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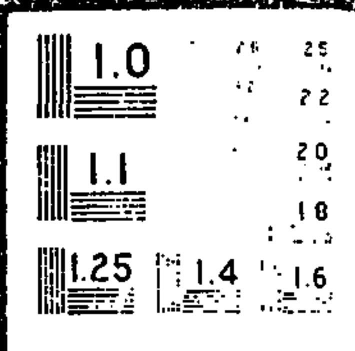

Internal Defoliant Dispenser A/A45Y-1

A. W. Smallwood
R. L. Dear
A. R. Ortell
HAYES INTERNATIONAL CORPORATION

TECHNICAL REPORT AFATL-TR-67-127

OCTOBER 1967

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AIR FORCE ARMAMENT LABORATORY
AIR FORCE SYSTEMS COMMAND
EGLIN AIR FORCE BASE, FLORIDA

INTERNAL DEFOLIANT DISPENSER

A/A45Y-1

A. M. Smallwood
R. L. Dear
A. R. Ortell

FOREWORD

Under Contracts AF 08(635)-3609 and AF 08(635)-4894, Hayes International Corporation, Birmingham, Alabama has developed the A/A45Y-1 Internal Defoliant Dispenser as a quick in-out system for the C-130 and C-123 aircraft. This report, covering the period of October 1965 thru October 1967, formally records the engineering data generated under the above contracts including results, conclusions, and recommendations. This report is covered under project number 2525 and task order number 02 and deals primarily with AF Contract AF 08(635)-4894.

The cognizant USAF project engineers for this program were Lt Arnold W. Blomquist, Lt Jon H. Arvik, Lt W. J. Crea, Jr. and Lt K. A. Reynard of the Air Force Armament Laboratory, RTD, Biological-Chemical Division (ATCB), Eglin Air Force Base, Florida. Messrs. A. M. Smallwood (project engineer), R. L. Dear, and A. R. Ortell were the principal investigators and authors of this report. Mr. J. F. Cundiff provided considerable technical assistance in programming the digital computer for the program and writing the field analysis. Messrs. F. J. Weatherbee, J. D. Stewart, and B. L. Lewis provided considerable technical assistance in the design of the A/A45Y-1 dispenser. Mr. J. L. Harrington, Chief of the Airborne Weapons Group, was responsible for the overall effort.

Information in this report is embargoed under the Department of State International Traffic In Arms Regulations. This report may be released to foreign governments by departments or agencies of the U.S. Government subject to approval of the Air Force Armament Laboratory (ATCB) Eglin AFB, Florida 32542, or higher authority within the Department of the Air Force. Private individuals or firms require a Department of State export license.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Nicholas H. Cox, Colonel, USAF
Chief, Bio-Chemical Division

ABSTRACT

Hayes International Corporation has developed the internal defoliant dispenser, A/A45Y-1, suitable for quick in-out installation in the C-130 and C-123 aircraft. The internal defoliant dispenser provides for loading, transporting, and dispensing of 958 gallons of defoliant chemical, and in case of an emergency, dumping the full load of chemical overboard in less than one minute. The dispenser was designed to deliver agent at a concentration of three gallons per acre over an effective swath width of 120 feet from an altitude of 150 feet in either the C-123 or C-130 aircraft. The results of tests conducted at Eglin Air Force Base, Florida indicated that the optimum parameters for the C-130 aircraft were an altitude of one hundred feet and a maximum swath of seventy feet to obtain a concentration of three gallons per acre. The optimum parameters for the C-123 aircraft were an altitude of 150 feet and a maximum swath of 40 feet for the same concentration. The fuselage-mounted spray boom does not deliver the defoliant agent far enough outboard to be affected by the action of the wingtip vortices. Previous testing with defoliant agent demonstrated that wing mounted booms subject the spray to these vortices and produce wider swath width. It is recommended that an optimized wing boom be developed in order to increase the swath width.

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LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS AND SYMBOLS

D = internal diameter of pipe, feet

d = internal diameter of pipe, inches

f = friction factor in formula $h_L = fLv^2/D2g$

g = acceleration of gravity, 32.2 feet per second per second

H = total head, feet of fluid

h_L = loss of static pressure head due to fluid flow, feet of fluid

K = resistance coefficient or velocity head loss in the formula, $h_L = Kv^2/2g$

L	=	length of pipe, feet
L/D	=	equivalent length of a resistance to flow, pipe diameters
P	=	pressure, pounds per square inch gauge
Q	=	rate of flow, gallons per minute
q	=	rate of flow, cubic feet per second at flowing condition
R_e	=	Reynolds number
S	=	specific gravity of liquids relative to water, both at standard temperature (60°F)
v	=	mean velocity of flow, feet per second
Δ	=	differential between two points
ρ	=	weight density of fluid, pounds per cubic feet
μ_e	=	absolute viscosity, pound mass per foot second or poundal seconds per square foot
μ'_e	=	absolute viscosity, slugs per foot second or pound-force seconds per square foot

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SECTION I

INTRODUCTION

The purpose of this technical report is to present engineering data generated under Contracts AF 08(635)-3609 and AF 08(635)-4894. These contracts resulted in the development of the internal defoliant dispenser, A/A45Y-1, designed to disseminate various chemical agents utilizing C-123 and C-130 aircraft.

The capability for quick installation and removal of the dispensing system with minimum modification to the aircraft was a prime requirement under these contracts. Compliance with this requirement resulted in the use of a fuselage-mounted spray boom. Due to the narrow spray swath width generated by the fuselage-mounted boom, an Air Force-developed wing spray boom is used to achieve a wider swath width in current tactical applications.

The report contains a description of the dispenser. This is followed by a section on development tests of the internal defoliant dispenser. System performance is then provided encompassing liquid level gage calibration, conversion factors for various agents, refill by jet-pump, emergency dump test, flow rate test using an induced pressure, fluid analysis of system with thirty-foot fuselage-mounted spray boom and dispenser performance. Within the appendices are fuselage spray-boom drag analysis, weight and balance analysis for C-123 and C-130 aircraft, stress analysis, and dispenser specifications.

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SECTION II

DESCRIPTION OF A/A45Y-1 INTERNAL DEFOLIANT DISPENSER

The A A45Y-1 Internal Defoliant Dispenser is a complete airborne defoliant dispensing system. The dispenser is packaged to permit rapid installation into, and removal from, C-130 and C-123 aircraft, with only minor modifications required to the affected aircraft. See figures 1 and 2.

The Internal Defoliant Dispenser, Part No. A/A45Y-1, provides for loading, transporting and dispensing of 958 gallons of defoliant chemical, and in case of an emergency, dumping the full load overboard in less than one minute. The tank and cradle assembly is mounted on detachable casters which are removed before anchoring in the host aircraft. A control console is electrically connected to the aircraft electrical system, controls and indicators in the flight compartment, and the electrically operated units within the system. Pressure is applied to defoliant chemical by an engine and pump assembly mounted on the cradle assembly. The defoliant is transported to a 30-foot fuselage-mounted spray boom. The fuselage boom incorporates eighteen (18) whirljet spray nozzles through which the defoliant chemical is discharged into the airstream.

LEADING PARTICULARS

Length (app)	16 feet, 4 inches
Width (app)	4 feet, 10 inches
Height (app) (without casters)	6 feet, 5 inches
Weight	
Empty	1905 lbs
Full	12,055 lbs with agent having a specific gravity of 1.27
Capacity	958 gallons
Normal operating pressure	55 ± 5 psi
Normal dispensing interval	3 to 4 minutes
Emergency dump time	Less than 1 minute
Electrical system	28 volts dc (supplied by host aircraft)
Dump valve operation	Electrical or manual
Refill time (app)	15.5 minutes with an agent having a specific gravity of 1.27 through a 50-foot length of refill line
Dump valve	Electrical, 10-inch diameter
Spray valve	Electrical, 3-inch diameter
Suction valve	Manual, 3-inch diameter

The dispensing operation and emergency dump valve operation can be controlled from either the control console near the tank and cradle assembly or from the pilot's position in the flight compartment. The pump is capable of maintaining 55 ± 5 psi pressure during the normal 3-1/2 minute (approx) period of operational spraying. Refilling the tank assembly is accomplished with power and equipment contained within the dispensing system.

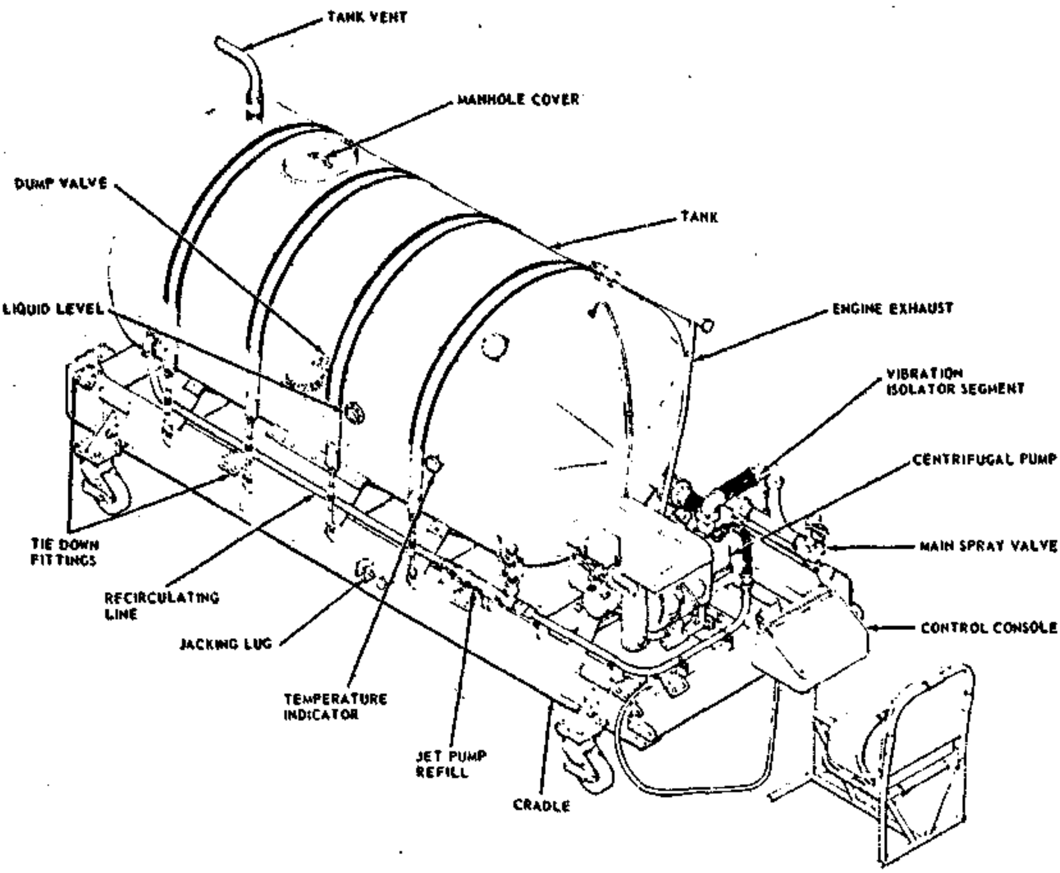

Figure 1. Major Components of Defoliant Dispenser

Tank and Cradle Assembly

The tank and cradle assembly is the major unit of the entire system comprising (1) a 958 gallon tank with baffles, manhole, tube connections and stabilizing and tiedown brackets; (2) an engine and pump assembly consisting of a four cylinder horizontally opposed engine and pump directly coupled to the engine crankshaft; and (3) a cradle equipped with four detachable casters which carries the tank and engine and pump assembly. A temperature gage and a fluid quantity gage are installed in the tank. The engine is slightly modified from its original configuration to achieve adaptability to the requirements of the dispenser system. The detachable casters are provided for limited mobility and are removed after the unit has been positioned in the aircraft.

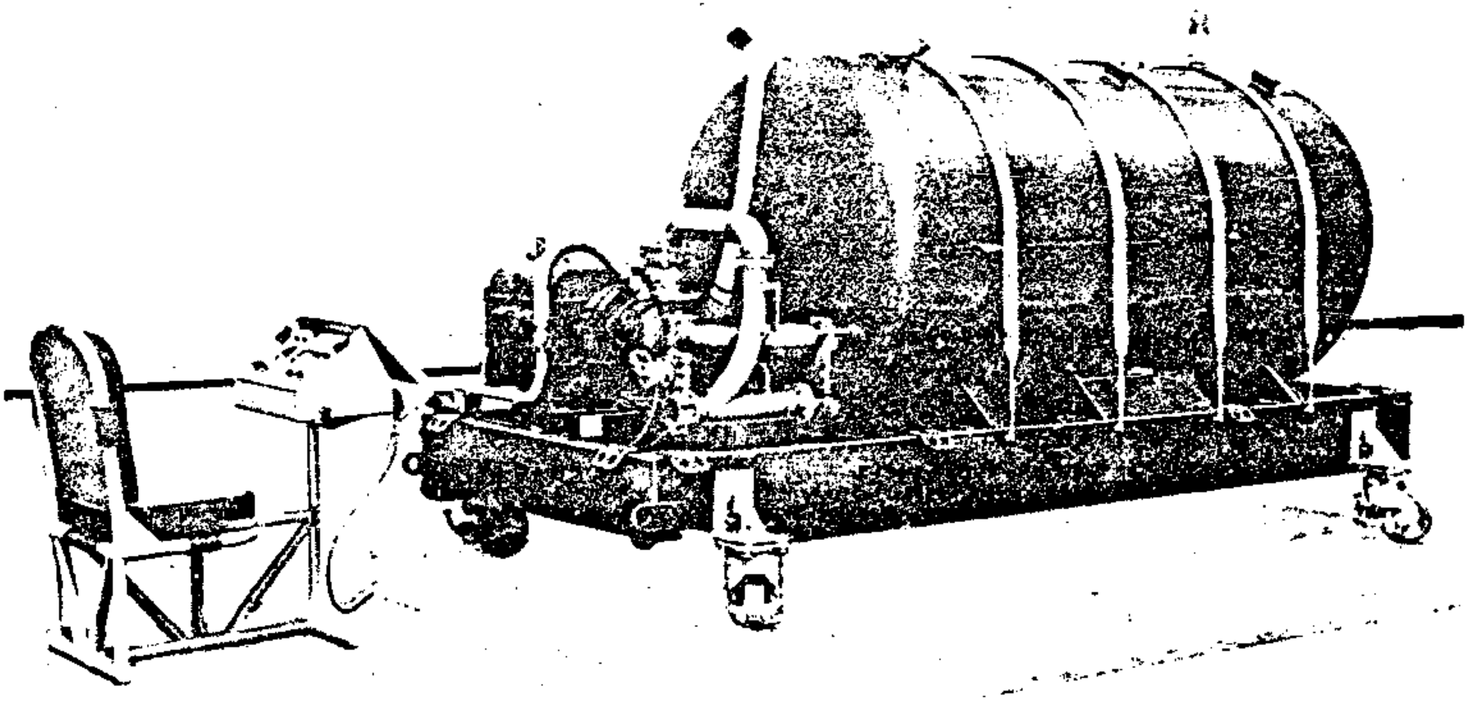

Figure 2. Defoliant Dispenser (Right Side)

The defoliant in the tank is fed through a suction line to the pump (two assemblies used on C-130 aircraft). The pump driven by an air-cooled engine forces the defoliant through a discharge line to a spray valve. A recirculation line is provided so that the defoliant will recirculate back through the tank when the spray valve is closed. When the spray valve is open, the defoliant is forced into the spray boom and atomized by spray nozzles. When the tank is empty, a float-operated switch located in the tank automatically stops the engines. On C-130 aircraft, when either tank is empty, the engine of the empty unit will automatically shut down. The spray valve will not automatically close until the second unit's tank empties and the float switch is actuated.

The centrifugal pump (figure 3) consists essentially of an impeller and pump body and is driven by the engine through a direct drive. The speed of the engine controls the quantity of defoliant being dispensed.

The recirculation line incorporates a jet-pump (ejector) tank refilling system which utilizes the fluid left in the tank from prior operation to initially operate the jet pump. A temperature gage and liquid-level indicator located on the side of the tank indicate defoliant temperature and quantity respectively in the tank.

Dump Valve

The dump valve is an electrically or manually operated 10-inch diameter gate valve (figure 4). It is designed for horizontal (vertical flow) installation and liquid flow in only one direction. The bottom of the defoliant tank incorporates a vortex interrupter and adapter to which the dump valve is secured. The dump valve assembly is aligned with an opening in the belly of the aircraft. This opening is covered by a spring-loaded door. A high speed motor coupled to an actuator provides 2-second operation of the dump valve in either direction. Valve-open condition is electrically indicated on the control console and on the pilot's instrument panel.

