# STARLIFTER TRAINING MANUAL • VOLUME IV

# ENVIRONMENTAL

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## ILLUSTRATIONS

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## FUNDAMENTALS

In order to understand any subject, its purpose and basic principles must be known. This volume deals with pneumatics and the systems of the StarLifter which use pneumatic principles for doing work.

Pneumatics is that branch of science which deals with the physical properties of gases. A pneumatic system has four major parts:

- o A compressor
- o A reservoir for storing the compressed gas
- o A distribution system to direct the compressed gas to the point of use
- o A method of using the gas to do work

The gas most often used in the field of pneumatics is air which is plentiful and is easily obtained and compressed. Typical applications of pneumatics are shown in Figure 1-1.

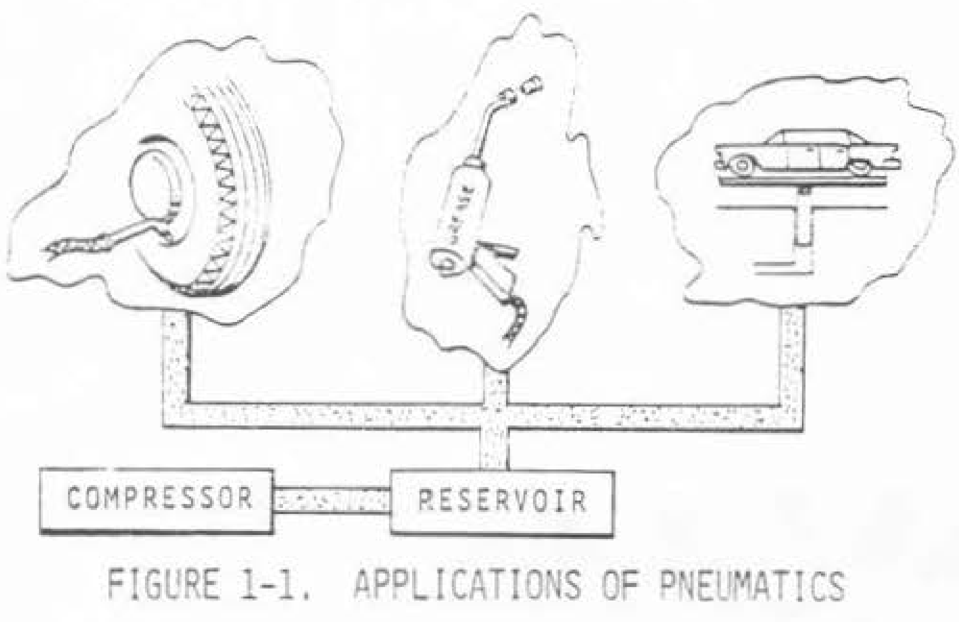



FIGURE 1-1. APPLICATIONS OF PNEUMATICS

## DEFINITION OF A GAS

A gas is made up of small particles called molecules which are separated by space. Each molecule has weight and is always in motion. The velocity of a molecule is proportional to its temperature. A gas, like a liquid, is a fluid which is a substance that can be moved about easily and takes the shape of its container. In addition to these properties, a gas tends to expand indefinitely. This characteristic means that the molecules tend to spread out and completely fill their container regardless of its size or shape.

## CHARACTERISTICS OF THE ATMOSPHERE

The atmosphere is the mass of air surrounding the earth. It is composed of a mixture of gases consisting of approximately 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent is made up of argon, neon, carbon dioxide, and several other gases in small quantities.

The weight of the air exerts a force on the earth. This force, applied to the surface area, is called atmospheric pressure and can be measured with an instrument called a barometer. The barometer uses atmospheric pressure to support a column of mercury. A pressure of 14.7 pounds per square inch (psi), for example, supports a column of mercury about 30 inches high. Thus, the pressure of the atmosphere can be determined by measuring the height of the mercury column. When the reading is given directly in inches of mercury, the term generally used is "barometric pressure:" The term "inches of mercury" is abbreviated in. Hg.

Since weather conditions constantly change, the National Aeronautics and Space Administration has arbitrarily chosen certain atmospheric conditions in describing what is known as the NASA standard day. These conditions at sea level are, as follows:

| | |
|---|---|
| o Atmospheric Pressure | 14.73 psi (29.92 inches of mercury) |
| o Temperature | 15°C (59°F) |
| o Density (weight) | 0.0765 pound per cubic foot |

These reference values are often used in computing information on the engines, air conditioning system, and similar systems.

Due to the lesser pull of gravity at higher altitudes, the air is thinner and the pressure is less. At an altitude of 18,000 feet the atmospheric pressure is 7.34 psi, which is about one-half of the atmospheric pressure at sea level. At 36,000 feet, atmospheric pressure is 3.29 psi, or about one-half the pressure at 18,000 feet.

Atmospheric pressure at other altitudes is shown below.

- o Sea Level - 14.7 psi
- o 10,000 feet - 10.1 psi
- o 20,000 feet - 6.75 psi
- o 30,000 feet - 4.35 psi
- o 40,000 feet - 2.72 psi

Under standard lapse rate conditions, the temperature of the air decreases approximately 3.5°F for every 1000-foot increase in altitude. This decrease continues up to about 36,000 feet, where the temperature is nearly minus 70°F. Above 36,000 feet, the temperature remains fairly constant up to 65,000 feet. Above this altitude, the temperature increases.

## PHYSICAL PROPERTIES OF GASES (AIR)

When a volume of air is confined in a container, the motion of the molecules causes them to collide with each other and with the sides of the container. These collisions can be measured in the form of pressure. Since the velocity of the molecule is proportional to its temperature, an increase in temperature causes the molecules to move faster. This greater speed causes the molecules to collide with greater force, which results in a higher pressure indication as illustrated in Figure 1-2.

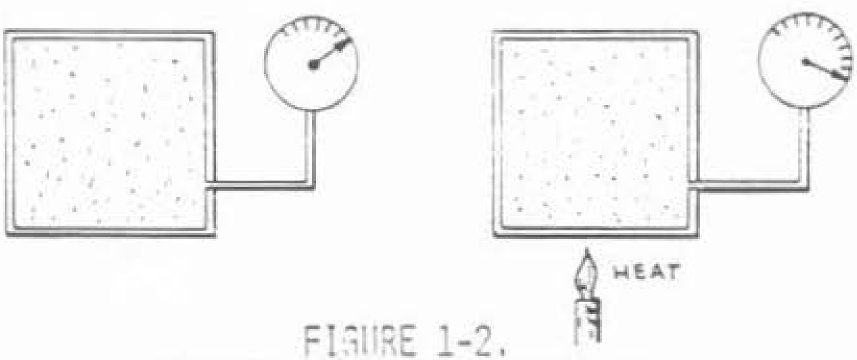



FIGURE 1-2.
EFFECT OF HEAT ON PRESSURE

At constant volume, the pressure increase is directly proportional to the amount of heat added. If the air is allowed to expand freely as the heat is applied, there is no change in pressure, and the volume increase is directly proportional to the increase in temperature.

Another method of obtaining a higher pressure is to confine a quantity of air in a container and then reduce the volume of the container. This action packs the molecules closer together and causes them to collide more often. As more molecular collisions occur, energy in the form of heat is produced. This heat is called the heat of compression. Thus, when air is compressed, its pressure and temperature increase in proportion to the decrease in volume as illustrated in Figure 1-3.

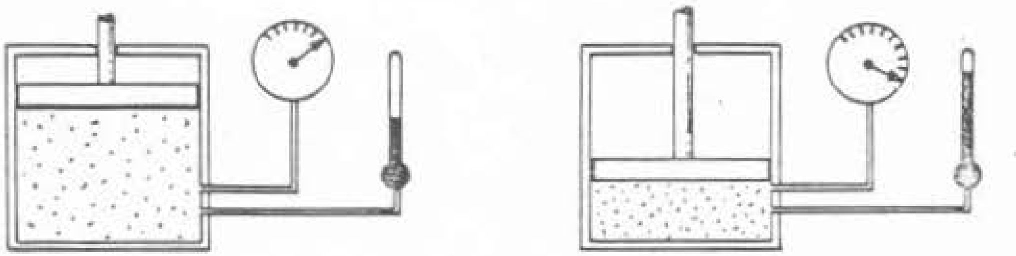


FIGURE 1-3. EFFECT OF COMPRESSION ON PRESSURE AND TEMPERATURE

If the heat of compression is dissipated as fast as it occurs so that the compression takes place at constant temperature, the increase in pressure is directly proportional to the decrease in volume.

These pressure-volume-temperature relationships are defined by the characteristic gas equation:

$$\frac{P\,v}{T} = R$$

where

P is total pressure

v is specific volume

T is total temperature

R is a constant.

## MEASUREMENT OF PRESSURE

Three types of pressure gages commonly used on aircraft are the bourdon tube type, the aneroid type, and the electrical type.

The bourdon tube is a hollow, oval-shaped tube with the inner end closed, bent into the shape of a question mark. The closed end is connected to a pointer mechanism as shown in simplified form in Figure 1-4. When pressure is applied inside the tube, the tube expands and uncurls. This movement is transfered through a gear mechanism to the pointer.

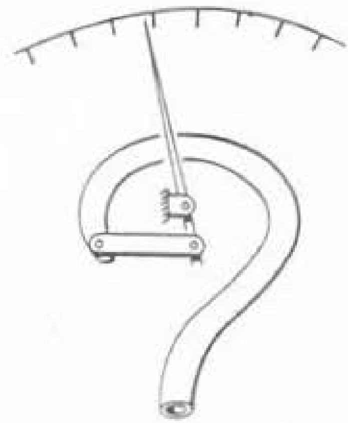


FIGURE 1-4. BOURDON TUBE GAGE

The aneroid-type gage consists of a hollow metal chamber connected to a pointer mechanism. The chamber can be either a bellows type or a disk type. The disk type is made of two dish-shaped metal disks soldered together around the edges. The bellows type is shown in a simplified form in Figure 1-5. The inside of the bellows is usually evacuated. As the pressure around the outside of the bellows increases or decreases, the bellows contracts or expands which moves the pointer. This type of gage can be used to indicate pressures both above and below that of the surrounding atmosphere. A common use of the aneroid type instrument is the aircraft altimeter, which senses atmospheric pressure and indicates corresponding feet of altitude.

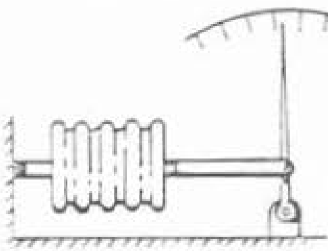


FIGURE 1-5. ANEROID GAGE

The electrical type pressure indicator consists of a synchro transmitter and a synchro receiver. Pressure causes the transmitter to send corresponding electrical signals to the receiver. In the receiver unit, these signals cause a pointer to move and indicate pressure that is sensed in the transmitter unit.

## MEASUREMENT OF TEMPERATURE

Temperature is a measure of the presence of heat. It is usually measured by a thermometer in degrees Centigrade (°C) or degrees Fahrenheit (°F). Each of these scales is an arbitrary one and either can be used equally well to indicate temperature. A comparison of the scales is shown in Figure 1-6. The relationship between the two scales is shown in the following formulas:

$$\frac{F - 32}{180} = \frac{C}{100}\ ; \qquad F = 9/5\,C + 32\ ; \qquad C = 5/9\,(F - 32)\ ;$$

where

F is the temperature in °F, and

C is the temperature in °C.

In some aircraft, an electrical-type temperature indicator is used. Temperature is sensed by a special type of resistor called a thermistor. The thermistor is part of an electrical circuit and is connected by wires to a remote indicator. Electrical signals cause the pointer on the indicator to deflect in proportion to the temperature sensed by the thermistor.

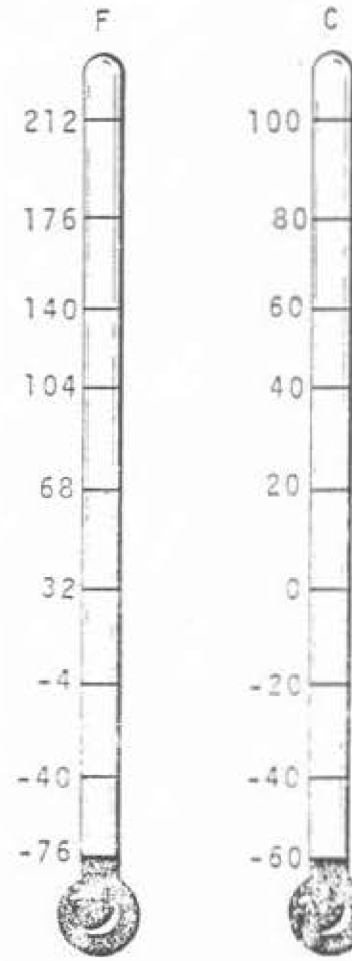



FIGURE 1-6. COMPARISON OF FAHRENHEIT AND CENTIGRADE TEMPERATURES

## DENSITY AND ITS EFFECT ON PRESSURE

The density of air is its weight per unit volume, such as pounds per cubic foot. At sea level on a standard day, a cubic foot of air weighs 0.0765 pound. This weight is the combined weight of the individual molecules. The number and force of molecular collisions cause the air to have a pressure of 14.7 psi. At higher altitudes where the attraction of gravity is less, the molecules of air are spaced farther apart. There are fewer molecules per cubic foot, so the density is less. Due to the lower density, molecular collisions occur less often. Hence, the pressure is less at these higher altitudes. A cubic foot of air at 30,000 feet, for example, weighs only 0.0286 pound and has a pressure of only 4.35 psi.

Since air expands when subjected to heat, temperature affects density. When the temperature is high, the molecules spread farther apart. Therefore, the air density is less on a hot day than on a cold day, and the pressure is lower.

The amount of moisture in the air (humidity) is another condition which affects density. Water, in the same state, weighs less than air. Therefore, a cubic foot of air with a higher humidity weighs less than a cubic foot of air with a lower humidity. Hence, air with a higher humidity has a lower pressure than air with a lower humidity.

## EFFECT OF COOLING ON RELATIVE HUMIDITY

Relative humidity is the ratio of the amount of moisture actually contained in the air compared with the amount of moisture the air is capable of holding at any given temperature. Air at a high temperature is capable of holding more moisture than air at a lower temperature. If the actual water content is not changed, relative humidity increases as temperature decreases. If the temperature decreases to the point where the air can no longer hold the moisture that is in it, the moisture condenses and falls out. The temperature at which this condensation occurs is called the dew point.

## COMPRESSOR-MANIFOLD RELATIONSHIP

When a volume of air is compressed, the compression can continue only until the rising pressure equals the compressing force. In practice, this condition is not allowed to happen; if it did, the compressor would stop. At the end of the compression cycle, air is delivered at a definite pressure dependent upon the compression ratio of the compressor. This ratio is based on the number of times the air volume is decreased during compression as shown in Figure 1-7.

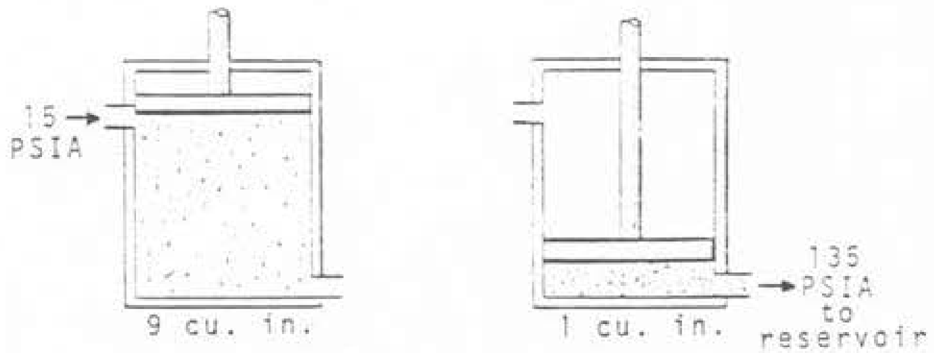



FIGURE 1-7. COMPRESSION RATIO

In a pneumatic system, compressed air is delivered to a reservoir or manifold, where it is stored until ready for use. A means of bypassing the air is generally provided to prevent compressor stall when the manifold pressure approaches the pressure delivered by the compressor as shown in Figure 1-8.

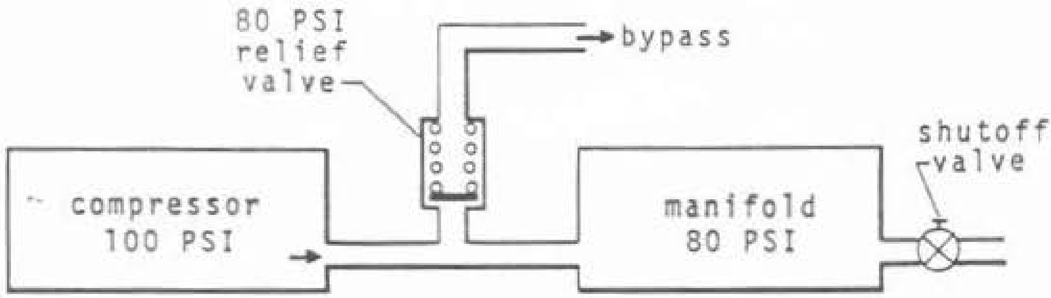



FIGURE 1-8. COMPRESSOR-MANIFOLD RELATIONSHIP

This bypass feature keeps a constant air load available to the manifold, which means that air can be used from the manifold without lowering its pressure. Of course, the amount of air used cannot exceed the amount available.

## FLOW CHARACTERISTICS - VENTURI PRINCIPLE

Within a system, air always flows from the point of highest pressure to the point of lowest pressure. When air flows through a duct, there is a definite relationship between its velocity and its pressure. If the duct narrows, the velocity increases and the pressure decreases. A duct which is shaped to make use of this characteristic is called a venturi. In Figure 1-9, the system flow is from point A to point C.

At point B, the "throat" of the venturi, velocity increases and pressure decreases. System flow rate depends on the pressure difference between point A and point C. The flow rate, in turn, determines what the pressure-drop will be at the throat. With a high rate of flow the pressure drop is greater than with a low rate of flow. With no flow, of course, the pressure is the same throughout the duct.

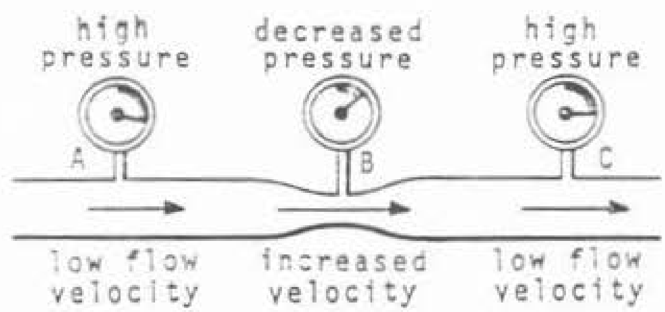



FIGURE 1-9. VENTURI PRINCIPLE

A jet pump (ejector) is a device which makes practical application of the pressure drop in a venturi. If a tube is attached to the throat of the venturi, a suction is created in the tube due to the low throat pressure, and the unit can be used to transfer fluids from an external source. This principle is used in the common paint spray gun.

A venturi which makes use of the velocity increase is an excellent flow limiter. When air under pressure is applied to the venturi, the air flows through the unit at a given rate dependent on the pressure. If the inlet pressure is increased, the flow rate increases. This increase can continue until the design critical pressure is reached, and the flow at the throat of the venturi reaches sonic velocity. At this time, a shock wave is produced which creates a high back-pressure, and the inlet pressure can be further increased with no further increase in flow.

