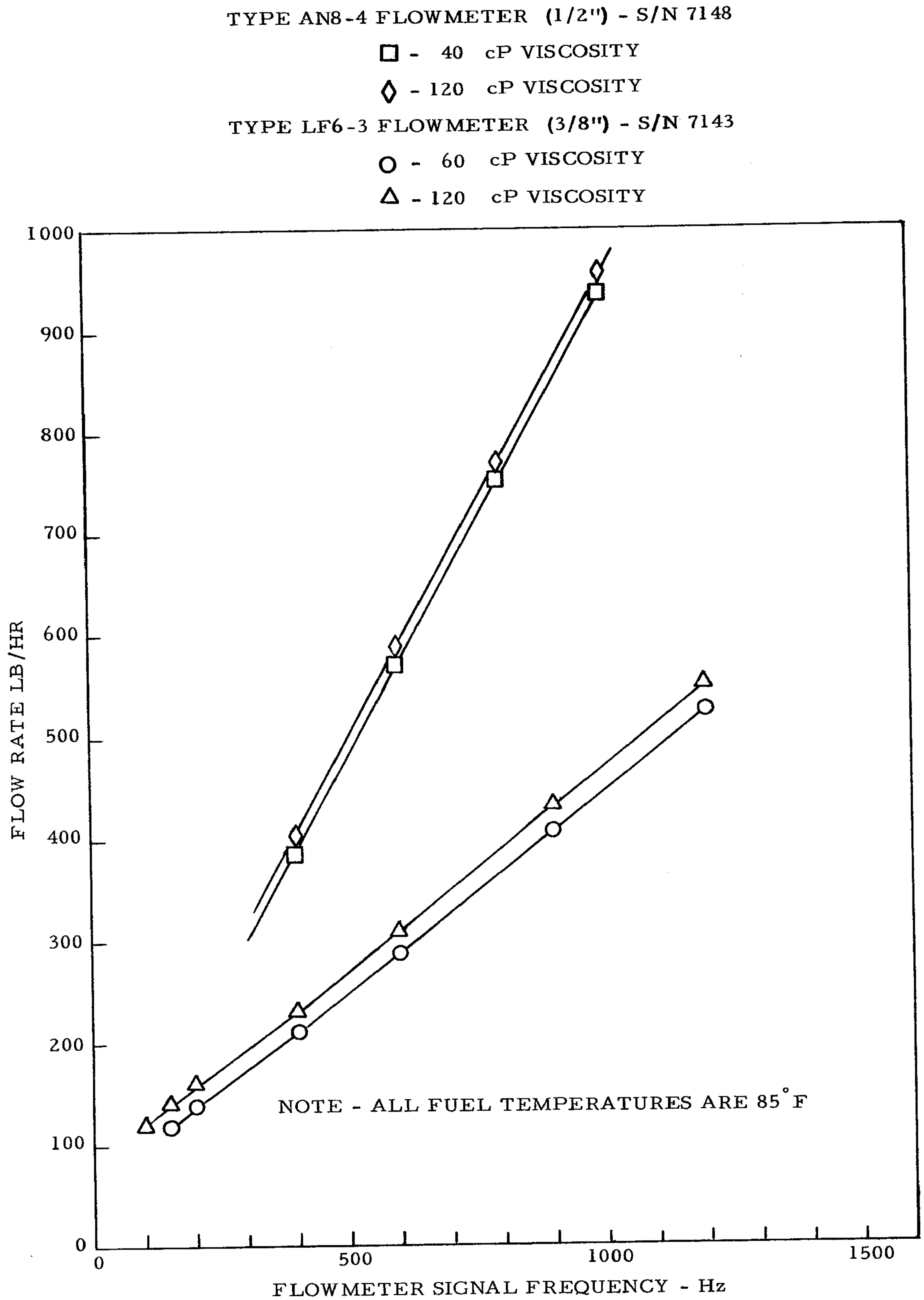


FIGURE 8. EFFECT OF GELLED FUEL VISCOSITY

TABLE 1. ENGINE FUEL FEED SYSTEM TESTS

Gelled Fuel						JP-5R Reference Fuel			
Fuel Temp. °F	Fuel Visc. cP	Quantity Pumped lbs.	Pumping Time min.	Residual Fuel lbs.	Altitude Chamber Test Conditions	Fuel Temp. °F	Quantity Pumped lbs.	Pumping Time min.	Residual Fuel lbs.
36 to 38	395 at 40°F	2315	26	225	Ambient to 25°F Air Temp. and 17 in. HgA Press. in 10 minutes.	27 to 31	1698	15.5	109
74 to 71	330 at 67°F	2440	24	200	Same as above except the gelled fuel test only was at sea level pressure throughout.	60 to 53	1846	17	109
53 to 50	360 at 55°F	2300	31	206	Ambient to -16°F Air Temp. and 10.7 in. HgA Press. in 10 minutes.	56 to 50	1835	18.5	115

