TL. 113-57/06

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ARROW 2
FLYING CONTROLS HYDRAULIC SYSTEM

REPORT NO. 72/SYSTEMS 32/25

JUNE 1957

This brochure is intended to provide an accurate description of the system(s) or service(s) for purposes of the Arrow 2 Mock-up Conference, and is not to be considered binding with respect to changes which may occur subsequent to the date of publication.

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MALTON — ONTARIO

/25

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1. Introduction

1.1 Flying Control Requirements

The Arrow 2 aircraft will be equipped with a fully powered flying control system. This is the only practical way to cope with high surface loads resulting from stability and controllability requirements.

With fully powered controls, the power required to operate the surfaces is derived from the engines; the pilot's effort is only that required to overcome the operating loads of the surface control actuator valves, the control linkage friction, and the forces of the artificial feel systems. The control system may be described as irreversible. There is therefore, no feed-back of aerodynamic forces to the pilot and hence no natural feel of aircraft response through the controls.

1.2 System Considerations

1.2.1 Powered Controls

Hydraulic means of transmitting power to the control surface actuators has been chosen as the most suitable, and a system pressure of 4000 psi has been selected in order to meet the high response requirements and actuator size limitations imposed by the aircraft performance and configuration. To achieve a degree of reliability comparable to the highly developed mechanical systems used in the past, the powered control system is duplicated, the two systems being identified as "A" and "B" respectively, and confined to the operation of the ailerons, elevators and rudder. The aileron and elevator parallel and differential servos receive power from the "B" system only. The duplication covers input power to the pumping system, the pumps, the hydraulic circuits and the rams of each surface actuator. It is arranged that adequate flying control power is available in the event of the failure of one engine or one hydraulic system.

1.2.2 Astra I Scanner Drive

The "A" flying controls hydraulic system has a secondary function, in that it also supplies high pressure fluid to power the Astra I scanner drive hydraulic sub-system.

1.3 Special Design Features

Certain innovations in the detail design of the hydraulic circuits ensure proper functioning of the system, with a minimum of maintenance, during operation under the most adverse environmental conditions. Some of these innovations are noted below.

1.3.1 Air-Less Circuit

The principle of an "air-less circuit" has been adopted, i.e. a circuit in which the air inclusion is kept to a minimum. Compensators are used instead of the usual reservoirs. In the compensators stored fluid is kept constantly under pressure, there being no direct contact of the fluid with air.

1.3.2 High Fluid Temperature

Drag considerations dictate the desirability of using the fuel supply as a heat sink for dissipating heat generated by the hydraulic systems. This is precluded, under low fuel consumption conditions, by fuel temperature limitations at engine inlets. It is, therefore, necessary to utilize ram air cooling under these conditions. For efficient heat exchange the hydraulic fluid must be operated at as high a temperature as is practicable, and 275°F has been established as the upper limit in order to permit the use of standard MIL-O-5606 fluid and of sealing materials and techniques which are in a satisfactory state of development.

1.3.3 Line Fittings

To provide greater line resistance to fatigue, MS-type flareless fittings, up-rated to 4000 psi working pressure, have been used in preference to the AN flared type. This feature parallels mandatory requirements on all new designs in the USAF and USN and therefore contributes to standardization. (See Fig. 2.8).

1.3.4 Flexible Connections

To avoid problems normally associated with the use of flexible hoses and, in particular, those associated with the high operating temperatures and pressures of this system, flexing steel lines have been used extensively wherever relative motion has to be catered for.

1.4 Selection of Line Sizes

The line sizes selected for the hydraulic circuits are based on full flow and full control effectiveness with a fluid temperature of $0^{\circ}F$.

This operating condition has been chosen as a satisfactory compromise between the system operational characteristics and weight and space-saving considerations.

It was considered impracticable to size the lines for full flow and control effectiveness at $-65^{\circ}F$ because of the weight and space penalties involved, since fluid cooling is necessary after a few minutes of operation to keep the system temperature below $250^{\circ}F$.

NOTE: Information on the Flying Control Actuators and Servos is given in Brochure 72/Systems 15/28 entitled: "DESCRIPTION OF ARROW 2 FLYING CONTROL SYSTEM".

2. Design Objectives

The design objectives for the flying control hydraulic system are:

2.1 To provide an irreversible hydraulic system to move the control surfaces individually or in combination meeting the following maximum rate and hinge moment requirements at fluid temperatures down to 0^{o}F:

(a) Elevators - 60,000 lb. - ft. at 40^{o}/sec.

(b) Ailerons - 25,000 lb. - ft. at 35^{o}/sec.

(c) Rudder - 12,000 lb. - ft. at 40^{o}/sec.

2.2 To provide adequate control power for flight (with limited manoeuverability) under the following conditions:

(a) Fluid temperature as low as minus 20^{o}F.

(b) Asymmetric flight due to single engine operation.

(c) Failure of one of the duplicated flying controls hydraulic systems.

2.3 To restrict system operating temperatures to a maximum of 250^{o}F (with temperatures up to 275^{o}F in local sections of the circuit) by the use of heat exchangers, to permit the use of currently available sealing techniques and MIL-O-5606 hydraulic fluid.

2.4 To provide a high degree of system reliability, through the use of pump inlet pressurization, to overcome cavitation tendencies at low temperature and high altitude.

2.5 To provide a system which will meet the requirements of RCAF Specification AIR 7-4, which in turn calls for the design requirements of CAP 479, "Manual of Aircraft Design Requirements for the Royal Canadian Air Force" and ARDCM 80-1, "Handbook of Instructions for Aircraft Designers".

2.5

3. Description of System

3.1 Simplified Schematic

Fig. 1.2 shows a simplified schematic of one of the flying control hydraulic systems. The primary flow path is indicated by heavy lines, the solid portion representing the pressure side and dotted portion representing the return side of the closed circuit. Secondary paths are indicated by thin lines, and the ground power unit is shown in phantom lines.

3.1.1 Primary Flow Path

Variable delivery pumps supply filtered hydraulic fluid to the flying control valves and actuators. Returning fluid passes through a heat exchanger to a compensator and from there enters the pump. The system is of the airless type, with the compensator fulfilling the function of a pressurized reservoir.

3.1.2 Secondary Flow Paths

The two principle secondary flow paths, as shown in Fig. 1.2, are as follows:

(1) The path through the pressure relief valve protects the system from excessive rises in pressure.

(2) The path through the pressure reducing valve supplies standby pressure to the compensator in case of failure of the normal pressure supply from the Utility System.

3.2 Filtration

All pressure fluid flowing to the flying control actuators passes through a 40 (US) gpm 10 micron filter. The aileron and rudder actuators, being remote from this filter, are provided with further protection for their valves by filters close to the actuators. All return fluid passes through a filter mounted on the compensator inlet. (See Fig. 2.0).

3.3 Temperature Control

The pump inlet temperature is maintained below 230°F by the use of heat exchangers in the circuit upstream of the compensator. Energy losses in the hydraulic circuit, (principally in the pumps and control valves) are transferred, in part, to the hydraulic fluid, resulting in a rise in temperature.

The maximum fluid temperature at the inlet to the heat exchangers will be +250°F, but localized heating up to +275°F may occur. Under these conditions the outlet temperature will not exceed 230°F. These operating conditions have been taken into consideration in the design of units, seals and in selecting MIL-O-5606 as the hydraulic fluid.

3.4 Ground Service Connections

Two ground service connections are provided, one on the pressure side and the other on the return side of the system. This permits the system to be operated by an external source of power without operating the pump or the compressor. The low pressure service connection is also used as a filling point for the system. A filter in the return line of the main flow path protects the pumps from any foreign matter which may be introduced when filling the system.

3.5 System Warm Up Times (Fig. 3.1)

If the aircraft has been cold soaked on the ground, it will be necessary to warm up the hydraulic oil before take-off to obtain adequate control power for flight. This is done by manual movements of the cockpit control during engine running. An approximate measure of the time required to warm up to operating temperature from cold soak ambient air temperatures of -20, -40 and -65^{o}F is given in Fig. 3.1.

3.6 Astra I Scanner Drive Sub-System

Power for the Astra I Scanner drive hydraulic system is obtained from the flying controls hydraulic system ("A"). High pressure fluid is taken from the supply line for the rudder unit, at a point downstream of the main filter. The fluid is then passed through a stop valve, and a check valve, into the hydraulic motor end of a hydraulic transformer unit. This unit is part of the Astra I hydraulic system and is basically a 4000 psi hydraulic motor mechanically driving a 1000 psi constant delivery pump. A flow regulator is installed in the motor to prevent the removal of more than

3.5 gpm flow from the flying controls system. An 80 cu. in. accumulator is "T" jointed into the 4000 psi supply line, downstream of the check valve, to supply the hydraulic motor during peak flying control flow requirements. The solenoid operated stop valve receives its electrical supply from the main D.C. bus; therefore on double engine flame-out this valve will close, preventing the removal of power from the flying control system. The stop valve can also be de-energized on the ground to prevent scanner system operation during testing of the flying control hydraulic system.

4. Description of Main Components

4.1 Compensator (See Figs. 2.0 and 2.1)

4.1.1 Purpose

The compensator is a variable volume, air-less pressure vessel, designed to keep the pump inlet under pressure at all times. It compensates for volumetric changes in the flying controls hydraulic system due to the thermal expansion and leakage. It also serves as an air separator. The low pressure filter, on the inlet of the compensator filters, return fluid before it reaches the main compensator chamber.

4.1.2 Physical Description (See Fig. 2.0)

The compensator consists of a large bore cylinder, of 475 cu. in. capacity, with a coaxial small bore cylinder rigidly attached. A large diameter piston with a hollow stem allows the main cylinder volume above the piston to be pressurized by system reduced pressures which are imposed on the hollow stem area in the small cylinder.

4.1.3 Pressurization

There are two pressure connections on the small cylinder arranged so that either one will function in the event of failure of the other. Reduced pressure at 1500 to 1600 psi, from the utility system pressure control valve, provides the normal means of pressurizing the small cylinder through the central stand pipe. In the bottom of the chamber is a floating piston, which is pressurized at 1250 psi from the flying controls hydraulic system pressure control valve. On failure of the normal pressure source, the alternative pressure forces the floating piston against the end of the hollow stem to maintain pressurization in the low pressure chamber.

15 (The stand pipe maintains the separation between the systems.)

4.1.4 Relief Valve

A relief valve, designed to relieve at 220 psi, is fitted in the dome at the top of the main chamber. Should this valve open, any air trapped in the dome will be discharged prior to discharge of fluid.

4.1.5 Bleed Valve

A manually operated bleed valve is provided in the low pressure end of the compensator. In addition to providing an air-bleed for servicing, this valve also enables surplus fluid to be drawn off if the compensator is over-full.

4.1.6 Functioning of Compensator (See Fig. 2.1)

4.1.6.1 Volume of System Decreasing

As the hydraulic system cools down, its total volume decreases, reducing the system return pressure acting on the top of the piston. (See detail (b) Fig. 2.1). When the pressure falls to the point where the hydraulic force plus the seal friction is insufficient to balance the 1500 psi pressurization in the small cylinder, the piston will rise to re-establish pressure equilibrium.

4.1.6.2 Volume of System Increasing (See detail (c) of Fig. 2.1)

When the volume of the system increases, the pressure in the head of the compensator increases until it is sufficient to overcome the hydraulic force on the high pressure piston area, plus the seal friction. The piston then moves down, discharging fluid from the high pressure chamber at 1720 psi. through the relief valve, until a pressure balance is re-established.

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4.1.6.3 Failure of Normal Pressurization (Between reducing valve and compensator) (see detail (d) in Fig. 2.1)

When the normal (utility system) fluid pressure falls to a value less than 1250 psi, the stand-by system pressure moves the floating piston upwards, until it contacts the rim of the hollow piston rod and thus restores return line pressurization. Due to higher seal friction and the reduced effective area of the small cylinder (bore area minus the central stem area), the effective pressurization in the top chamber in this stand-by condition is reduced to approximately 75 psi. As the system volume increases, the pressure in the small cylinder increases to 1800 psi before fluid is released through the relief valve.

4.1.6.4 Failure of Normal Pressurization (With line from reducing valve to compensator intact) (See detail (e) of Fig. 2.1)

Pressure will be transmitted to the low pressure chamber, from the stand-by system, through the column of fluid trapped on the normal high pressure supply side of the smaller piston.

If the system return pressure increases and the resulting pressure rise in the lower cylinder exceeds 1720 psi, the trapped fluid will be discharged through the utility relief valve, permitting the floating piston to contact the hollow piston stem. The compensator will then operate in the manner described in paragraph 4.1.6.3 above.

4.1.7 Compensator Servicing

Providing the system is filled correctly initially and no leakage occurs, the compensator will be completely full only if the maximum system temperature is reached. For every mean fluid temperature within the design temperature range there is a corresponding piston position that indicates a full system. A constant reading piston position indicator, calibrated in degrees of temperature, is fitted to each compensator to indicate the volume of the contained fluid. Comparison of the actual system temperature (determined within acceptable limits from a thermometer in an insulated mounting on a hydraulic component in the aircraft), with the piston indicator reading, gives the required information on system volume.