## WHEATSTONE BRIDGE

The wheatstone bridge is a basic but very important electrical circuit which is often used in aircraft systems such as temperature monitoring, temperature control, and overheat detection. It is a series-parallel voltage divider circuit consisting of four resistors as shown in Figure 1-10. If $R_1$ equals $R_2$ and $R_3$ equals $R_4$, then the current flow from B+ to ground is the same through $R_1$ and $R_3$ as it is through $R_2$ and $R_4$ and the potential (voltage) at point "A" is the same as the potential at point "B." Since these points are of equal potential, there is no current flow between them: the pointer therefore indicates zero and the bridge is said to be balanced. If the resistance value of one of the resistors changes, however, the bridge becomes unbalanced, and this condition is indicated on the meter, e.g. if the resistance of $R_4$ increases, the potential at point B increases. Current flows through the meter from point B to point A, and the pointer deflects accordingly. If the resistance of $R_4$ decreases, the potential at point B also decreases. Current flows through the meter from A to B and the pointer deflects in the opposite direction.

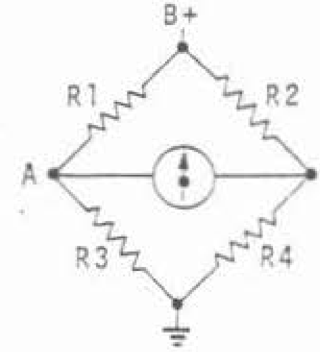


FIGURE 1-10. WHEATSTONE BRIDGE

This circuit is the same one used in the electrical-type temperature indicator discussed previously, where $R_4$ is the remotely located thermistor.

If the coil of a relay is connected across the bridge in place of an indicator, the current flow resulting from an unbalance condition is used to energize the relay. The relay can then be used to produce some further action such as driving a valve. A control winding of a magnetic amplifier (a special application of a transformer) can also be connected across the bridge. This type circuit is commonly used in temperature control systems.

## DEFINITIONS

Certain terms used in this manual are defined as follows:

Absolute Pressure - Total pressure measured from a value of zero pressure (complete vacuum), designated as psia. It equals atmospheric pressure plus gage pressure.

Absolute Temperature - Total temperature measured from zero degrees at the theoretical point where no molecular activity exists. Taken in practice to be -273°C (-460°F), and designated as degrees Kelvin or degrees Rankine. Conversion to Centigrade and Fahrenheit is as follows:

$$°R = °F + 460 \quad ; \qquad °K = °C + 273.$$

Air - A combination of gases consisting of approximately 21 percent oxygen, 78 percent nitrogen, and 1 percent other gases.

Air Conditioning - Controlling the temperature and humidity of air.

Ambient Air Pressure, Temperature - The pressure and temperature of the air immediately surrounding a given object.

Atmosphere - The mass of air surrounding the earth.

Compression - Reducing a given amount (weight) of a substance to a smaller volume. Packing more of a substance into a given volume.

Compression Ratio - Number of times the volume is decreased during a single compression cycle.

Density - Weight per unit volume, such as pounds per cubic foot.

Depressurize (Such as an Aircraft Cabin) - To reduce the inside pressure to that of ambient pressure.

Differential Pressure - Difference between two opposing pressures, designated as psid.

Gage Pressure - Measure of pressure (inside an enclosure) by a gage, designated as psig.

Humidity - The amount of water or moisture in the air. (See Relative Humidity.)

Isobaric - Designation given to a constant pressure level.

Jet Pump (Ejector) - A device which uses the venturi principle to create a negative pressure or "suction."

Negative Pressure - Term applied to a pressure (inside a container) that is less than the ambient pressure. (A vacuum or partial vacuum.)

Pneumatics - The branch of science that deals with the physical properties of gases, particularly air.

Pressure - The force applied on a unit area, usually designated as pounds per square inch (psi).

Pressurize (Such as an Aircraft Cabin) - To bring the inside pressure to a higher value than the ambient pressure.

Pressure Ratio - The ratio of the output pressure of a compressor to the input pressure. The number of times the pressure is increased.

Relative Humidity - The amount of water or moisture in the air compared to the amount the air is capable of holding at any given temperature. (Always expressed as a percentage.)

Specific Volume - Cubic magnitude per unit weight, such as cubic feet per pound.

NASA Standard Day Conditions for Air at Sea Level -

| | |
|---|---|
| o Pressure | 14.73 psia (29.92 in. Hg) |
| o Temperature | 15°C (59°F) |
| o Density | 0.0765 pounds per cubic foot |

Temperature - Measure of the presence of heat, usually indicated by a thermometer in degrees Centigrade (°C) or degrees Fahrenheit (°F).

Thermistor - A special type of resistor whose resistance varies proportionally with temperature change. Said to have a positive coefficient if resistance varies directly with temperature and a negative coefficient if resistance varies inversely with the temperature.

Volume - The cubic magnitude of a substance or an enclosure (length times width times height), designated as cubic inches, cubic feet, etc.

Weight Flow - Weight (of air) flowing by a given point in a given period of time, such as pounds per minute (ppm).

## STUDY QUESTIONS

1. Pneumatics is the branch of science that deals with ____________.

2. Air consists of ___% _______, ___% ______, and ___% __________.

3. Aneroid type instruments are operated by ____________ pressure.

4. At sea level on the NASA standard day, atmospheric temperature and pressure are __________ in. Hg and __________ $^oC$ (_________ $^oF$).

5. When air flows through a narrow portion of a duct, velocity _________ and pressure _______________.

6. When a quantity of air is compressed, volume ________, pressure __________, and temperature _____________.

7. If an enclosed container of air is subjected to a higher temperature, pressure _________, temperature _________, and volume ________________.

8. Compute the output gage pressure of a compressor with a 16 to 1 pressure ratio if the input pressure is 15 psia. Ans. __________ psig.

9. If a volume of air is compressed to 10 psig, what is the differential pressure on the walls of the container? (Assume atmospheric pressure is 15 psia) Ans. _______ psi.

10. If the air in a container is compressed to 45 psia, what is the differential pressure on the walls of the container? (Assume ambient pressure is 15 psia) Ans. _______ psi.

11. What is the total force on a one foot square surface under a pressure of 100 psi? Ans. _______ pounds.

12. What is the total net force acting on a 3-foot by 5-foot area under a pressure of 5 psid? Ans. __________ pounds.

13. If the pressure inside a 10-cubic foot container is 8 psi higher than the ambient pressure, what is the net force exerted against each square inch of the container's inside surface? Ans. ____________ pounds.

14. A closed, rigid container is fitted with a pressure gage and pressurized to 30 psig at sea level. If the

container is elevated to an altitude of 40,000 feet, what pressure will th gage indicate? (Assume NASA standard day conditions and neglect temperature change.) Ans. ______________ psi.

15. A pressure of 10 in. Hg equals ____________ psi.

16. A temperature of 77°F equals __________ °C.

17. A temperature of 60°F equals __________ °R.

18. Relative humidity increases as temperature ____________.

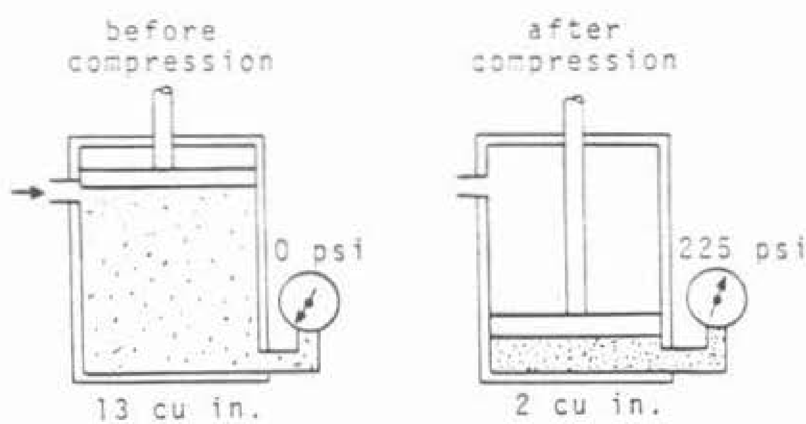
19. When air temperature drops below the dew point, ________ occurs.

20. Two compressors deliver compressed air to a manifold. Each compressor will deliver 200 ppm at 120 psig. What is the total amount and pressure of air available from the manifold? Ans. __________ppm at ___________ psig.

21. Consider the wheatstone bridge in Figure 1-10. If the meter indicates the direction of current flow, which way will the pointer deflect if the resistance of $R_3$ is greater than $R_4$? Ans. To the ________________.

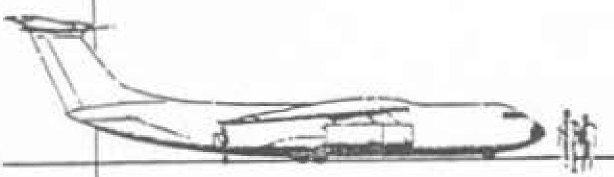
22. Which way will the pointer deflect if $R_1$ is less than $R_2$? Ans. ______________________.

23. In the diagram below, what is the pressure ratio of the compressor? (Assume atmospheric pressure is 15 psia.) Ans. ______________________ to 1 .




24. What is the compression ratio of the above compressor? Ans. ______________________ to 1 .

25. *What is the compressed air temperature if the air temperature before compression is 60°F?* Ans ________ °F .





# BLEED AIR SYSTEM

The bleed air system is a system of ducts and valves which supplies, controls, and distributes air for use in the environmental and adverse weather systems. These air-using systems include the following:

- o Air Conditioning
- o Pressurization
- o Wing Leading Edge Anti-Icing
- o Windshield Rain Removal

Relays are used extensively in the control circuits for these systems. The relays are mounted on a relay panel located under the flight station floor on the right side. Access to the panel is through a snap-on type curtain at the forward end of the toilet compartment.

## SOURCES OF AIR

The compressed air used in the StarLifter pneumatic systems can be obtained from three sources: the engines, the Auxiliary Power Unit (APU), or a mobile ground compressor.

### APU

The APU is located in the forward end of the left main landing gear pod and supplies air and electrical power necessary for starting the engines or for operating the air conditioning systems while the aircraft is on the ground. It is a gas turbine engine with a two-stage centrifugal compressor and is capable of delivering 133 ppm of air at 40 psig and 211°C (412°F) based on NASA standard day conditions at sea level.

The APU starter is a hydraulic motor, using pressure from No. 3 hydraulic system accumulators. Fuel is supplied by gravity feed from the No. 2 main tank, and the battery supplies necessary electrical power. Controls for operating the APU are located on the flight engineer's console.

Ground Compressor

A mobile ground compressor may also be used to supply air for operation and checkout of the pneumatic systems. The unit can be attached to the ground high pressure connection provided in the forward end of the left main landing gear pod as shown in Figure 2-1. When such a unit is used, a ground power cart must also be used to supply necessary electrical power to the systems.

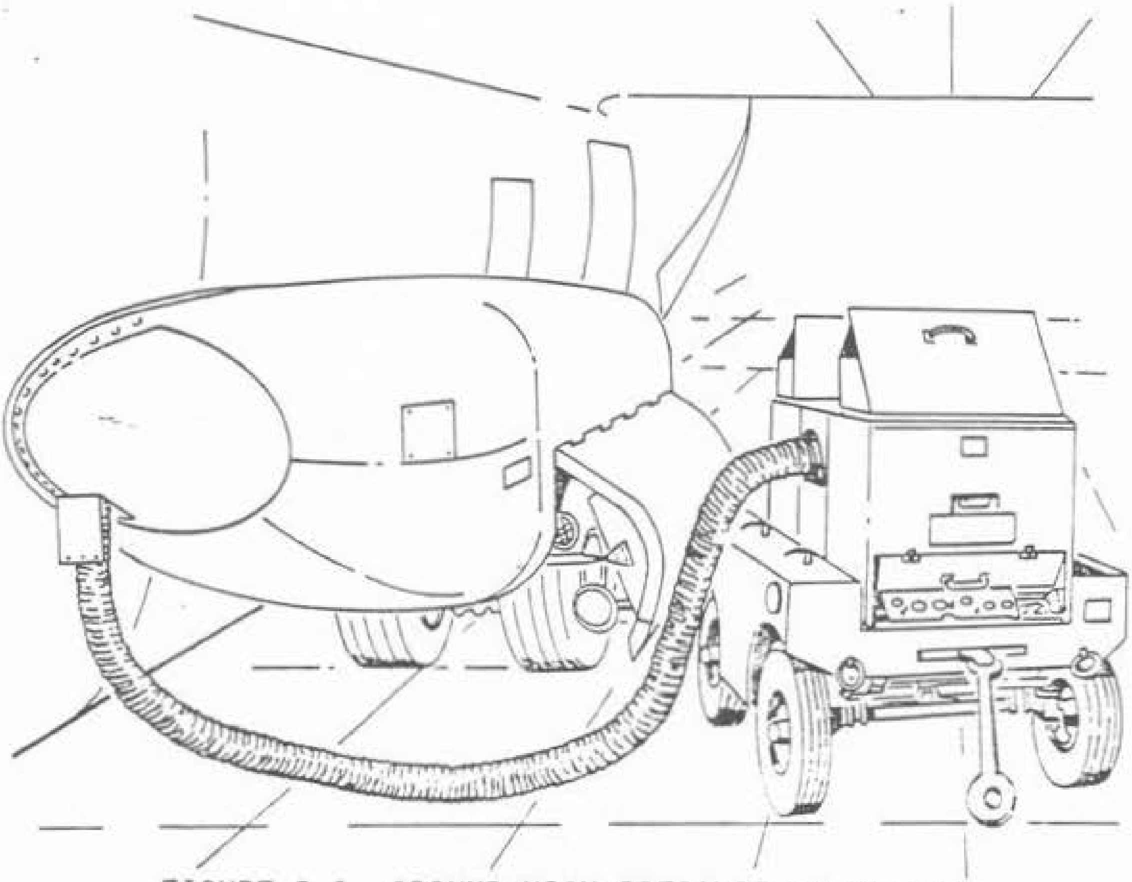


FIGURE 2-1. GROUND HIGH PRESSURE CONNECTION

Engines

The four engines of the aircraft are the normal source for obtaining compressed air for the pneumatic systems. Each engine has a 16-stage compressor with a 16 to 1 pressure ratio as shown in Figure 2-2. Compressed air is bled from the inner diameter of the last stage. Venturies in the bleed struts limit the bleed to a maximum of 4.6 percent of the air available.

At sea level on a NASA standard day with the engines running at takeoff power, each engine can deliver 200 ppm of bleed air at 220 psig and 421°C (790°F). When

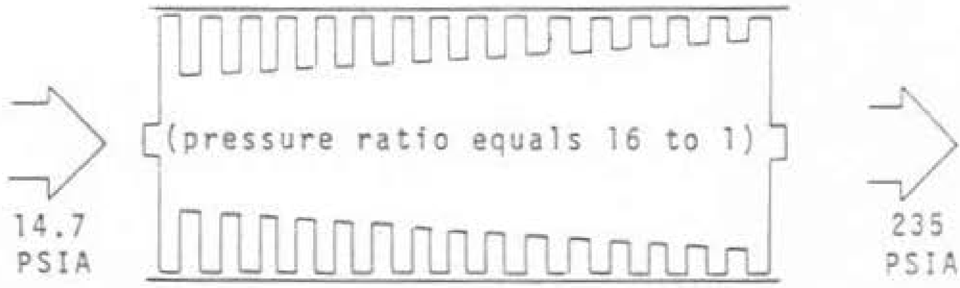



FIGURE 2-2. ENGINE COMPRESSOR

manifolded, the combined outputs of compressed air from all four engines can supply the needs of all the pneumatically operated equipment. Air can be used from the engines when the aircraft is flying or on the ground. However, it is important to note that if the engines are running at less than takeoff power, the pressure, temperature, and amount of bleed air are decreased proportionally. At ground idle power, for example, the delivered bleed air is about 40 ppm at 15 psig and 88°C (190°F).

## BLEED AIR DUCTING

### Duct Routing

Sixteenth-stage bleed air is collected in the engine bleed manifold. This manifold straddles the engine and attaches to the diffuser case in four places, two on each side as shown in Figure 2-3.

The air is then ducted up through the pylon to the main manifold in the wing leading edge. The wing bleed air manifold extends from outboard of the No. 1 engine to outboard of the No. 4 engine as shown in Figure 2-4.

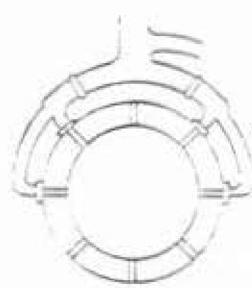


FIGURE 2-3. ENGINE BLEED DUCT

The APU bleed air supply duct and the ground high-pressure connection tee together in the APU compartment. A floor heat supply duct also tees into these ducts in this area. The duct is then routed up through the fuselage and forward, where it tees into the bleed air manifold in the center wing section at BL54 left. Between the inboard pylon and the center section on each side, a duct tees off the manifold to supply air to the air conditioning and windshield rain removal systems. Distribution of air from the manifold to the various systems is controlled by a number of valves. These valves are discussed individually.

FIGURE 2-4. BLEED AIR DUCTING

Construction and Installation

The bleed air ducting is made of stainless steel sections. The pylon ducts, bleed air manifold, and APU supply duct are four inches in diameter. Outboard of the No. 1 and No. 4 pylons, the manifold reduces in diameter as it continues out to supply the outer wing leading edge anti-icing system. The duct sections have compressible flanges welded onto the ends and are held together with V-band clamps. When the clamps are properly installed and tightened, the flanges are compressed together, which forms an air-tight seal as illustrated in Figure 2-5.

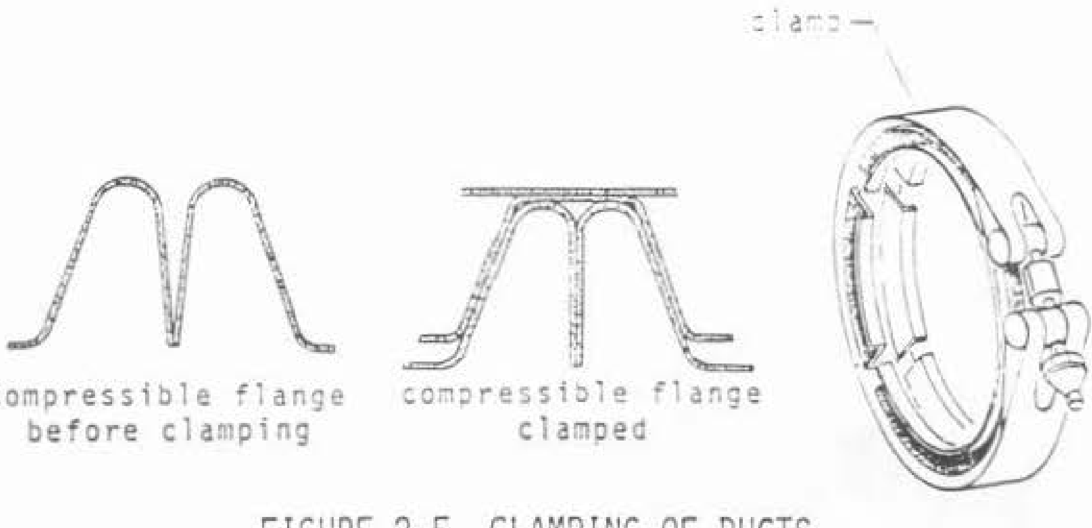



FIGURE 2-5. CLAMPING OF DUCTS

Since metal expands when subjected to heat and contracts when allowed to cool, the bleed air ducting is attached to the aircraft structure with slip-joint supports. This type of support, shown in Figure 2-6, holds the ducting in place, yet allows it to expand and contract with termal loads. These supports are made in two parts and are easily taken apart to facilitate removal of a duct section.