BOOST PUMP TESTS. Figure 9 is a plot of the boost pump tests. The initial high flows depict the pump output with the flow control valve wide open for the first 10 minutes of the test period. The JP-5R flows were essentially constant at about 8,900 lb/hr. The gelled fuel flows increased gradually from about 6,700 to 7,700 lb/hr, averaging approximately 19 percent less than the JP-5R flow. This decrease in capacity was not critical since full capacity of the pump was not required and maximum engine fuel flow could be provided, although at a lower pressure.

After 10 minutes the flow rates were manually reduced roughly 50 percent to simulate cruise flow rates. When the fuel in the tank was depleted the flow rate decreased sharply. This decrease occurred after approximately 14 to 17 minutes of test time with JP-5R and 24 to 30 minutes with gelled fuel. The pump was then shut off within 1 to 2 minutes after decrease in fuel flow.

The fuel system was originally filled with nine 55-gallon drums of the gelled fuel. The test period was longer when using the gelled fuel because a greater quantity of gelled fuel was used than JP-5R. The quantity of JP-5R in the wing was restricted because several leaks developed in the upper sections of the wing, so the initial fuel level was maintained at a point below the leaks. The leaks did not occur with the gelled fuel which was tested first. The viscosity of the gelled fuel did not deteriorate significantly during the test period.

JETTISON TESTS. Jettison tests of the B-57 wing tank were conducted at test conditions simulating 10,000 feet, 0.6 Mach number, standard day (57 ±3°F, 26.3 ±0.2 in HgA), and 25,000 feet, 0.8 Mach number, standard day conditions (25 ±3°F, 17.0 ±0.2 in HgA). The results of the tests were shown in Table 2.

The high fuel residual after dumping was due to the mounting of the dump valve too high above the bottom surface of the wing tank. Comparing the residual quantities with 57°F fuels, it was seen that 94 pounds more of the gelled fuel remained than of the JP-5R after the dumping period. This compared well with the 91-pounds difference with the boost pump tests using 50°F to 56°F fuel. After 2 additional hours only 22 pounds more gelled fuel drained from the wing tank. At the lower temperature (23°F gel) 265 pounds more gelled fuel remained than remained when JP-5R was tested. However, as may be seen from Figure 10, the 23°F gel after 25 minutes did not yet approach an asymptotic value.

Other effects on comparative dumping performance of the gelled fuel were apparent from Figure 10. The initial dumping rate of the gelled fuel was 138 lbs/min, or almost 64 percent less than the initial rate for JP-5R of 380 lbs/min. Also the transition from high dumping rates to low values, as the final quantity was being asymptotically approached, was more rapid for JP-5R, occurring 5 to 10 minutes for JP-5R versus approximately 30 minutes for the gelled fuel. In the 57°F fuel tests, the dumping operation was completed in about 15 to 20 minutes with JP-5R fuel, whereas 35 to 55 minutes were required to dump an equal quantity of the gelled fuel. The times required to dump equal quantities of JP-5R fuel at 26°F and gelled fuel at 23°F