4.2 Variable Delivery Pump (See Fig. 2.2 & 2.3)

4.2.1 Pump Drive

Each flying control hydraulic system incorporates two identical pumps, one of which is driven through a geared drive from the L.H. main engine, and the other from the R.H. main engine.

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4.2.2 Pump Inlet Pressure

The inlet pressure to each pump is maintained at a nominal value of 90 psi by the compensator. The pumps will operate satisfactorily with any inlet pressure from 30 to 130 psi, and will withstand intermittent operation with inlet pressure down to 2 psi absolute.

4.2.3 Delivery Rate

The pumps are of the variable displacement type, with integral outlet pressure sensing unit which varies the delivery rate to meet the system demands as reflected in pressure drop. This unit is set to maintain a nominal 4000 psi outlet pressure. Available delivery rate varies directly as the engine speed, reaching a maximum of approximately 20 (US) gpm, per pump, at 3250 rpm (equivalent to full engine rpm). The pumps will withstand an overspeed up to 3900 rpm in the event of engine malfunction.

4.2.4 Pump Inlet Connection

The system return is connected to the pump through a quick disconnect self-sealing coupling. This prevents loss of system fluid, and minimizes the possibility of air inclusion in the system when the pump is removed for servicing.

4.2.5 Pump Delivery Manifold

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The outputs from the two pumps in each system are united in a manifold, which incorporates a check valve in each inlet. In the event of one pump failure, the check valve in the respective manifold inlet will prevent the reverse flow of fluid through the inoperative pump. The check valves also prevent reverse flow through both pumps during operation of the ground servicing unit.

4.2.6 Pump Case Drain

A pump case drain line from each pump is connected to the system return line upstream of the heat exchangers. This drain line provides for disposal of the internal leakage from the pump, thus providing the necessary lubrication and cooling of the pump mechanism. This port also serves for case filling after pump installation, as it is located at the highest point in the casing to prevent entrapment of air.

4.3 Filters

4.3.1 Filter - Bowl Type, High Pressure, 40 (US) GPM (See Fig. 2.6)

4.3.1.1 Purpose

High pressure 40 (US) gpm filters are located in the pressure side of the system, downstream of the pumps and ground servicing coupling. These filters protect the flying control valves and actuators and the automatic flight command (parallel) servos. They are the master high pressure filters and are designed to provide filtration down to 10 micron size.

4.3.1.2 Self-Sealing Provisions

The filter bowl and element can be removed without completely depressurizing the system, provided pressure on the high pressure side is reduced to the normal return pressure (approx. 90 psi). When the bowl is being removed, internal valves in the filter head move to positions which prevent loss of any appreciable amount of fluid and the consequent entry of air into the system lines.

4.3.1.3 Relief Valve Operation

The relief valve is set for 50 ±5 psi cracking pressure differential across the filter element. Should excessive clogging of the element cause the pressure drop to exceed this valve it will be bypassed.

In normal conditions, i.e. when the clogging does not exceed a certain allowable value (equivalent to blocking off 25% of the filter element area), the filter is designed to work without by-passing in the following conditions:

(1) at rated flow at all temperatures above $0^{o}F$,

(2) at 50% of the rated flow at all temperatures above $-20^{o}F$,

(3) at 7.5% of rated flow at all temperatures above -65°F.

4.3.1.4 Filter Element

The 40 gpm filter elements used in the flying controls system filters are of the cleanable, re-usable type.

4.3.2 Filter - Bowl Type, Low Pressure, 40 (US) GPM (See Fig. 2.6)

This filter is installed in the return side of the system, mainly to protect the pumps. It is placed upstream of the compensator to ensure a positive pressure at the pump inlet. It is mounted on the inlet of the compensator to filter particles of 10 microns and larger from the fluid returning from relief valves, pump case drains, actuators, and ground servicing connection, thus protecting the pumps and the compensator. The low pressure filters are equipped with self-sealing valves and relief valves, to provide the same operating and servicing facilities as specified for the high pressure filters in paragraph 4.3.1.2 and 4.3.1.3 above. This filter will use the same element of 40 (US) gpm capacity developed for the high pressure filter.

4.3.3 Filter - Secondary High Pressure (See Fig. 2.5)

4.3.3.1 Purpose in System

Due to the long lines separating the main 40 (US) gpm, high pressure filter from the rudder and aileron actuators, additional filtration protection is provided near these units, by means of individual filter assemblies of 4 and 7 (US) gpm nominal capacity, respectively. After the initial cleansing of the system, it is anticipated that these filters will require infrequent servicing, as the main filter, which is more readily accessible, will retain most of the contaminants.

4.3.3.2 Filter Element

The filter elements are made from the same material as the main 40 gpm high pressure filter elements and are designed to provide protection from particles down to 10 microns. They will be re-usable after cleaning.

4.3.3.3 By-Pass Relief Valve

Each filter assembly incorporates a by-pass relief valve, so that undue restriction of flow through the filter element will result in flow being by-passed around the element. The relief valve is set to open when the pressure drop across the element exceeds 50 ± 5 psi.

4.4 Pressure Control Valve (See Fig. 2.4)

The three valves described below have been combined into one unit to simplify piping, conserve space and reduce the number of mounting points. This unit is termed the pressure control valve.

4.4.1 System Pressure Relief Valve

The pressure relief valve is set to crack at a maximum pressure differential of 4370 psi which, with the normal pressure of 90 psi in the return side of the system, gives an actual pressure of 4460 psi. The valve provides full flow relief at a pressure of 4750 psi.

4.4.2 Pressure Reducing Valve

The pressure reducing valve reduces normal system pressure to a nominal value of 1250 psi for emergency pressurization of the flying controls system compensator.

4.4.3 Service Relief Valve

A service relief valve is provided to permit relief flow of fluid from the high pressure side of the compensator when fluid is forced into the low pressure side. It is set to crack at a pressure differential of 1800 psi.

4.5 Accumulator - 25 Cubic Inch, Floating Piston Type (See Fig.2.7)

4.5.1 Purpose in System

Whenever the control valve of an actuator is moved from its neutral position there is a demand for high pressure fluid. The accumulator with its nitrogen charge can supply this demand momentarily faster than the pump, thus giving quicker control response. The accumulator will be recharged by the pump when the demand has been met. It also provides damping for pressure surges and pulsations caused by rapid valve operation. Tests have proven that a 25 cu. in. accumulator is adequate to perform both these functions.

4.6 Switch - Hydraulic Pressure (See Fig. 2.12)

4.6.1 General Description

The switch body has a hydraulic port at one end and an electrical connection at the other. Inside the case a pressure-sensitive mechanism actuates a snap-action type electrical switch, which has a wide range between snap and reset. A warning light glows in the cockpit when system pressure falls too low and actuates this pressure switch.

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4.6.2 Pressure Settings

The switch contacts close as the system pressure falls to 1000 psi and open when the system pressure rises to 3000 psi or higher. In normal flight manoeuvres, the cockpit warning light should not glow, even momentarily, unless system failure occurs.

4.7 Heat Exchanger (Figs. 2.10 and 2.11)

4.7.1 Heat Source

The high powered pumps and actuators generate large quantities of heat in the hydraulic fluid which is circulating through them. Little heat can be transferred to the surrounding air because of the high ambient temperatures which may be encountered. Therefore, a heat sink is required to keep the fluid temperature from exceeding 275°F. The fluid temperature at the pump inlets must not exceed 230°F, in order that sufficient cooling capacity is available for the minimum fluid flow case.

4.7.2 Heat Sinks

The principal heat sink is the oil to air heat exchanger. The cooling air is bled off of the engine intake and is vented overboard after passing through the heat exchanger. A secondary heat sink is the oil to fuel heat exchanger, downstream of the oil to air one, which transfers the residual heat load into the fuel being delivered to the engines.

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4.7.3 Oil-to-Air Heat Exchanger

This heat exchanger has a relief valve by-pass which opens at low temperatures and allows the fluid to by-pass the main exchanger passages. This occurs when the high viscosity due to low temperature causes a pressure drop through the heat transfer surfaces in excess of 10 psi. For cold starting, the low flow circulation through the main exchanger passages and the high flow circulation through the by-pass passages rapidly heats the whole exchanger, to provide full heat exchange capacity when the system fluid temperature has risen to 275°F at the heat exchanger inlet.

4.7.4 Oil-to-Fuel Heat Exchanger

The oil-to-fuel heat exchanger serves to carry the extra cooling load that cannot be handled by the primary oil-to-air heat exchanger.

This exchanger has a by-pass relief valve which, for low temperature operation, will permit the main part of the flow to short-circuit the oil-to-fuel heat transfer surfaces if the pressure drop through them is in excess of approximately 3 psi.

A special feature of this valve is a thermostatic element which is sensitive to fluid outlet temperature. At maximum temperature the by-pass valve closes, forcing the main flow through the heat transfer area. Thus the secondary heat exchanger shares the load with the oil-to-air heat exchanger when the latter is overloaded.

4.8 Expansion Couplings (Fig. 2.9)

Expansion couplings have been incorporated where necessary on long straight runs in hydraulic lines, to relieve stresses due to structural flexing or thermal expansion and contraction. A system of internal passages and carefully dimensioned pressure areas ensure that each unit is hydraulically balanced for any degree of expansion.

5. Ground Servicing (See Fig. 1.2)

5.1 Requirements - General

Equipment must be attached to the external disconnect couplings of the aircraft hydraulic systems to perform the following servicing tasks:

1. Filling of the flying control and utility hydraulic systems.
2. Refilling the compensators after they have been bled of any entrapped air.
3. Operation of any one of the systems for checkout or trouble shooting without running the engines.

5.2 Ground Servicing Equipment Requirements

The following two units will be required to perform the servicing tasks listed above:

1. A mobile hydraulic power unit, complete with motor driven pump, reservoir, pressure gauges and hose connections to couple to the aircraft systems. This equipment is to recharge the accumulator and to power each hydraulic system when the engines are shut down.
2. A hand pump with hose connections and self-sealing couplings, adapted for temporary support on the aircraft or on the ground servicing unit. This is required for filling the compensators in any of the three aircraft systems.

5.3 Disconnect Self-Sealing Couplings and Accumulators

Due to the fact that most self-sealing couplings cannot be attached or detached while pressure remains in the system, it is necessary to relieve all pressure prior to disconnecting. The emergency braking and compensator-pressurizing accumulator of 200 cu. in. capacity, being isolated by a check valve in the pressure control valve, is unaffected when the utility system pressure is released.

5.4 Protection of the Aircraft Hydraulic Systems (See Fig. 1.2)

5.4.1 Filters

To prevent the introduction of foreign material into the hydraulic fluid during connecting and disconnecting self-sealing couplings, no fluid is permitted to enter the main system components (valves, compensators and pumps) without first passing through the main high pressure or the main low pressure filter. High pressure fluid from the ground servicing unit enters the main line upstream of the pumps and their check valves, and then passes through the main high pressure filter.

5.4.2 Filling Connection Location

To fill the system, fluid is pumped in through the system return self-sealing coupling at the inlet to the filter attached to the compensator, hence the added fluid is filtered before it reaches the compensator. An additional filter upstream of the hand pump provides further protection for the aircraft hydraulic systems.