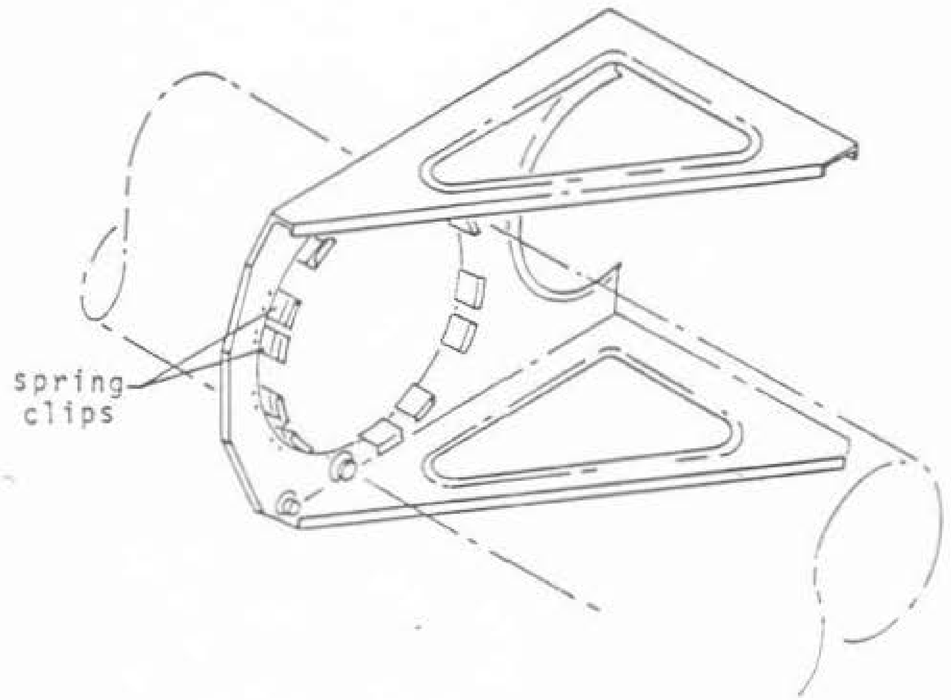



FIGURE 2-6. MANIFOLD SLIDING SUPPORT

The bleed air manifold is rigidly attached to the front wing spar at the tee connections where the four pylon ducts join with the manifold. This is done to prevent any side movement of the pylon ducts due to manifold expansion and contraction. The APU supply duct is rigidly attached to the structure where it passes through the fuselage at both the top and bottom.

Expansion Compensators

Special expansion joints are installed in the ducting to compensate for thermal loads. These joints are located in strategic places, such as between rigid supports. They allow the ducting to expand and contract without placing undue stress on the supporting structure. Flexible elbows such as the one shown in Figure 2-7 are used to retain flexibility where the ducting must be

FIGURE 2-7. TYPICAL ELBOW COMPENSATOR

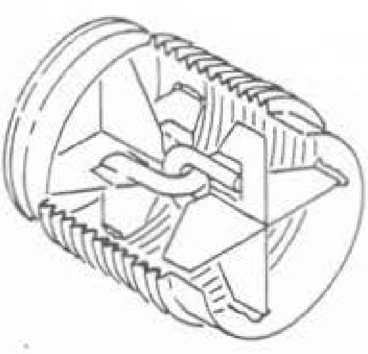


FIGURE 2-8. TIE ROD EXPANSION JOINT

bent. Two types of expansion joints are used in straight ducting. The tie rod type joint shown in Figure 2-8 allows two duct sections to expand toward each other, compressing the bellows of the joint. The expansion absorbing unit shown in Figure 2-9 is called a duct compensator. It provides a slip-joint to allow for duct growth, while a bellows arrangement absorbs the movement of the slip-joint. Air pressure distribution within the bellows assembly keeps the bellows contracted so that the compensator is actually pulling the duct sections together. This action prevents the ducts from buckling when they expand.

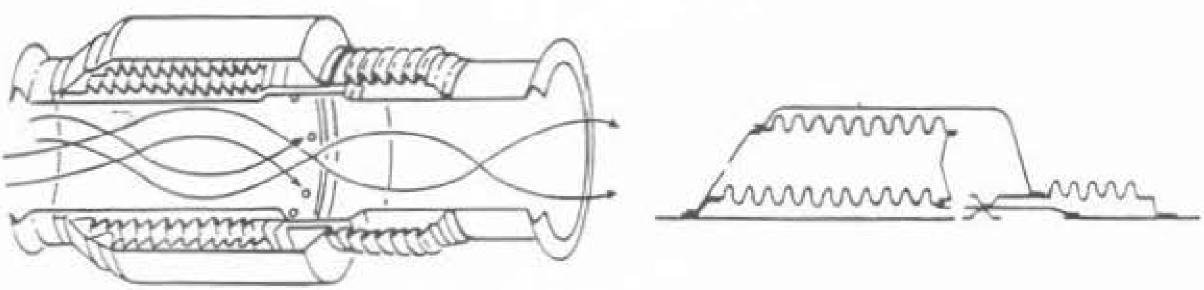


FIGURE 2-9. DUCT COMPENSATOR

Duct Insulation

Since the air flowing through the bleed air ducts is very hot, it is necessary to insulate the ducts so that the heat will not be transmitted through the duct walls to cause possible damage to surrounding equipment, wiring, and sealing. The insulation also prevents combustible fluids from coming in contact with the duct walls.

After fabrication and prior to installation, the ducts are insulated with spun quartz encased in a hard epoxy-impregnated fiberglas cover, either in sheet or tape form as shown in Figure 2-10. This insulation, considered a permanent part of the duct, is moisture-proof and very durable. It can be patched easily in the event of damage.

Since the insulation does not expand at the same rate as the ducts, a silicone-rubber bellows is provided in the insulation on long duct sections to prevent the insulation from being cracked or torn loose by the duct expansion.

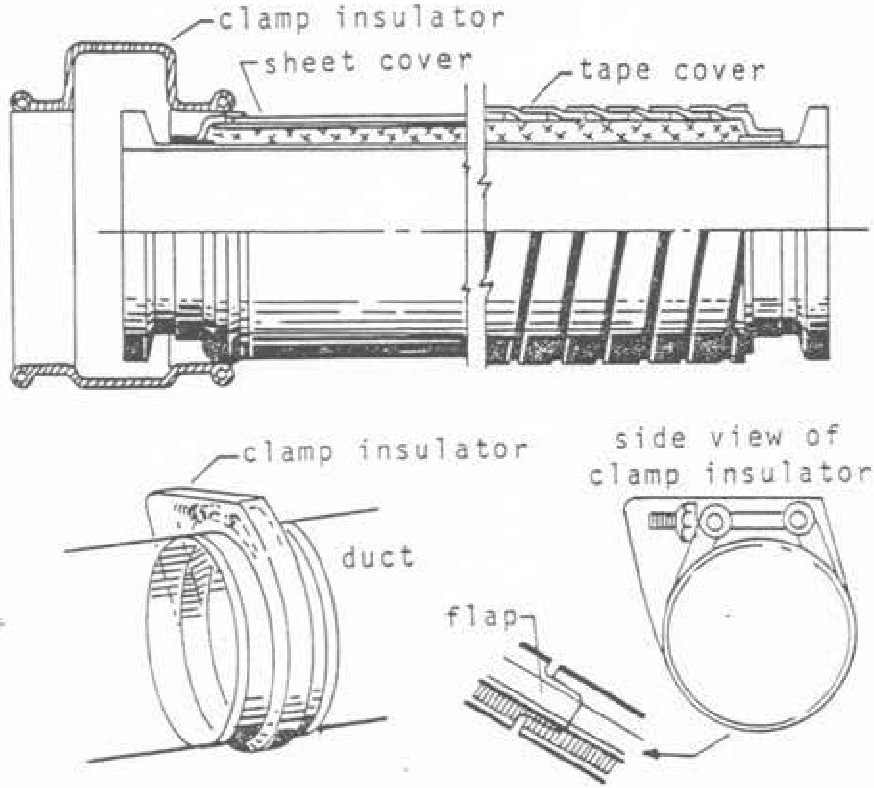



FIGURE 2-10. DUCT INSULATION

After installation, the valves in the bleed air system are insulated with fiberglas covered with stainless steel foil. These insulating covers are made in sections to fit the valves. They contain eyelets and are held together with wire lacing.

Wing leading edge sections, joined to the front spar with Phillips head screws, must be removed to gain access to the bleed air manifold. In the center section, three panels cover the manifold. They are also fastened with Phillips head screws.

## BLEED AIR SYSTEM CONTROLS

Distribution of bleed air is controlled by the operation of several valves. Controls for these valves are located on the Environmental Control Panel at the flight engineer's station. The panel also contains controls and indicators for air conditioning, temperature control, and pressurization. These items are discussed in following chapters. Figure 2-11 shows a flow schematic of the bleed air system. The system is displayed schematically on the Environmental Control Panel as shown in Figure 2-12.

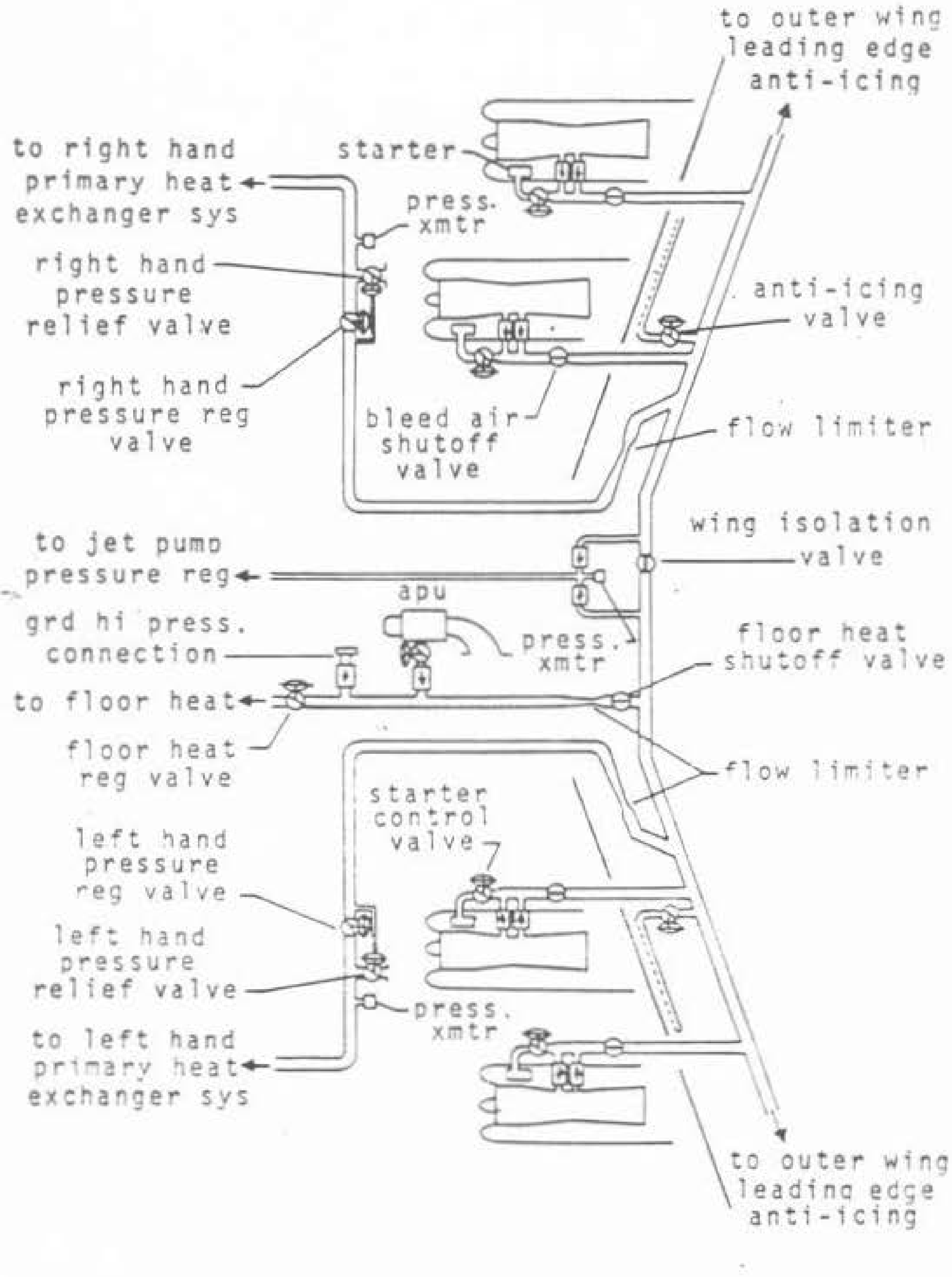



FIGURE 2-11. BLEED AIR SYSTEM FLOW SCHEMATIC

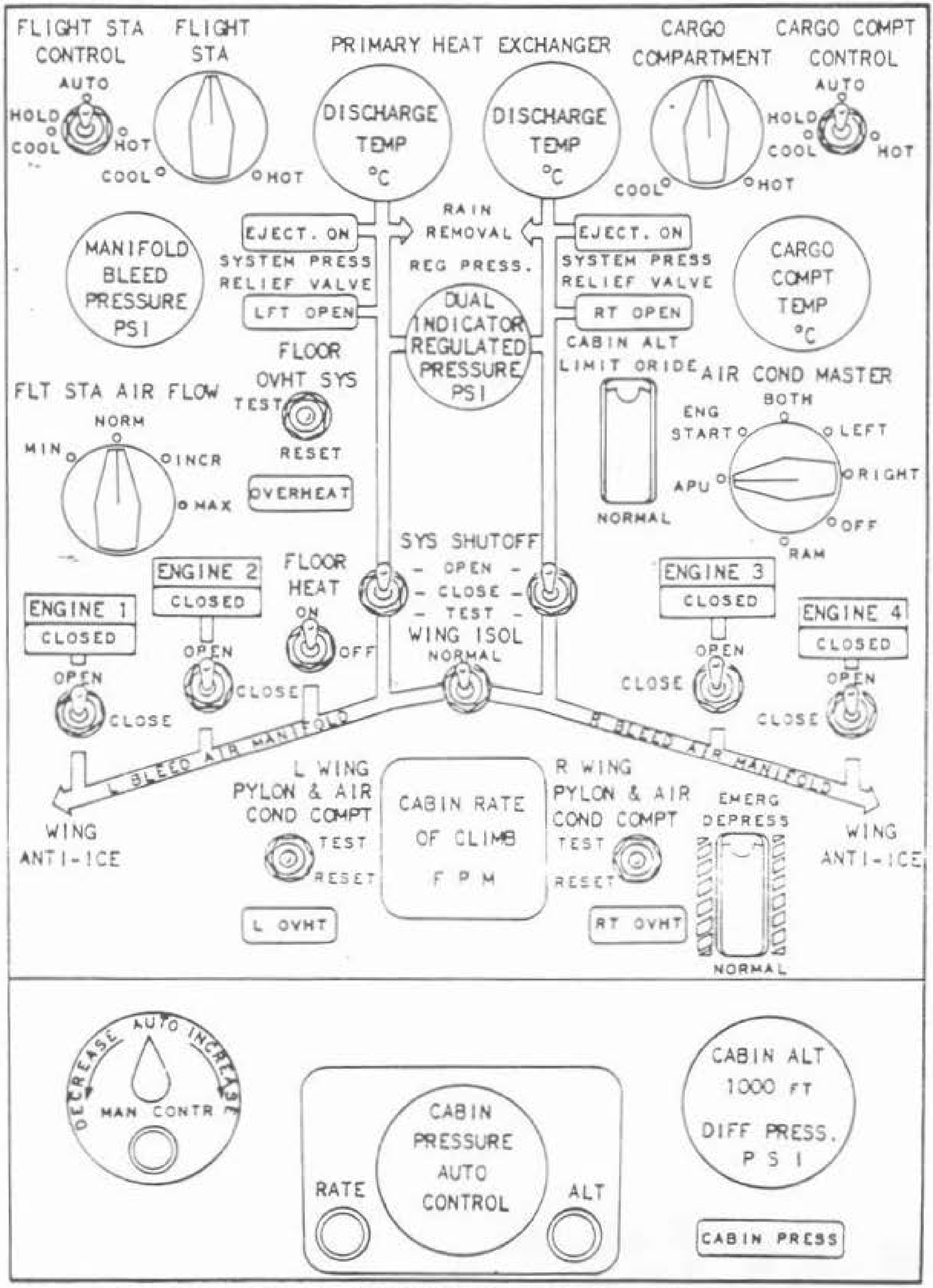



FIGURE 2-12. ENVIRONMENTAL SYSTEMS CONTROL PANEL

The various valves in the bleed air system serve as a means of controlling airflow. Each valve has a specific purpose, and different methods are used to control different valves.

## Check Valves

The APU and ground high-pressure supply ducts each contain a dual, flapper-type check valve such as the one shown in Figure 2-13. The check valves permit air to flow from the APU and the ground high-pressure connection to the bleed air manifold, but prevent flow in the opposite direction. Reverse flow would result in an air loss from the manifold through the APU or ground high-pressure connection when the APU and ground compressor are not being used. The two valves are identical.

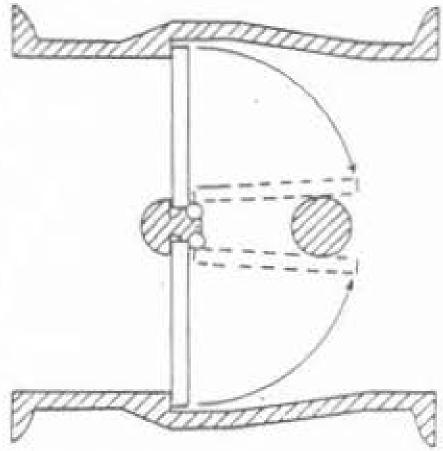


FIGURE 2-13. APU CHECK VALVE

There is also a dual flapper check valve installed in each side of the engine bleed manifold to prevent reverse flow through the compressor of a shutdown engine as shown in Figure 2-14. These valves are of a flat plate design and fit between the duct sections as shown in Figure 2-15. All eight valves are identical. They are easily accessible when the engine aft cowl doors are open.

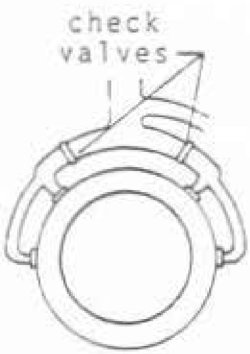



FIGURE 2-14. CHECK VALVE LOCATION

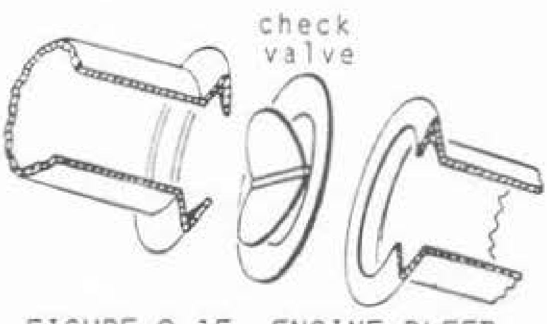



FIGURE 2-15. ENGINE BLEED AIR CHECK VALVE INSTALLATION

## Engine Bleed Air Shutoff Valve

A bleed air shutoff valve is located in each pylon bleed air duct. When closed, the valve isolates the engine, which prevents airflow either to the engine from the manifold or to the manifold from the engine. The bleed air shutoff valves are of the motor-driven butterfly type. They are normally controlled by individual switches on the Environmental Control Panel, and the normal flight position is "OPEN." An automatic override feature is incorporated in the wiring to close individual valves if an engine's FIRE EMERGENCY handle is pulled to the emergency position. Certain other operating conditions also cause the valves to be overridden closed. These conditions are discussed later in this chapter.

A CLOSED indicator light for each valve is provided on the control panel. These lights are controlled by microswitches in the valves and are actuated when the valves are closed. Access to the valves is through small panels, one on each side of the pylon. The two panels are directly opposite each other and are located slightly above the valve as illustrated in Figure 2-16.