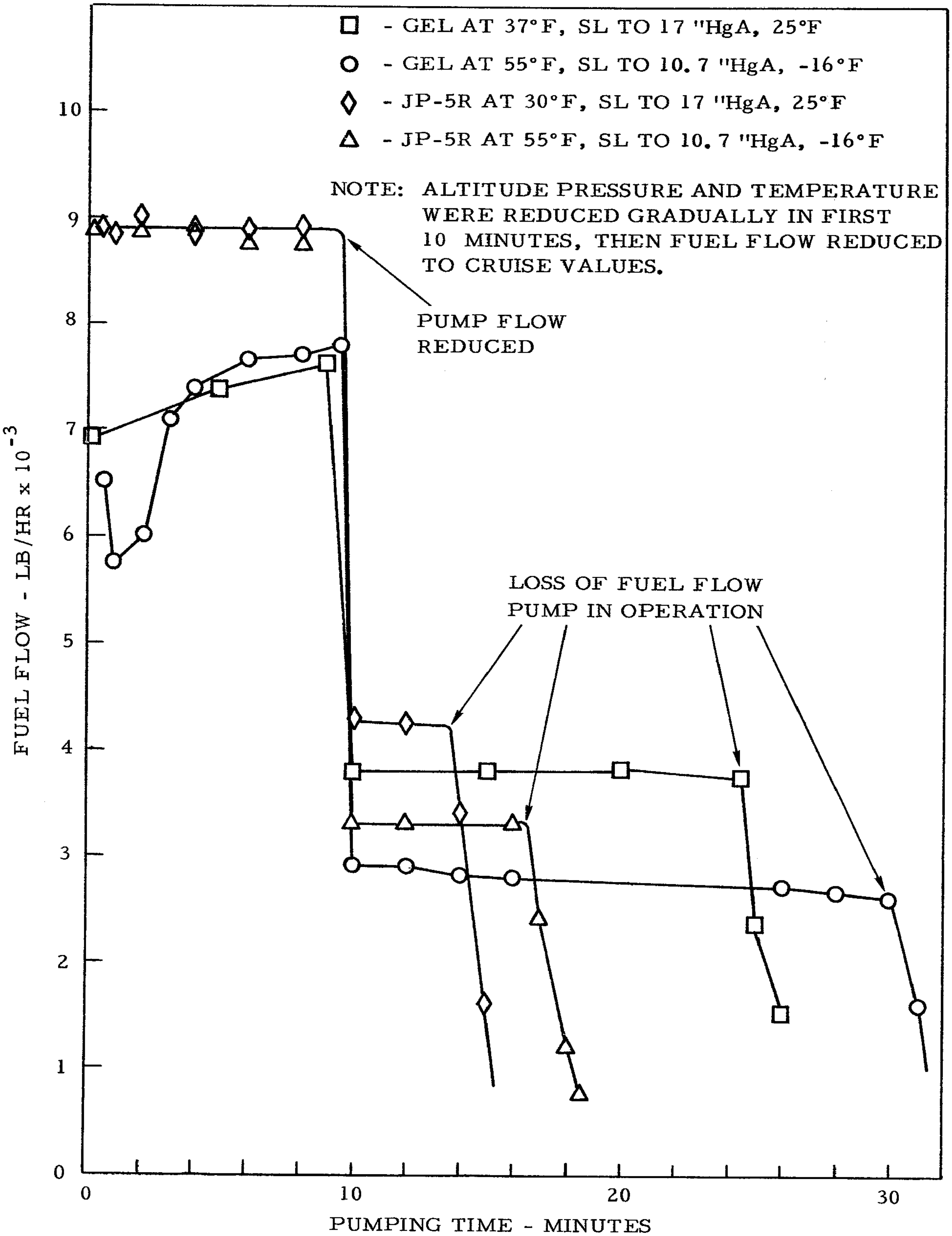


FIGURE 9. B-57 WING TANK FUEL BOOST PUMP TESTS WITH GELLED FUEL AND JP-5R REFERENCE FUEL

TABLE 2. FUEL JETTISON TESTS

Gelled Fuel: Fuel Temp. °F	Gelled Fuel: Fuel Visc. cP	Gelled Fuel: Quantity Dumped lbs	Gelled Fuel: Dump Time min	Gelled Fuel: Residual Fuel lbs	Altitude Chamber Test Conditions	JP-5R Reference Fuel: Fuel Temp. °F	JP-5R Reference Fuel: Quantity Dumped lbs	JP-5R Reference Fuel: Dump Time min	JP-5R Reference Fuel: Residual Fuel lbs
23	520 at 30°F	1713	25	970	8-hr soak at 25°F - Test at 25°F Air Temp. 17 in. HgA Press.	25	1985	20	705
57	-	1677	60	808	8-hr soak at 57°F	57	1148	20	714
			After 2 hrs Additional	786	Test at 57°F Air Temp. and 26.3 in. HgA Press.				