Control Console

The control console is the nerve center of the defoliant system (figure 5). All functions are controlled from this position; all monitoring equipment is located in this position; and the electrical supply is channeled and protected at this position. Prefabricated electrical cables tie the control console to all related parts of the system including the controls on the pilot's instrument panel and the aircraft electrical supply system. Tandem or single installations are controlled and monitored from the control console without any changes or alterations being performed. In the event of failure of the aircraft electrical system, certain critical functions have an option of manual operation.

Magneto Switch - The MAGNETO switch (AFT UNIT and FWD UNIT) is a single-pole double-throw toggle switch used to control the engine magneto. In the down position the engine magneto is grounded. In the up position the ground is removed from the magneto permitting the engine to run (if tank is not empty).

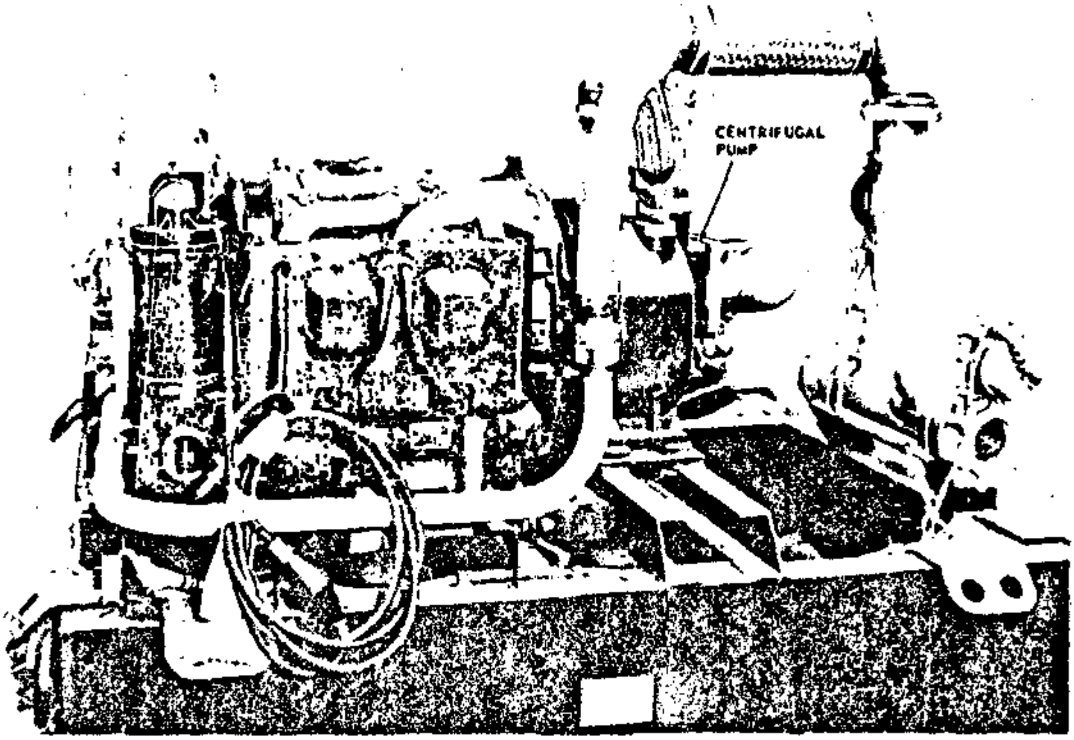

Figure 3. Centrifugal Pump

Choke Switch - The CHOKE switch (AFT UNIT and FWD UNIT) is a spring-loaded pushbutton switch used to control the solenoid that actuates the engine choke. When depressed, the CHOKE switch applies power to the engine choke solenoid.

Sta Switch - The START switch (AFT UNIT and FWD UNIT) is a spring-loaded pushbutton switch used to control the engine starter. When depressed, the START switch applies power to the engine starter. The START switch is guarded to prevent accidental engagement of the engine starter.

Throttle Switch - The THROTTLE switch (AFT UNIT and FWD UNIT) is a three-position toggle switch spring-loaded to the neutral position. The switch has INCREASE and DECREASE positions and is used to electrically control the engine throttle through a geared servo-motor. The engine throttle may be set at any intermediate position between minimum and maximum engine rpm by positioning the switch to INCREASE or DECREASE and releasing to the neutral position when desired engine RPM is reached. A governor on the engine maintains engine speed at a given setting.

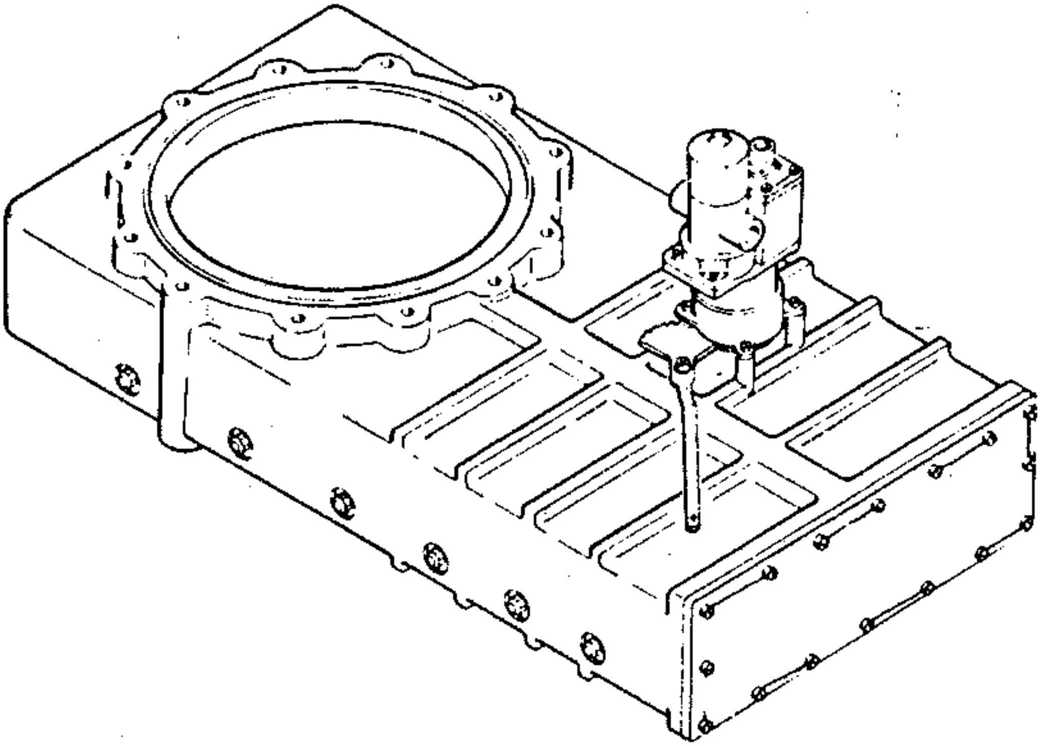

Figure 4. Dump Valve

Spray Valve Switch - The SPRAY VALVE switch is a single-pole double-throw toggle switch used to electrically open and close the spray valve. In the OPEN position power is applied to open the spray valve. In the CLOSED position power is applied to close the spray valve. The SPRAY VALVE switch is guarded in the PILOT position. A cockpit SPRAY VALVE switch is also provided for control of the spraying operation by the pilot.

Dump Valve Switch - The DUMP VALVE switch, located at the extreme left side of the control panel (figure 5), provides electrical control of the dump valve. The switch is provided with a guard which maintains the switch in the CLOSED position. Placing the switch in the OPEN position actuates the valve motor and opens the dump valve.

The cockpit DUMP VALVE switch provides electrical control for opening of the dump valve by the pilot. Operation is in conjunction with the console DUMP VALVE switch. Placing either switch in the OPEN position actuates the dump valve motor and opens the dump valve.

Float Switch Override - The FLOAT SWITCH OVERRIDE (AFT UNIT and FWD UNIT) is a single-pole double-throw toggle switch (with a holding coil) used to override the float switch (in tank) when the float switch has grounded the magneto. The FLOAT SWITCH OVERRIDE is spring-loaded in the down position and when

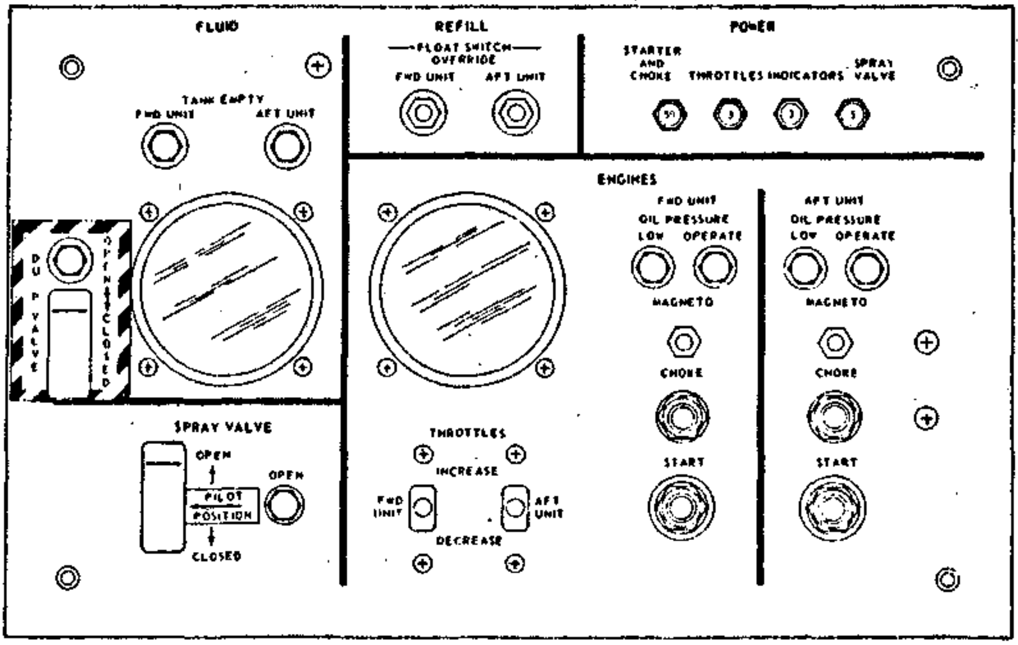

Figure 5. Control Console

placed in the up position, enables the engine to be run when the tank is empty (in order to fill the tank using the pump). The holding coil holds the FLOAT SWITCH OVERRIDE in the up position until the float switch is actuated.

Engine Tachometer - The engine tachometer is dual indicating (two needles) and indicates engine speed in hundreds of RPM.

Fluid Pressure Indicator - The FLUID pressure indicator indicates fluid pressure in increments of 2 PSI. When properly calibrated this gage can be used as a flow-rate indicator.

Circuit Breakers - Four circuit breakers (STARTER AND CHOKE, THROTTLES, INDICATORS, and SPRAY VALVE) control power to the control panel and provide protection from electrical overload and short circuits.

Spray Boom

The spray boom (figure 6) can accommodate 18 spray nozzles for dispensing the defoliant. The spray boom is constructed of 4-1/2-inch diameter steel tubing. The discharge line is off-set from the centerline of the spray boom to allow the aircraft's ramp to operate with the dispenser installed. The spray boom is attached to the fuselage with six struts.

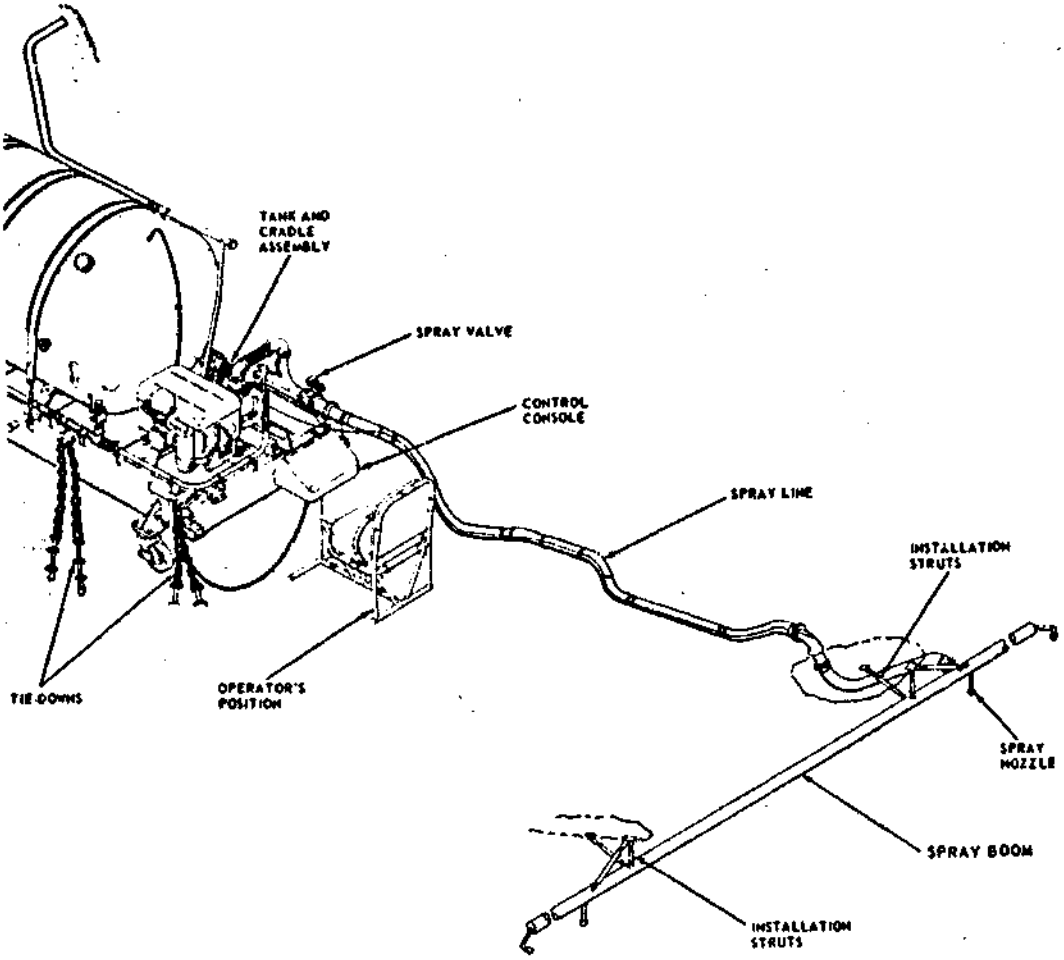

Figure 6. Spray Boom and Associated Plumbing

Aircraft Installation

Installation of the dispenser in C-123 aircraft consists of towing the tank and cradle assembly (unfilled) into the aircraft and securing it to the aircraft floor utilizing twenty 10,000-pound hook and chain assemblies and the cargo floor tie-down fittings (figures 7 and 8). All piping and hose assemblies, and the dump valve chutes, are installed and the console assembly mounted to the aircraft floor. The spray boom and connecting struts are attached to outside fittings on the aircraft and the electrical cables are connected. In the case of the C-130 aircraft, two dispensers are installed in the same manner and interconnected.