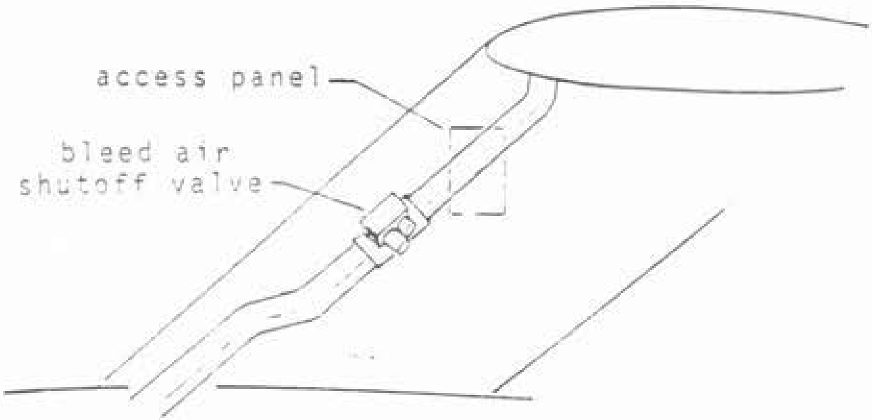



FIGURE 2-16. BLEED AIR SHUTOFF VALVE LOCATION

## Wing Isolation Valve

A wing isolation valve is located in the bleed air manifold at BL36 left in the center wing section. The valve separates the left side of the manifold from the right side and is normally closed. If the valve is opened, the entire manifold can be pressurized from the APU, ground compressor, or any one engine. It is a motor-driven butterfly type shutoff valve very similar to the bleed air shutoff valves. The valve is normally controlled by the WING ISOLATION switch which is labeled "OPEN" and "NORMAL" (closed). Certain operating conditions, discussed later in this chapter, cause the valve to be overridden to the open position. Access to the valve is through the center wing section left-hand manifold access panel.

Floor Heat Shutoff Valve and Floor Heat Regulator Valve

Although these valves are in the floor heat system and are normally controlled by the FLOOR HEAT switch, they are discussed briefly in this section since they function as bleed air control valves during certain ground operations. During these ground operations, there are override conditions which control these valves in order to control the distribution of bleed air.

The floor heat shutoff valve is located in the APU and ground high-pressure supply duct where the duct joins the bleed air manifold in the center wing section. It is a motor-driven butterfly type shutoff valve identical to the wing isolation valve, and must be opened to allow the APU or ground compressor to pressurize the bleed air manifold.

The floor heat regulator valve is a solenoid-controlled, air-actuated, modulating butterfly valve with a shutoff feature. It is located in the APU compartment in the floor heat supply duct. When the APU or ground compressor is being used to supply air for engine starting, the regulator valve is closed to prevent a loss of air under the floor. This action ensures an adequate supply of air to start the engine.

Bleed Air Pressure Regulator and Shutoff Valve

A bleed air system pressure regulator valve is located in each air conditioning and rain removal systems supply duct in the inboard wing leading edge sections. When the valve is open, it supplies these systems with a regulated bleed air pressure of approximately 70 psig. It is a solenoid-controlled, air-actuated, modulating butterfly valve with a shutoff feature. The valves are normally controlled by the individual SYSTEM SHUTOFF switches. They are energized open and are normally open in flight. There are certain override features incorporated into the control circuits of these valves. These circuits are discussed later in this chapter. The valves may be reached through access panels provided in the bottom of the leading edge sections. A schematic cutaway diagram of the valve is shown in Figure 2-17.

Bleed Air Pressure Relief Valve

A bleed air system pressure relief valve is located immediately downstream of each regulator valve. In the event of a failure of the regulator valve to the open position, the relief valve regulates the system pressure at approximately 110 psig. It does this by dumping excess air overboard through a port on the under-side of the wing leading edge section. The valves are automatically pressure-actuated. However, they may be tested by use of the SYSTEM SHUTOFF

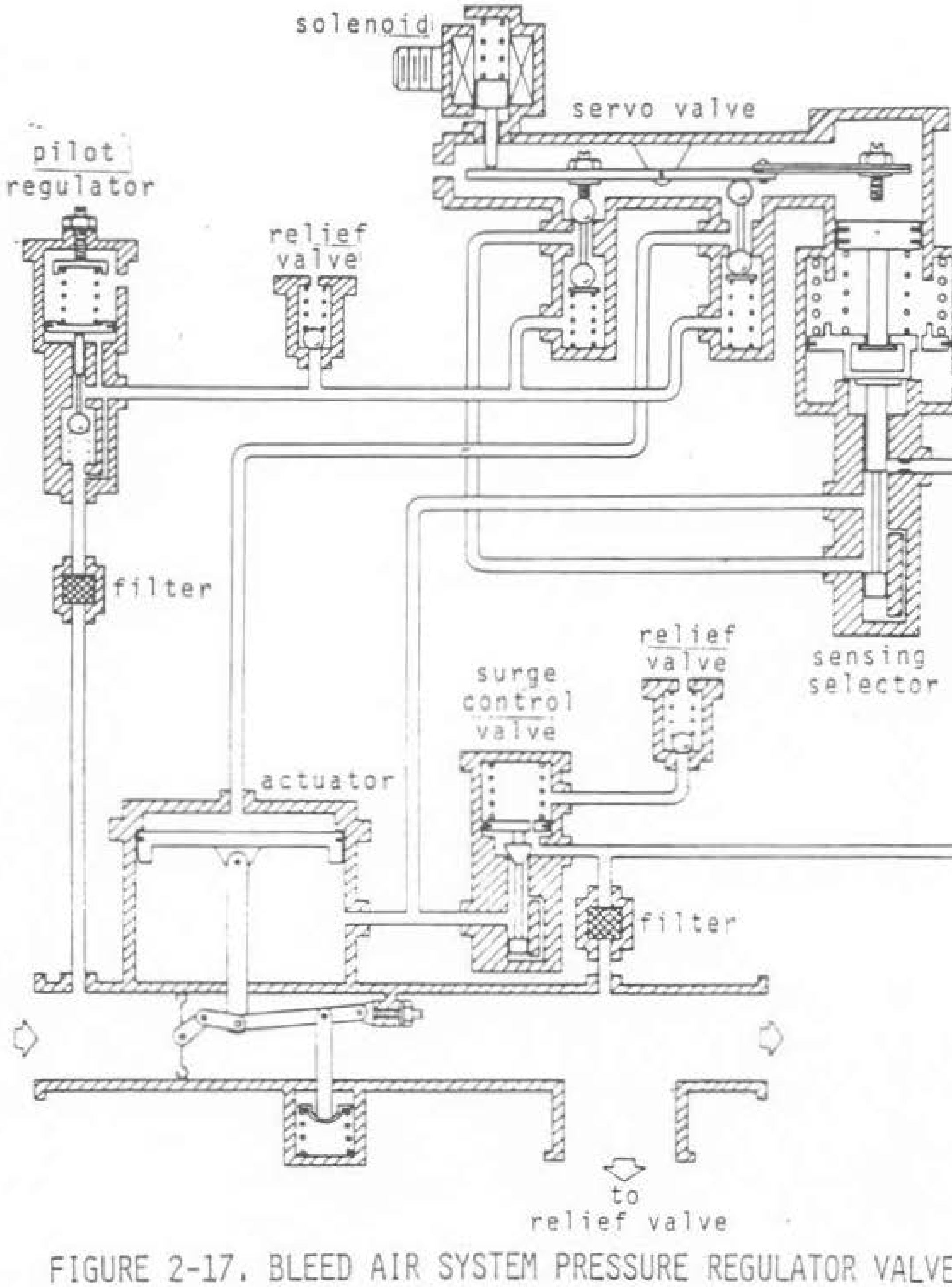



FIGURE 2-17. BLEED AIR SYSTEM PRESSURE REGULATOR VALVE

switches. When one of these switches is placed in the "TEST" position, it energizes a solenoid valve on the appropriate relief valve. The relief valve is then opened by high-pressure bleed air, ported through the solenoid valve directly from the bleed air manifold. When a relief valve opens, a corresponding RELIEF OPEN indicator light illuminates on the Environmental Control Panel. Access to the valves is through the same panels that provide access to the regulator valves. A schematic cutaway of the valve is shown in Figure 2-18.

Pressure Transmitters

A pressure transmitter is installed in the center wing section and is connected through check valves to the bleed air manifold on both sides of the wing isolation valve. The transmitter transmits electrical signals, in proportion to manifold bleed air pressure, to the MANIFOLD BLEED PRESSURE indicator on the Environmental Control Panel. Access to the transmitter is through the center wing section center manifold access panel.

Another pressure transmitter is located in each inboard wing leading edge section, near the bleed air pressure regulator and relief valves. These transmitters connect to the ducts just downstream from the relief valves. They transmit pressure signals to the duct regulated pressure indicator on the Environmental Control Panel.

Venturies

A venturi is installed in the APU and ground high pressure supply duct where it is routed along the top of the fuselage. In the event of a duct rupture, the venturi would limit the maximum air loss to about 300 ppm.

Similar flow limiting venturies are also installed in the bleed air ducts immediately upstream of the bleed air system pressure regulator valves. In addition to limiting the air loss in the event of a ruptured duct, they also limit the amount of air that would have to be dumped overboard by the relief valves if a regulator valve fails.

## BLEED AIR SYSTEM OPERATION

In order to facilitate management of the bleed air system during certain operations, particular aspects of control are accomplished automatically. These automatic control features are built into the AIR COND MASTER switch and are discussed in order of rotation of the switch in the following paragraphs.

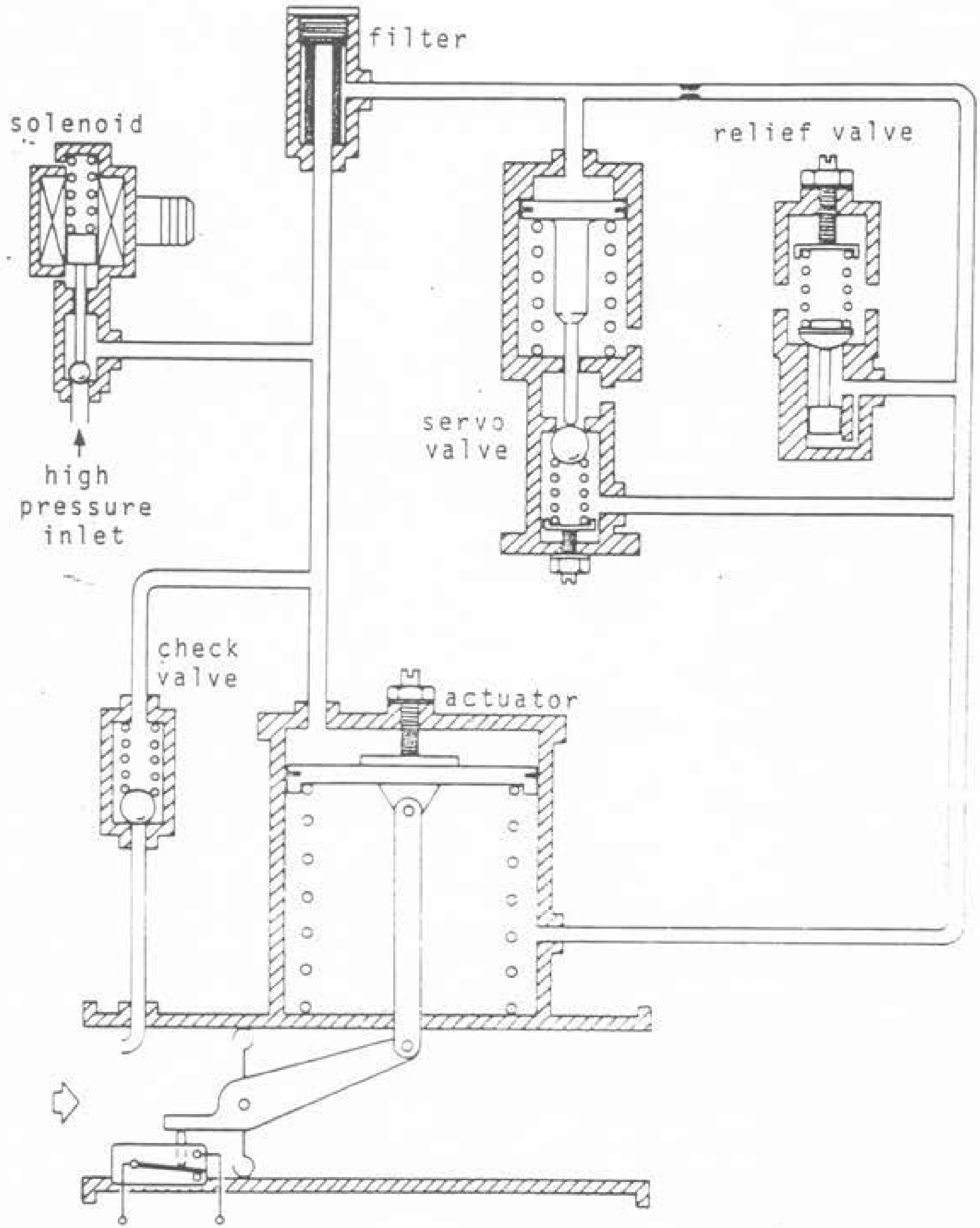



FIGURE 2-18. BLEED AIR SYSTEM PRESSURE RELIEF VALVE

"APU" Position

The "APU" position of the master switch is an air conditioning selection. The switch should be placed in this position when either the APU or ground compressor is used to supply air for operating the air conditioning systems on the ground.

NOTE

*It is not necessary to place the master switch in "APU" in order to operate the APU. It is merely a convenient means of controlling several valves with one operation in order to control the distribution of bleed air.*

When the master switch is positioned to "APU," certain override actions occur, as follows:

- o The floor heat shutoff valve is driven open as shown in Figure 2-19. This action permits airflow to the left manifold.
- o The wing isolation valve is driven open as shown in Figure 2-20. This action permits airflow to the right manifold.
- o All four bleed air shutoff valves are driven closed as shown in Figure 2-20 in order to prevent engine starting.
- o The primary heat exchanger system ejector shutoff valves are driven closed. (These valves are discussed in the following chapter.)

The valves are positioned as indicated above, regardless of the position of the individual control switches. These overrides are provided to ensure a supply of air for air conditioning, since the output of the APU or ground compressor is not sufficient to supply more than one system at a time.

The underfloor heating system may be operated by placing the FLOOR HEAT switch in the "ON" position. Placing the SYSTEM SHUTOFF switch in the "OPEN" position opens the bleed air pressure regulator valves and provides air to the air conditioning systems.

With the master switch in "APU," the following indications should be present on the Environmental Control Panel:

- o The manifold bleed pressure indicator should show the pressure being supplied from the APU or ground compressor (about 40 psi).

- o The EJECTOR ON lights should be extinguished. (These lights are discussed in the following chapter.)
- o The bleed air shutoff valve CLOSED indicator lights should be illuminated.

If the SYSTEM SHUTOFF switches are in the "OPEN" position, pressure should be indicated on the regulated pressure indicator, and both pointers should show approximately the same pressure as the manifold bleed pressure indicator. The temperature of the air can also be monitored on the primary heat exchanger system temperature indicators. These indicators are discussed in the following chapter.

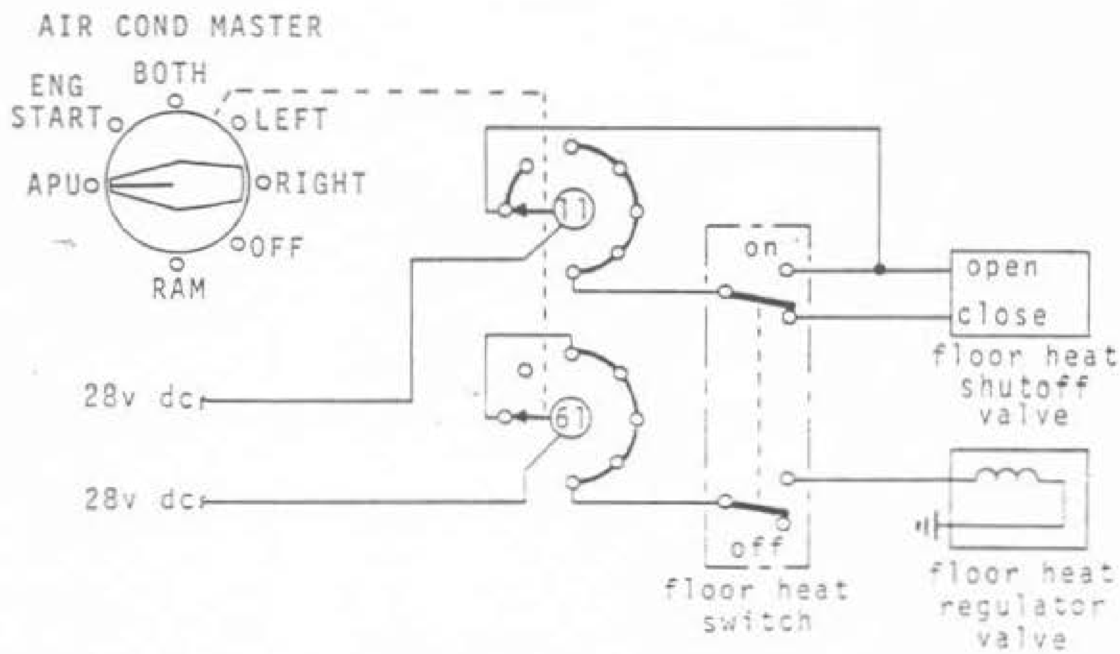



FIGURE 2-19. FLOOR HEAT VALVE CONTROL

"ENGINE START" Position

The master switch should be placed in "ENG START" when either the APU or ground compressor is being used to supply air for starting an engine. As in the case of the "APU" position, the "ENG START" position merely provides a convenient means of controlling several valves with one switch in order to control the distribution of bleed air. In this case, however, the air is directed to the engines. Override features cause the following actions to occur:

- o Power is removed from the floor heat regulator valve, as shown in Figure 2-19, which prevents operation of the floor heat system.