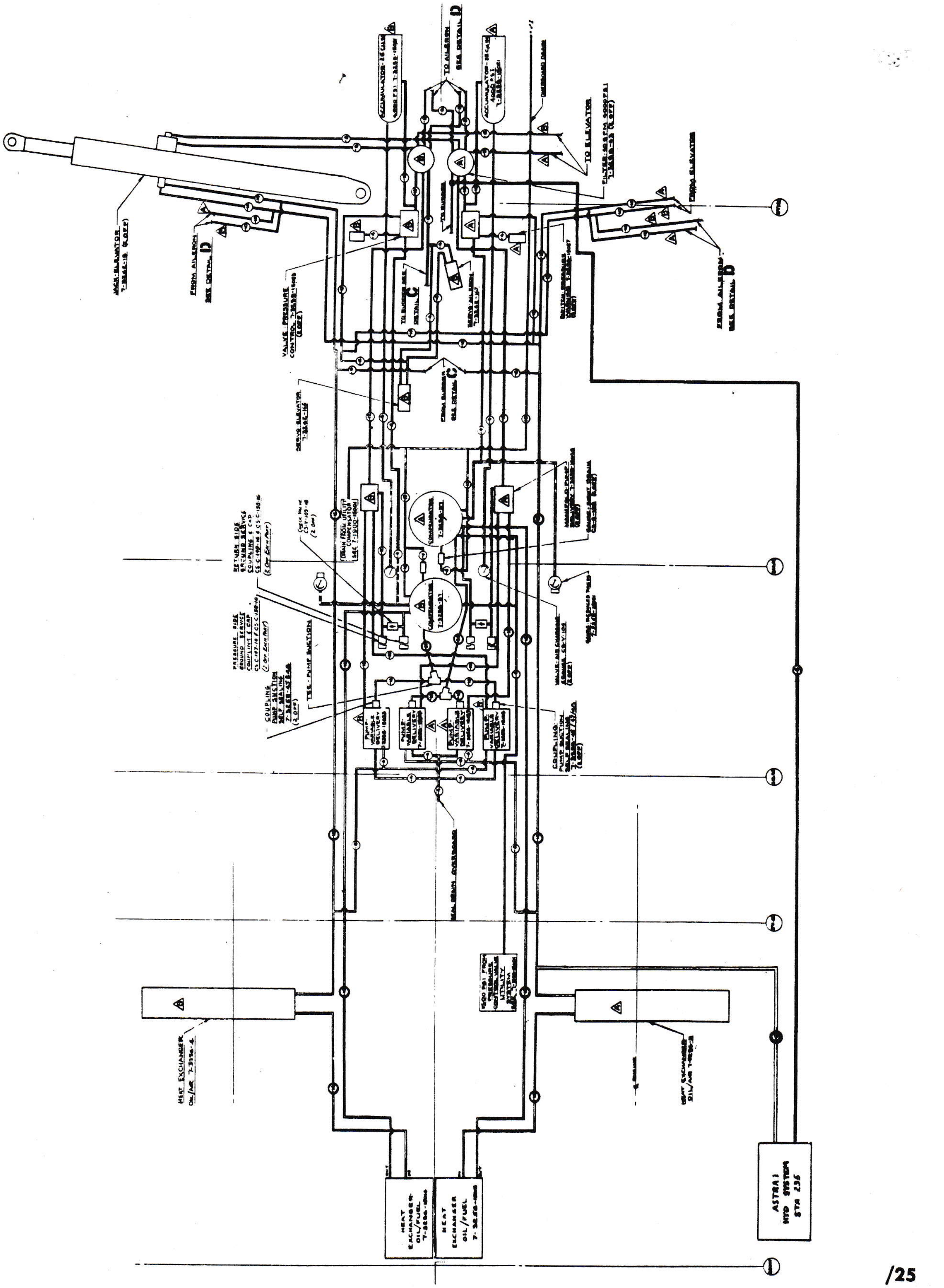

FIG. 1.0 DIAGRAMMATIC FLYING CONTROLS HYDRAULICS SYSTEM

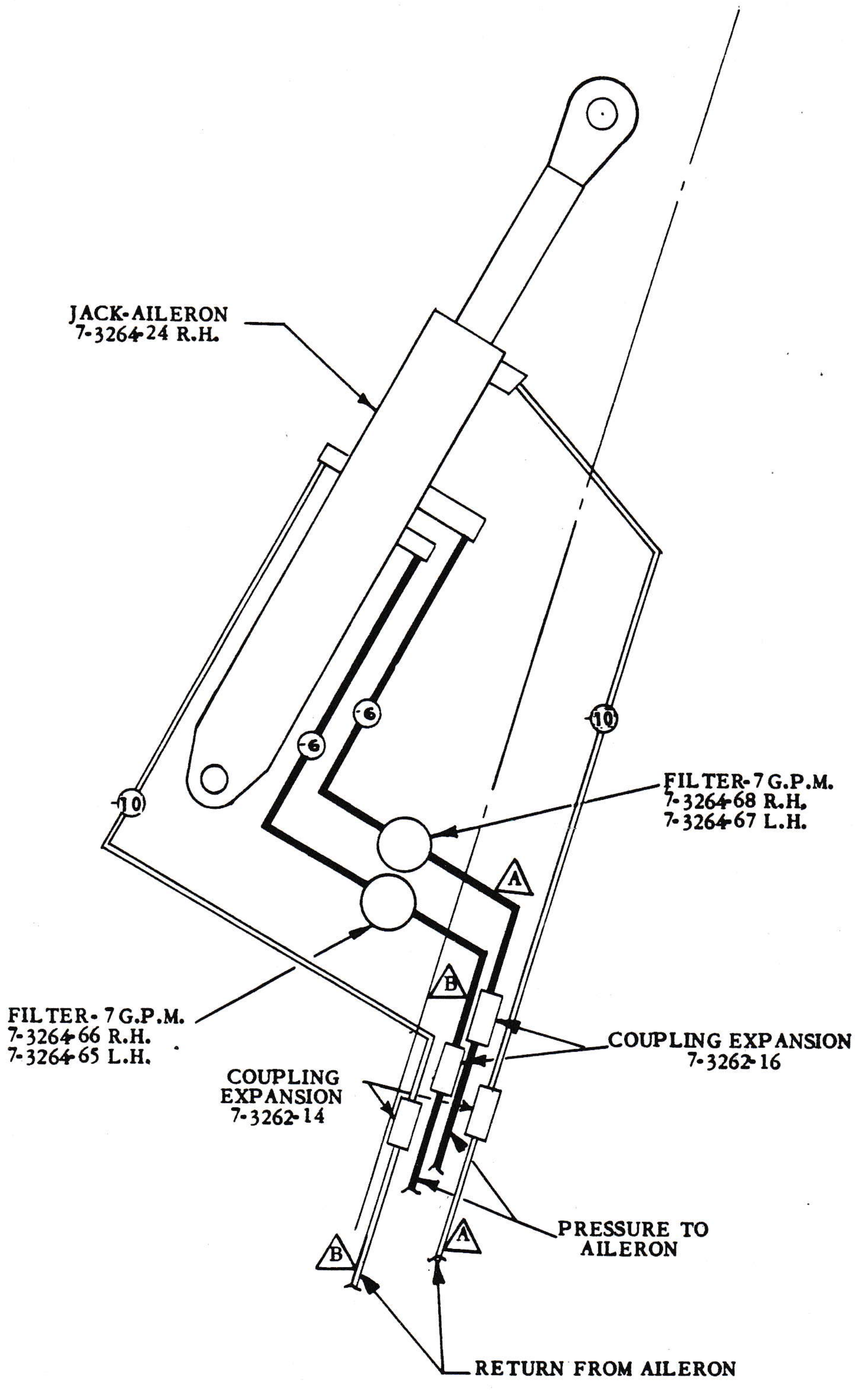

FIG. 1.0.1 DIAGRAMMATIC FLYING CONTROL HYDRAULIC SYSTEM (OUTER WING)

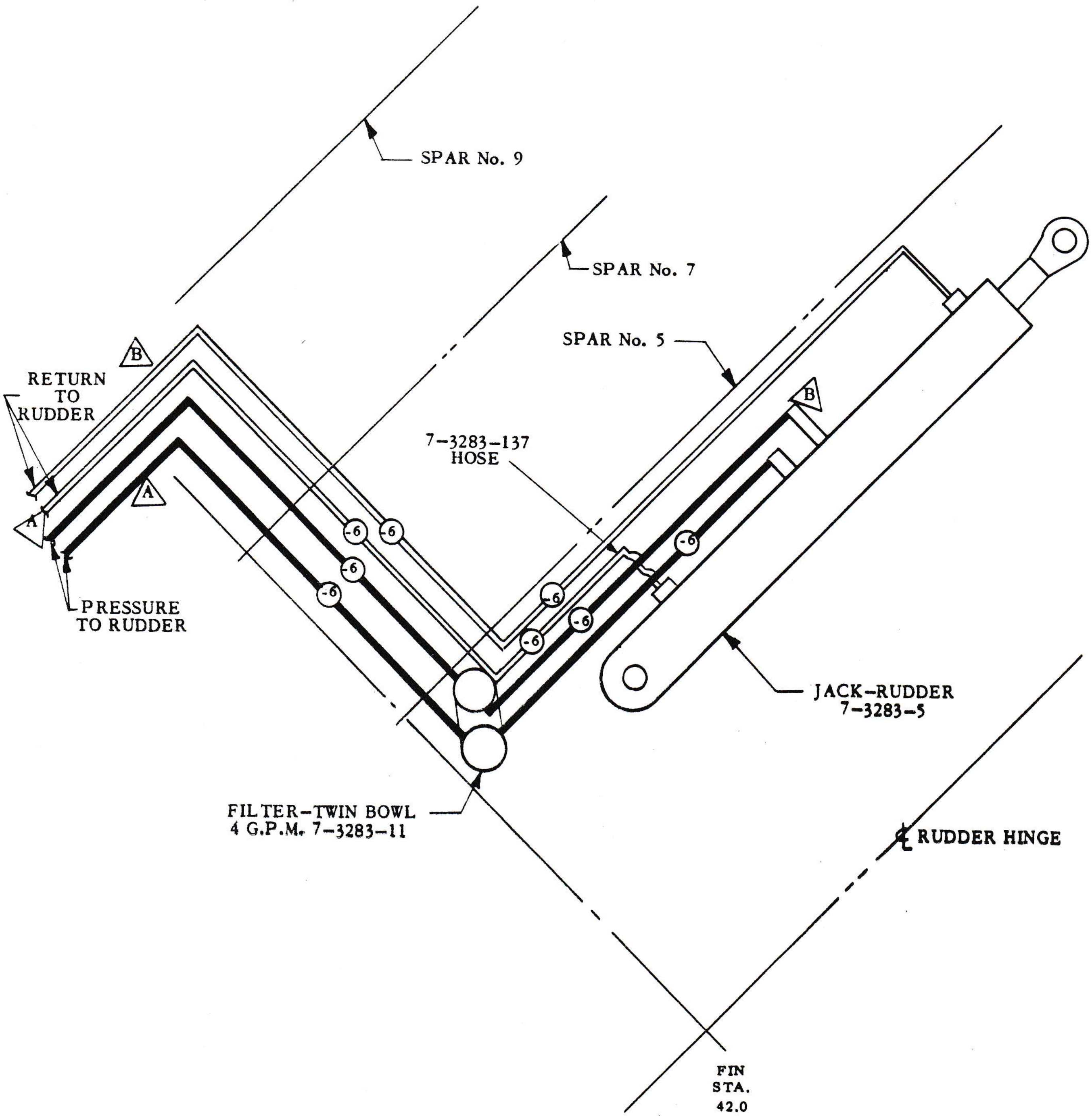

FIG. 1.0.2 DIAGRAMMATIC FLYING CONTROL HYDRAULIC SYSTEM (FIN)