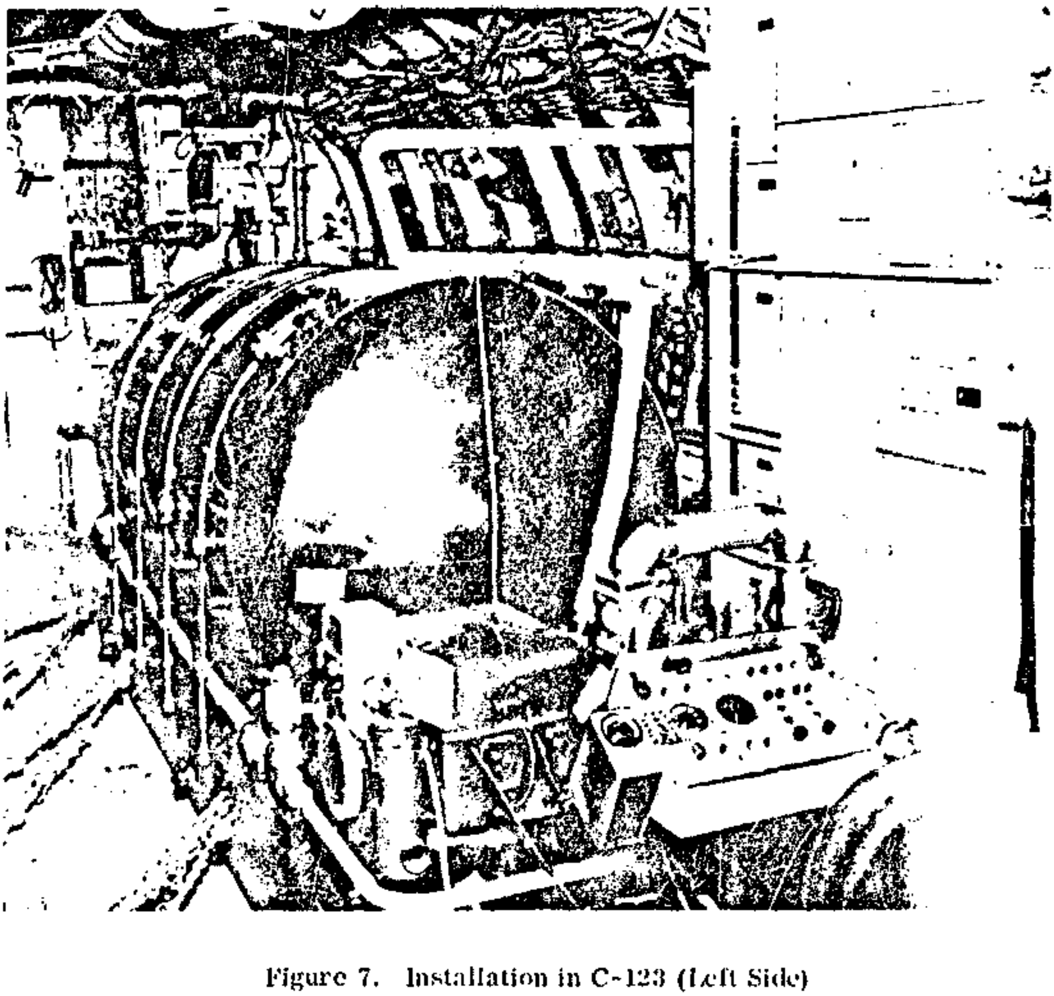

Figure 7. Installation in C-123 (Left Side)

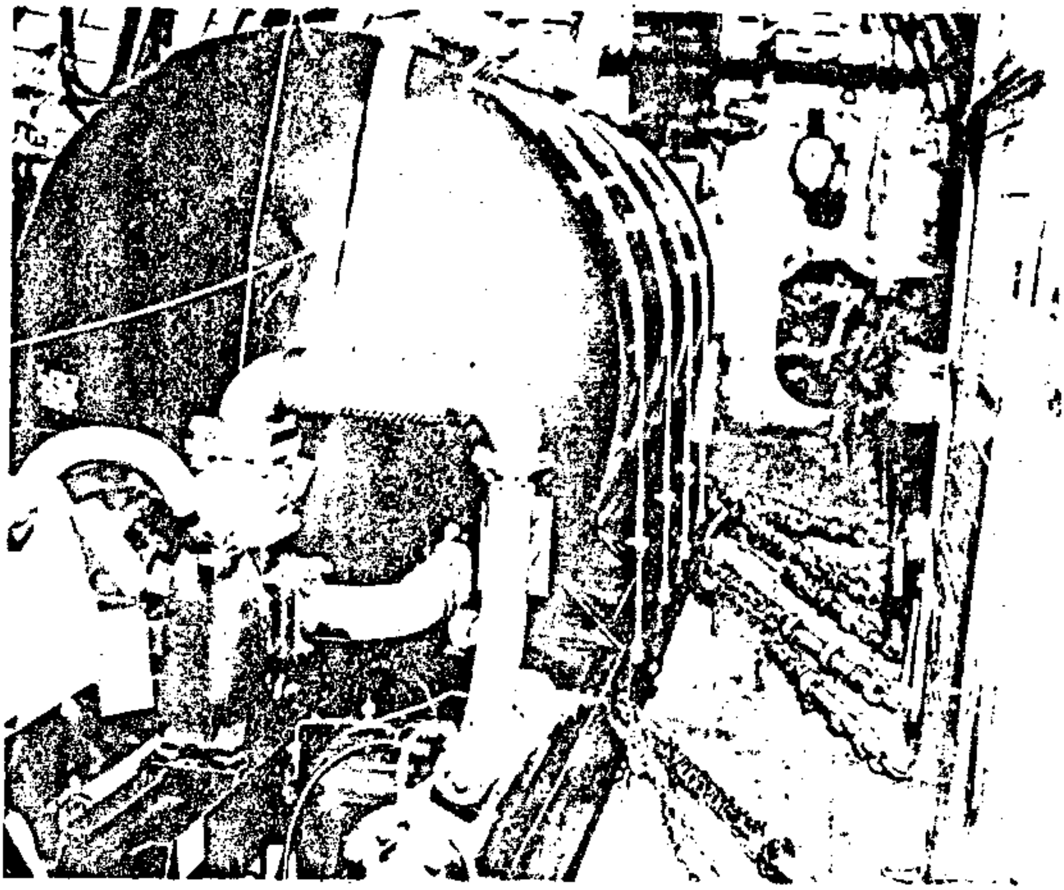

Figure 8. Installation in C-123 (Right Side)

SECTION III

DEVELOPMENT TEST OF THE A/A45Y-1 INTERNAL DEFOLIANT DISPENSER

Development tests and evaluations of the internal defoliant dispenser, A/A45Y-1, in the C-130 and C-123 aircraft were conducted by APGC, Eglin Air Force Base, Florida, during the period of 2 October 1963 to 20 December 1963 for the C-130 and 26 June 1964 to 22 July 1964 for the C-123. The test objectives were to determine:

- compatibility of the dispenser with the aircraft
- capability of installation
- servicing (refilling) capability
- removal of the dispenser from the particular aircraft in accordance with Hayes' operation and maintenance manuals
- area coverage capability.

It was found during these evaluations that the dispensers were compatible with both aircraft. The aircraft commander reported no unusual effects on the flight characteristics of either aircraft in transporting the loaded dispenser.

Dispenser installation and removal tests scheduled for the C-130 aircraft were not accomplished due to design changes that affected the ground handling of the dispenser. Three installation and removal tests were conducted during the C-123 test program. The three tests (install and remove) required 12, 5, and 4 manhours, respectively. The refilling procedure as recommended by Hayes' operations and maintenance manuals was satisfactory but somewhat inefficient (40 minutes per dispenser for the C-130 aircraft). A self-filling feature was incorporated by Hayes prior to the C-123 test program which reduced the time required to fill each tank from 40 minutes to 20 minutes when filling is done from 55-gallon drums.

The area coverage capability test of the dispenser(s) in the C-130 and C-123 aircraft was conducted to determine ground concentration of defoliant agent (gallons per acre), swath width (feet), droplet size (microns), and flow rate (gallons per minute). The desired ground concentration of three gallons per acre for a 120-foot swath width was not obtained. Figures 9 and 10 illustrate typical agent deposition from the two aircraft. In both tests, the desired droplet size of 150 to 300 microns mass median diameter was obtained. The maximum flow rate obtained during the C-130 and C-123 tests were 390 and 275 gallons per minute, respectively.

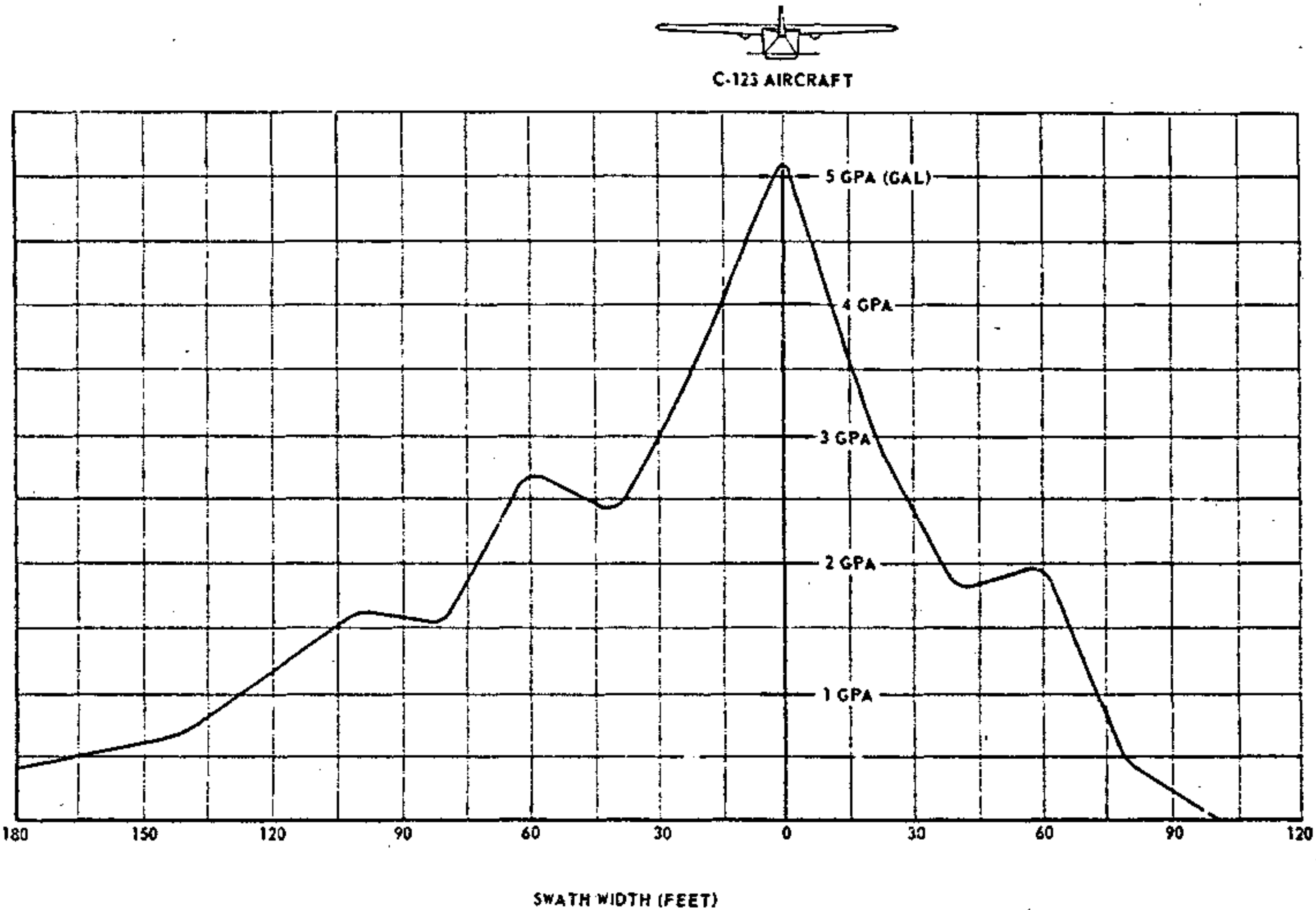

Figure 9. Typical Agent Deposition (C-123 Aircraft)

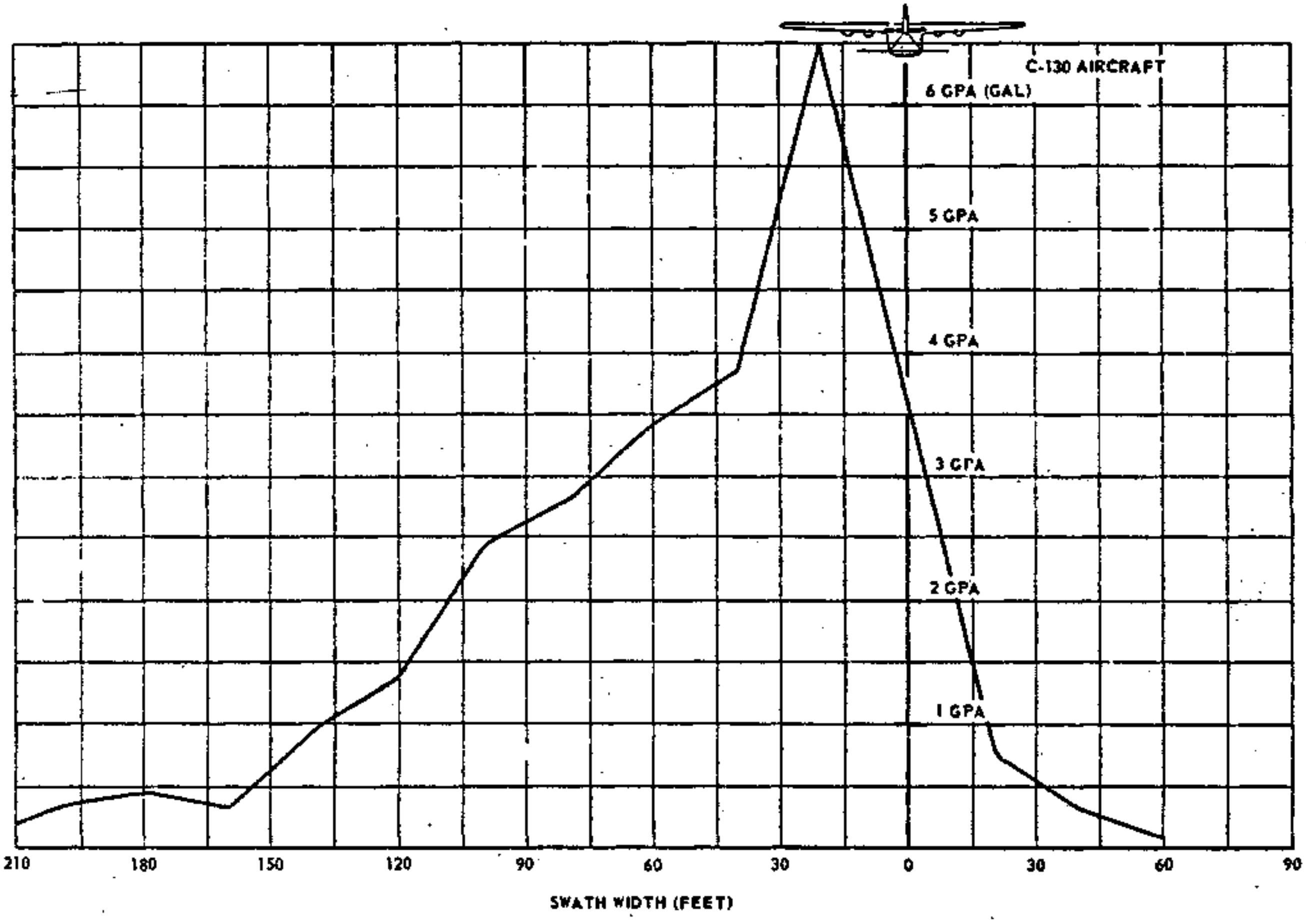

Figure 10. Typical Agent Deposition (C-130 Aircraft)

SECTION IV

SYSTEM PERFORMANCE

Liquid-Level Gage Calibration

Before any system performance tests could be conducted, it was necessary to calibrate the liquid-level gage which is mounted on the side of the defoliant dispenser.

To calibrate this gage, the dispenser was first weighed in the empty condition and the weight recorded. The tank was then filled with water to the 1/4 mark on the gage and weighed. Water was then added until the 1/2 mark on the gage was reached, and the tank again weighed. Filling then continued to the 3/4 mark and the weight recorded. The dispenser was then filled to the "Full" level and the weight recorded. At this point, the water was pumped out through the spray valve until it reached the level at which the float switch cuts the system off. The dispenser was then weighed again and the weight recorded. This procedure was repeated twice to obtain an average weight for each level.

From these weights, the volume (in gallons) was calculated for each level on the gage. The results were:

Gage Level	Volume (Gal)
Full	958
3/4	807
1/2	495
1/4	184
Float Switch Cut-Off	54

Conversion Factors for Various Agents

All system performance testing was conducted using water as the agent; however, values were also needed for the agents which are used in the system. For this reason, additional small-scale tests were conducted to determine factors whic. could be used to convert the values obtained for water to values for each agent.

To determine the conversion factors applicable to refilling the tank, a small pump rated at 2.3 gallons per minute was used to pump one gallon of water and one gallon of each agent from one container into another through 3/4-inch tubing. The time required to accomplish this for each liquid was recorded. The conversion factors were then calculated by dividing the average values of pumping time for each agent by the pumping time for water.

Results were as follows:

Agent	Specific Gravity	Viscosity (75°F) (Centistokes)	Conversion Factor
Purple	1.27	38.2	1.161
Orange	1.27	38.2	1.161
Blue	1.335	8.8	1.124
White (Tordon 101)	1.15	243.0	1.312

In determining conversion factors applicable to the gravity dump time through the A/A45Y-1 dispenser's emergency dump valve, a Zahn #3 cup was used. Forty-four milliliters of each agent and water were allowed to flow through cup and the time recorded for each. Here again, conversion factors were obtained by dividing the values for each agent by the value for water.