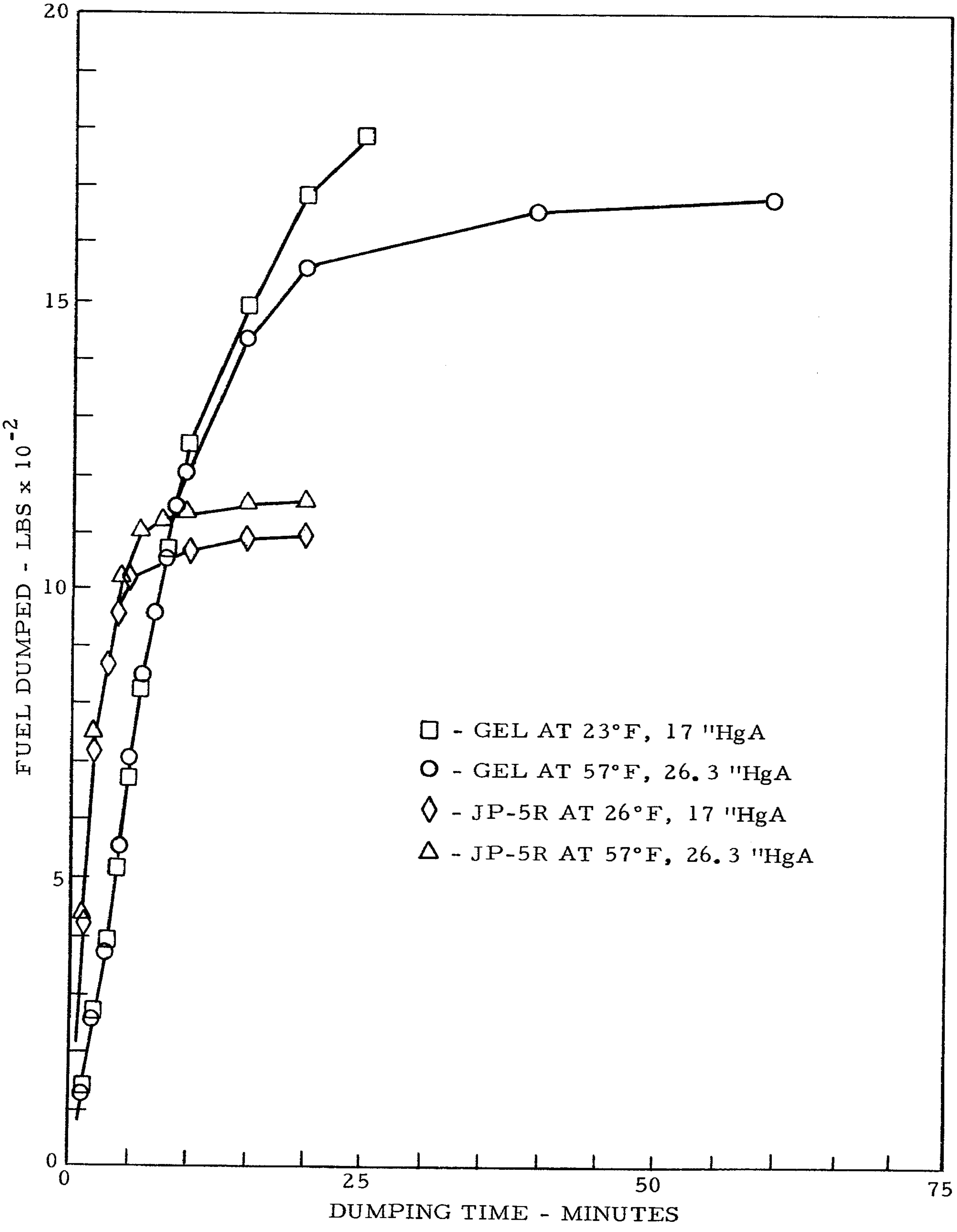


FIGURE 10. DUMPING RATES - B-57 WING TANK WITH GELLED FUEL AND JP-5R REFERENCE FUEL

were approximately the same as in the 57°F fuel test; being 15 minutes for JP-5R and 40 to 60 minutes for the gelled fuel. The longer dumping time could seriously affect safety in an emergency when fuel must be dumped quickly.