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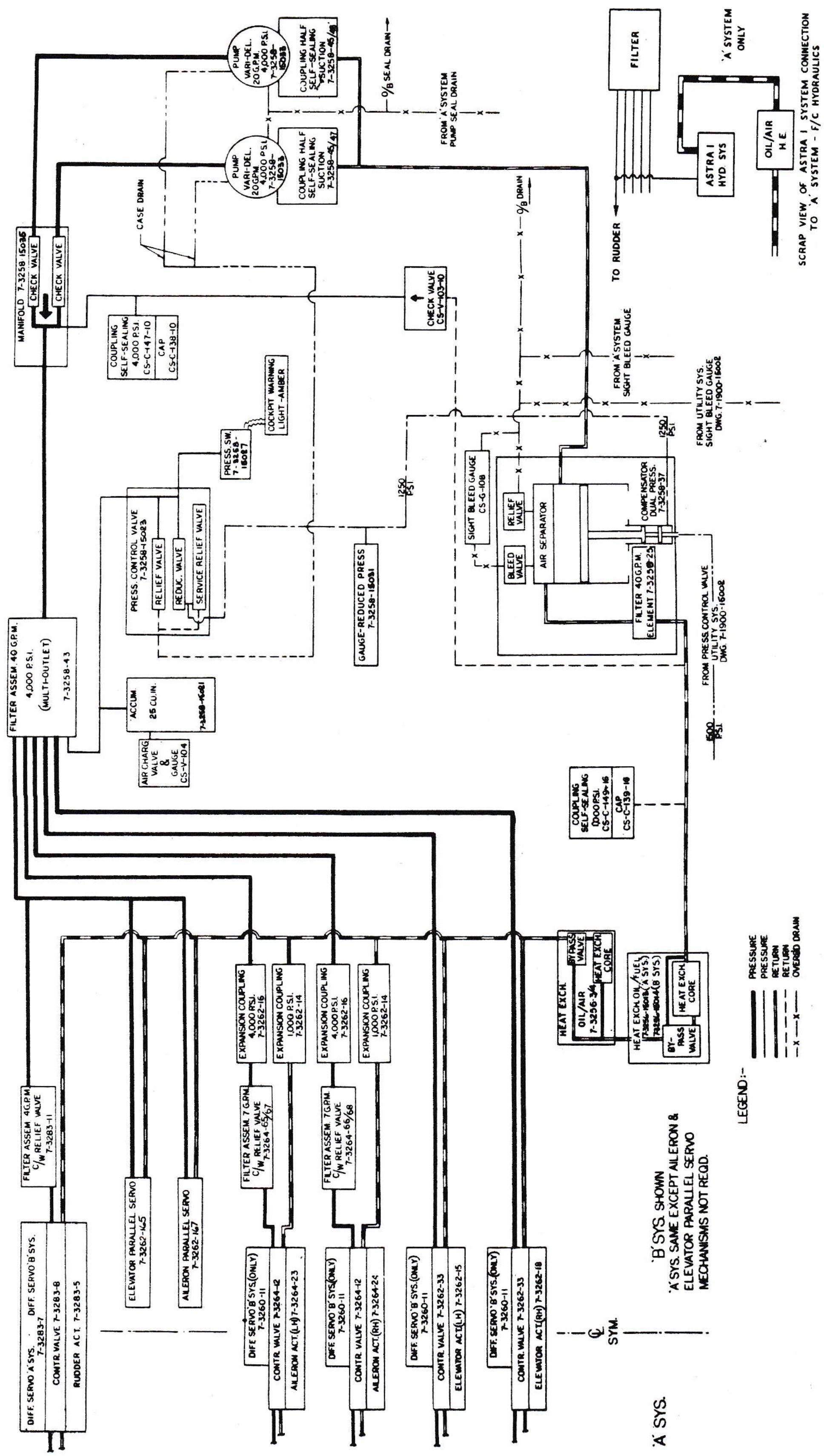
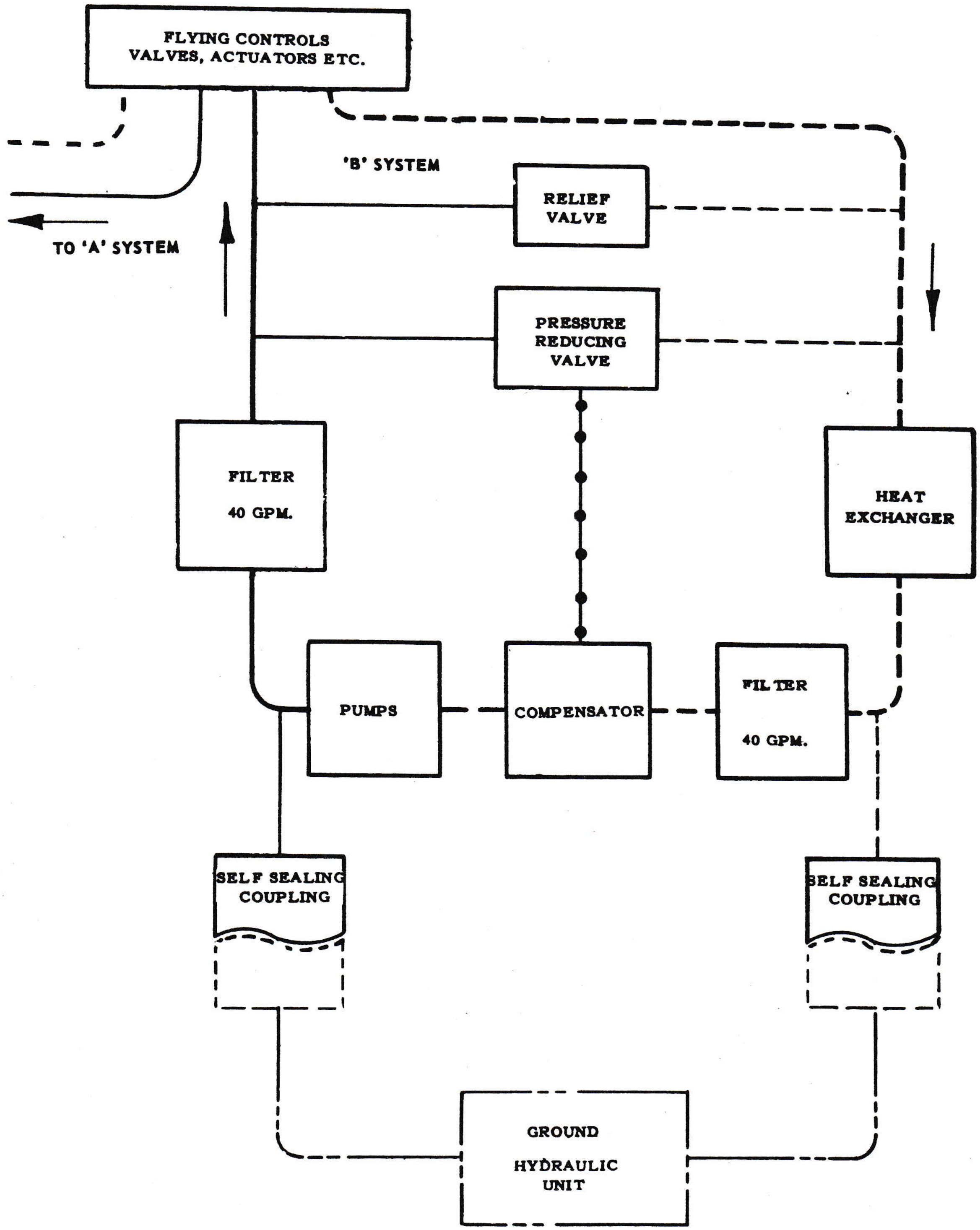


FIG. 1.1 SCHEMATIC FLYING CONTROLS HYDRAULIC SYSTEM



'B' SYSTEM SHOWN
'A' SYSTEM IDENTICAL

FIG. 1.2 SIMPLIFIED SCHEMATIC FLYING CONTROLS HYDRAULIC SYSTEM

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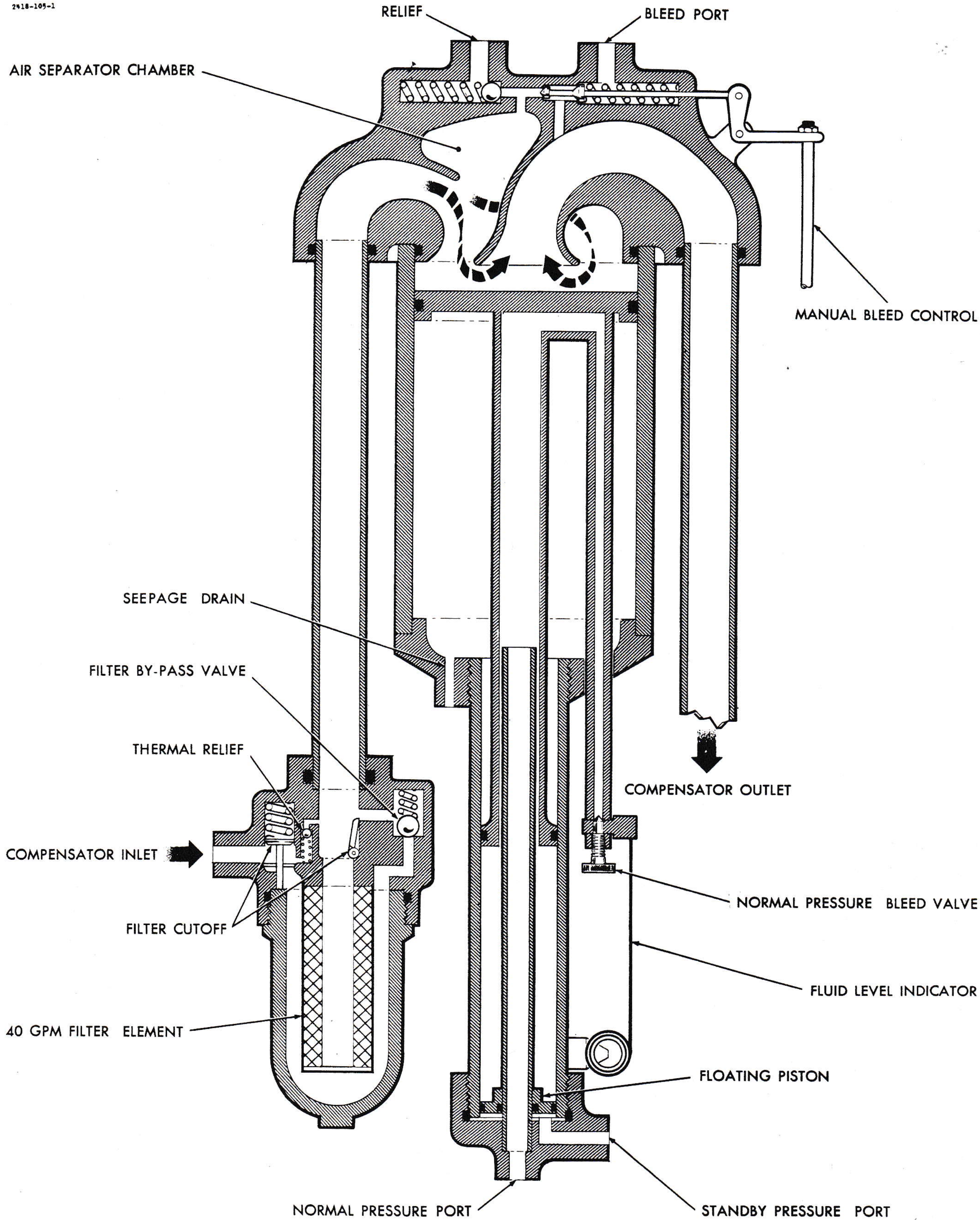


FIG. 2.0 FLYING CONTROL HYDRAULIC SYSTEM - COMPENSATOR

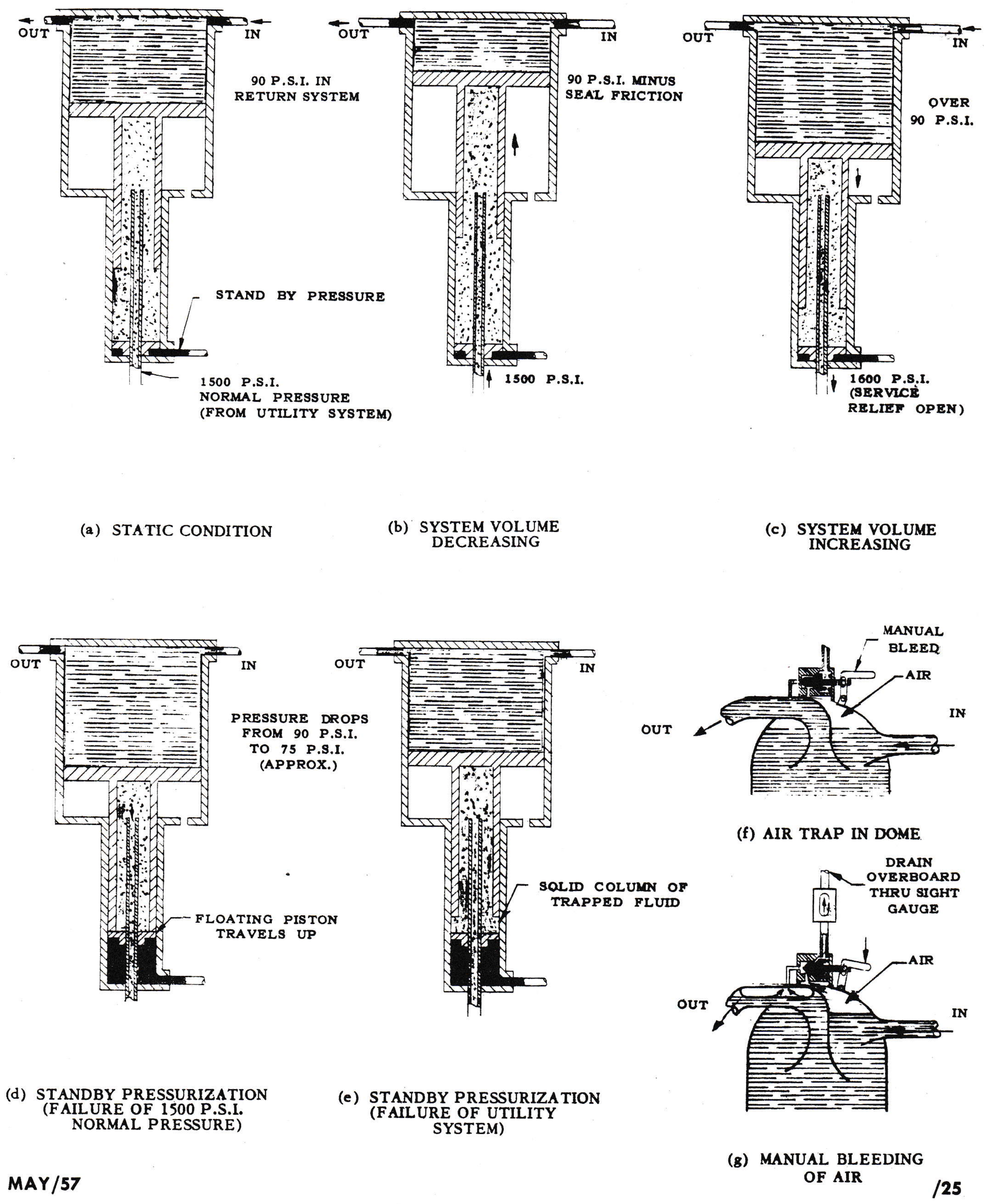
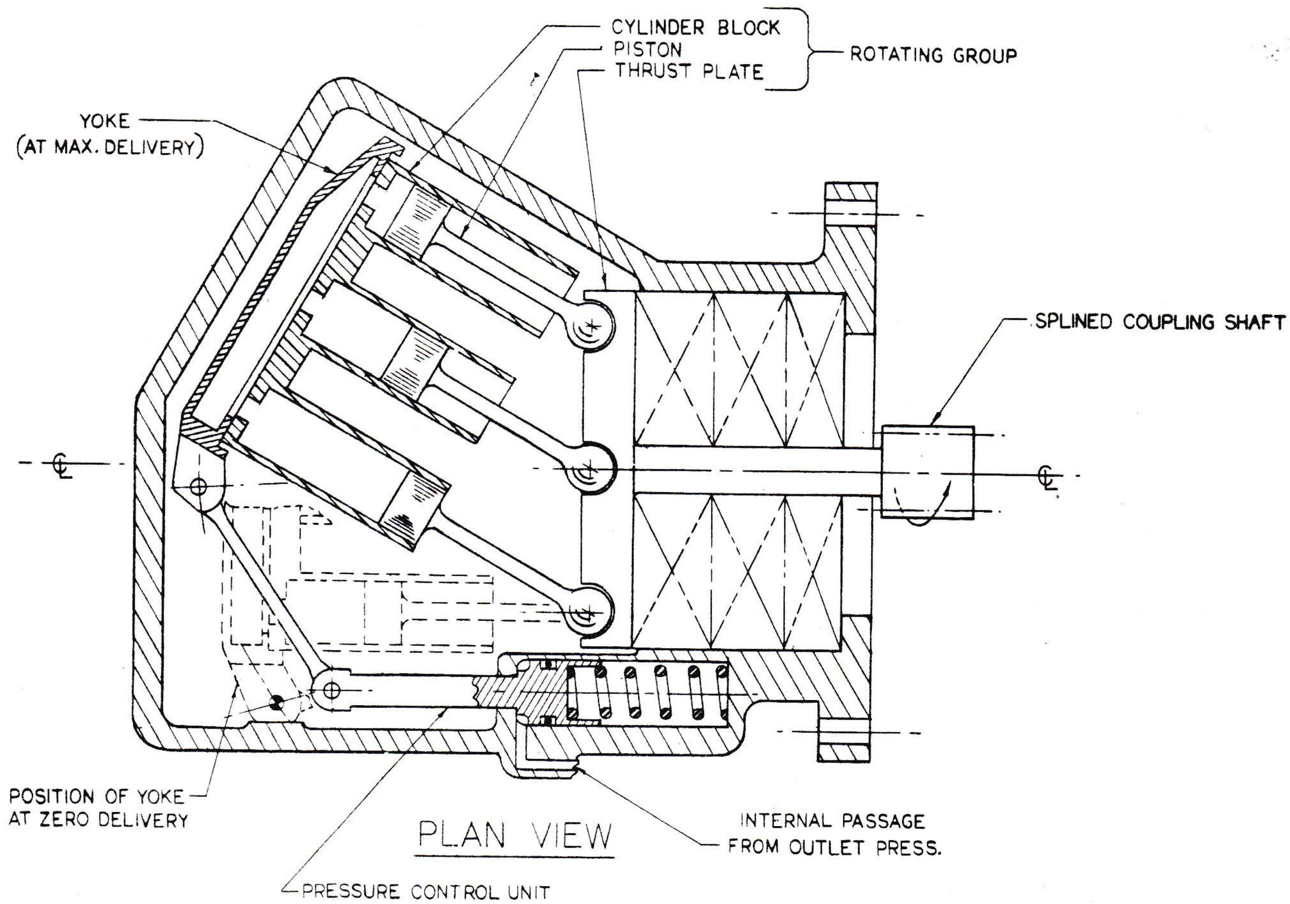