Results were as follows:

Agent	Conversion Factor
Orange	0.90
Purple	0.90
Blue	0.85
White (Tordon 101)	1.45

Refill by Means of the Internal Defoliant Dispenser Jet Pump

The apparatus used in performing this test is illustrated in figure 11. It was set up such that the inlet end of the refill hose was at the same elevation as the jet pump so that induced head loss would not be present. Using a ten-foot section of refill hose (MIL-H-8974-32), the time was recorded for filling the dispenser to the 1/4 level on the liquid level gage. The water was then pumped out until the float switch cut off the system. Time was then recorded for filling the system to the 1/2 level. This procedure was repeated for 3/4 and "Full". Three tests were run at each level in order to obtain an average time. These tests were repeated using 20, 30, and 50-foot lengths of refill hose.

The values of refill time obtained for water were converted to the agent values by the methods discussed in the previous section. Refill time as a function of quantity of liquid is presented in figures 12 through 15 for each agent.

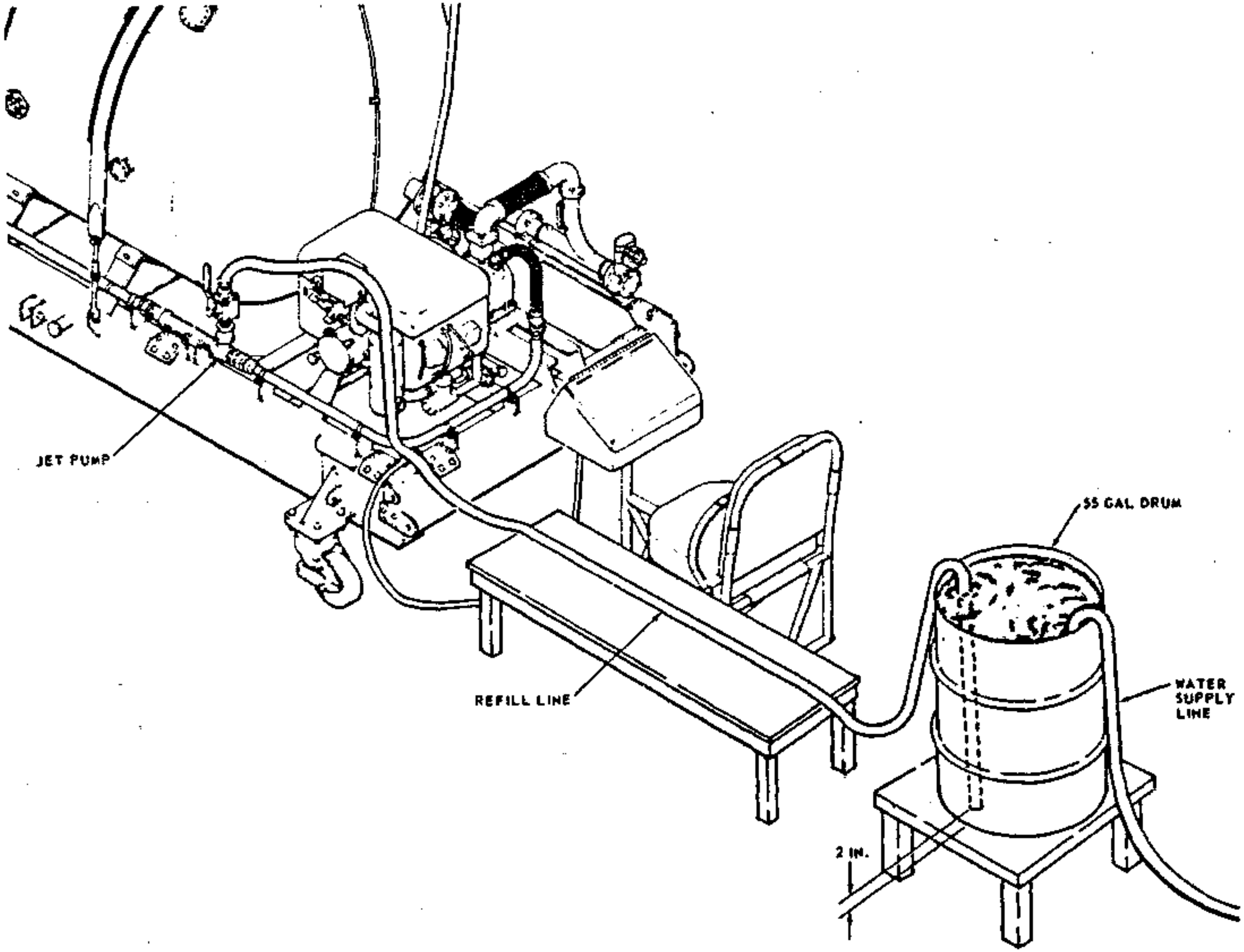

Figure 11. Refill Test Apparatus

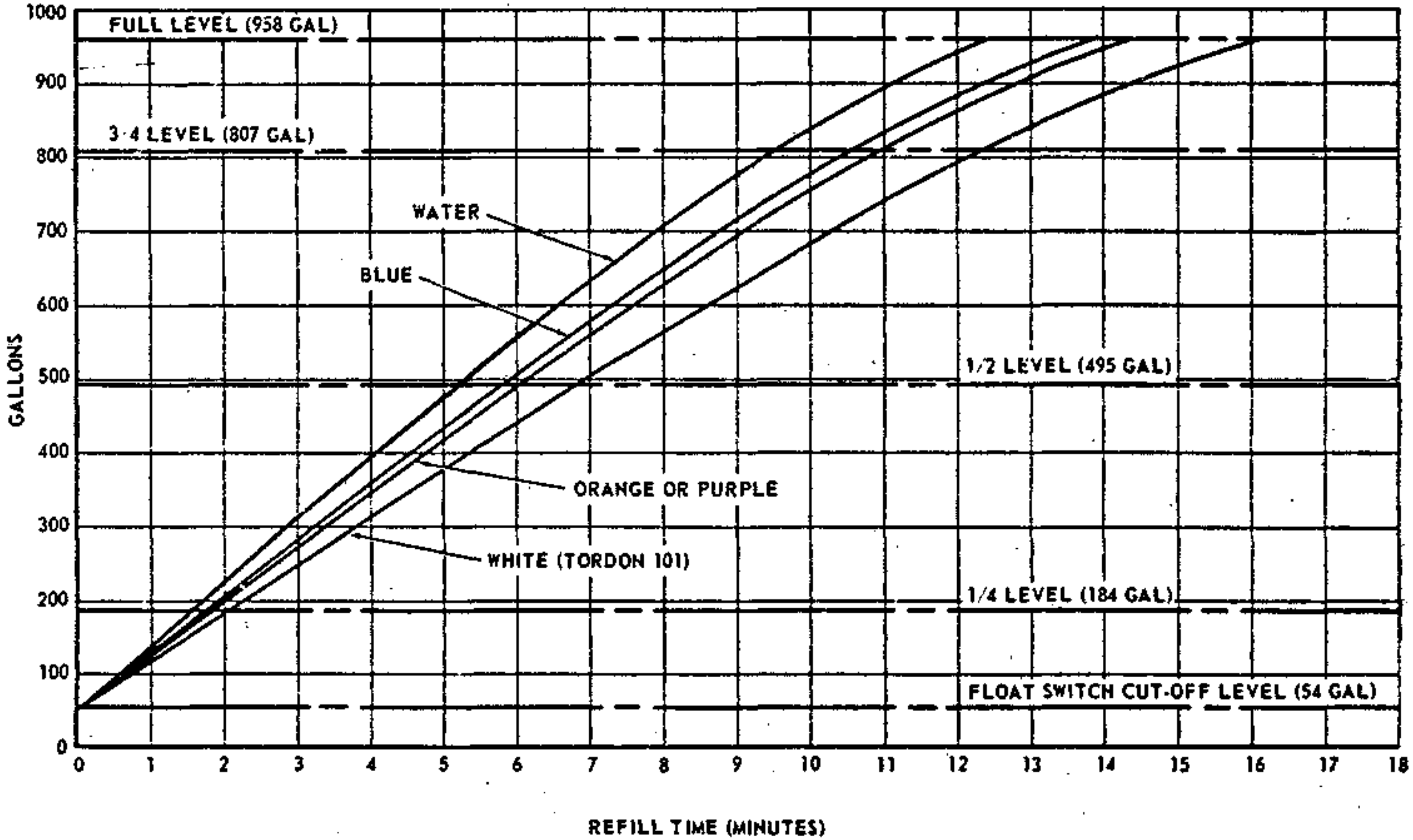

Figure 12. Refill Rate with Various Agents Using A 10-Foot Length of Refill Hose

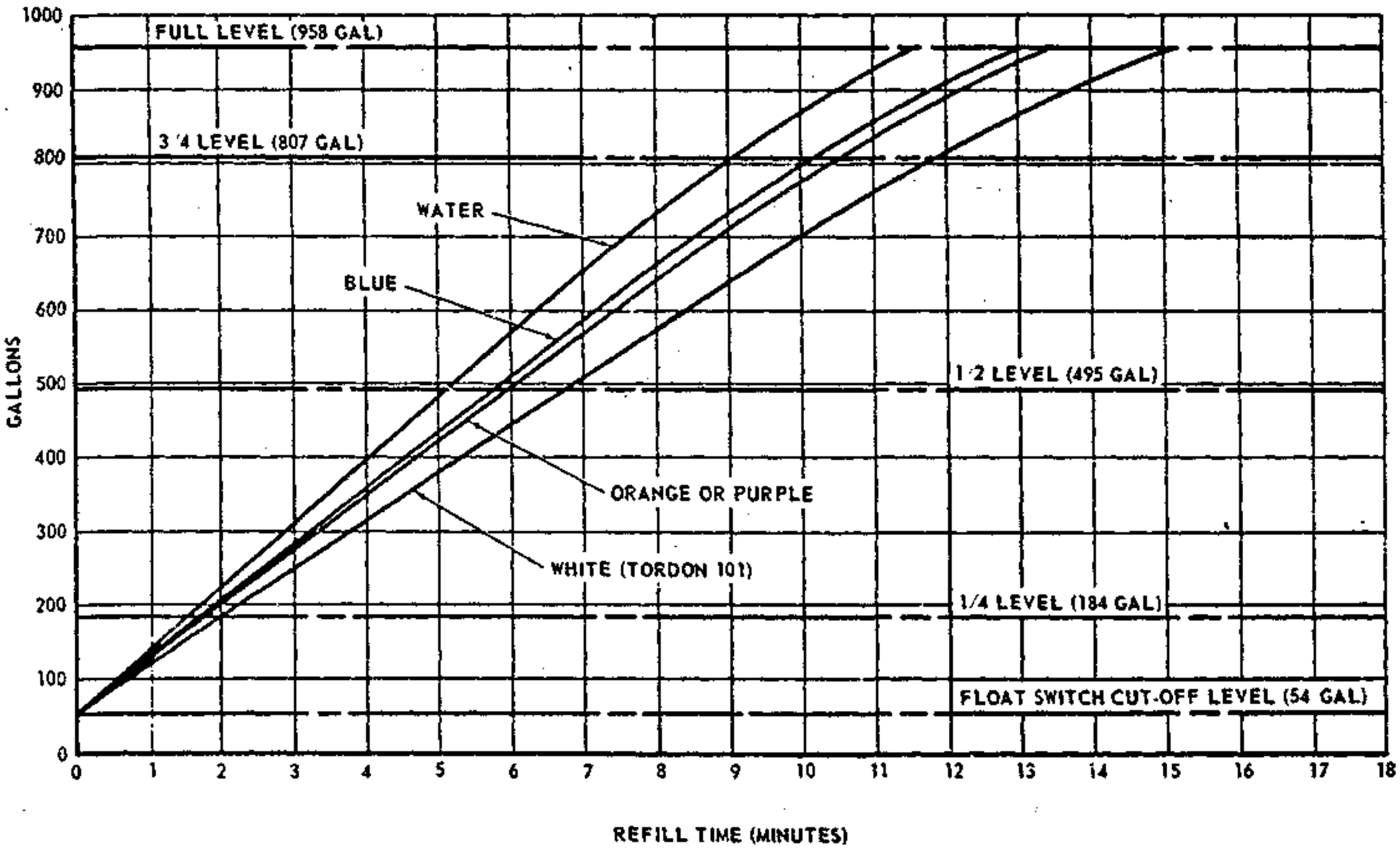

Figure 13. Refill Rate with Various Agents Using A 20-Foot Length of Refill Hose

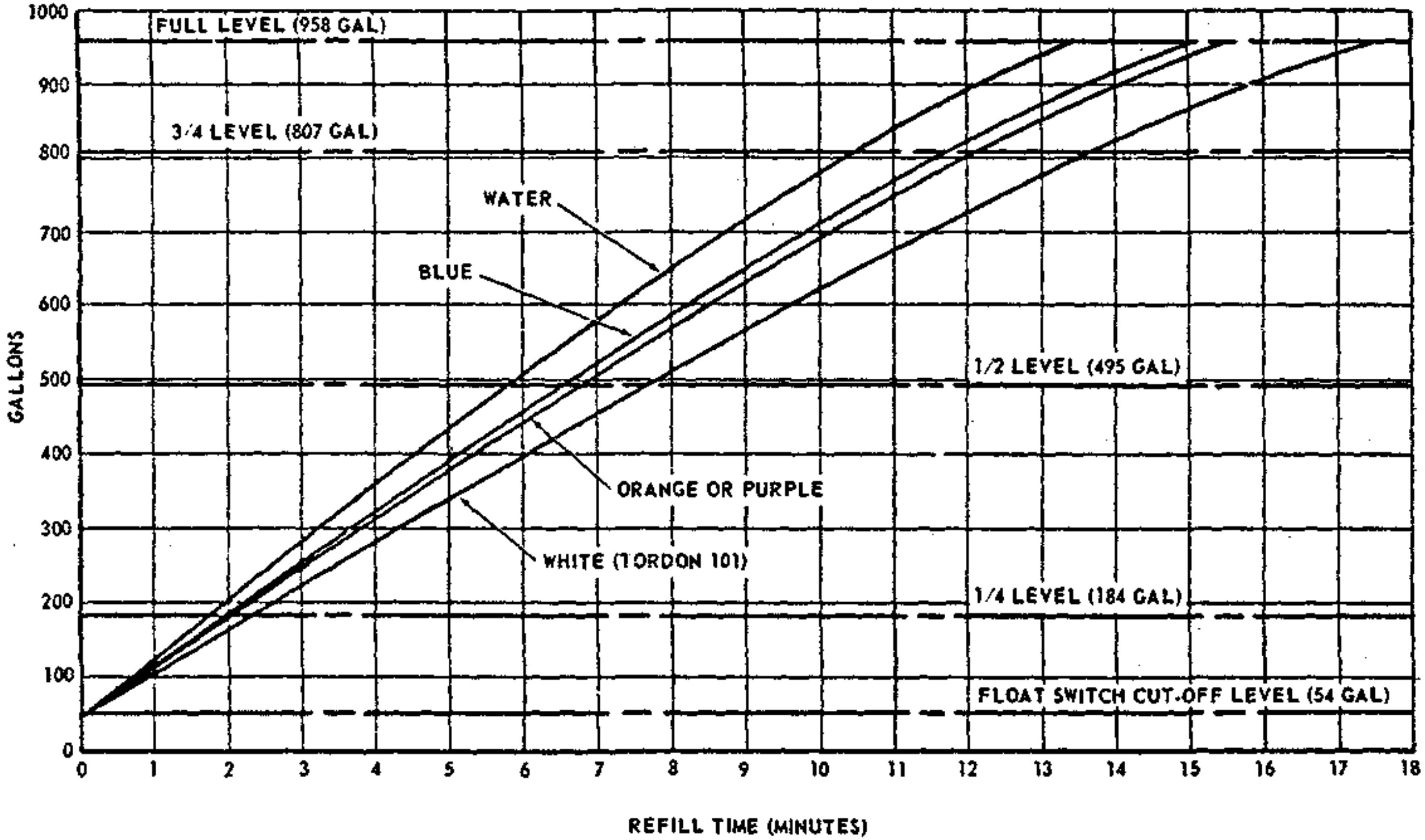

Figure 14. Refill Rate with Various Agents Using A 30-Foot Length of Refill Hose

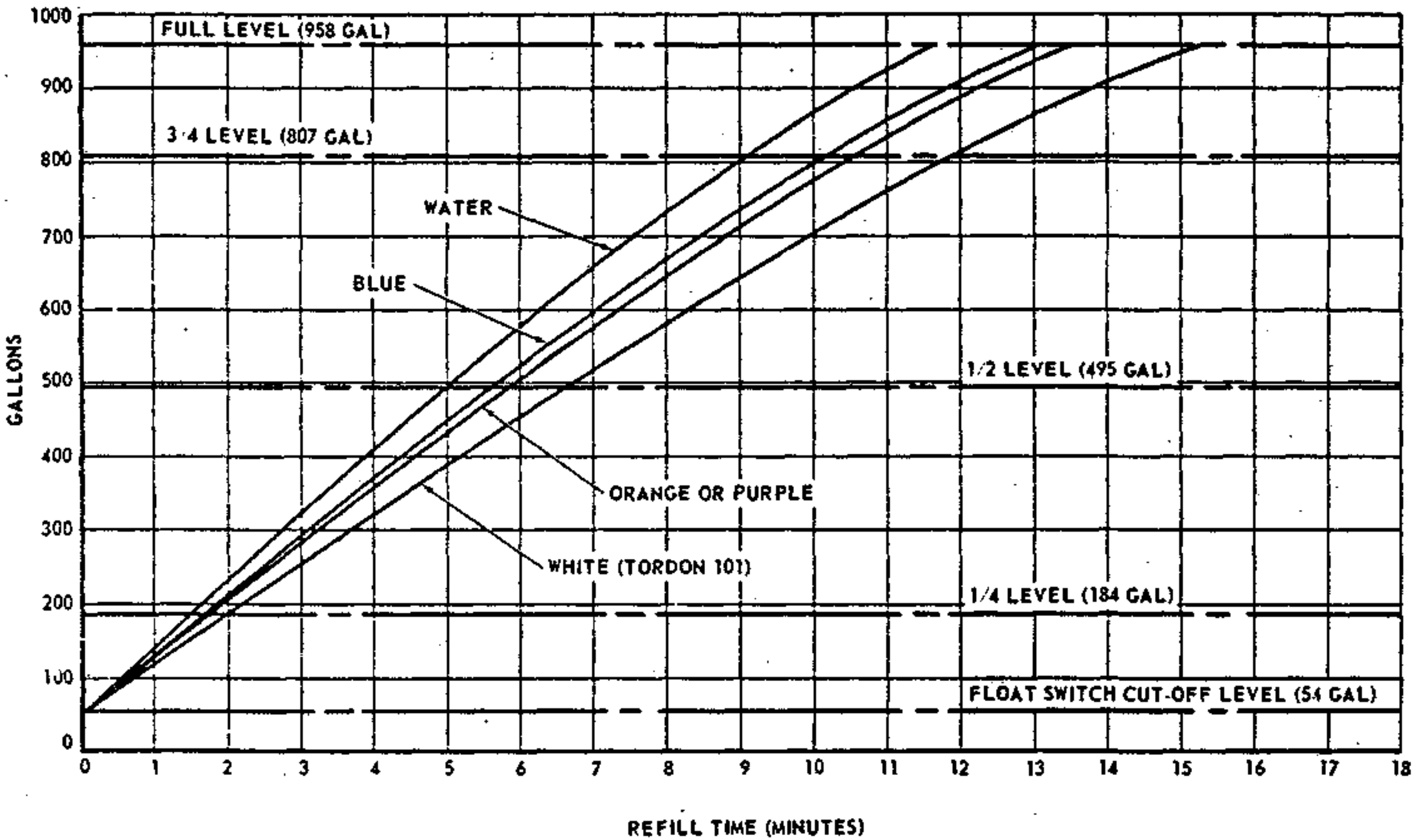

Figure 15. Refill Rate with Various Agents Using a 50-Foot Length of Refill Hose

Emergency Dump Test

In determining the dump rate through the A/A45Y-1 emergency dump valve, the tank was filled with water three times to each of the liquid levels indicated on the liquid level gage. In each case, the valve was actuated electrically and the flow of water from the tank timed until the water level reached the float switch cut-off point (54 gallons). The values of time were converted for each agent and plotted as a function of gallons of water or agent to be dumped (figure 16).

Flow Rate Test Using an Induced Pressure

The objective in conducting this test was to determine the flow rate of the dispenser for any given pressure or head. The apparatus used in the performance of this test is illustrated in figure 17. A flowmeter (Series 5000, Pottermeter) with a three-inch nominal inside diameter was mounted to the downstream side of the spray valve. A three-inch manual gate valve was mounted immediately downstream of the flowmeter. In addition, an indicator (Potter Aeronautical Corporation Model 519) was connected to the flowmeter to indicate flow rate in gallons per minute.