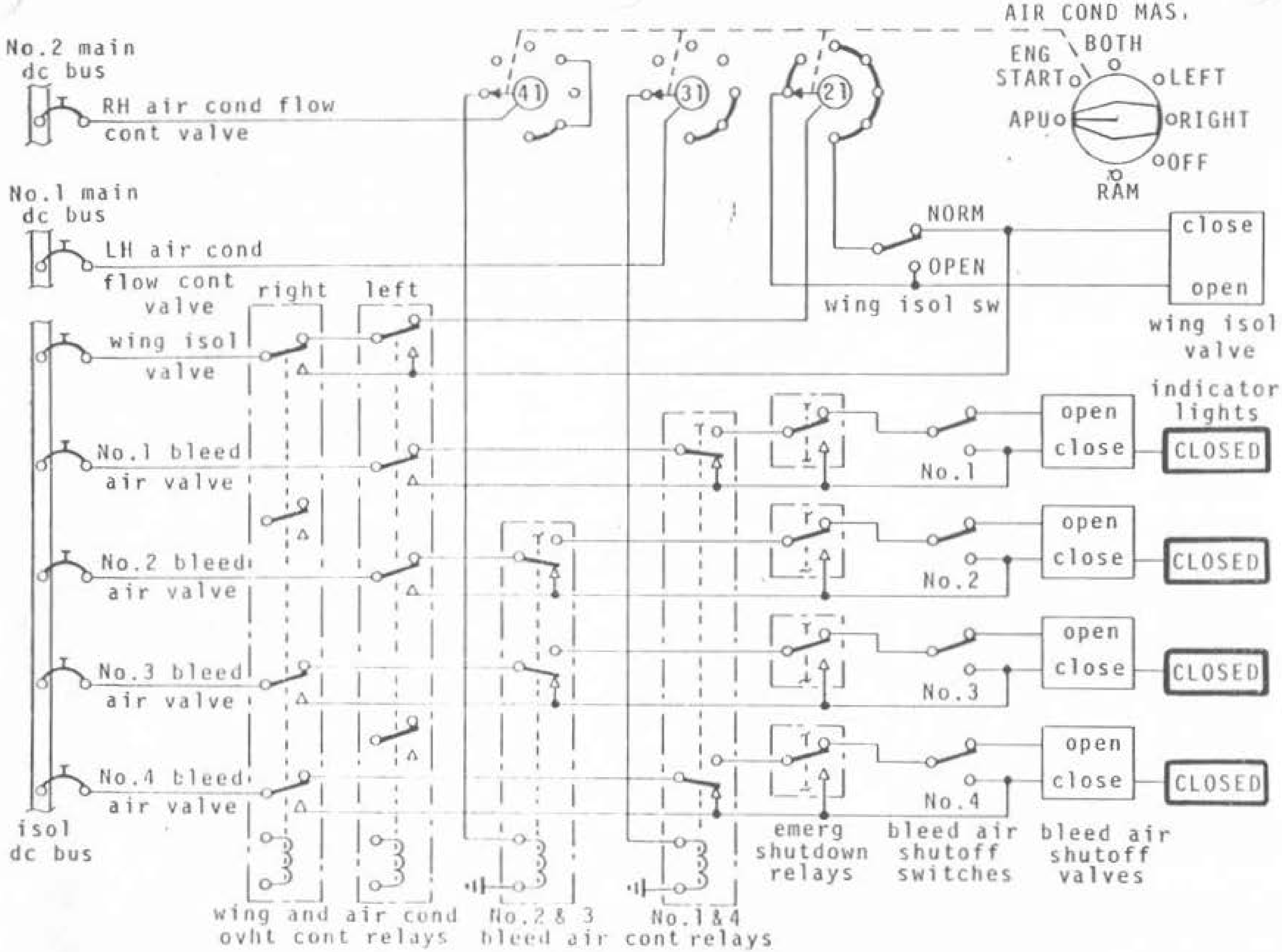



FIGURE 2-20. BLEED AIR VALVE CONTROL SCHEMATIC

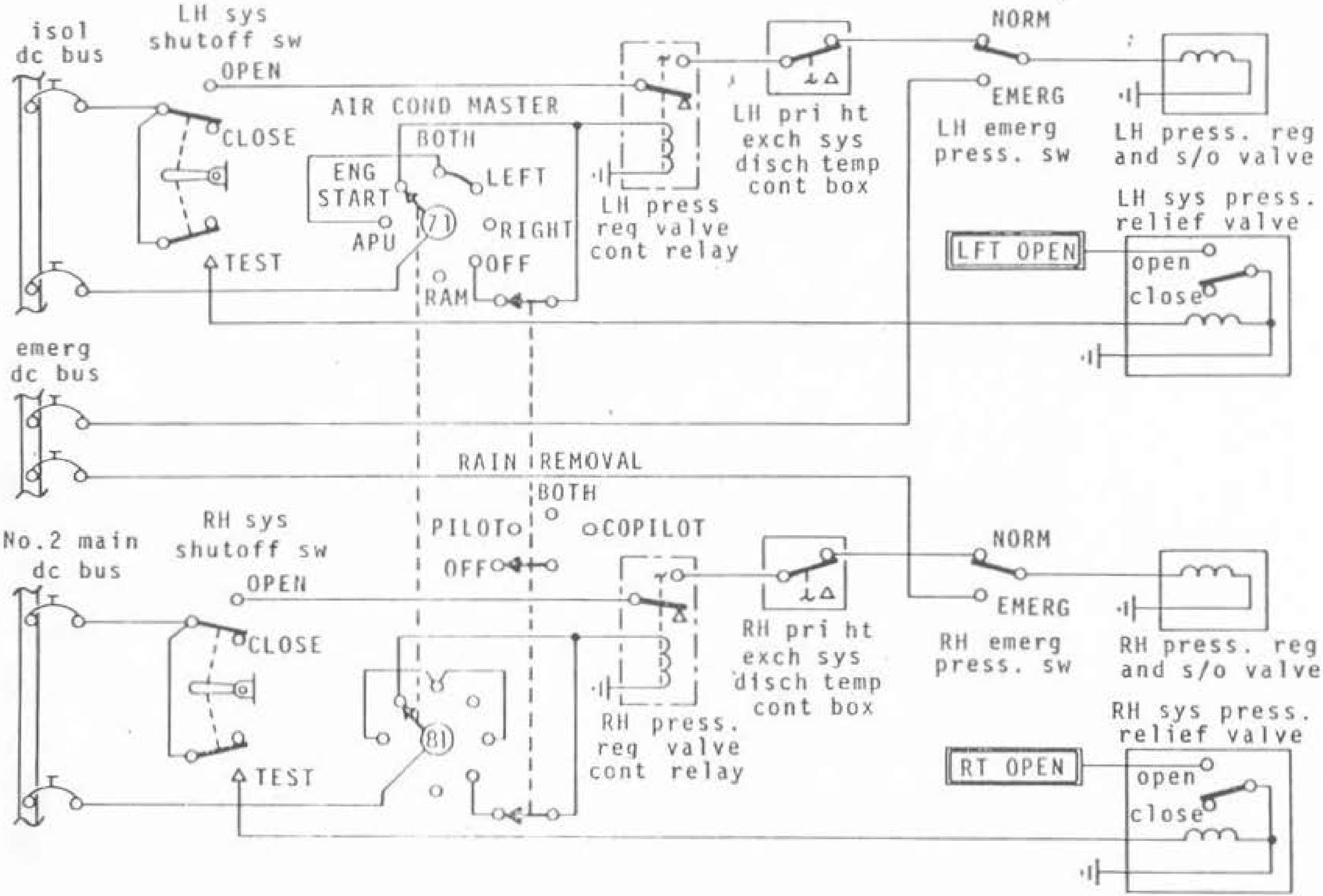



FIGURE 2-21. PRESSURE REGULATOR VALVE CONTROL SCHEMATIC

- The floor heat shutoff valve is driven open, as shown in Figure 2-19, which premits airflow to the left manifold.

- The wing isolation valve is driven open, as shown in Figure 2-20, which permits airflow to the right manifold.

- Power is removed from both bleed air pressure regulator valves, as shown in Figure 2-21, which prevents operation of the air conditioning systems.

The bleed air shutoff valves can now be opened with the individual control switches to provide air to the starter valves.

With the master switch in "ENG START," the following indications should be present on the Environmental Control Panel:

- The manifold bleed pressure indicator should show the pressure being supplied by the APU or ground compressor.

- Both pointers of the regulated pressure indicator should read zero.

- The primary heat exchanger system temperature indicators should show ambient temperature.

- Both EJECTOR ON lights should be illuminated.

- The bleed air shutoff valve CLOSED indicator lights should extinguish as the switches are placed in the "OPEN" position.

It should be noted that the pressure regulator valves are closed when the master switch is positioned to "OFF" as shown in Figure 2-21. This action prevents an unnecessary loss of air through the primary heat exchanger system ejectors since the air conditioning systems are shut off at this time. However, the valves are opened again to supply air if the rain removal system is turned on.

Bleed Air Overheat Detection System

In the event of a malfunction such as a ruptured bleed air duct or a failed duct clamp, hot bleed air could spill out into the surrounding area and cause serious damage to wiring and equipment. To prevent such damage, a bleed air overheat detection system is installed on the aircraft. This system not only provides a warning to the pilot and flight engineer in the event of an overheat condition but also automatically isolates the entire area where the overheat condition occurs.

The detection system consists of three separate sections:

- o Left wing, pylon, and air conditioning compartment
- o Right wing, pylon, and air conditioning compartment
- o Underfloor area and APU compartment

Since all three sections are very similar in operation, only the right wing section electrical schematic is shown in Figure 2-22.

The overheat sensor is a continuous loop-type element made in sections. The wing loops run from the air conditioning compartment, through the wing leading edge, and down into the upper sections of the pylons. The underfloor sensor runs along the APU and ground high pressure supply duct from the floor heat shutoff valve down into the APU compartment and out under the floor. A temperature of 155°C (310°F) in any of these areas is considered an overheat condition and activates the isolation system.

If an overheat condition is detected by either wing section, the detection system imposes a closed override on the wing isolation valve and both bleed air shutoff valves on the affected side. If an overheat is detected by the underfloor and APU compartment loop, both the floor heat regulator valve and floor heat shutoff valve are overridden closed. When an overheat occurs in any of these areas, appropriate warning lights are illuminated on the pilot's annunciator panel and on the Environmental Control Panel. The lights will extinguish when the overheat dissipates, but the valves cannot be reopened until the appropriate TEST-RESET switch is toggled to the "RESET" position.

Each overheat detection loop is wired in series through the contacts of all four bleed air overheat cutout relays. These relays are energized by the individual engine starter pushbuttons. If any one of the engine starter buttons is actuated, its associated relay prevents all three sections of the overheat detection system from closing any of the valves until after the engine is running.

All three sections can be tested by toggling the associated TEST-RESET switches to the "TEST" position. The test condition produces the same results as an actual overheat. A time delay is built into the control boxes so that the output is present for a few seconds after the test switch is released, which allows actuation of the holding circuits. When this time delay elapses, the indicator lights extinguish and the system can be reset. The three control boxes are located in the center fuselage junction box.

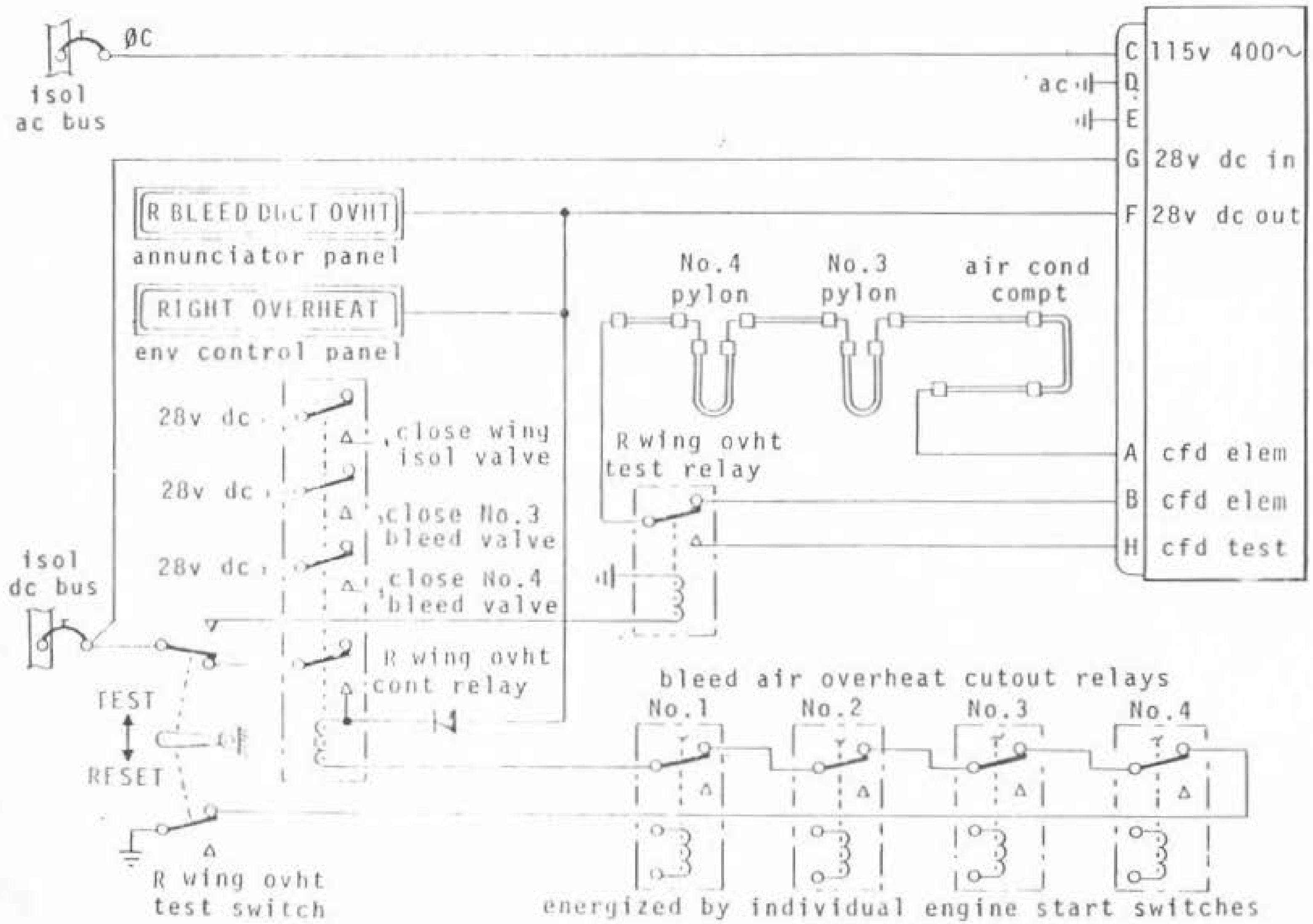



FIGURE 2-22. RIGHT WING, PYLON, AND AIR CONDITIONING COMPARTMENT OVERHEAT DETECTION

## Manifold Leakage Test

A manifold leakage test should be made to determine system integrity whenever a component is replaced in the system or at any other time circumstances deem necessary. With the floor head switch in "OFF," the master switch in "ENG START," and the bleed air shutoff valves open, the manifold should then be pressurized with APU bleed air. The master switch should then be turned to "OFF" and the time required for the pressure to drop from 30 to 15 psi should be measured with a stopwatch. The pressure drop time should be a minimum of 20 seconds. If the time is less, there is excessive leakage in the system and corrective action should be taken.

*STUDY QUESTIONS*

1. *What limits the amount of bleed air delivered to the manifold from the engine compressor?*
2. *What systems use air from the bleed air manifold?*
3. *On an NASA standard day at sea level, the sixteenth-stage bleed air temperature is ______ (takeoff thrust)*
4. *This high temperature is the result of ______________.*
5. a. *Why are the bleed air ducts insulated?*

   b. *How are they insulated?*
6. *The bleed air manifold is made of __________________.*
7. a. *What is a duct compensator?*

   b. *Why are they used in the bleed air ducting?*
8. *What are the three sources of air for the bleed air system?*
9. a. *Where are the bleed air shutoff valves located?*

   b. *What type of valves are they?*

   c. *How are they controlled?*
10. *The APU delivers approximately ______ ppm of air at ______ psig and ______ °F. (NASA standard day at sea level)*
11. *The maximum amount of air delivered to the bleed air manifold from the engine is approximately _______ ppm.*

12. Through what two valves must the sixteenth-stage bleed air pass to enter the bleed air manifold?

13. a. What is the purpose of the bleed air check valves?

b. Where are they located?

14. What is the purpose of the bleed air shutoff valves?

15. a. Where is the bleed air manifold pressure indicator located?

b. In what units of pressure does it indicate?

16. a. What is the purpose of the wing isolation valve?

b. What is its normal flight position?

c. Where is it located?

d. What type of valve is it?

e. How is it controlled?

17. a. What is the purpose of the bleed air system pressure regulator valve?

b. What type of valve is it?

c. Where is it located?

d. How is it controlled?

e. To what pressure does it regulate the air?

18. a. What is the purpose of the bleed air system pressure relief valve?

b. Where is it located?

c. At what pressure does it relieve?

d. How is it tested?

19. What override conditions occur when the master switch is positioned to

a. "APU"?

b. "ENGINE START"?

20. a. What valves are affected if an overheat condition is detected in the No. 3 pylon upper section and how are they affected?

b. At what temperature does this overheat occur?

c. What indications are given?

## PRIMARY HEAT EXCHANGER SYSTEM

Two identical primary heat exchanger systems are used to precool and regulate the temperature of the bleed air supplied to the air conditioning and rain removal systems. The two heat exchanger systems are located in the leading edges of the wing root fillet areas, one on each side. The right hand system is depicted in Figure 3-1 and consists of the following:

- o Heat exchanger
- o Ejector assembly and shutoff valve
- o Ram cooling air control valve
- o Three temperature sensing units
- o Temperature control box

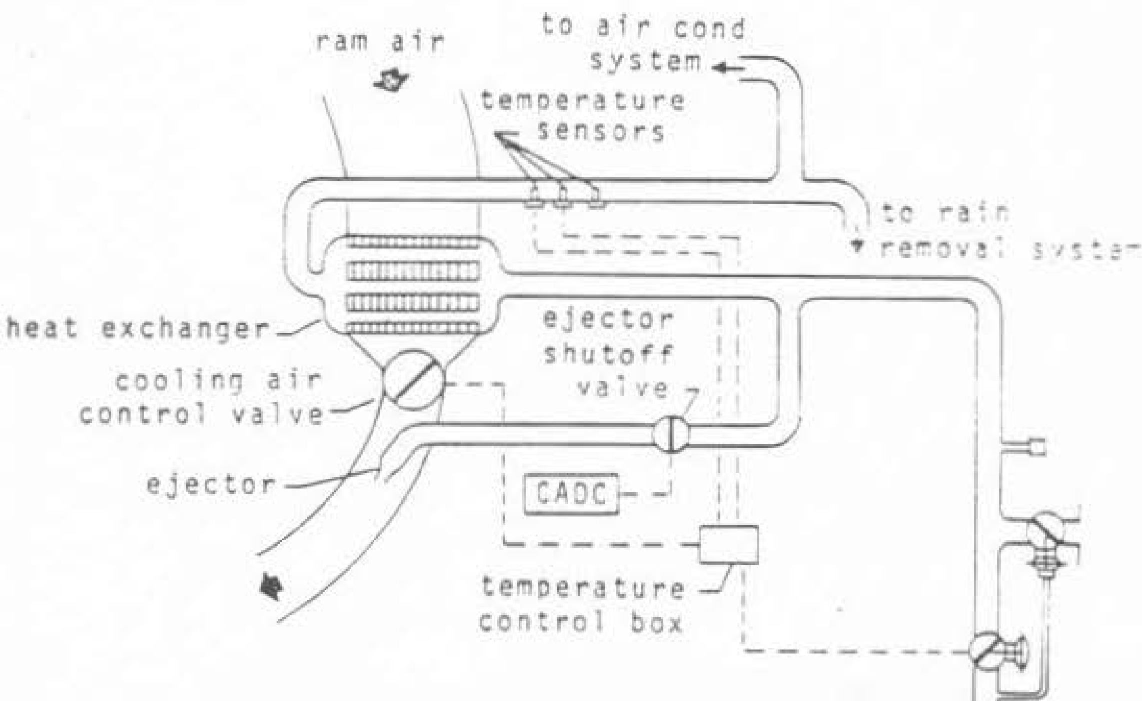



FIG. 3-1. PRIMARY HEAT EXCHANGER SYSTEM

Access to all of the components, except to the temperature control box, is through cam-lock fastened panels on top of the wing.

A temperature indicator for each system is located at the top center of the Environmental Control Panel. Although system control is entirely automatic, these indicators can be used to monitor system operation. The indicators, calibrated on the Centigrade scale, show a normal range from 220 to 240°C.

COMPONENTS

Heat Exchanger

The primary heat exchanger is a single-pass unit of welded and brazed construction, utilizing stainless steel throughout except for the cooling fins which are nickel. Cooling is accomplished by air-to-air heat exchange, much the same as hot water is cooled in an automobile radiator. As hot bleed air flows through the heat exchanger, it is cooled by a crossflow of ram air. The ram air does not mix with the bleed air but flows directly through the heat exchanger and discharges overboard. The amount of cooling obtained is determined by the temperature and amount of cooling air flowing through the unit.

Ejector Assembly and Shutoff Valve

An ejector assembly is located in the ram air discharge duct of the heat exchanger. It is used to induce a flow of cooling air through the unit whenever the aircraft speed is not high enough to provide sufficient flow. Bleed air is supplied to the ejector from the input of the heat exchanger. The unit uses approximately 66 ppm of air at 70 psig.

A shutoff valve is located in the bleed air supply duct to the ejector and is used to turn the supply of bleed air to the ejector on or off. The valve is a motor-driven butterfly type, powered by 28 volts, dc. It is normally controlled by the Central Air Data Computer (CADC) and opens when the aircraft speed drops below 0.3 Mach. The pilot's (No. 1) CADC controls the left-hand ejector shutoff valve, and the copilot's (No. 2) CADC controls the right-hand ejector shutoff valve.