FIG. 2.1 FLYING CONTROLS COMPENSATOR FUNCTIONING



PLAN VIEW

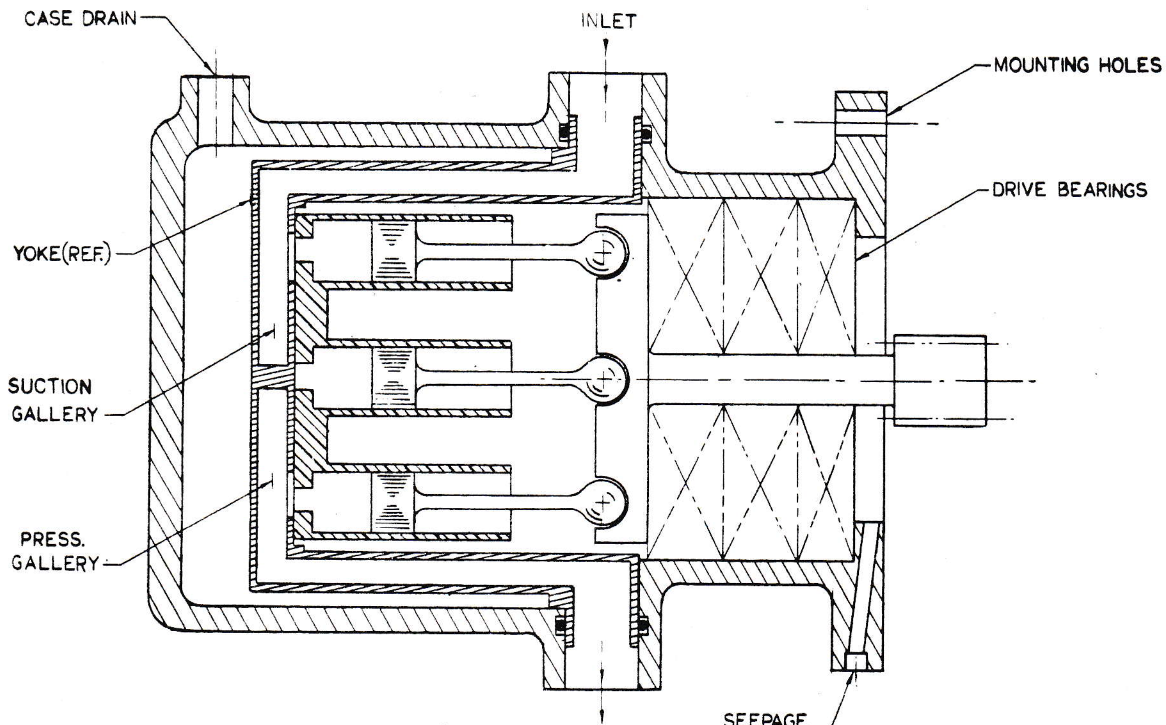


FIG. 2.2 - VICKERS - VARIABLE DEL. PUMP (DIAGRAMMATIC)

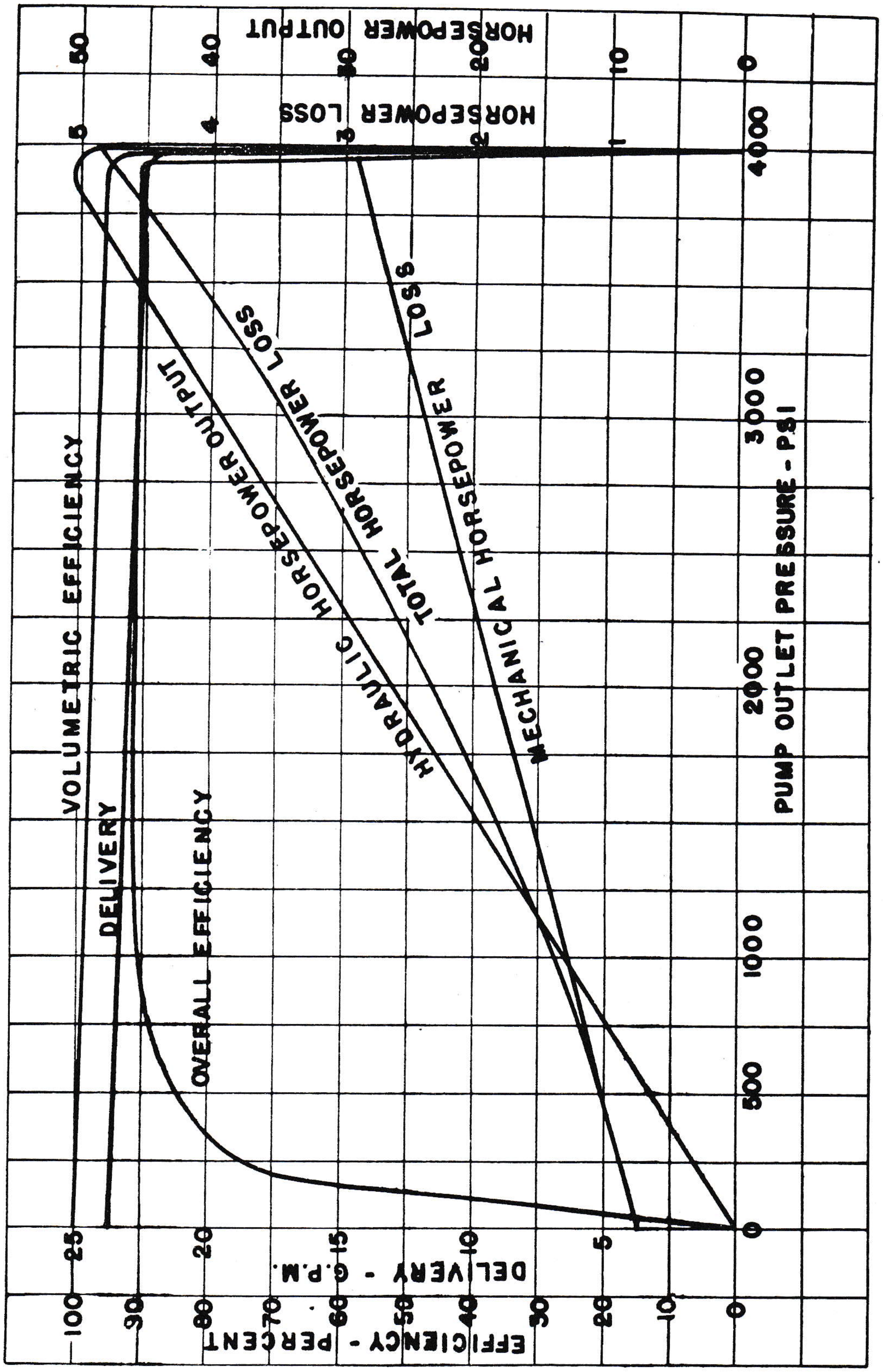
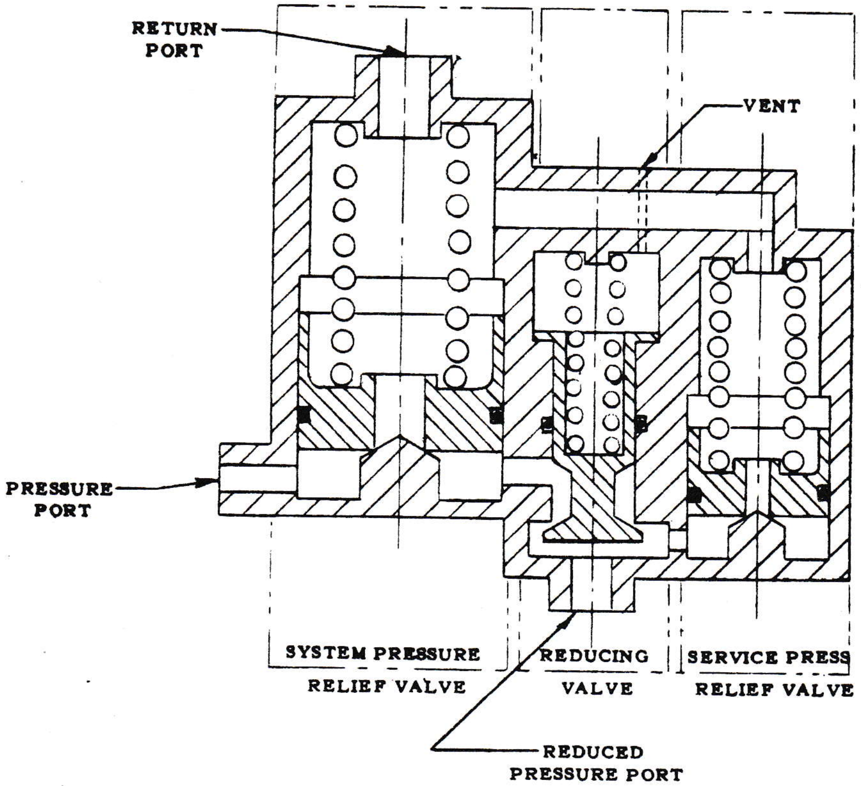
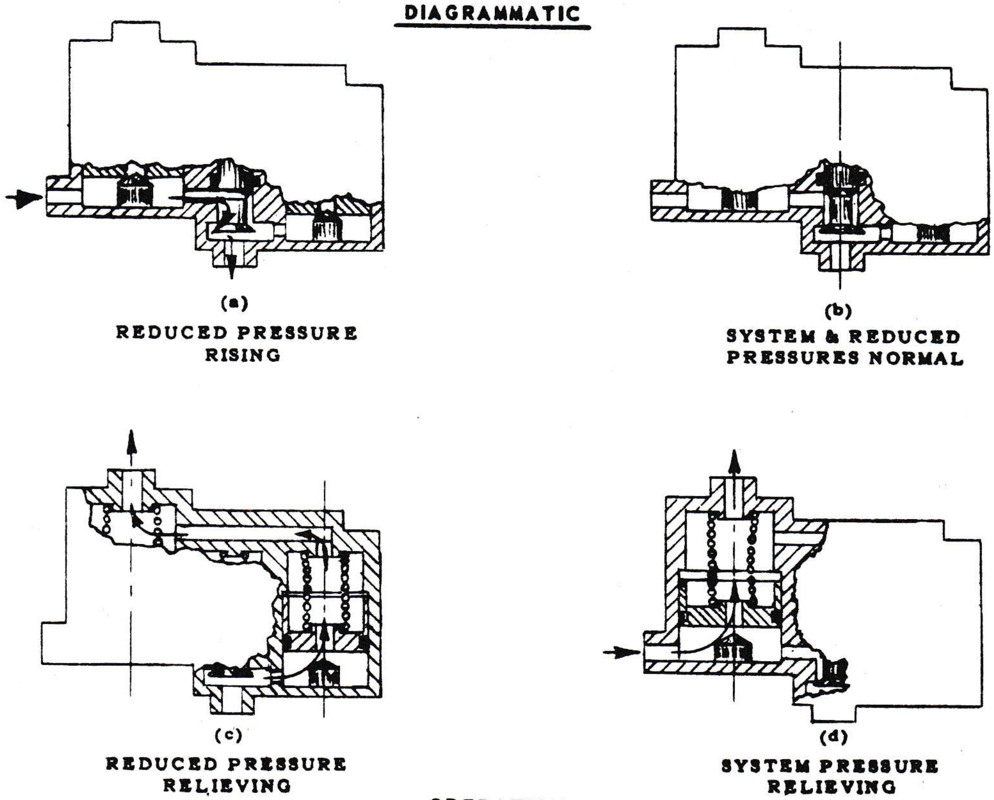