In conducting the test, pressure was induced into the system by manually changing the orifice area of the gate valve thus varying the restriction imposed upon the flow of water. At all times the level of the water in the tank was held between the "3/4 level" and "full" to insure the same positive head of liquid on the suction side of the pump and a constant engine speed of 3600 RPM was maintained. At each position of the gate valve blade, the spray valve was electrically actuated to the open position. The pressure from the indicator on the console and the flow rate from the flow indicator were recorded. The test was conducted three times, moving the valve blade from "closed" to "full open" in small increments, to insure reliable data.

The test results were plotted in terms of induced back pressure versus flow rate. The conversion factors, previously discussed, were applied to the values for water and curves were plotted for the specific agents involved. These test results are presented in figure 18.

System Pressure Loss Analysis

The purpose of this analysis is to analytically determine the dispenser pressure loss at various fluid flow rates. In the following section the results of the analysis is combined with the previously mentioned flow rate test to form the dispenser performance range.

The majority of the formulae used in this analysis is extracted from Reference 2. Many of the values used are extracted from Reference 2. When a formula or value taken from this paper is used, the page number on which it is found is noted on the right hand side of the page.

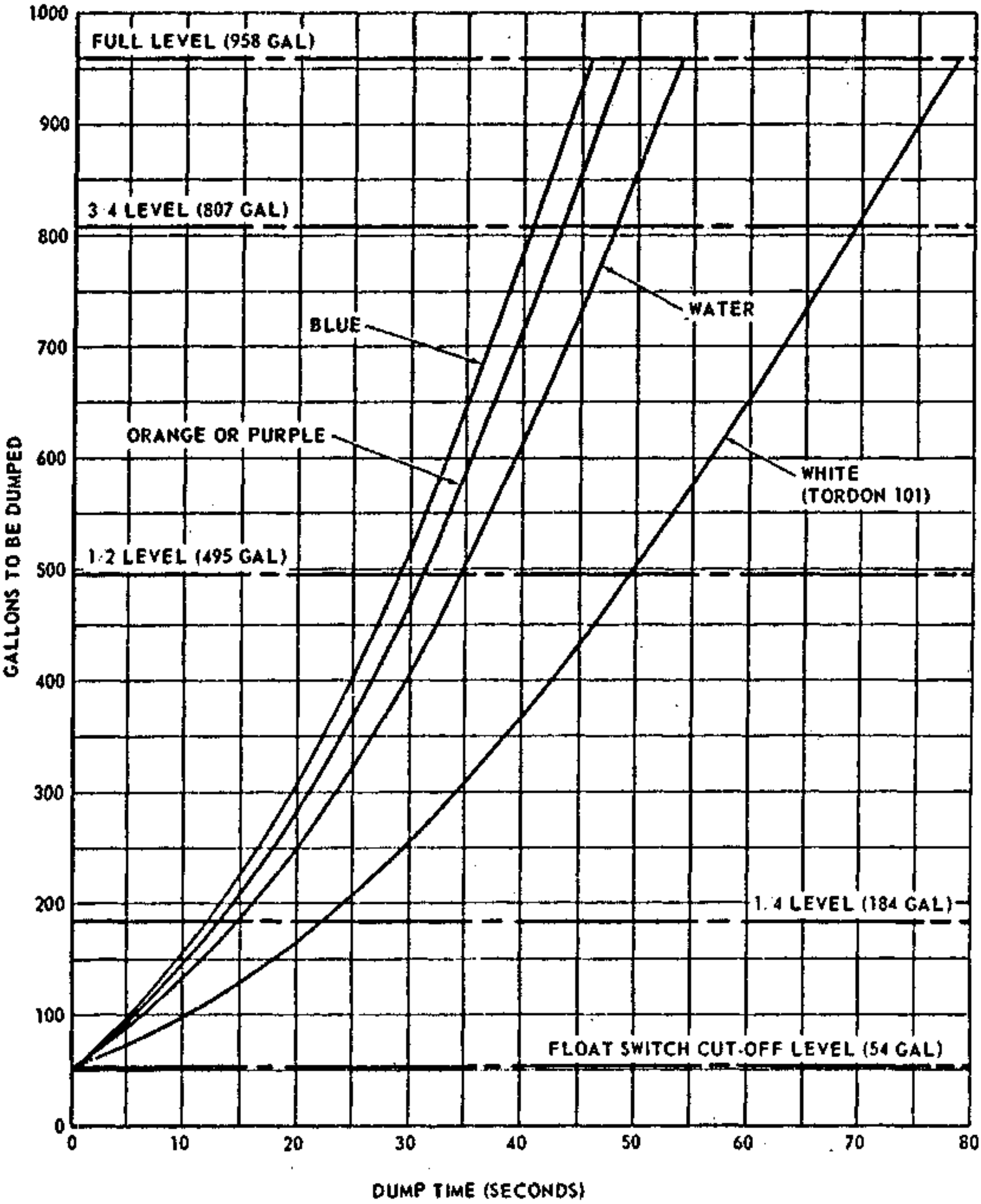

Figure 16. Emergency Dump Rate for Various Agents with A/A45Y-1 Dump Valve

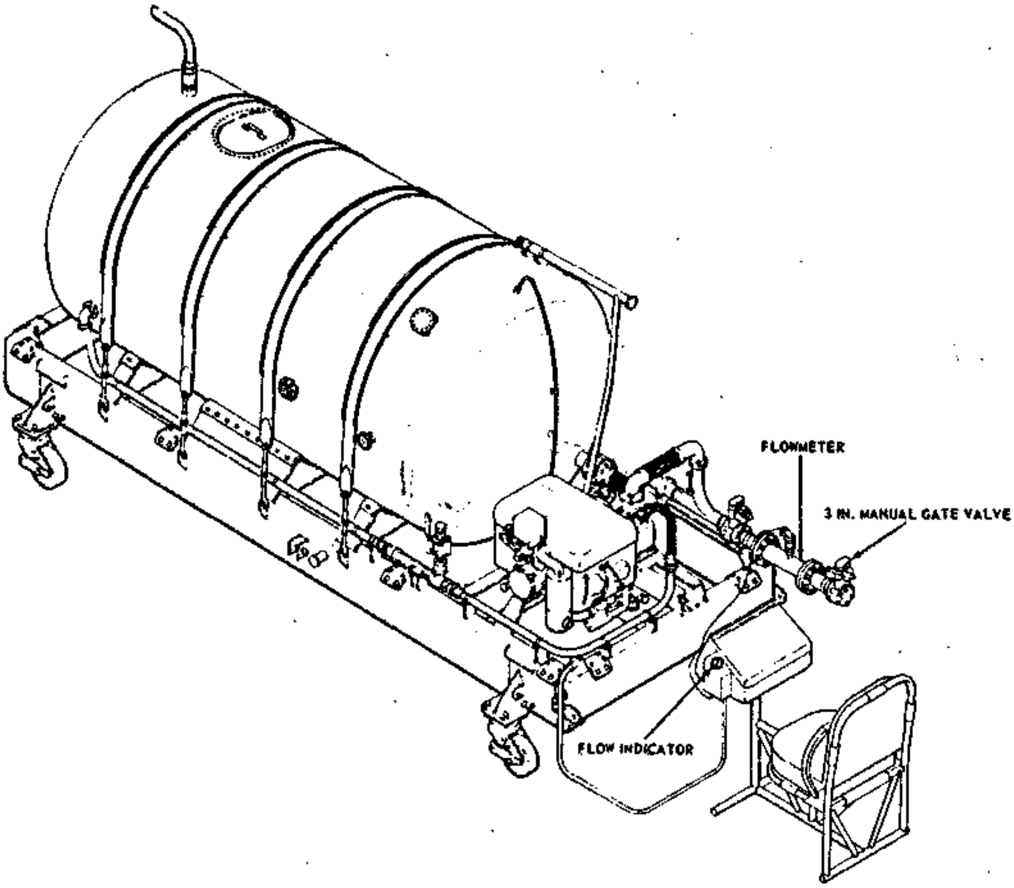

Figure 17. Flow Rate Test Apparatus

First of all, the line sizes must be determined.

Determination of line size from tank to spray boom:

Requirements: 400 gpm @ 15 ft/sec

$$v = 0.408\ Q/d^2 \qquad \text{Page 3-2}$$

$$d = 0.408\ Q/v$$

$$d = 0\ 408\ \frac{400}{15}$$

$$d = 3.298 \text{ inches}$$

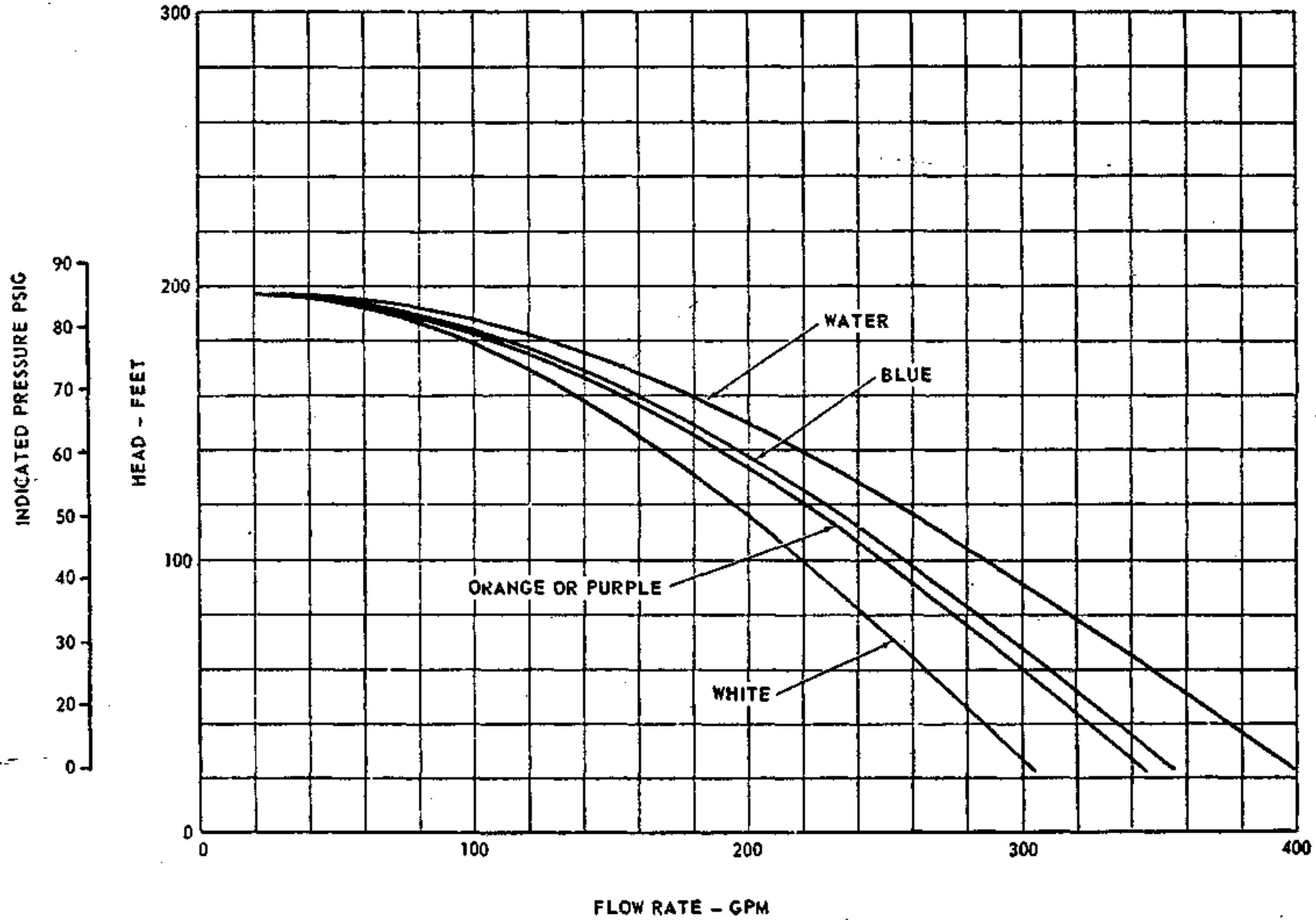

Figure 18. System Performance Test Results

However, the 3-inch suction and discharge ports on the Gorman-Rupp pump necessitated using 3-inch outside diameter (O.D.) tubing with a 0.0625-inch wall thickness. Thus, a slight increase in velocity occurs.