When the aircraft is on the ground and the APU or ground compressor is being used to supply bleed air for air conditioning, the ejector is not needed since the temperature of this air is less than the control point of the system. Therefore, in order to prevent an unnecessary loss of air overboard and to conserve this air for use in air conditioning, the ejector shutoff valves are overridden closed when the AIR COND MASTER switch is positioned to "APU." The control circuit for these valves is shown schematically in Figure 3-2.

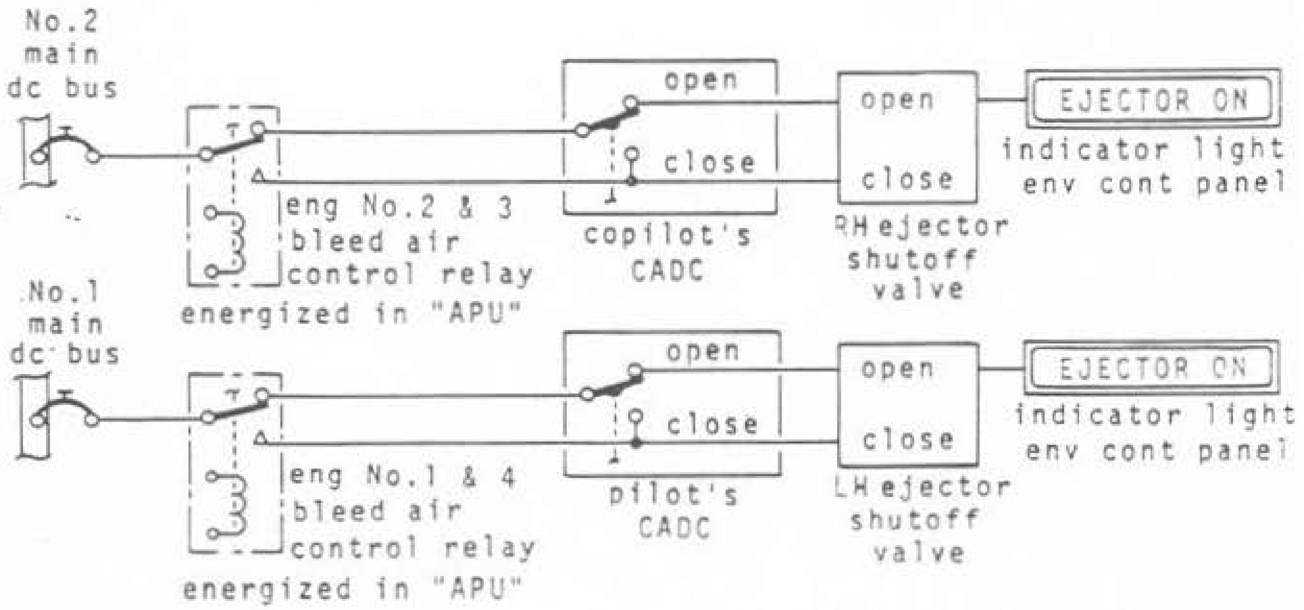



FIG. 3-2. EJECTOR SHUTOFF VALVE CONTROL SCHEMATIC

Two "EJECTOR ON" indicator lights are located on the Environmental Control Panel just below the primary heat exchanger system temperature indicators. These lights are illuminated whenever the ejector shutoff valves are open.

Cooling Air Control Valve

The cooling air control valve is located in the ram air discharge duct between the heat exchanger and the ejector assembly. It is an ac motor-driven modulating butterfly valve, which controls the flow of cooling air through the heat exchanger. The valve is driven by a control box in response to temperature signals from sensors located in the bleed air duct.

Temperature Sensors

Three thermistor-type sensing units are located in the bleed air duct at the output of each heat exchanger. Two of these are used in controlling temperature; the third is the indicator sensor. Of the two temperature control sensing units, one is the control sensor which determines when, and in what direction, the cooling air control valve drives. The other unit contains two separate sensors in the same housing: an anticipator sensor and a high-limit sensor. The anticipator sensor is sensitive to temperature change and controls the driving rate of the valve to help prevent overshooting. It also corrects for transient temperature changes caused by changes in ambient air temperature.

If an overheat condition occurs, the high-limit sensor activates a circuit in the control box which removes power from the bleed air pressure regulator valve. This action causes the valve to close and to shut off the supply of air to the system.

Temperature Control Box

The two primary heat exchanger system temperature control boxes are located above the emergency escape hatch on the forward right side of the cargo compartment. Except for a relay in each box, they are composed of solid state type components and are powered by 115 volts, ac.

## SYSTEM OPERATION

A simplified electrical schematic of the temperature control system is shown in Figures 3-3 and 3-4. The temperature of the bleed air leaving the heat exchanger is regulated at approximately 232°C (450°F) by varying the amount of ram air allowed to pass through the heat exchanger. The ram air is inducted through an opening in the wing leading edge and discharges overboard through a louvered panel on the side of the aircraft under the wing. When the bleed air temperature at the output of the heat exchanger exceeds 232°C (450°F), the

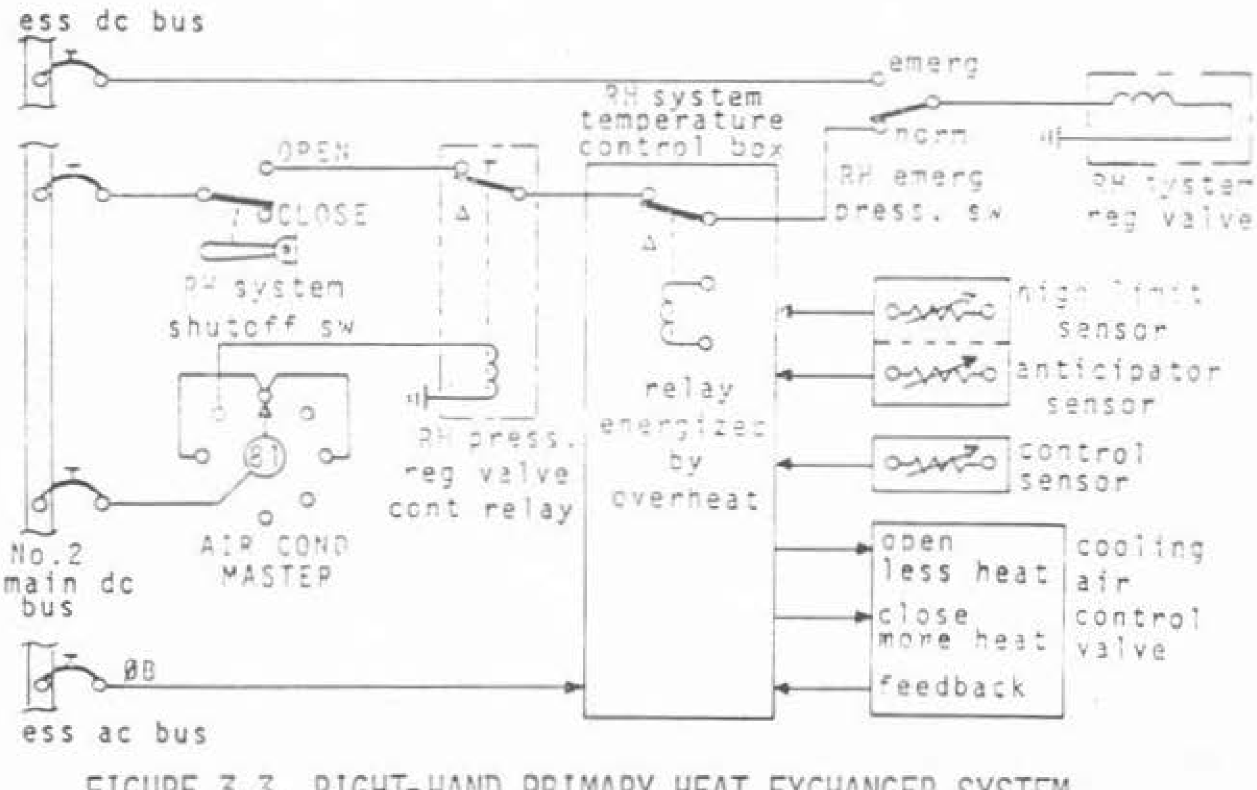



FIGURE 3-3. RIGHT-HAND PRIMARY HEAT EXCHANGER SYSTEM TEMPERATURE CONTROL SCHEMATIC

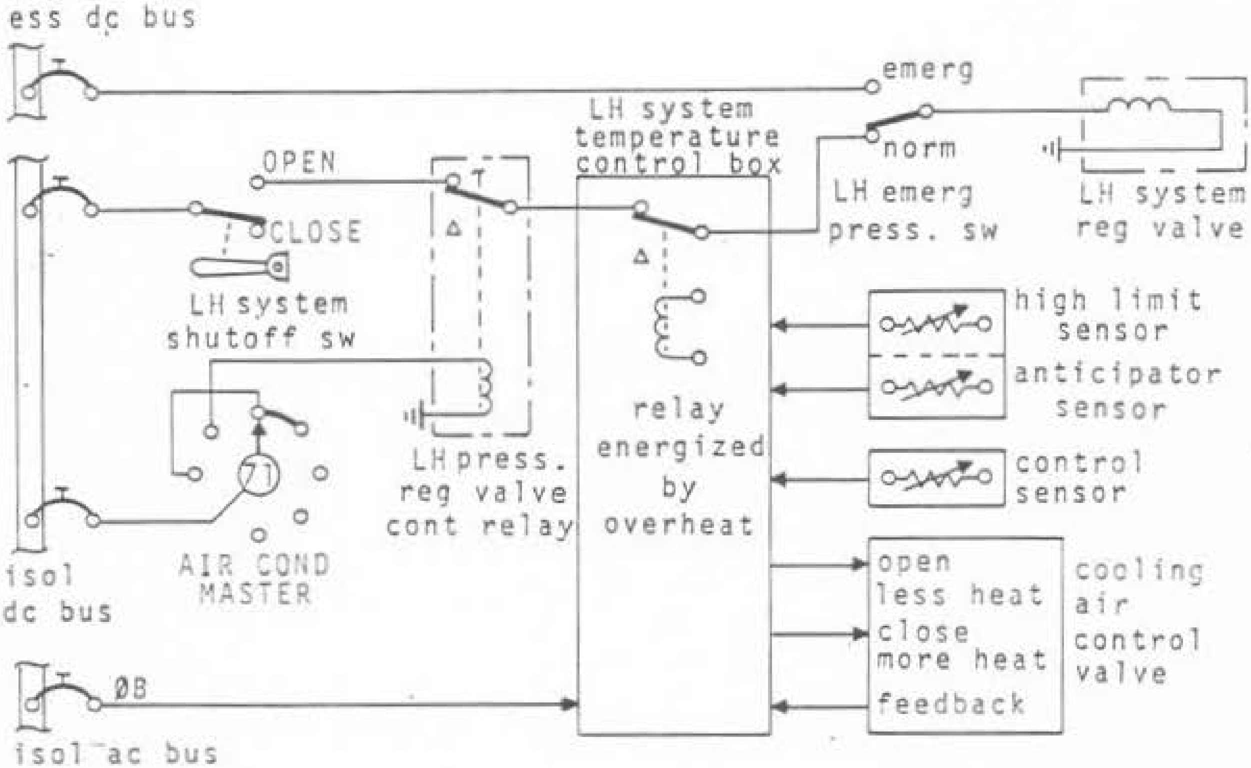



FIGURE 3-4. LEFT-HAND PRIMARY HEAT EXCHANGER SYSTEM TEMPERATURE CONTROL SCHEMATIC

cooling air control valve drives toward open to allow more cooling air to flow through the unit. When the temperature drops below 232 °C (450 °F), the valve drives toward closed to reduce the flow of cooling air. A rate generator in the valve actuator assembly provides negative feedback to the control box to help prevent overshooting. The valve is normally closed when using the APU or ground compressor to supply bleed air since the temperature of this air is about 211 °C (412 °F), which is less than the control point of the system.

If any condition occurs which would cause the duct temperature to exceed 282 °C (540 °F), the high-limit sensor activates a circuit in the control box to close the bleed air pressure regulator valve. With the air supply shut off, duct temperature drops and the circuit automatically resets. If the overheat condition persists, the regulator valve cycles open and closed, which causes air surges. In this event, the system should be shut down by placing the SYSTEM SHUTOFF switch in the "CLOSE" position.

In the event of any system malfunction which would close the regulator valve or cause it to cycle, the valve may be overridden to the open position by use of an EMERGENCY PRESSURIZATION switch. Two of these switches, one for each valve, are located on the EMERGENCY CIRCUIT BREAKER PANEL on the pilot's left side.

These switches, when actuated to the emergency position, supply power directly to the valves from the emergency dc bus and remove all other sources of power. In this configuration, however, the operator should continuously monitor the primary heat exchanger system temperature indicators so that if an overheat occurs, the system can be shut down before any damage is incurred.

## STUDY QUESTIONS

1. The primary heat exchanger system regulates bleed air temperature to approximately ________ °C.

2. A bleed air temperature of ________ °C in the primary heat exchanger system is considered an overheat condition.

3. The primary heat exchanger temperature indicators are located ________ and receive signals from ________.

4. What is the purpose of the ejector assembly? ________.

5. The primary heat exchanger systems supply air for the ________ and ________ systems.

6. Why should the master switch be positioned to "APU" when the APU or ground compressor is being used to supply air for air conditioning? ________.

7. What controls the amount of air allowed to pass through the heat exchanger at flight speeds above 0.3 Mach? ________.

8. If the primary heat exchanger system fails to provide proper cooling of the bleed air, the flight engineer should ________.

9. A failure of the cooling air control valve to the closed position whold cause ________.

10. The ________ normally controls the ejector shutoff valve, but the valve is overridden by ________.

## AIR CONDITIONING AND VENTILATING SYSTEMS

Two separate but identical air conditioning systems supply conditioned air to the interior of the aircraft. The systems provide both heating and cooling in addition to supplying the air necessary for pressurization. Conditioned air is also used for cooling the electrical and electronics equipment. A separate floor heat system may be used either in conjunction with, or independently of, the air condition systems. Provisions are included for using ram air ventilation when air conditioning and pressurization are not required.

### AIR CONDITIONING

The right hand air conditioning system is depicted in Figure 4-1 and consists of the following:

- o Venturi type flow control valve
- o Refrigeration unit consisting of a heat exchanger and a cooling turbine and compressor fan assembly
- o Water separator
- o Low-limit temperature control system consisting of a turbine bypass valve, a low-limit sensor, and a low-limit temperature control box
- o Temperature control valve

All of the components listed for both systems are located in the center wing leading edge section except the low-limit temperature control boxes. Camlock fastened panels on top of the wing provide easy access to the entire area. The low-limit control boxes are located above the emergency door on the forward right-hand side of the cargo compartment, next to the primary heat exchanger discharge temperature control boxes.

Each air conditioning unit receives hot bleed air from its respective primary heat exchanger system. The airflow is regulated by the flow control valve and ducted to the heat exchanger and the temperature control

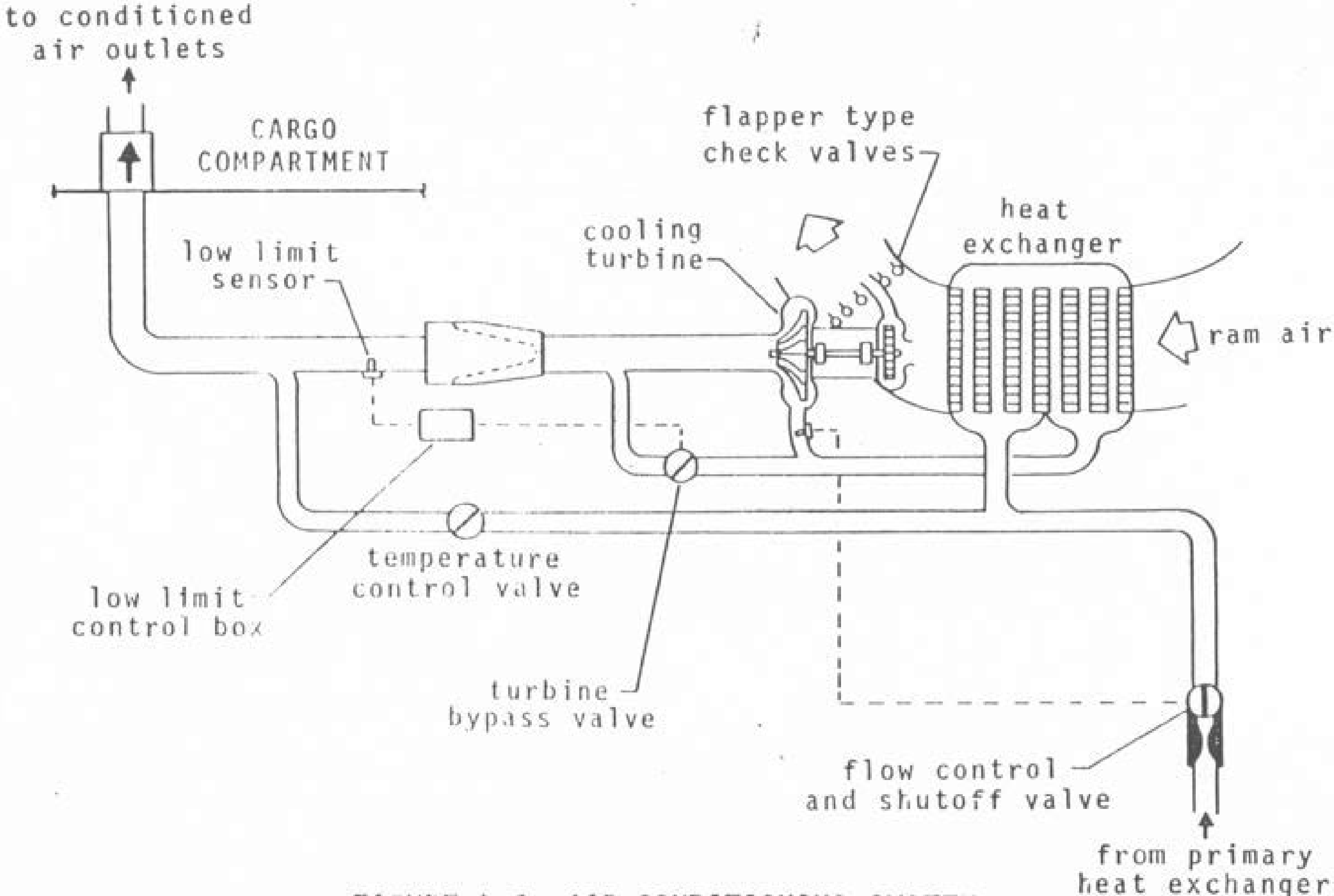



FIGURE 4-1. AIR CONDITIONING SYSTEM

valve. As the hot air flows through the heat exchanger, it is cooled by a cross-flow of ram air. The cooler bleed air is then ducted to the turbine and to the turbine bypass valve. This air is normally supplied to the turbine at a temperature of less than 93°C (200°F). As the air expands through the turbine, it is further cooled to below freezing temperature. A compressor fan is mounted on the turbine shaft and is driven by the turbine. The compressor draws ram air from the heat exchanger and discharges it through an ejector assembly in the ram air discharge duct of the heat exchanger. The jet pump action of the ejector assembly induces a flow of cooling air through the heat exchanger for ground operation. It also increases the cooling efficiency of the heat exchanger during air operation

Turbine discharge air is ducted to the water separator which removes excess condensation caused by the cooling. Enough warm air from the heat exchanger bypasses the turbine through the turbine bypass valve to maintain a temperature of 2°C (35°F) through the water separator. When heating is required, hot air, which bypasses the refrigeration unit, is added downstream of the water separator. The mixture is ducted to the outlets in the flight station and cargo compartment. Cool air from the output of the left-hand system is ducted to separate individual outlets in the flight station.