FIG. 2.3 CALCULATED PERFORMANCE CURVES FOR VICKERS 7-3258-15033 VARIABLE DELIVERY PUMP



DIAGRAMMATIC



OPERATION

FIG. 2.4 PRESSURE CONTROL VALVE

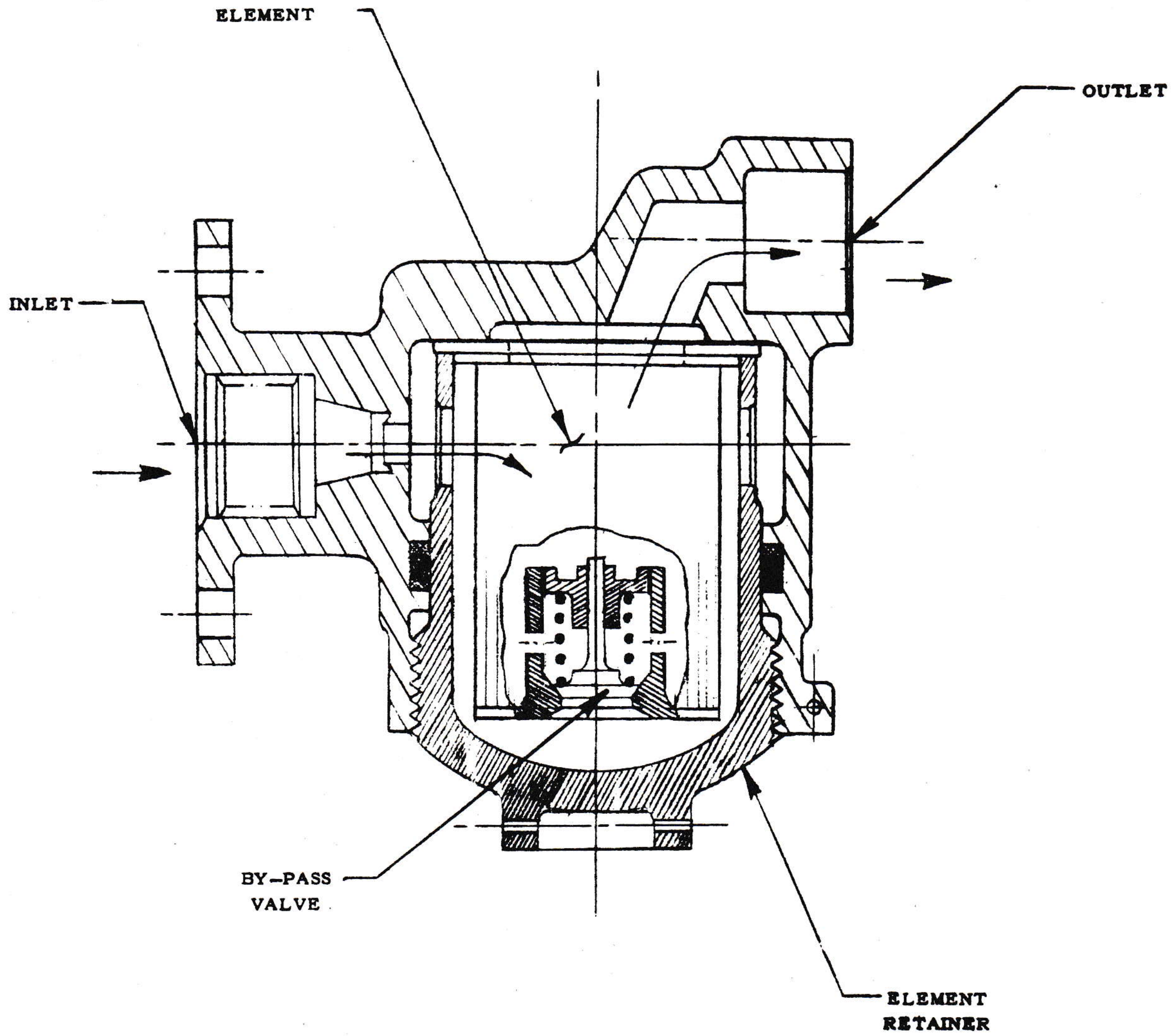


FIG. 2.5 HYDRAULIC FILTER 7 GPM

2919-109-1

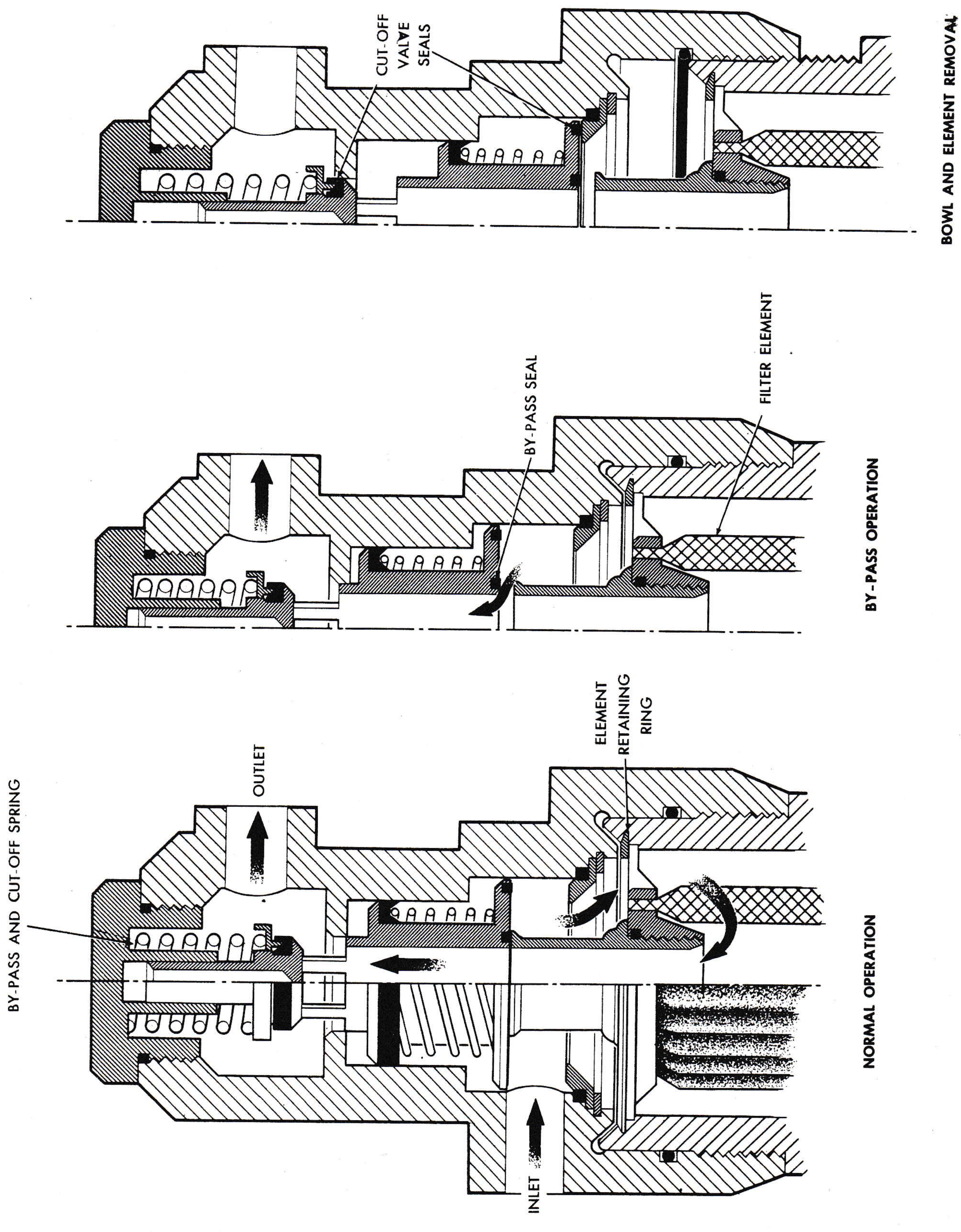


FIG. 2.6 FLYING CONTROL HYDRAULIC SYSTEM - HYDRAULIC FILTER 40 G.P.M.