The fuselage-mounted spray boom is constructed of 4.5-inch O.D. stainless steel tubing with a wall thickness of 0.237 inches. The increase in line size in the boom was dictated by structural stiffness requirements for the C-130 aircraft which has a considerably greater speed capability than the C-123 aircraft.

The agent which is pumped through the tubing system shown in figure 19 has a specific gravity of 1.3 and a viscosity equal to 30.0 centistokes @ 80°F.

The total head is found in four parts. The first part to be analyzed is the suction line; i.e., the section of line between the spray tank and the pump.

Suction Head:

Suction line velocity:

$$v = .408 \frac{Q}{d^2}$$ Page 3-2 Equation 3-2

$$v = .408 \frac{(400)}{(2.875)^2}$$

$$v = 19.74 \text{ ft/sec}$$

Reynolds number:

$$R_e = \frac{\rho D v}{\mu e}$$ Page 3-2 Equation 3-3

$$R_e = \frac{\rho D v}{32.2 \quad \mu' e}$$

$$\mu'_e = 8.2 \times 10^{-4}$$ Page B-5

$$R_e = \frac{(81.2)(0.240)(19.74)}{(32.2)\ (8.2 \times 10^{-4})}$$

$$R_e = 1.456 \times 10^4$$

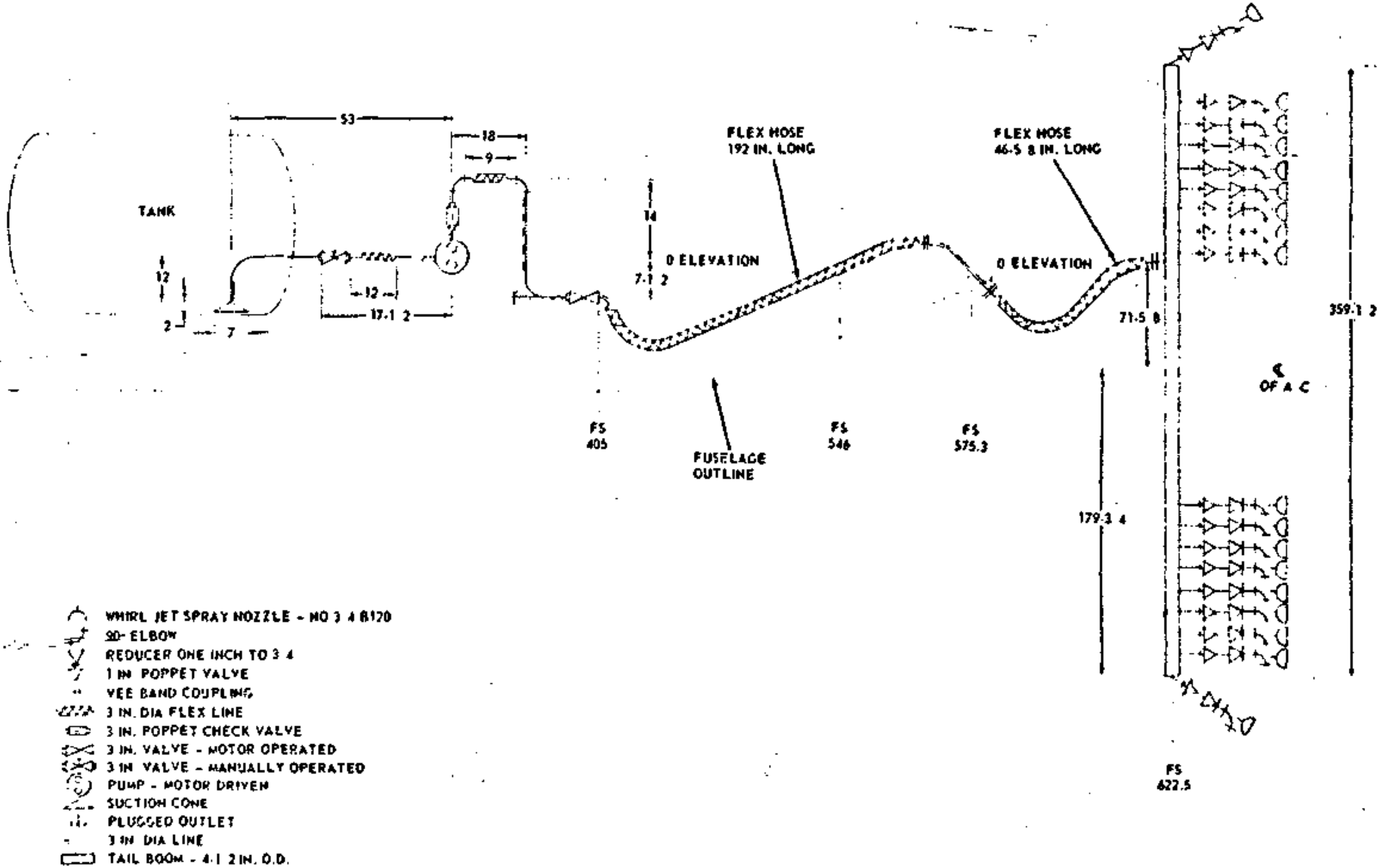

Figure 19. A/A45Y-1 Fluid Flow Schematic

Friction factor:

For a 3-inch Schedule-40 pipe at a flow having an $R_e = 1.456 \times 10^4$ the friction factor is:

$$f = 0.029$$ Page A-25

Suction cone:

$$L/D = \frac{K}{f} = \frac{.04}{.029} = 1.38$$ Page A-26

12 inch radius 90° bend:

$$L/D = 13.6$$ Page A-27

12 inch radius 29° bend:

$$L/D = 7.5$$ Page A-27

Schedule 40 90° standard elbow:

$$L/D = 30$$ Page A-30

Exit into pump:

$$L/D = \frac{K}{f} = \frac{1}{.029} = 34.48$$

Summation of L/D's:

$$L/D = 1.38 + 13.6 + 7.5 + 30.0 + 34.48$$

$$L/D = 86.96$$

$$L = (D)(L/D) = (86.96)(0.240)$$

$$L = 20.87 \text{ feet}$$

Total equivalent length of pipe:

$$L = 2/12 + 12/12 + 53/12 + 20.87$$

$$L = 0.167 + 1.0 + 4.417 + 20.87$$

$$L = 26.45 \text{ feet}$$

Head loss due to flow through suction cone, tubing, bends, and exit into pump:

$$h_L = 0.1863 \frac{fLv^2}{d}$$ Page 3-2 Equation 3-5

$$h_L = 0.1863 \frac{(.029)(26.45)(19.74)^2}{2.875}$$

$$\underline{h_L = 19.368 \text{ feet of agent}}$$

Head loss for 9-inch flexible hose (3-inch O.D.):

For 400 gpm, the pressure drop is 0.7 psi/ft — Anaconda Catalog G-700, Page D-5

0.7 psi/ft x 0.75 ft = 0.525 psi

$$h_L = (0.525)(2.31) = 1.213 \text{ feet of water}$$

$$h_L = (1.213)(1.3) = \underline{1.577 \text{ feet of agent}}$$

Head loss for a 3-inch gate valve:

The formula for ΔH in inches is: $\Delta H = 0.0000459Q^2$

For 400 gpm, ΔH = 7.34 inches

$$h_L = \frac{(7.34)(1.3)}{12} = \underline{0.796 \text{ feet of agent}}$$

<u>Total Suction Head:</u>

$$h_L = 14/12 + 19.368 + 1.577 + 0.796$$

$$h_L = 1.167 + 19.368 + 1.577 + 0.796$$

$$\underline{\underline{h_L = 22.908 \text{ feet of agent}}}$$

Next the head is found for the discharge line; i.e., the line between the pump and the spray boom. The line velocity and the friction factor are the same as for the suction line.

Sharp edged entrance to pump:

$$L/D = \frac{K}{f} = \frac{0.5}{0.029} = 17.24$$ Page A-26

Two (2) Schedule-40 90° standard elbows:

$$L/D = (2)(30) = 60.0$$ Page A-30

45° 12-inch radius:

$$L/D = (14.0)(.533) = 7.50$$ Page A-27

45° Miter bend:

$$L/D = 15.0$$ Page A-27

45° 9-inch radius through fuselage:

$$L/D = 12.0(.533) = 6.4$$

Summation of L/D's:

$$L/D = 17.24 + 60.0 + 7.5 + 15.0 + 6.4$$

$$L/D = 106.14$$

$$L = L/D(D) = (106.14)(0.240) = 25.47 \text{ feet}$$

Total equivalent length of pipe:

$$L = \frac{14}{12} + \frac{18}{12} + \frac{21.5}{12} + \frac{26.75}{12} + \frac{192}{12} + \frac{46.625}{12} + 25.47$$

$$L = 1.167 + 1.500 + 1.792 + 2.229 + 16.00 + 3.885 + 25.47$$

$$L = 52.043 \text{ feet}$$

Head loss due to flow of agent through elbows, bends, tubing, and sharp-edged entrance to pump:

$$h_L = 0.1863 \frac{fLv^2}{d}$$

$$h_L = 0.1863 \frac{(0.029)(52.043)(19.74)^2}{2.875}$$

$$\underline{h_L = 38.109 \text{ feet of agent}}$$

Head loss for 3-inch check valve:

The formulae for the pressure drop and head loss through this check valve are:

$$\Delta P = -0.005Q + 2.0$$

$$h_L = (\Delta P)(2.31)(S)$$

For the Q of 400 gpm:

$$\Delta P = 0$$

therefore $h_L = 0$

However, for flow rates less than 400 gpm, there will be appreciable head loss.

Head loss for 3-inch gate valve:

This value is the same as for the gate valve in the suction line.

$$\underline{h_L = 0.796 \text{ feet of agent}}$$

Head loss for flexible hose (3-inch O.D.):

There are three (3) sections of flexible line between the spray valve and the spray boom.

$$L = \frac{12 + 192 + 46.63}{12} = 20.89 \text{ feet}$$

Pressure drop = 0.7 psi/ft (see 9-inch flex hose in suction line)

$$h_L = (0.7 \text{ psi/ft})(20.89)(2.31)(1.3)$$

$$\underline{h_L = 43.913 \text{ feet of agent}}$$

Total Discharge Head:

$$h_L = 38.109 + 0.796 + 43.913 - \frac{1.250}{12}$$

$$h_L = 38.109 + 0.796 + 43.913 - 0.104$$

$$\underline{\underline{h_L = 82.714 \text{ feet of agent}}}$$

At this point in the system, the flow of agent leaves the 3-inch line and enters the spray boom, which is shown in figure 20. The line size for the spray boom has already been determined as 4.5-inch O.D. stainless steel pipe with a wall thickness of 0.237 inches. The nozzle arrangement is symmetrical about the centerline of the spray boom; however, the entrance to the boom is offset approximately six feet from the centerline. In this analysis, the worst condition, which is the longer section of spray boom, is analyzed for a flow rate of 200 gpm.

There are a total of eighteen nozzles on the spray boom. Each nozzle dispenses agent at a rate of 400 gpm/18 nozzles or 22.22 gallons per minute. As the flow passes each nozzle, the total flow rate is reduced by this amount. With each change in flow, the agent velocity, friction factor, and Reynold's number also change. These values must be recalculated at each nozzle location in order to find the head loss in the next section of line.

In calculating the spray-boom head loss, the first head loss is encountered where the 3-inch O.D. discharge line exits into the 4.5-inch O.D. boom. This is calculated on the basis of a sharp-edged exit.

$$K = 1.00$$ Page A-26

$$L/D = \frac{K}{f} = \frac{1.00}{0.029}$$

$$L/D = 34.48$$

$$L = L/D(D) = (34.48)\ (0.240)$$

$$L = 8.275 \text{ feet}$$

Head loss due to exit from discharge line:

$$h_L = 0.1863\ \frac{fLv^2}{d}$$

$$h_L = 0.1863\ \frac{(0.029)(8.275)(19.74)^2}{2.875}$$

$$\underline{h_L = 6.059 \text{ feet of agent}}$$

Station 0.0 to Station 149.63

$$L = \frac{149.63}{12} = 12.47 \text{ feet}$$

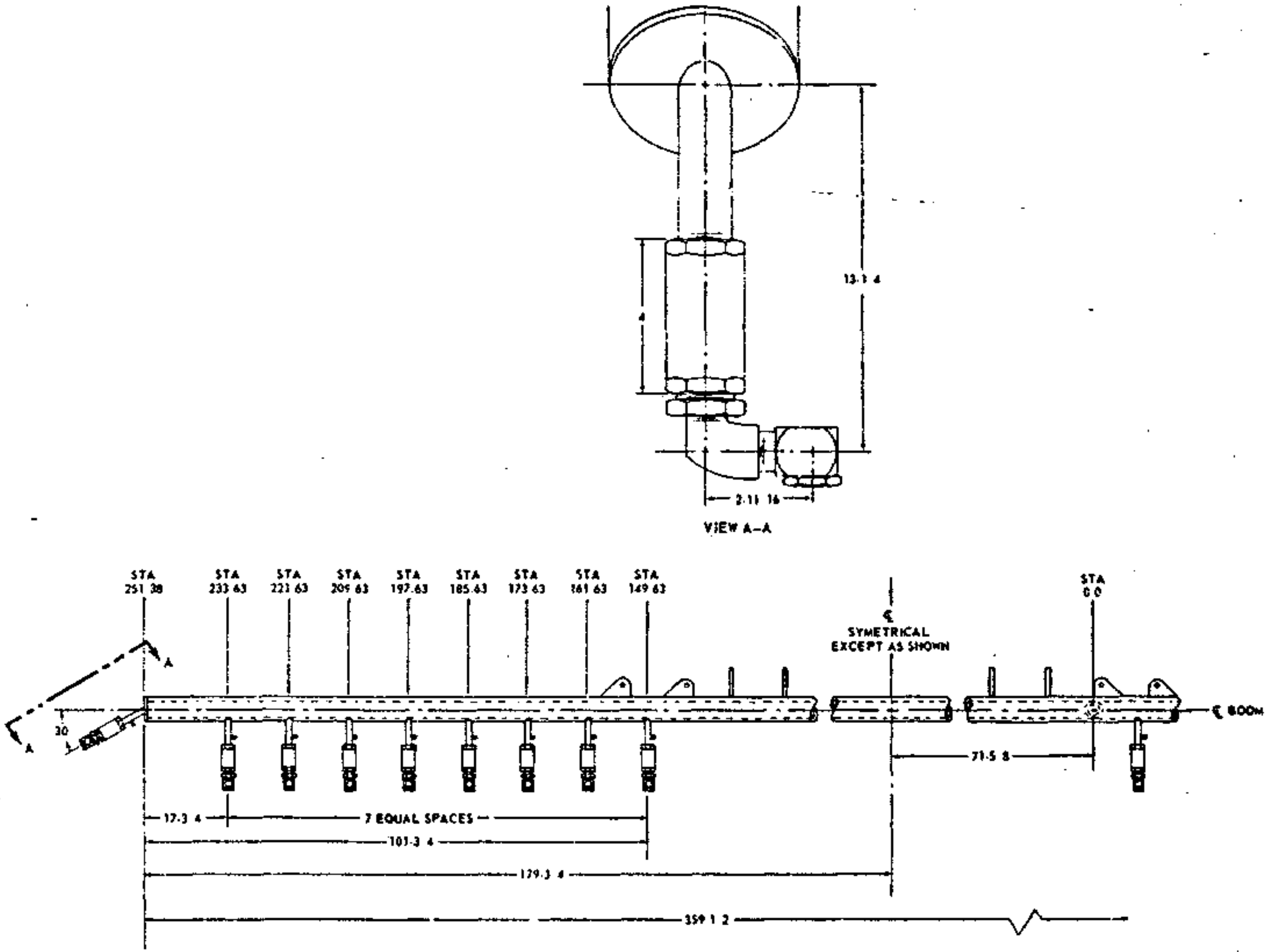

Figure 20. A/A45Y-1 Fuselage-Mounted Spray Boom

Velocity:

$$v = .408\ Q/d^2$$

$$v = .408 \frac{200}{(4.026)^2}$$

$$v = .408\left(\frac{200}{16.087}\right)$$

$$v = 5.034 \text{ ft/sec}$$

Reynolds number:

$$R_e = \frac{\rho Dv}{32.2\ \mu'_e}$$

$$R_e = \frac{(81.12)(.3355)(5.034)}{32.2\ (8.2 \times 10^{-4})}$$

$$R_e = 5190$$

Friction factor:

$$f = 0.037$$

Head loss:

$$h_L = .1863 \frac{fLv^2}{d}$$

$$h_L = .1863 \frac{(.037)(12.47)(5.034)^2}{4.026}$$

$$\underline{h_L = 0.541 \text{ feet of agent}}$$

Station 149.63 to Station 161.63

$$L = 1.0 \text{ feet}$$

$$Q = 200 - 22.22$$

$$Q = 177.78 \text{ gpm}$$

$$v = .408\ Q/d^2$$

$$v = .408\ \frac{177.78}{(4.026)^2}$$

$$v = 4.475\ \text{ft/sec}$$

$$R_e = \frac{(81.12)(.3355)(4.475)}{(32.2)(8.2 \times 10^{-4})}$$

$$R_e = 4613$$

$$f = 0.038$$

$$h_L = .1863\ \frac{fLv^2}{d}$$

$$h_L = .1863\ \frac{(.038)(1.0)(4.475)^2}{4.026}$$

$$\underline{h_L = .035\ \text{feet of agent}}$$

Station 161.63 to Station 173.63

$$L = 1.0\ \text{feet}$$

$$Q = 177.78 - 22.22 = 155.56\ \text{gpm}$$

$$v = .408\ \frac{155.56}{(4.026)^2}$$

$$v = 3.916\ \text{ft/sec}$$

$$R_e = \frac{(81.12)(.3355)}{(32.2)(8.2 \times 10^{-4})} \times \text{velocity}$$

$$R_e = 1030.90 \times \text{velocity}$$

$$R_e = 4037$$

$$f = 0.040$$

$$h_L = .1863 \frac{(.040)(1.0)(3.916)^2}{4.026}$$

$$\underline{h_L = 0.028 \text{ feet of agent}}$$

Station 173.63 to Station 185.63

$$L = 1.0 \text{ feet}$$

$$Q = 155.56 - 22.22 = 133.34 \text{ ft/sec}$$

$$v = .408 \frac{133.34}{(4.026)^2} = 3.356 \text{ ft/sec}$$

$$R_e = 1030.90 \times 3.356$$

$$R_e = 3460$$

$$f = 0.0415$$

$$h_L = .1863 \frac{(.0415)(1.0)(3.356)^2}{4.026}$$

$$\underline{h_L = 0.022 \text{ feet of agent}}$$

Station 185.63 to Station 197.63

$$L = 1.0 \text{ feet}$$

$$Q = 133.34 - 22.22 = 111.12 \text{ gpm}$$

$$v = .408 \frac{111.12}{(4.026)^2}$$

$$v = 2.797 \text{ ft/sec}$$

$$R_e = 1030.90 \times 2.797 = 2883$$

$$f = 0.044$$

$$h_L = .1863 \frac{(.044)(1.0)(2.797)^2}{4.026}$$

$$\underline{h_L = 0.016 \text{ feet of agent}}$$

Station 197.63 to Station 209.63

$$L = 1.0 \text{ feet}$$

$$Q = 111.12 - 22.22 = 88.90 \text{ gpm}$$

$$v = .408 \frac{88.90}{(4.026)^2} = 2.238 \text{ ft/sec}$$

$$R_e = (1030.90)(2.238) = 2307$$

$$f = 0.047$$

$$h_L = .1863 \frac{(.047)(1.0)(2.238)^2}{4.026}$$

$$\underline{h_L = 0.011 \text{ feet of agent}}$$

Station 209.63 to Station 221.63

$$L = 1.0 \text{ feet}$$

$$Q = 88.90 - 22.22 = 66.68 \text{ gpm}$$

$$v = .408 \frac{66.68}{(4.026)^2} = 1.678 \text{ ft/sec}$$

$$R_e = (1030.90)(1.678) = 1730$$

$$f = \frac{64}{1730} = 0.037$$

$$h_L = .1863 \frac{(.037)(1.0)(1.678)^2}{4.026}$$

$$\underline{h_L = 0.005 \text{ feet of agent}}$$

Station 221.63 to Station 233.63

$$L = 1.0 \text{ feet}$$

$$Q = 66.68 - 22.22 = 44.46 \text{ gpm}$$

$$v = .408 \frac{44.46}{(4.026)^2} = 1.119 \text{ ft/sec}$$

$$R_e = (1030.90)(1.119) = 1154$$

$$f = \frac{64}{1154} = 0.055$$

$$h_L = .1863 \frac{(.055)(1.0)(1.119)^2}{4.026}$$

$$\underline{h_L = 0.003 \text{ feet of agent}}$$

Station 233.63 to Station 251.38

$$L = \frac{17.75}{12} = 1.479 \text{ feet}$$

$$Q = 22.22 \text{ gpm}$$

$$v = .408 \frac{22.22}{(4.026)^2} = 0.559 \text{ ft/sec}$$

$$R_e = (1030.90)(0.559) = 576.27$$

$$f = \frac{64}{576.27} = 0.111$$

$$h_L = .1863 \frac{(0.111)(1.479)(0.559)^2}{4.026}$$

$$\underline{h_L = 0.002 \text{ feet of agent}}$$

Total Spray Boom Head

Exit from discharge line	6.059 feet
Station 0.0 to Station 149.63	0.541
Station 149.63 to Station 161.63	0.035
Station 161.63 to Station 173.63	0.028
Station 173.63 to Station 185.63	0.022
Station 185.63 to Station 197.63	0.016
Station 197.63 to Station 209.63	0.011
Station 209.63 to Station 221.63	0.005
Station 221.63 to Station 233.63	0.003
Station 233.63 to Station 251.38	0.002
Total Spray Boom Head	6.722 feet of agent

An illustration of the plumbing through which the flow of agent travels from the point it leaves the spray boom until it enters the airstream is presented also in figure 20. Since the maximum pressure change between pump and nozzle occurs at the outboard nozzle (Station 251.38), the head loss is calculated at this station.

In leaving the spray boom, the agent flows through a sudden contraction. However, the flow must also make a 30° turn. In order to properly analyze this condition, the L/D ratio is found for a sudden contraction and also a 30° miter bend.

Head Loss - Spray Boom to Check Valve:

Flow:

$$Q = 22.22 \text{ gpm}$$

Velocity:

$$v = .408 \frac{22.22}{(1.049)^2}$$

$$v = 8.239 \text{ ft/sec}$$

Reynolds number:

$$R_e = \frac{(81.12)(.087)(8.239)}{(32.2)(8.2 \times 10^{-4})}$$

$$R_e = 2203$$

Friction factor:

$$f = 0.050$$

30° Miter bend:

$$L/D = 8.0$$ Page A-27

Suddeh contraction:

$$d_1 = 1.049 \text{ inches}; \qquad d_2 = 4.026 \text{ inches}$$

$$\frac{d_1}{d_2} = \frac{1.049}{4.026} = 0.261$$

$$K = 0.43$$ Page A-26

$$L/D = \frac{K}{f} = \frac{0.43}{0.05} = 8.6$$

Summation of L/D's:

$$L/D = 8.0 + 8.6 = 16.6$$

$$L = L/D(D) + \frac{5.875}{12}$$

$$L = 16.6(.087) + 0.490$$

$$L = 1.444 + 0.490$$

$$L = 1.934 \text{ feet}$$

Head loss:

$$h_L = .1863 \frac{(0.050)(1.934)(8.239)^2}{1.049}$$

$$\underline{h_L = 1.166 \text{ feet of agent}}$$

Check valve head loss:

Pressure drop = 1.85 psi @ 22.22 gpm — James, Pond & Clark, Inc. Catalog, Pg 6.

$$h_L = (1.85)(2.31)(1.3)$$

$$\underline{h_L = 5.556 \text{ feet of agent}}$$

Contraction upstream of 3/4 inch street elbow:

d_1 = 0.719 inches d_2 = 0.897 inches

$$\frac{d_1}{d_2} = 0.801$$

$$K = 0.12$$

$$v = .408 \frac{22.22}{(0.719)^2}$$

$$v = 17.537 \text{ ft/sec}$$

$$R_e = \frac{(81.12)(.06)(17.537)}{(32.2)(8.2 \times 10^{-4})}$$

$$R_e = 3233$$

$$f = 0.045$$

$$L/D = \frac{K}{f} = \frac{0.12}{0.045} = 2.667$$

$$L = L/D(D) = (2.667) \frac{(0.719)}{12}$$

$$L = 0.160 \text{ feet}$$

$$h_L = .1863 \frac{(.045)(0.160)(17.537)^2}{0.719}$$

$$\underline{h_L = 0.573 \text{ feet of agent}}$$

90° street elbow:

$$L/D = 50$$

Average internal diameter = 0.88 inches

$$v = .408 \frac{22.22}{(0.88)^2}$$

$$v = 11.707 \text{ ft/sec}$$

$$R_e = \frac{(81.12)(.073)(11.707)}{(32.2)(8.2 \times 10^{-4})}$$

$$R_e = 2626$$

$$f = 0.0475$$

$$L = L/D(D) = 50\left(\frac{0.88}{12}\right) = 3.67 \text{ feet}$$

$$h_L = .1863 \frac{(.0475)(3.67)(11.707)^2}{0.88}$$

$$\underline{h_L = 5.058 \text{ feet of agent}}$$

Contraction downstream of 3/4-inch street elbow:

$$d_1 = 0.500 \text{ inches} \qquad d_2 = 0.941 \text{ inches}$$

$$\frac{d_1}{d_2} = \frac{0.500}{0.941} = 0.53$$

$$K = 0.32$$

$$v = 0.408 \frac{(22.22)}{(0.50)^2} = 36.263 \text{ ft/sec}$$

$$R_e = \frac{(81.12)(.042)(36.263)}{(32.2)(8.2 \times 10^{-4})} = 4680$$

$$f = 0.042$$

$$L/D = \frac{K}{f} = \frac{0.32}{0.042} = 7.619$$

$$L = L/D(D) = 7.619\left(\frac{0.50}{12}\right)$$

$$L = 0.317 \text{ feet}$$

$$h_L = .1863 \frac{(.042)(0.317)(36.263)^2}{0.50}$$

$$\underline{h_L = 6.523 \text{ feet of agent}}$$

Spray Nozzle:

From the data available in the Spray Systems Company Catalog 25, a formula was derived to calculate the pressure required to dispense a known flow of agent. The formula is:

$$P = 0.069215 \left[\frac{\text{Q per Nozzle}}{\text{Conversion Factor}} \right]^2$$

The value of the conversion factor can also be extracted from this catalog if the specific gravity of the agent is known.

$$QPN = 22.22 \text{ gpm} \qquad C.F. = 0.877$$

$$P = 0.069215 \left(\frac{QPN}{CF} \right)^2$$

$$P = 0.069215 \left(\frac{22.22}{0.877} \right)^2$$

$$P = 44.431 \text{ psi}$$

$$h_L = \frac{(44.431 \text{ lb/in}^2)(144 \text{ in}^2/\text{ft}^2)}{81.12 \text{ lbs/ft}^3}$$

$$\underline{h_L = 78.872 \text{ feet of agent}}$$

Total head loss downstream of spray boom:

Spray boom to check valve:	1.166 feet
Check valve:	5.556
Upstream contraction:	0.573
90° street elbow:	5.058
Downstream contraction:	6.523
Spray nozzle:	78.872
h_L =	97.748 feet of agent

Total pump head for 400 gpm:

Suction head:	22.903
Discharge head:	82.714
Spray boom head:	6.722
Head downstream of spray boom:	97.748
Total head (400 gpm) H =	210.092 feet of agent

This analysis demonstrates the procedure for determining the total head for a certain agent at a certain flow rate. The head for any flow rate can be calculated in the same manner. Likewise the total head can be found for any liquid agent by changing the values for specific gravity, viscosity, and the spray nozzle conversion factor.

This procedure has been programmed for the IBM Model 360-30 computer. The program was exercised for four different agents currently being used in conjunction with the A/A45Y-1 system in addition to water. Flow rates ranging from 1 to 400 gpm were analyzed. The agents and their characteristics are shown in the following table.

Liquid Agent	Specific Gravity	Viscosity @ 80°F (Centistokes)	Spray Nozzle Conversion Factor
Water	1.000	1.00	1.000
Orange	1.270	38.2	0.887
Purple	1.270	38.2	0.887
Blue	1.335	8.8	0.865
White (Tordon 101)	1.150	243.0	0.931

The results of the computer tabulations were plotted for total head (feet) versus flow rate (gpm) and are illustrated in figure 21.

Dispenser Performance Range

Successful operation of the dispenser depends upon the ability of the crew to recognize the dispenser's capabilities and limitations. The dispenser performance information presented herein is sufficient in scope to permit an estimate of what may be expected of the dispenser under normal conditions.

In order to determine the operating range of the dispenser, it was necessary to perform a test to establish the pump performance curve and secondly, to mathematically perform a fluid analysis of the entire dispenser from the tank to the spray nozzles. This test and analysis has been explained in the two previous sections.

Figures 22 through 25 combine the aforementioned test and analysis curves to establish the operating range of the dispenser for various chemical agents. The intersection of the two curves represents the maximum flow rate obtainable at 3600 engine RPM.

In using these graphs, locate the desired flow rate on the horizontal scale of the appropriate agent graph; move vertically to the point of intersection with the theoretical system loss curve; then move horizontally and read the required pressure from the vertical scale. The speed (rpm) of the engine must be adjusted while spraying, so that the required pressure is indicated on the pressure indicator located on the control console.

The cross-hatched area labeled "Operating Range" encompasses all values of back pressures or pressure losses that the system can theoretically pump against as a function of engine speed and flow rate.