## System Components

### Flow Control and Shutoff Valve

The flow control valve is an airflow regulator with a shutoff feature. Although its main purpose is to provide a constant flow of air through the air conditioning system, it also serves as the air conditioning system shutoff valve. The valve is an automatic modulating butterfly which regulates the airflow at 100 ppm. It is solenoid-controlled, pneumatically actuated, spring-loaded closed, and de-energized open. Both flow control valves are normally controlled by the AIR COND MASTER switch and are normally open during flight. Either valve, however, can be overridden closed by a turbine overheat condition. A thermal switch at the inlet of each cooling turbine automatically closes its respective flow control valve if the turbine inlet temperature exceeds 99°C (210°F). Both valves are overridden closed by the EMERG DEPRESS switches. Figure 4-2 shows a schematic cutaway of the valve.

### Refrigeration Unit

Each refrigeration unit is a two-stage cooling unit consisting of a two-pass heat exchanger and a single-stage expansion turbine. The heat exchanger is similar in construction to the primary heat exchanger except that the bleed air makes two passes through the ram air. It is of welded and brazed aluminum construction. Ram air for the heat exchanger is inducted through an opening

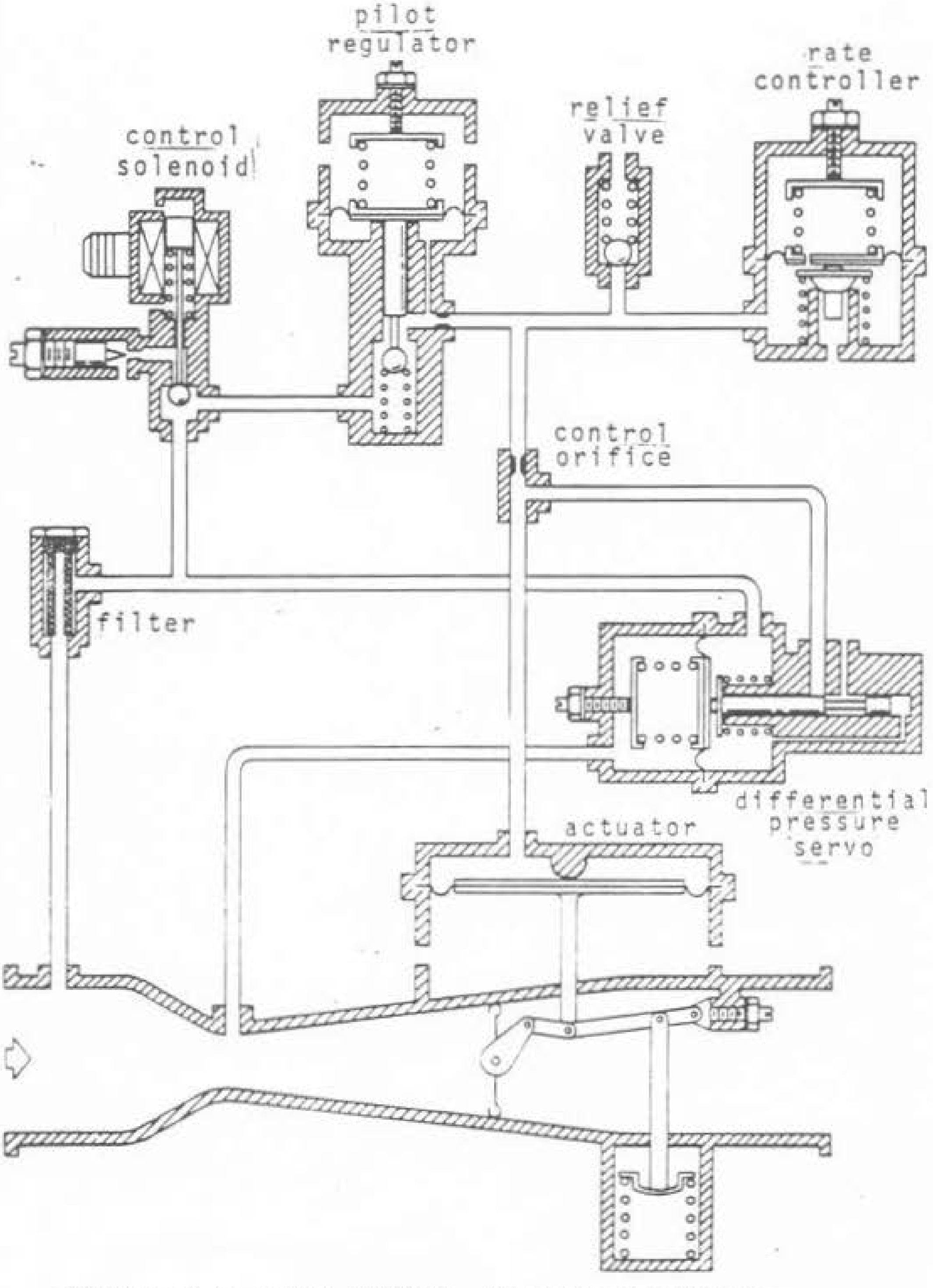



FIGURE 4-2. FLOW CONTROL AND SHUTOFF VALVE

in the wing leading edge (the same one that is used for the primary heat exchanger). It discharges through a louvered panel just aft of the primary heat exchanger ram air discharge duct.

Figure 4-3 shows a cutaway of the turbine and compressor fan assembly. The turbine and compressor wheels are mounted on opposite ends of a common shaft which is supported by two ball-type bearings. As the partially cooled air from the heat exchanger expands through the turbine, it drives the turbine at speeds of 10,000 to 85,000 rpm. The turbine drives the compressor, which provides a load for the turbine. This load helps to prevent overspeeding and also extracts more heat from the bleed air since more energy is required to turn the extra weight of the compressor. The compressor draws ram air from the heat exchanger, compresses it, and discharges it through a slot-type ejector assembly in the heat exchanger's ram air discharge duct. This jet pump action induces a flow of cooling air through the heat exchanger during ground operation and increases the mass of cooling air flowing through the heat exchanger for better cooling efficiency during air operation.

Oil is wick-fed to the bearings of the turbine and fan assembly from an oil sump incorporated in the bearing housing. The sump holds 300 cc (about 10 ounces) of turbine oil, MIL-L-6085A or equivalent. There is a magnetic plug in the sump which may be removed for inspection without draining the oil. A dip stick is provided to check the oil level. The level should be checked every 300 hours, and the oil should be changed every 600 hours.

Water Separator

As air flows through the turbine, the rapid expansion and cooling effect causes the water vapor in the air to condense and become "free" moisture (fog). To remove some of this moisture and provide humidity control, a cyclonic type water separator is installed in the duct downstream from the cooling turbine. About 55 percent of the free moisture is removed by the separator.

Figure 4-4 shows a cutaway view of the water separator. The unit contains a louvered, conical-shaped condenser assembly, covered with a fiberglas blanket or "sock." As the moisture-laden air flows through the separator, the sock becomes saturated with water. The force of the airflow carries the moisture through the sock in the form of large water droplets. A swirling motion is imparted to the air by the louvers, which causes the water droplets to be thrown out against the wall of the separator where they collect and run down to a drain outlet. An overboard drain line discharges the water through an opening on the side of the fuselage under the wing. The drain outlet is located so that the ram air discharge from the primary heat exchanger passes over the opening to prevent it from freezing. A pressure relief valve in the cone assembly of the water separator opens at approximately 8 psid to prevent a pressure buildup in the separator if the condenser blacket becomes clogged.

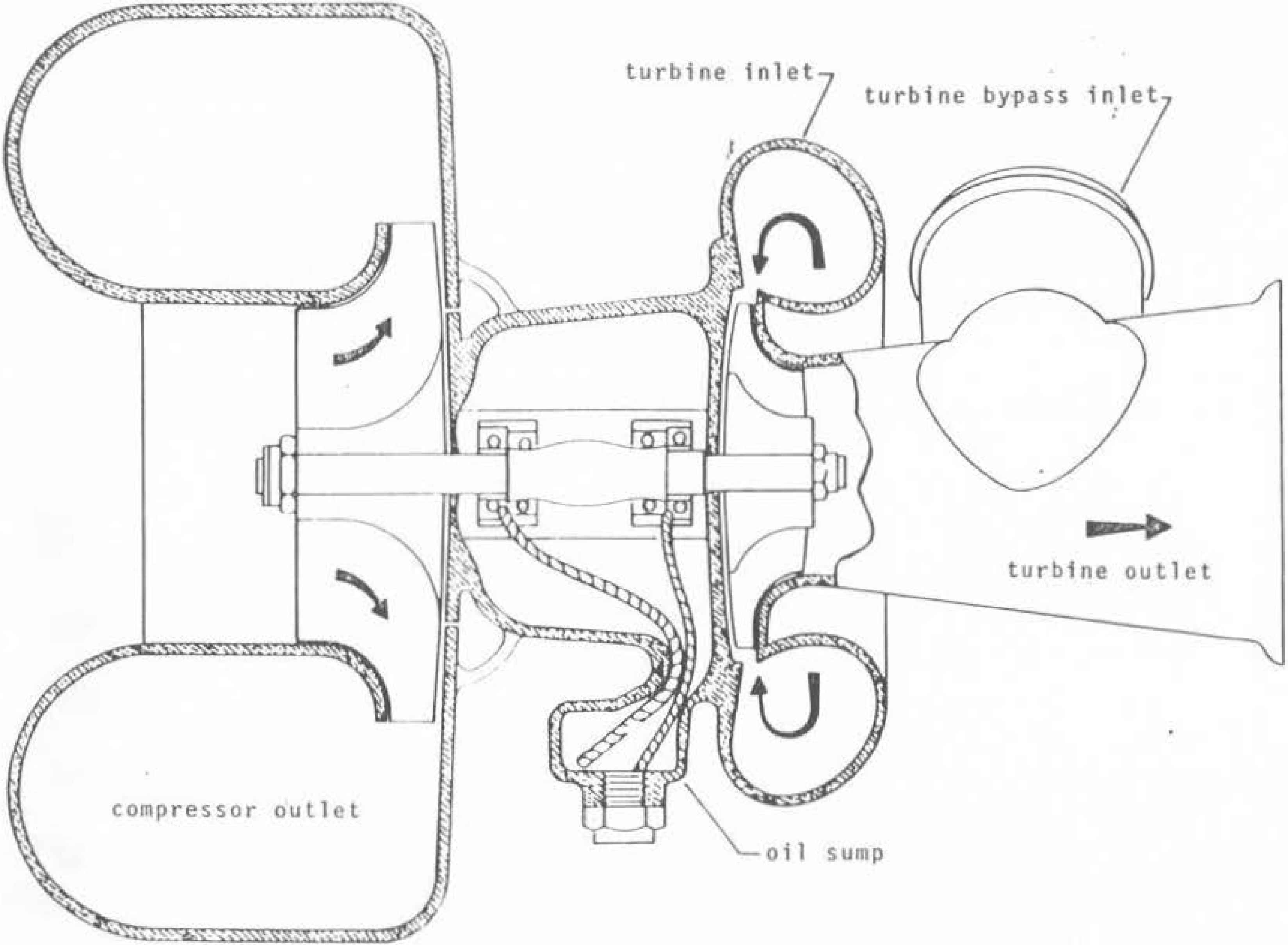
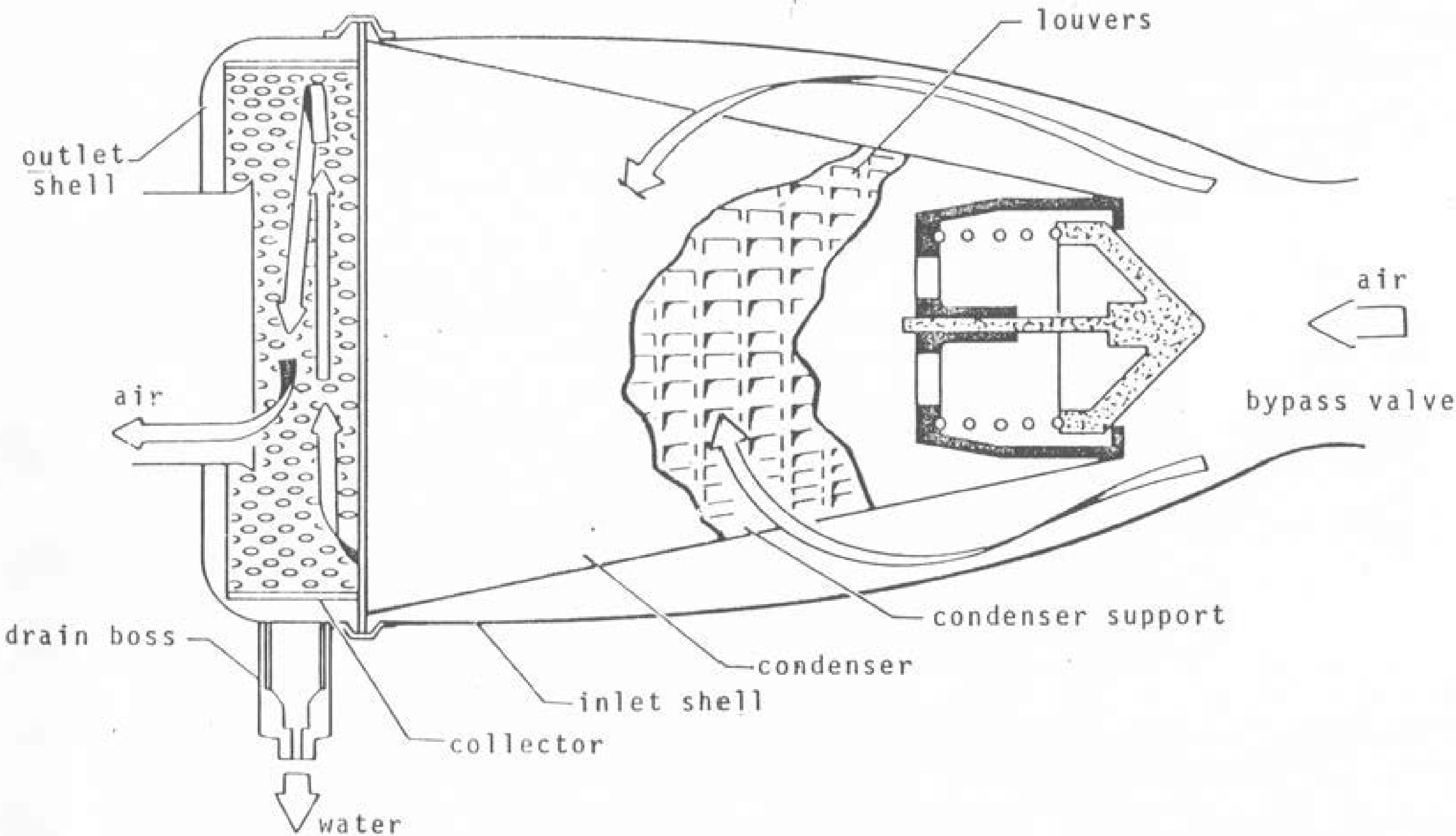



FIGURE 4-3. AIR CONDITIONING SYSTEM TURBINE AND FAN ASSEMBLY




WATER SEPARATOR

The condition of the condenser blanket should be checked periodically and should be replaced if torn or frayed. If it is dirty, it may be washed by hand in soap and water and should be re-installed while still wet.

Low-Limit Temperature Control System

A low-limit temperature control is incorporated into the system to prevent icing of the water separator. The system, shown in Figure 4-5, maintains a temperature of 35°F and consists of the following:

- o Temperature sensor
- o Control box
- o Turbine bypass valve

The low-limit sensor is a negative coefficient, thermistor-type temperature sensing unit located in the duct at the output of the water separator. It senses the air temperature at this point and provides corresponding electrical signals to the control box.

The low-limit temperature control box is a solid state type and is located above the emergency door on the forward right side of the cargo compartment. It receives temperature signals from the low-limit sensor and provides corresponding electrical signals to drive the turbine bypass valve.

The turbine bypass valve is located in the turbine bypass duct on the refrigeration unit. It is a modulating butterfly type valve, driven by a dc motor. When the valve is open, air from the heat exchanger bypasses the cooling turbine and is added in at the turbine outlet. Upon signals from the control box, the valve modulates to provide more or less warm air, as required, to prevent icing of the water separator.

Temperature Control Valve

A temperature control valve is located in the hot air supply duct which bypasses the entire refrigeration unit. It is a motor-driven, modulating butterfly type valve, powered by 28 volts, dc. When the valve is open, hot air from the primary heat exchanger system bypasses the refrigeration unit and is added into the distribution duct downstream from the water separator. Signals from a control box modulate the valve to provide more or less hot air, as required, to maintain the desired temperature in the airplane. The right-hand system temperature control valve is positioned by the cargo compartment temperature controls, while the flight station temperature controls position the left-hand system valve.