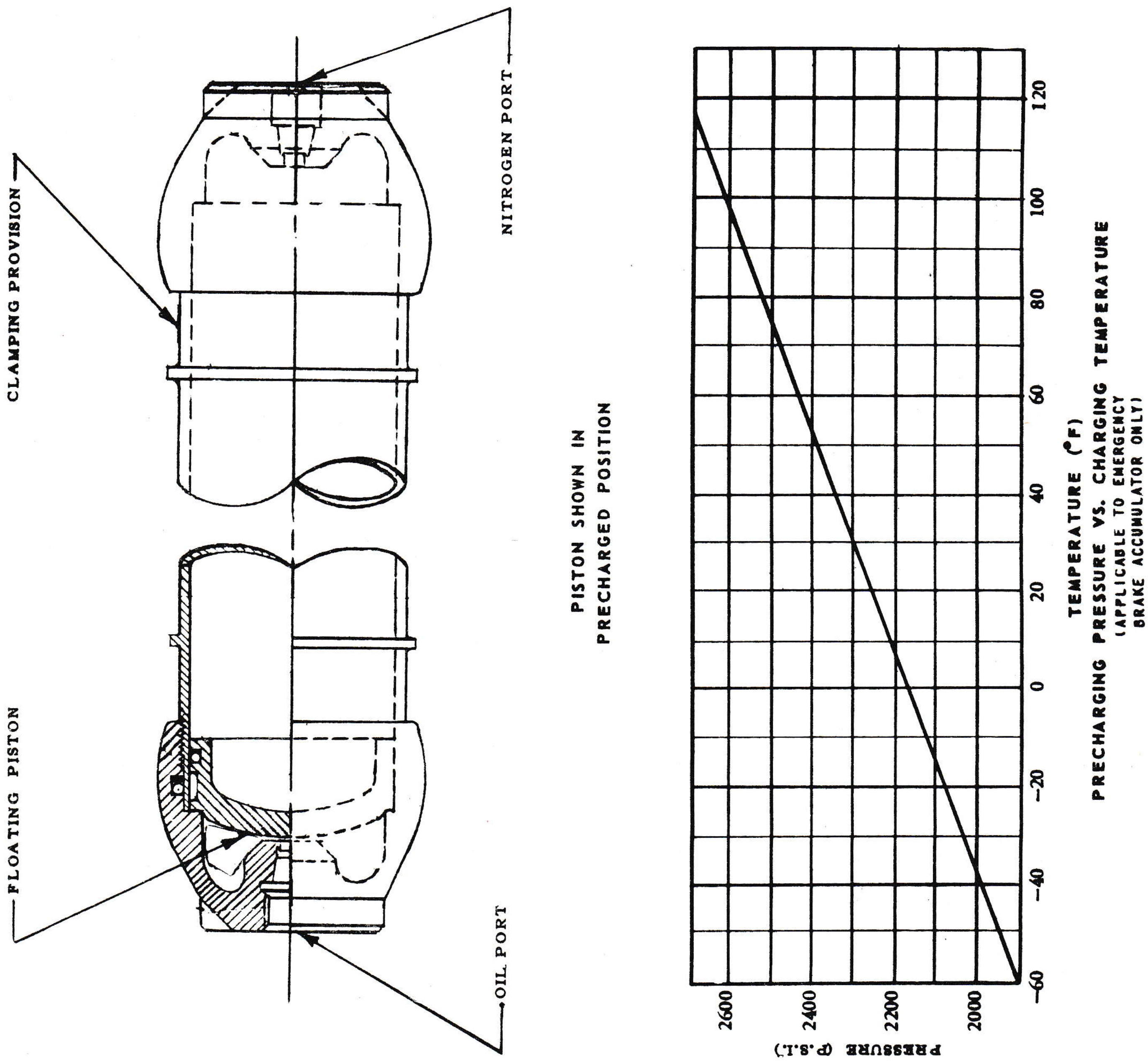


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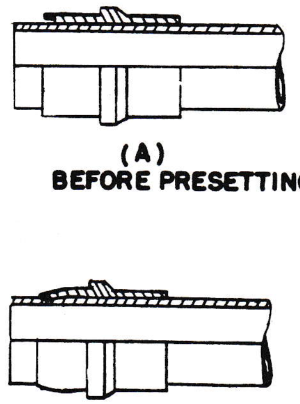
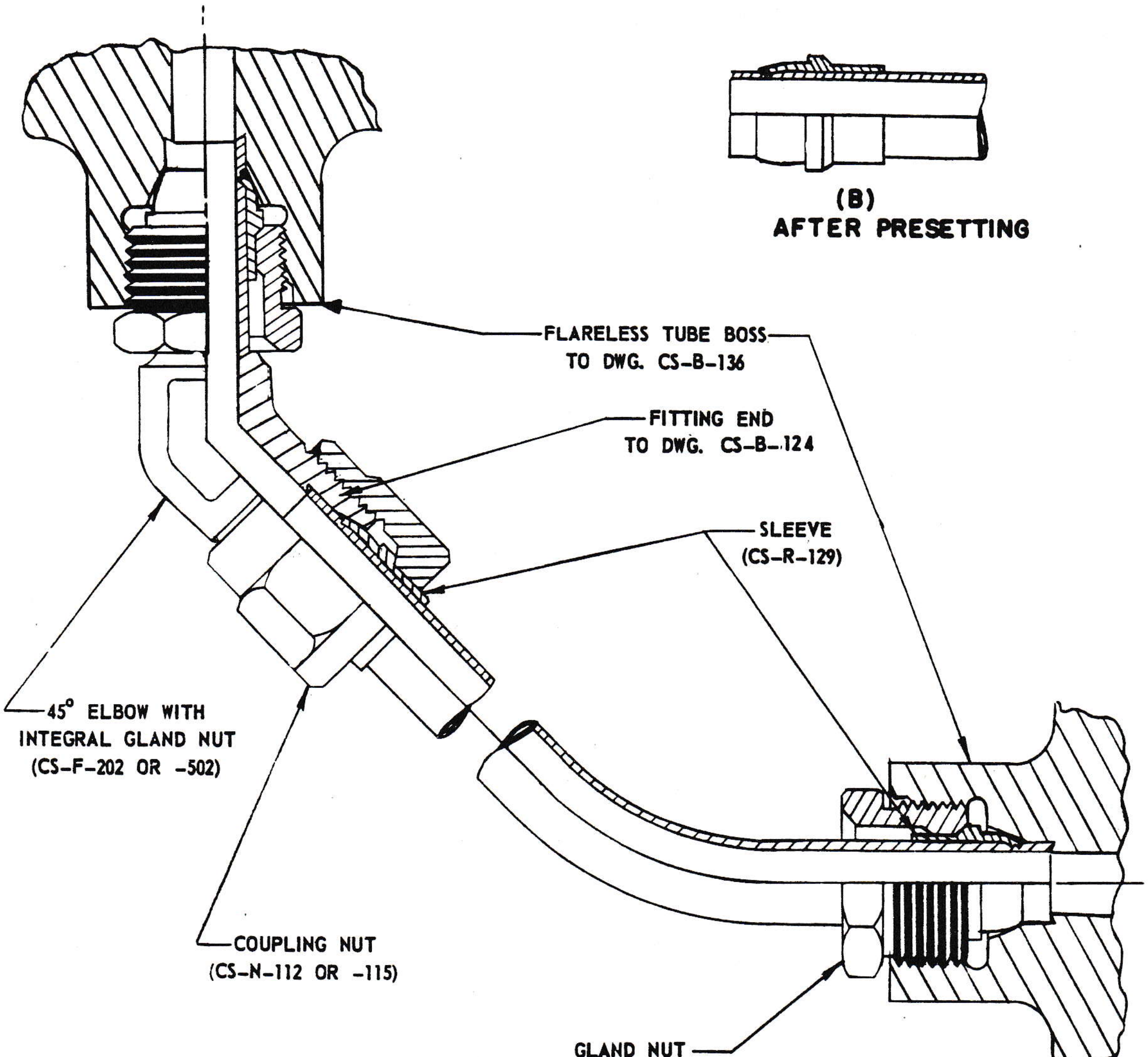
FIG. 2.7 ACCUMULATOR - FLOATING PISTON TYPE

ASSEMBLY OF SLEEVE AND TUBE





NOTE: CS NUMBERS REFER TO AVRO STANDARD DRAWINGS.

FIG. 2.8 FLARELESS TUBE CONNECTIONS

For Hydraulic Balance:

$$\frac{\pi D_1^2}{4} = \frac{\pi}{4}(D_2^2 - D_3^2)$$

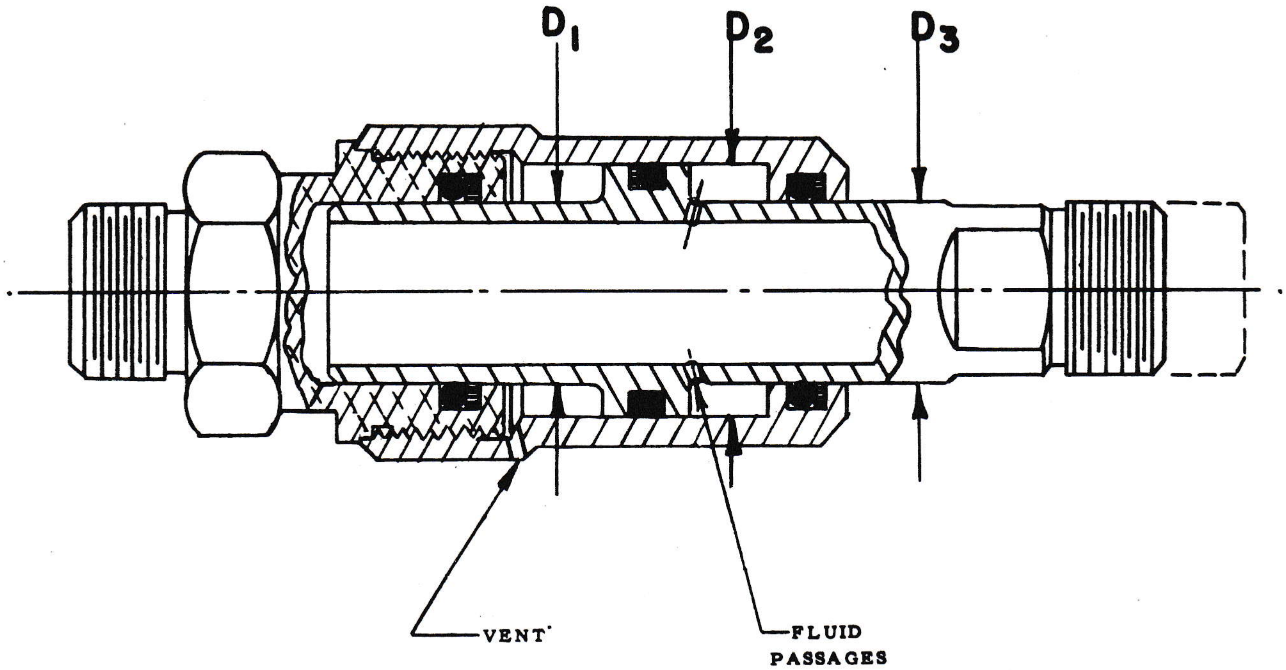


FIG. 2.9 EXPANSION COUPLING (BALANCE TYPE)