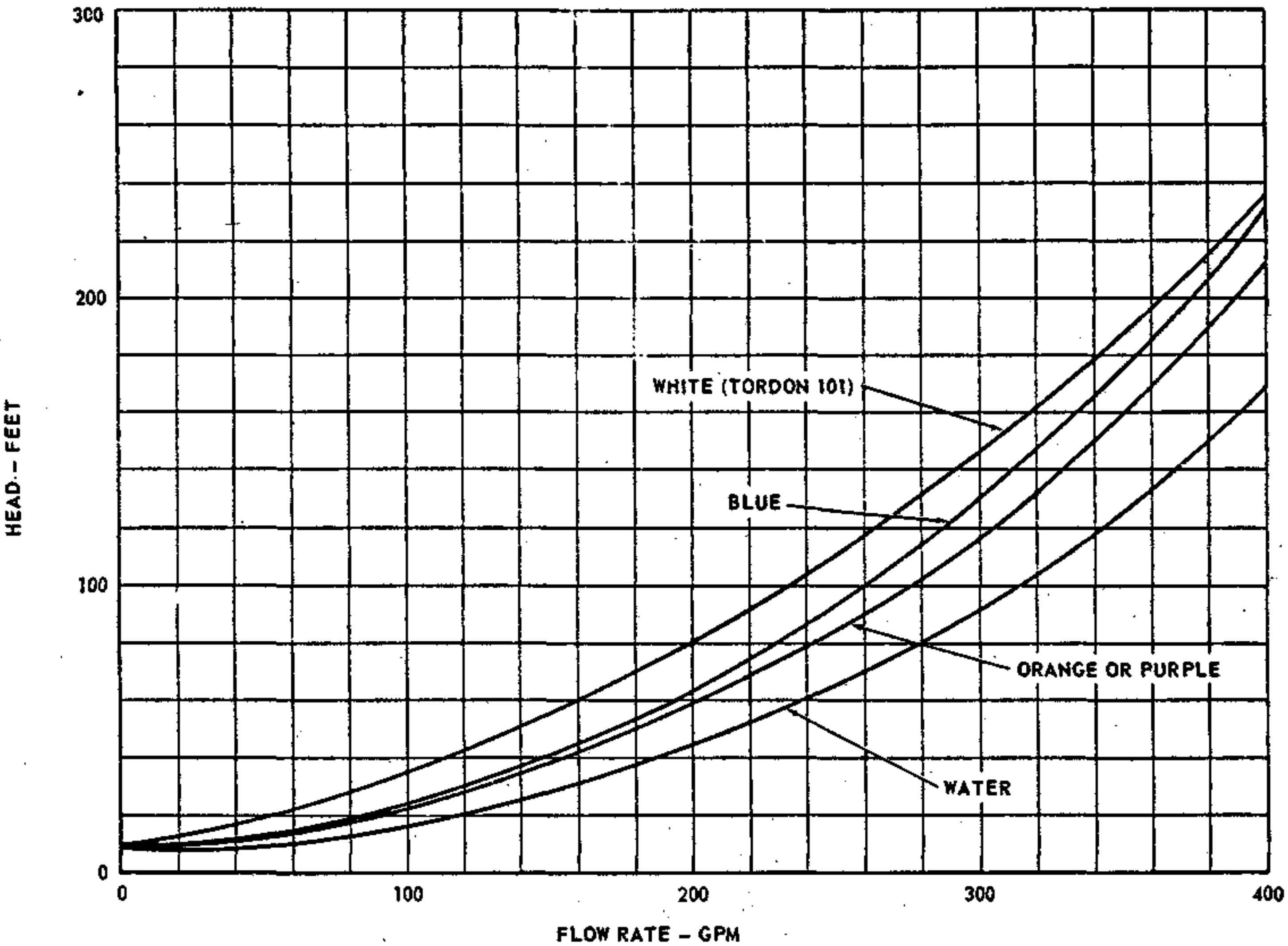

Figure 21. System Pressure Loss

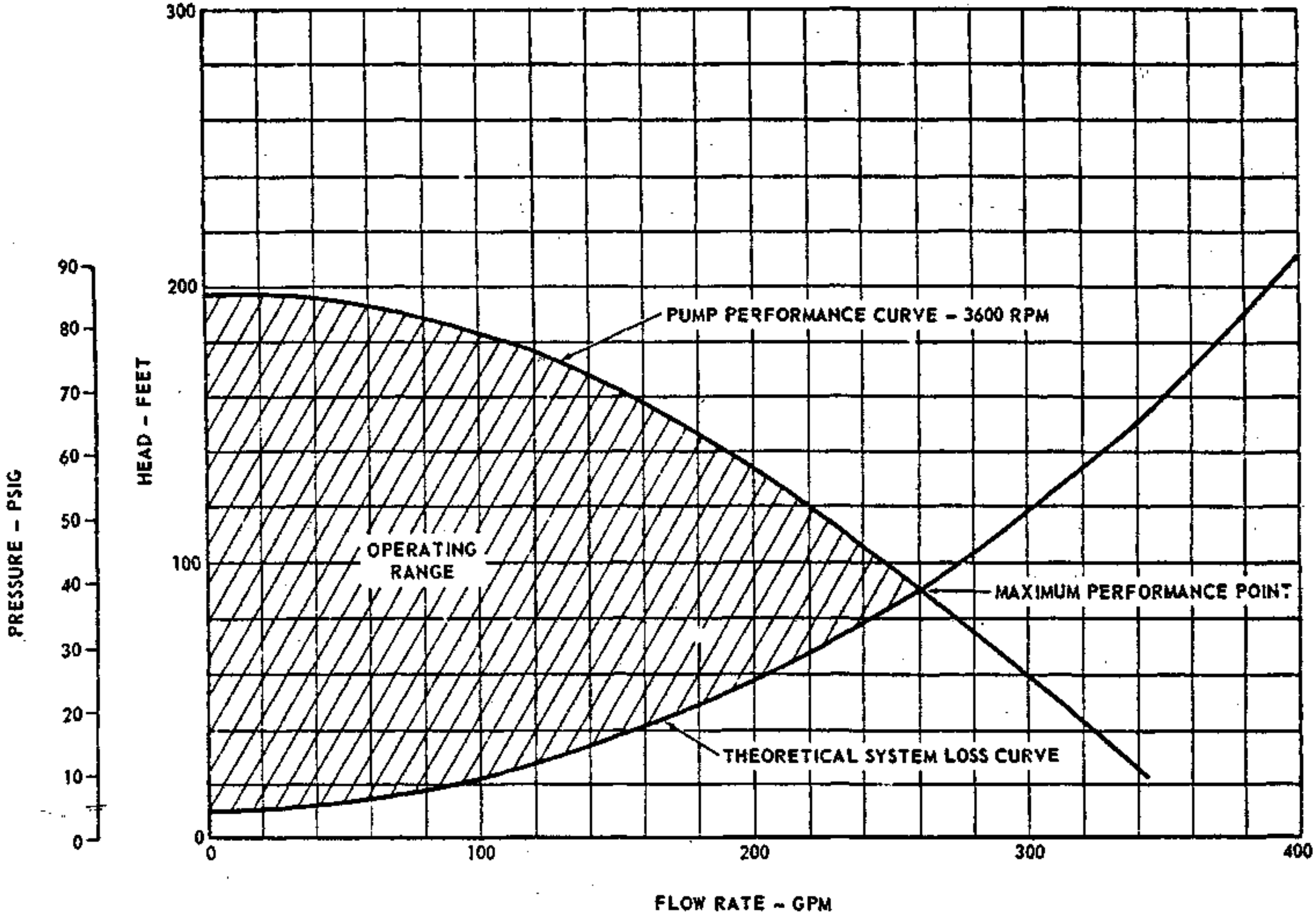

Figure 22. A/A45Y-1 Dispenser Performance Range - Agent: Water

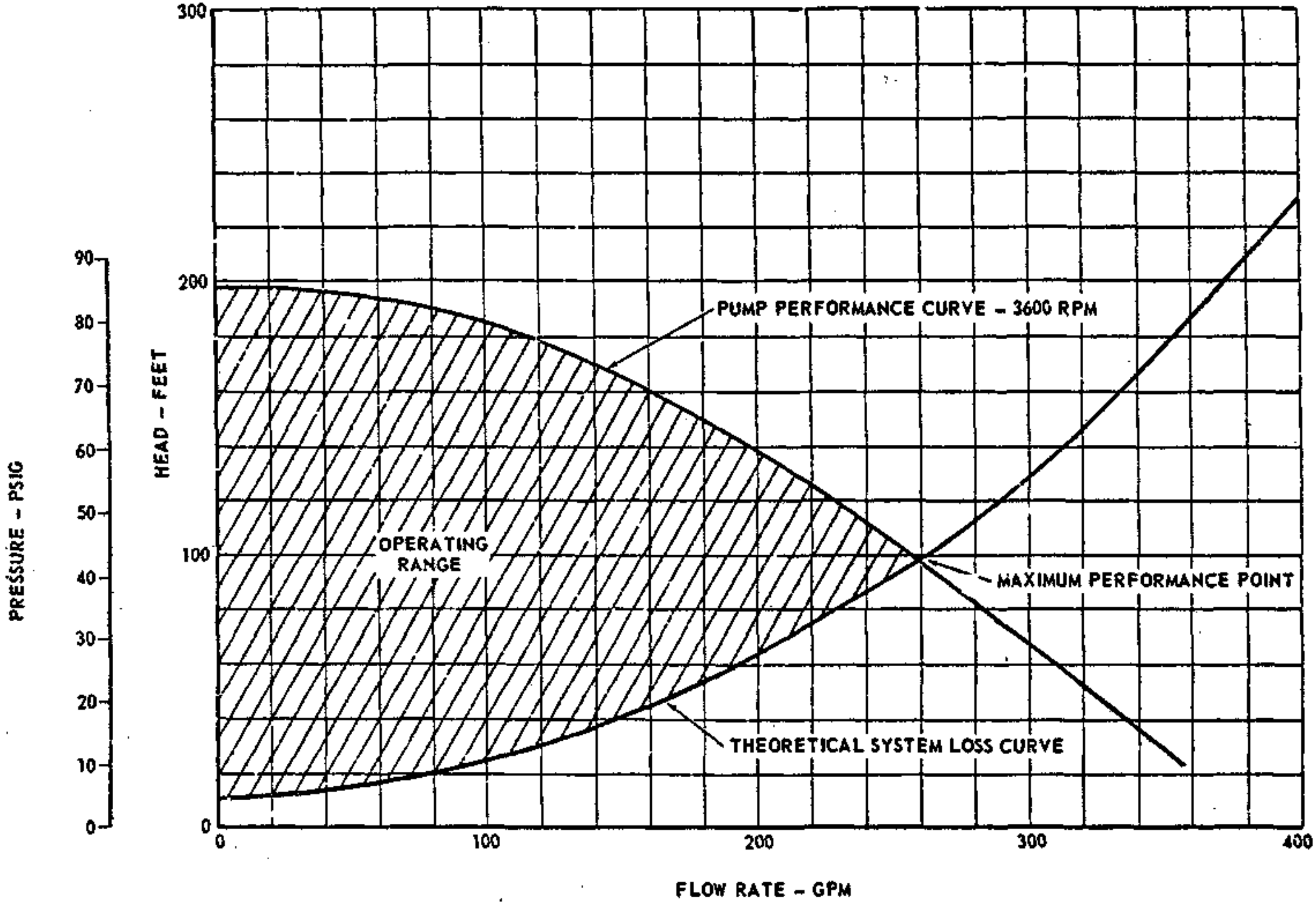

Figure 23. A/A45Y-1 Dispenser Performance Range - Agent: Orange or Purple

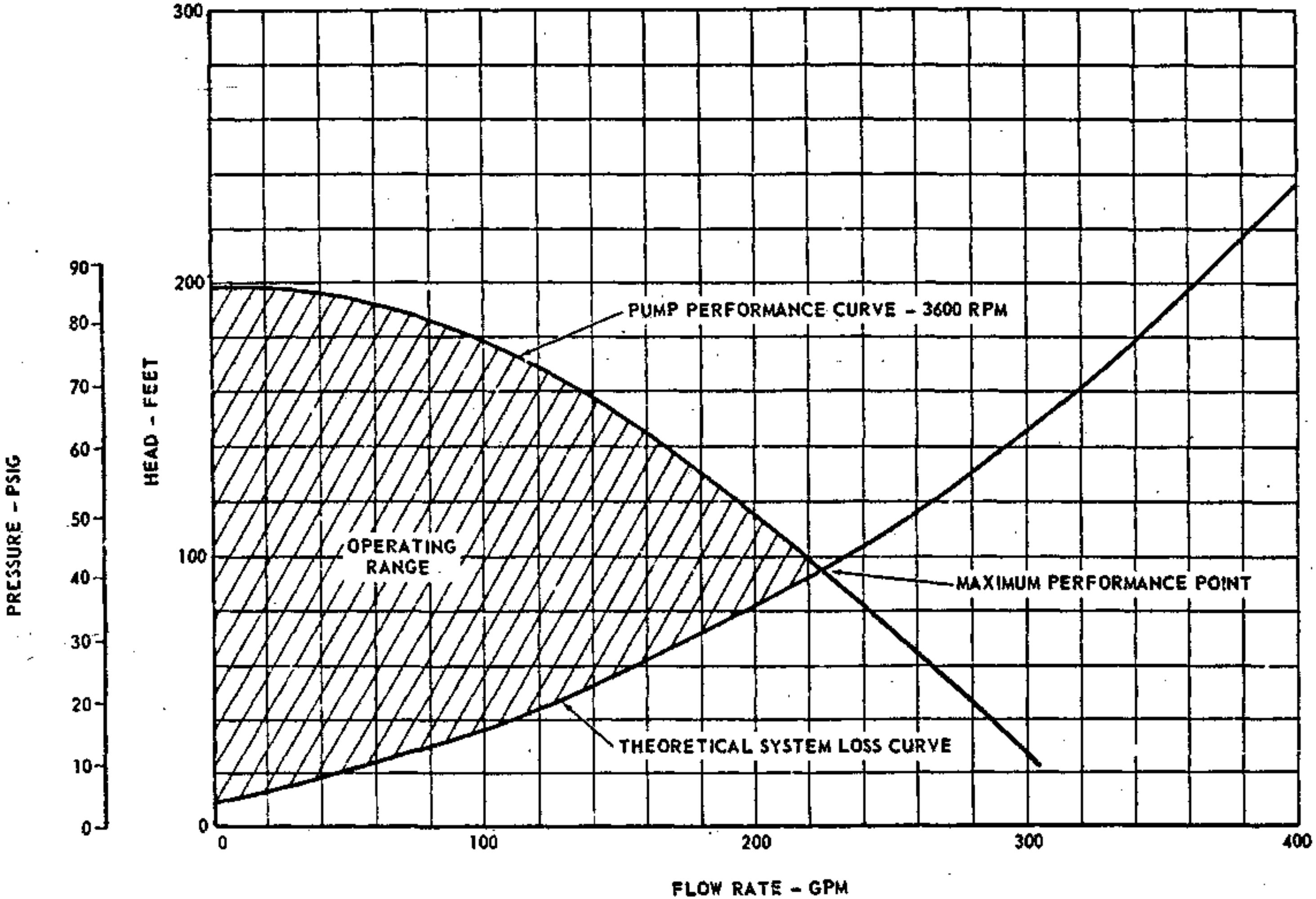

Figure 24. A/A45Y-1 Dispenser Performance Range - Agent: Blue

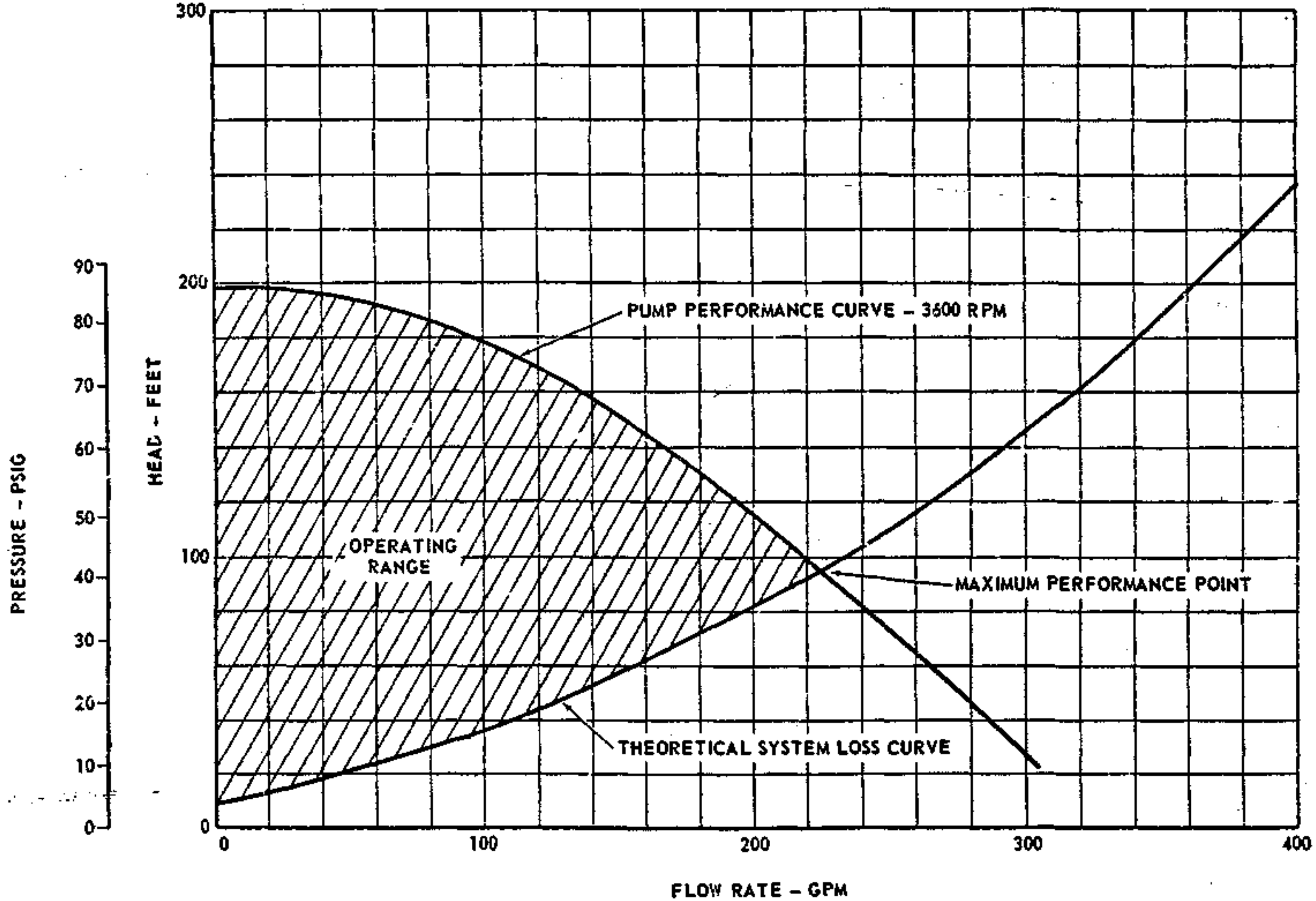

Figure 25. A/A45Y-1 Dispenser Performance Range - Agent: White