VISCOSITY DETERIORATION. The viscosity of the gelled fuel was found to deteriorate rapidly in storage. Table 3 lists data provided by the manufacturer on changes in viscosity with storage time of 16 batches of the gelled fuel. Eighteen drums from batches 7 and 8 were originally provided by the FAA for tests by the Naval Air Propulsion Test Center (NAPTC) under this program. The viscosity of batch 7 decreased to 12 percent of its original value after 7 months and that of batch 8 to 40 percent of its original value after 6 months storage. Viscosity checks of the 18 drums by NAPTC after 7 months agreed with the values in Table 3. The three drums of batch 7 supplied to NAPTC were down to 40 cP viscosity and the 15 drums of batch 8 measured from 100 to 120 cP.

Because of the viscosity change in the original shipment of gelled fuel, the FAA supplied 15 drums of fresh fuel for the tests under this program. Checks of the viscosity of each drum of the new fuel after receipt (in February 1972) showed that the viscosity varied widely; 10 drums varied from 200 to 250 cP, three drums from 350 to 450 cP, one drum was 750 cP and the last about 2,000 cP. During tests under Phase A the viscosity of the gelled fuel dropped from the original value of 230 cP to 100 cP. However, the viscosity remained reasonably constant throughout tests under Phase B, ranging between 300 and 330 cP.

TABLE 3. STORAGE STABILITY OF EXPERIMENTAL GELLED FUEL

(Large Scale Production Batches)

Batch No.	Lot No.	Date Produced	Destination	Brookfield Viscosity (cP) 10 RPM No. 3 Spindle: 1 day	1 mo.	4 mo.	5 mo.	6 mo.	7 mo.
* 1	10602-1	5-25/26-71	Navy (NAPTC)	300	170	70	70	70	65
2	10602-2	6-6-71	FAA	210	160	100	95	85	80
* 3		6-7/8-71	"	250	170	120	110	100	90
4	Truck	6-7/8-71	"	270	180	120	115	110	90
* 5		6-9/11-71	"	220	130	80	75	75	70
6		6-9/11-71	"	200	200	130	120	115	70
* 7	** 06141	6-11/15-71	"	210	110	60	60	60	25
8	** 06211	6-17/21-71	"	240	230	220	185	95	--
9	07031	6-28/30-71	"	210	150	90	90	100	--
*10	07031	(6-29) 7-2-71	"	280	140	30	30	20	--
*11	07231	7-21/22-71	SRI	240	150	75	60	--	--
12	07241	7-21/23-71	Army	290	270	170	95	--	--
*13	01062-1	1-10-72	FAA	160	--	--	--	--	--
14	01062-2	1-10-72	"	420	--	--	--	--	--
*15	01102-1	1-11-72	"	180	--	--	--	--	--
16	01102-2	1-11-72	"	540	--	--	--	--	--

* Manufactured with deviations from procedure originally developed.
** Batches in original shipment by the FAA to NAPTCC.

CONCLUSIONS

The tests of full-scale aircraft fuel system components using the gelled fuel described herein have led to the following conclusions:

1. Standard turbine-type flowmeters are suitable for measuring gelled fuel flow rates. Accuracies within 1 percent are attainable over at least the upper half of the flow range with gelled fuel at temperatures down to -16°F.

2. Pumpdown of a B-57 wing fuel tank using the engine fuel boost pump leaves a residual gelled fuel quantity of approximately 6 percent of the tank capacity compared to the 3-percent tare quantity when pumping JP-5R fuel.

3. After jettison, the residual gelled fuel left in the fuel tanks of an aircraft is essentially the same as the amount left after the pumpdown tests. However, the pumping rate is less with gelled fuel than with JP-5R fuel at the same temperature.

4. The gelled fuel tested is unstable in storage with respect to viscosity.

RECOMMENDATIONS

1. Further tests with the particular gelled fuel tested should be discontinued because of the unstable viscosity characteristics.

3. Gelled fuels having low, stable viscosity should be developed and tested in aircraft fuel systems.

REFERENCES

1. FAA Agreement No. DOT FA71NA-AP-94, Fuel System Evaluation with Gelled Fuel, (Project 503-303-05X) of June 1971.

2. Erickson, R. E., and Krajewski, R. M., Chemical and Physical Study of Fuels Gelled With Hydrocarbon Resins, The Dow Chemical Co., Midland, Michagan, DOT/FAA/NAFEC, Contract No. DOT-FA-70NA-496, Report No. FAA-RD-71-34, July 1971.