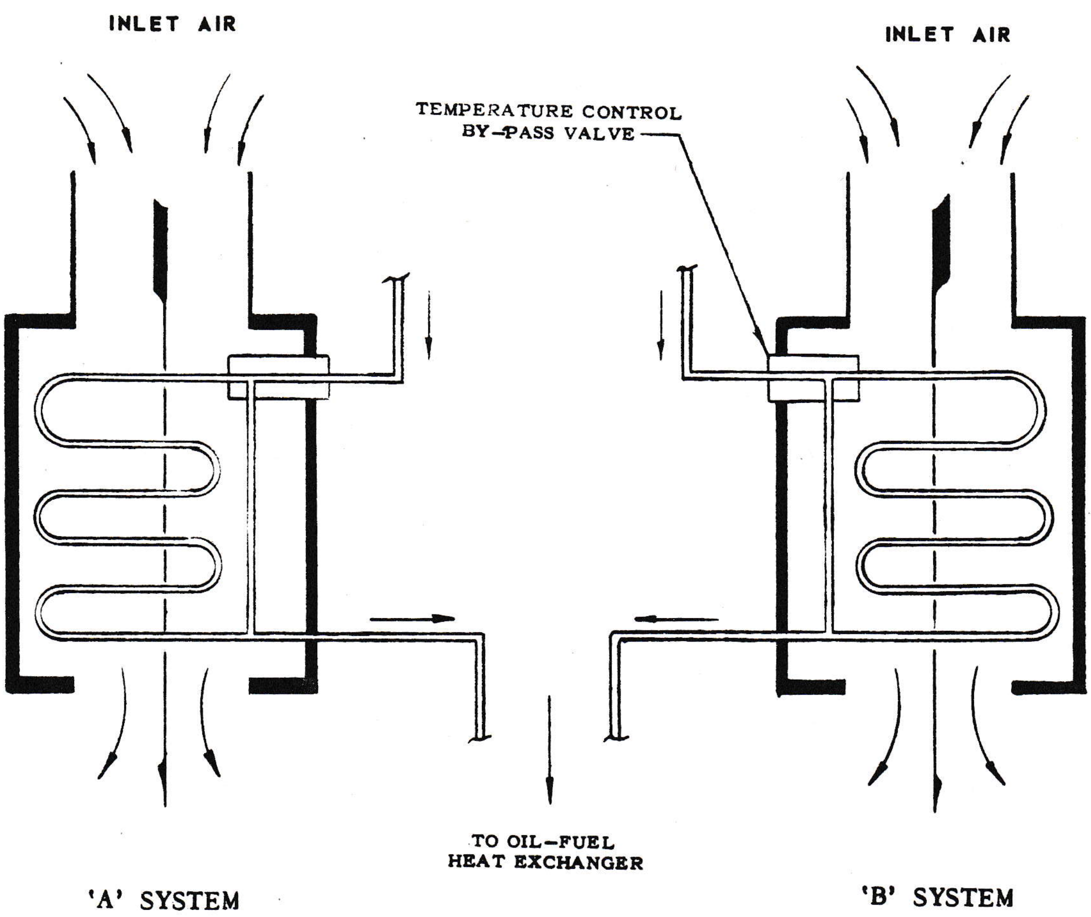


FIG. 2.10 HEAT EXCHANGER OIL TO AIR

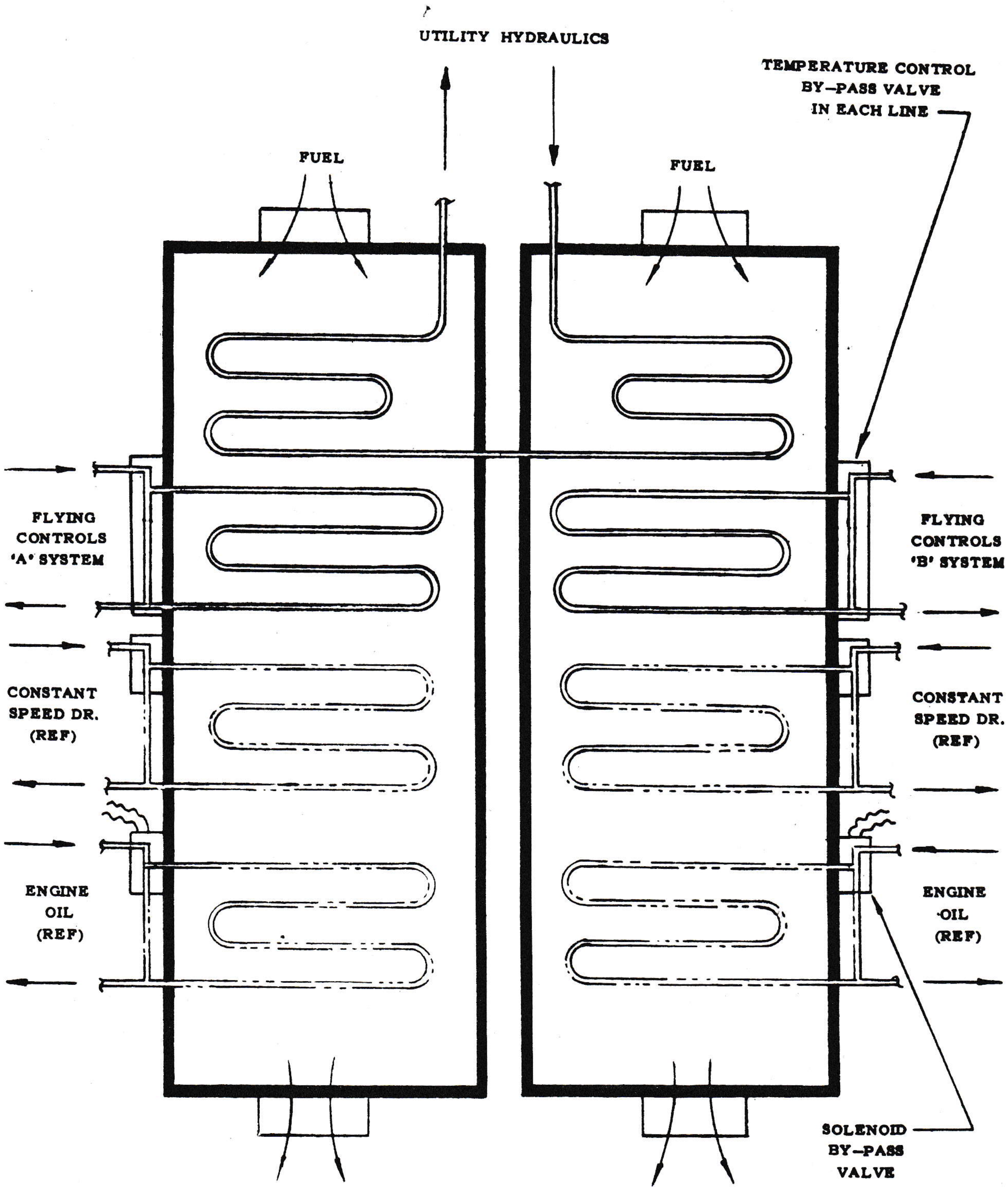


FIG. 2.11 HEAT EXCHANGER OIL TO FUEL

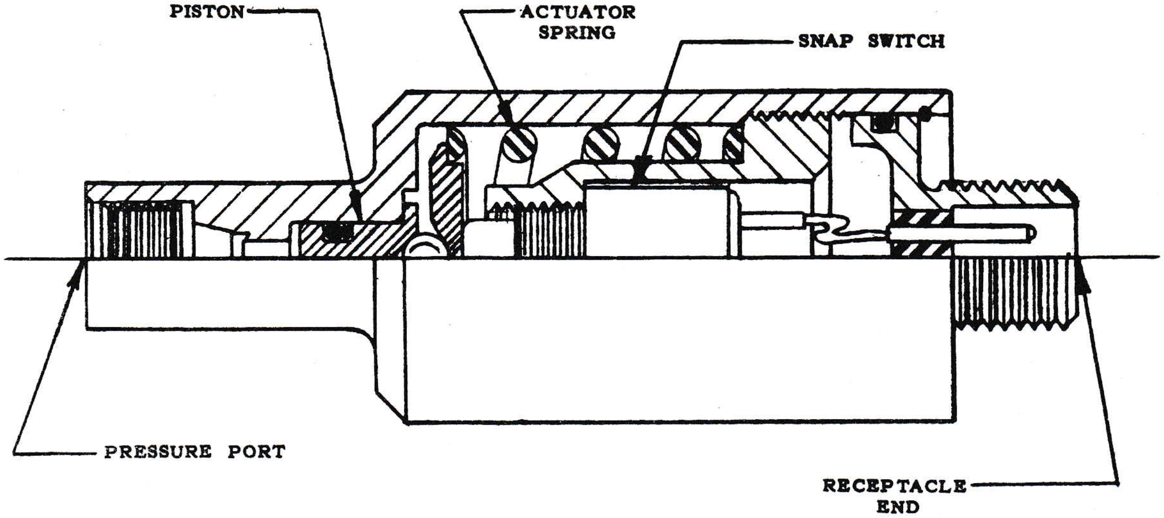


FIG. 2.12 HYDRAULIC PRESSURE SWITCH

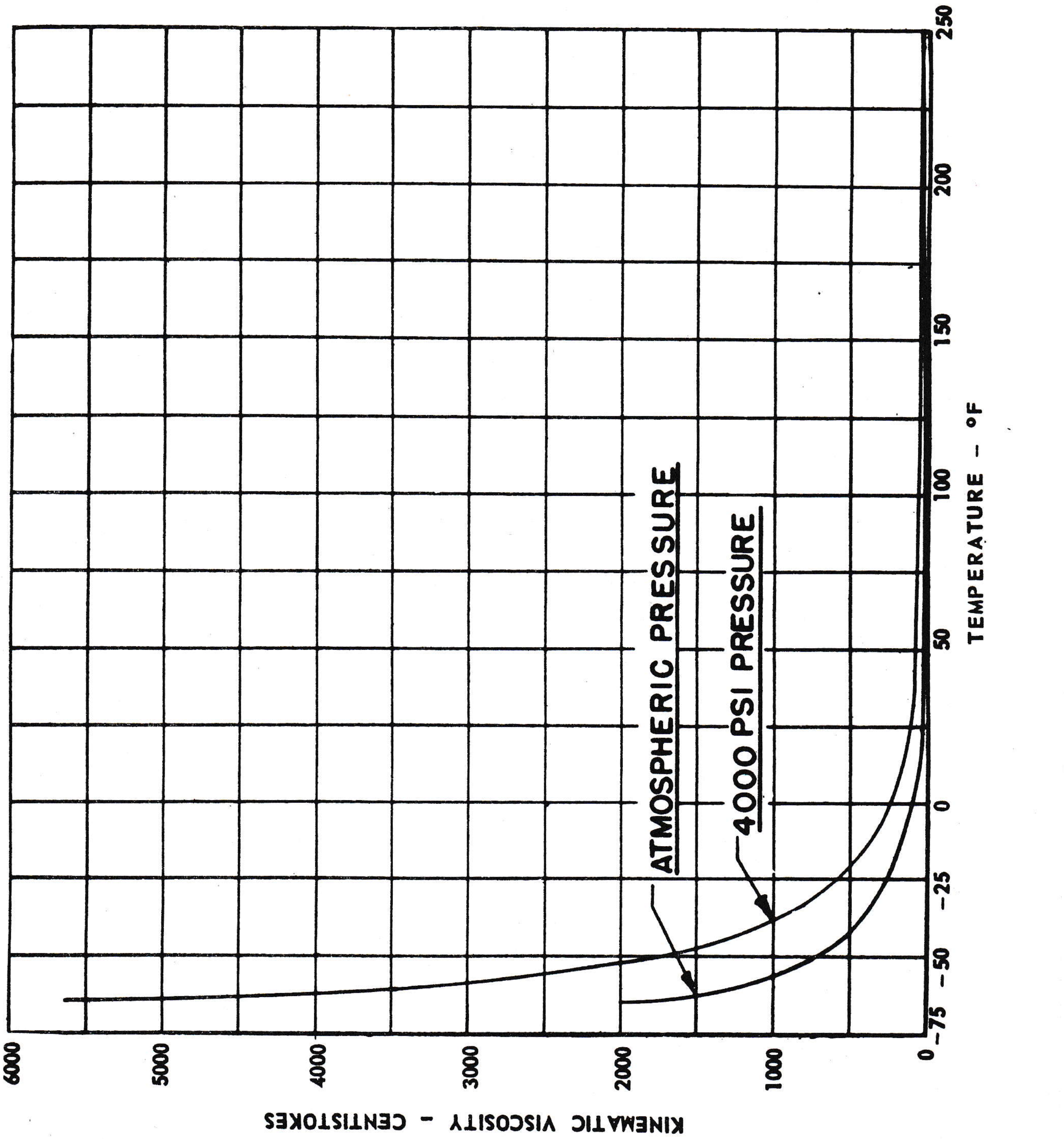
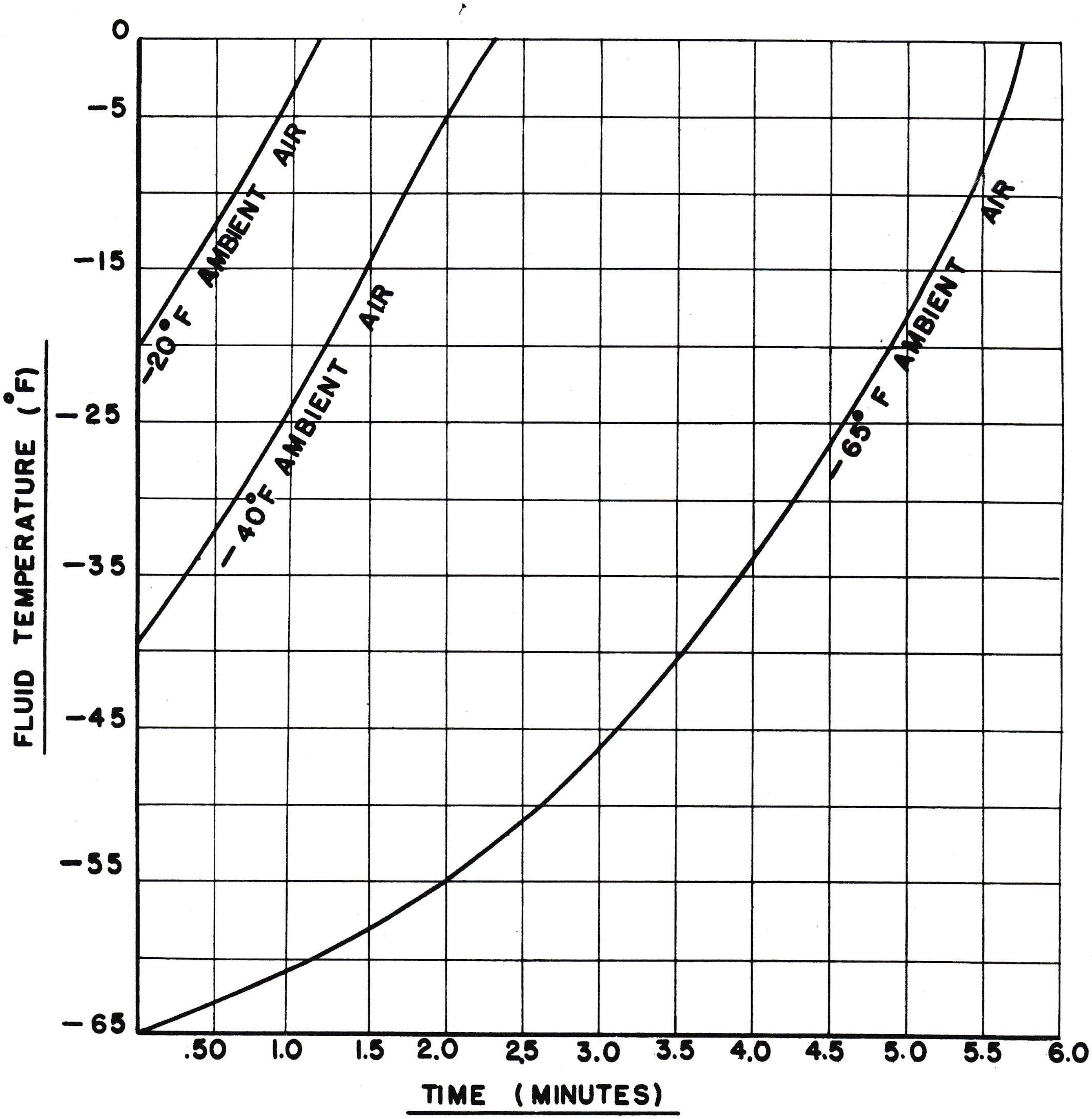


FIG. 3.0 KINEMATIC VISCOSITY VS TEMPERATURE



TIME REQUIRED TO WARM UP HYDRAULIC FLUID

FIG. 3.1 FLYING CONTROLS - GRAPH OF TIME REQUIRED TO WARM UP HYDRAULIC FLUID VS HYDRAULIC FLUID TEMPERATURE