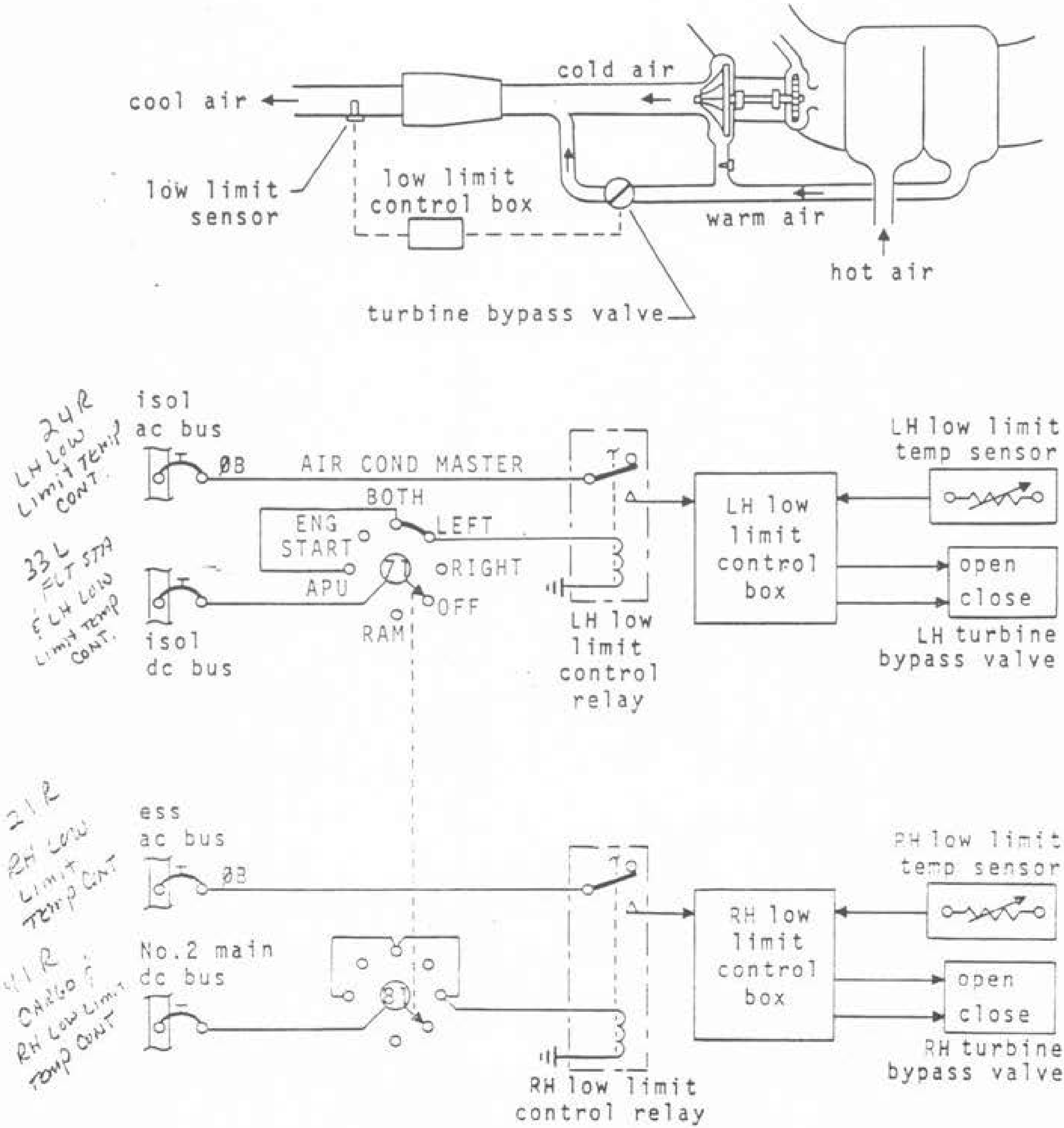



FIGURE 4-5. LOW-LIMIT TEMPERATURE CONTROL SYSTEM

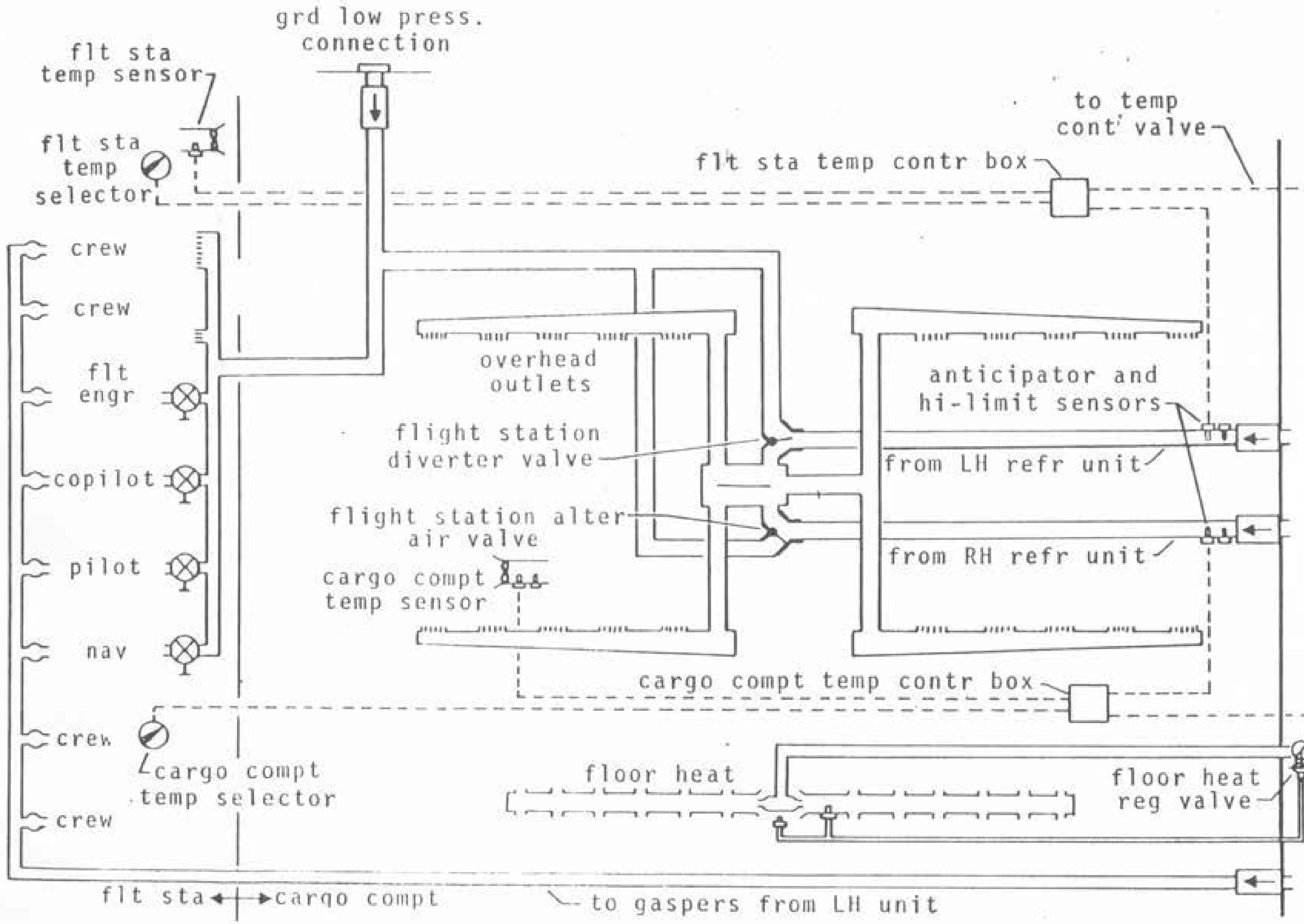



FIGURE 4-6. CONDITIONED AIR DISTRIBUTION SYSTEM

## Conditioned Air Distribution System

The conditioned air distribution system is shown in Figure 4-6. Air from the air conditioning systems is ducted through the top of the fuselage into the cargo compartment through check valves. These valves are 8-inch diameter, dual-flapper type check valves which prevent air from escaping back through a shut-down air conditioning unit. The right-hand air conditioning system distribution duct enters the cargo compartment on the left side, while the left-hand system distribution duct enters on the right side. This crossover is due to the layout of the air conditioning systems in the center wing section. Most of the distribution ducting is made of aluminum; however, there are a few fiberglas sections.

Air from the left-hand system is ducted to the flight station air diverter valve, located in the top of the cargo compartment forward of the wing. This valve is a Y-shaped, four-position, swinging gate type valve, actuated by a 28-volt, dc motor. It is controlled by the FLT STA AIR FLOW switch, located on the left side of the Environmental Control Panel. Depending on the switch position, the valve diverts a portion of the air from the left-hand system to the flight station, the remainder going to the cargo compartment. Figure 4-7 shows the control for the valve, and the air distribution for each switch position is listed in the following table.

| SWITCH POSITION | AIR TO FLT. STA. | AIR TO CARGO COMPT. |
|---|---|---|
| "MIN" | 0 percent | 100 percent |
| "NORM" | 38 percent | 62 percent |
| "INCR" | 68 percent | 32 percent |
| "MAX" | 100 percent | 0 percent |

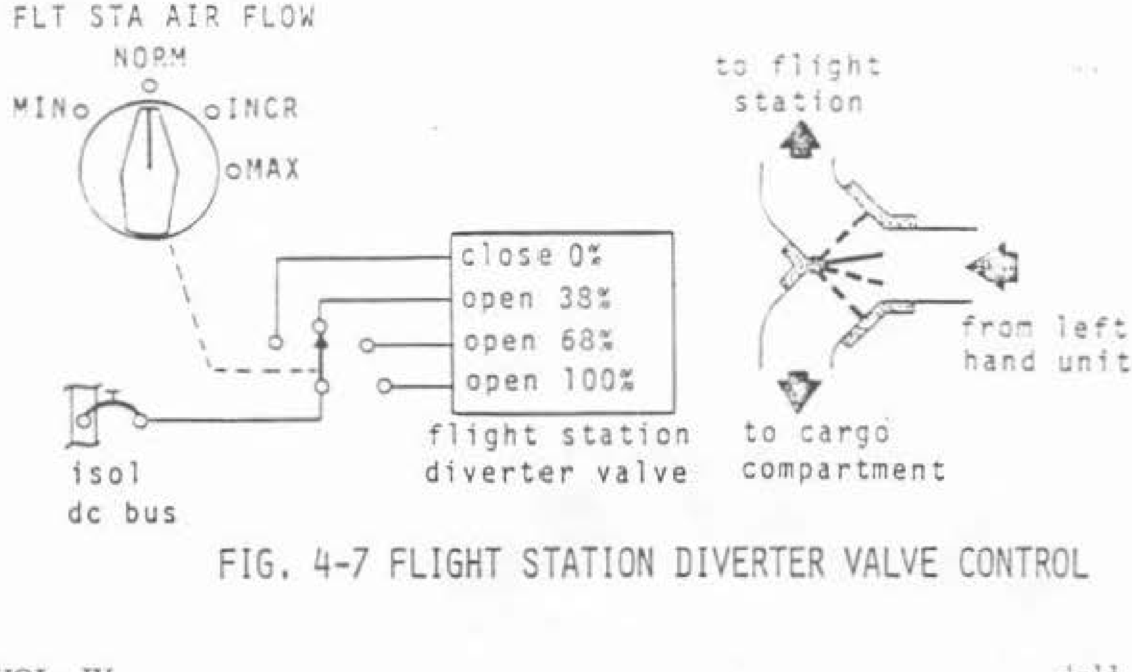



FIG. 4-7 FLIGHT STATION DIVERTER VALVE CONTROL

When the APU or ground compressor is used to supply bleed air for air conditioning, the switch should be placed in the "INCR" position. When so placed, approximately the same amount of air is supplied to the flight station as is normally supplied when engine bleed air is used and the switch is in the "NORM" position.

Air from the right-hand system is ducted to the flight station alternate air valve, located in the left distribution duct opposite the flight station diverter valve. The alternate air valve is similar to the diverter valve, except that it has only two positions. The valve is controlled by the AIR COND MASTER switch. It is normally closed, but is driven to the open position when the master switch is positioned to "RIGHT." In the closed position, all of the air from the right-hand system is directed to the cargo compartment. When the valve is open, 38 percent of this air is diverted to the flight station through an alternate supply duct. The control circuit for the valve is shown in Figure 4-8.

Conditioned air from both systems combines in a fiberglas mixing chamber located between the two diverter valves and is supplied to the cargo compartment through overhead ducting. Conditioned air for the flight station is supplied to two overhead outlets, and to individual outlets for the pilot, copilot, flight engineer, and navigator. The pilot and copilot each have a foot-warmer outlet

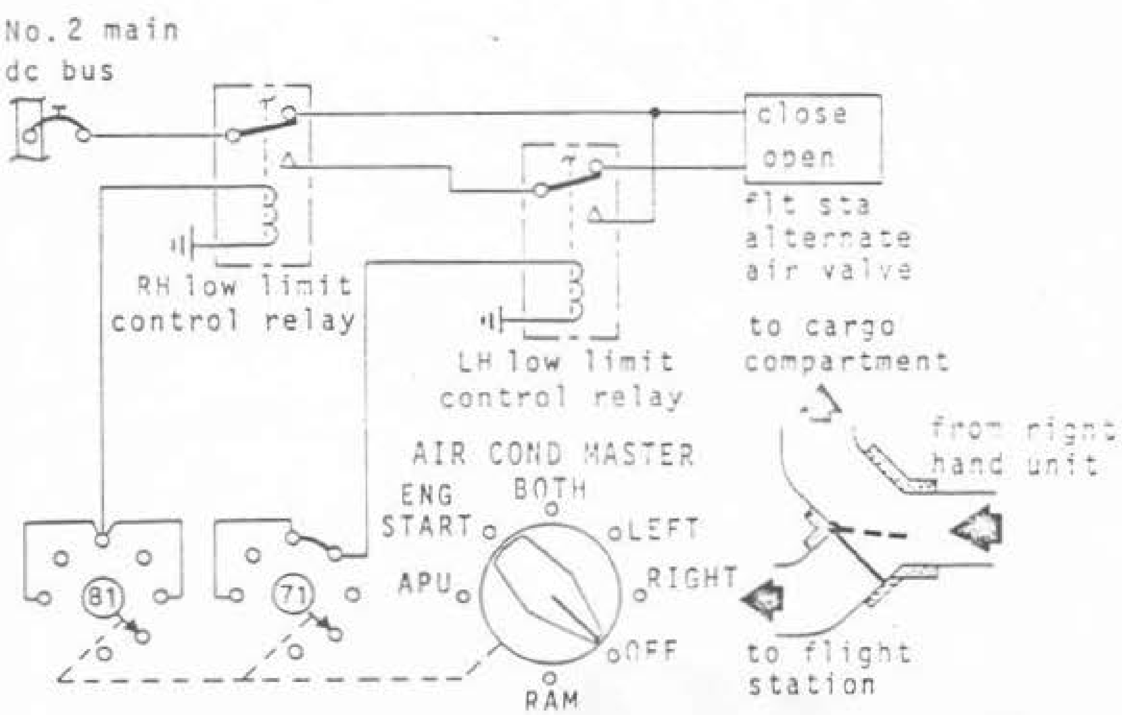



FIG. 4-8 FLIGHT STATION ALTERNATE AIR VALVE CONTROL

and a body-warmer outlet. Air for the flight engineer and navigator is supplied through louvered panels in the base of their control consoles. All of the individual outlets are equipped with manually operated valves so that each crew member can regulate his own supply of air.

Cool air is supplied from the left-hand air conditioning system to individual gasper ("eye-ball") outlets in the flight station. There are eight of these outlets, one for each member of the flight crew and one at each of the relief crew sections. Each outlet contains a manually operated valve which is actuated when the outlet is turned to the left or right.

All of the distribution ducts are insulated to prevent the air inside from gaining or losing heat due to ambient temperature. The insulating covers consist of a fiberglas blanket sandwiched between two layers of fiberglas cloth. They are made in stations to fit the ducts and are held in place by hose-type clamps.

## Air Conditioning System Control

Figure 4-9 shows the air conditioning systems control schematic. When the AIR COND MASTER switch is positioned to "RIGHT," "OFF," or "RAM," the left-hand flow control valve is energized closed. In the "LEFT," "OFF," and "RAM" positions, the right-hand valve is energized closed. Thus, when air is available to the valves, both valves open to supply air to the air conditioning systems when the master switch is in "APU" or "BOTH." Only the right-hand valve is open in "RIGHT," and only the left-hand valve is open in "LEFT." Because the valves are spring-loaded closed and require air pressure to open, it is not necessary to apply power to close the valves in "ENG START" since the system pressure regulator valves are closed at this time, which shuts off the air supply to the flow control valves. Either valve is closed by a turbine overheat condition, and "EMERG DEPRESS" closes both valves. For normal operation, the master switch is positioned to "BOTH."

## TEMPERATURE CONTROL SYSTEM

Cabin temperature is controlled by positioning the temperature control valve, adding more or less hot air, as required, to the cool air from the water separator. Separate temperature controls are provided for the flight station and cargo compartment. Each system has both automatic and manual operating features, and the two modes of operation are independent of each other. Both sets of controls are located on the Environmental Control Panel. The flight station temperature controls are in the upper left corner of the panel, and the cargo compartment controls are in the upper right corner.

Since the left-hand air conditioning system normally supplies air to the flight station, the flight station temperature controls position the left-hand system temperature control valve. The right-hand system supplies the cargo

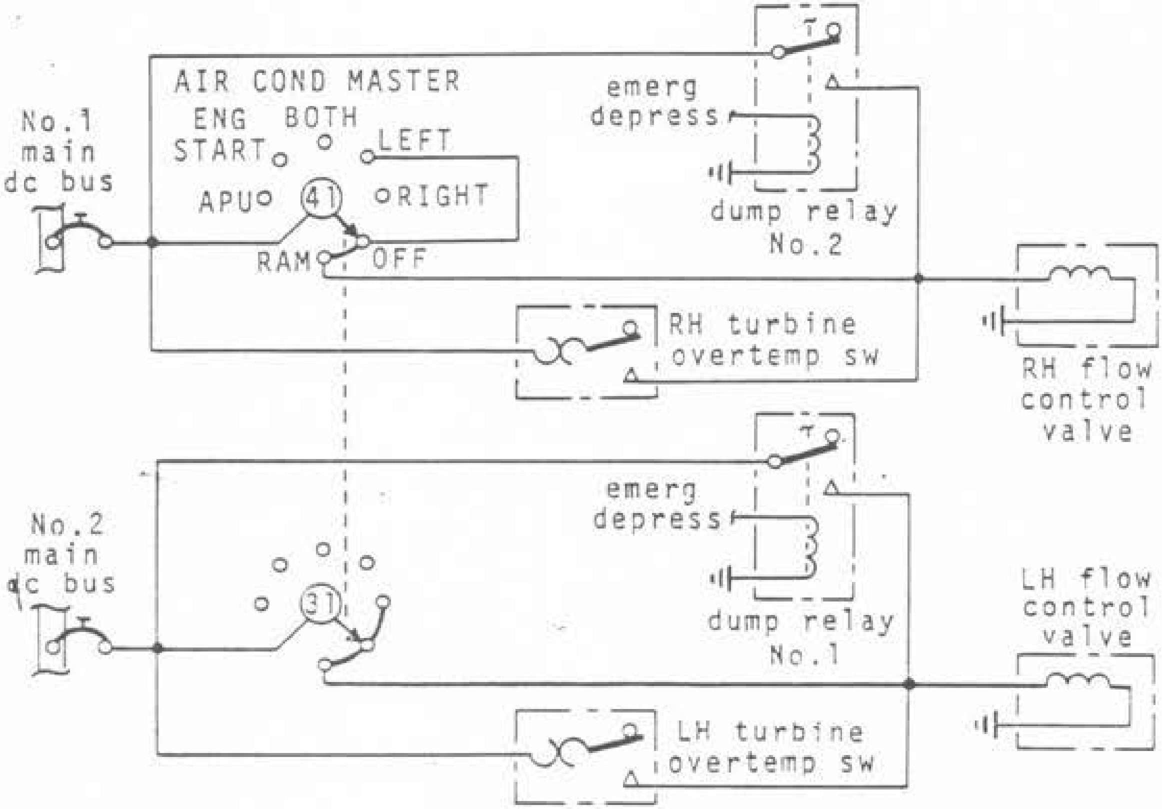



FIGURE 4-9. AIR CONDITIONING SYSTEMS CONTROL SCHEMATIC

compartment, so the cargo compartment temperature controls position the right-hand system valve. Both systems have similar components and are identical in operation. The systems receive electrical power through the master switch only when the corresponding air conditioning system is selected for use.

System Components

Each system consists of the following:

- o Temperature control switch
- o Temperature selector rheostat
- o High-limit thermal switch
- o Cabin temperature sensor unit
- o Duct anticipator and high-limit sensor
- o Temperature control box

The temperature control switch is a four-position toggle switch used for manual temperature control. When toggled to the "HOT" or "COOL" position, the switch applies power to drive the temperature control valve open or closed, respectively, and springs back to a center "HOLD" position when released. When the switch is placed in the "AUTO" position, power is applied to the automatic control circuit. The switch remains in "AUTO" until manually positioned back to "HOLD."

In the automatic mode of operation, cabin temperature may be selected by positioning a rheostat. The rheostat provides electrical signals to the temperature control box corresponding to the selection. The temperature selection range is from 5 to 43°C (40 to 110°F). Mid-range (12 o'clock position) is 23°C (75°F).

A high-limit thermal switch is installed in each system supply duct, upstream from the diverter valves in the cargo compartment. The switches actuate at 150°C (300°F) to protect the distribution ducts from excessively high temperature during manual control.

Two negative coefficient, thermistor-type temperature sensing units are installed in the aircraft to sense cabin temperature and to provide corresponding signals to the temperature control boxes. The flight station sensor is located behind the flight engineer's Lighting Control Panel in the upper right corner of the flight engineer's console. It senses flight station temperature through a hole provided on the aft side of the console. The cargo compartment sensor is located on the forward right side of the "hayloft" in the aft end of the cargo compartment. It contains an indicator sensor in addition to a temperature control sensor. The indicator sensor provides electrical signals to the CARGO COMPT TEMP indicator, located just above the AIR COND MASTER switch on the Environmental Control Panel. The indicator, calibrated in degrees centigrade, allows the flight engineer to monitor cargo compartment temperature. Both compartment sensing units contain a small blower which circulates air over the sensors to ensure a true sampling of air temperature.

A combination duct anticipator and high-limit sensor is located in each conditioned air supply duct, next to the high-limit thermal switch. It is a dual-purpose unit consisting of two separate negative coefficient thermistor-type sensors mounted in a common housing and is used only in the automatic mode of temperature control. The anticipator part of the sensor is sensitive to temperature change and is used to correct for transient temperature changes in the duct before these changes can be felt in the cabin. The high-limit sensor limits duct temperature to 150°C (300°F) to prevent damage to the ducting due to overheat.

Solid state type temperature control boxes position the temperature control valves during the automatic mode of operation. The cargo compartment temperature control box is located above the emergency door on the forward right side of the cargo compartment, next to the primary heat exchanger and low-limit control boxes. The flight station temperature control box is located under the flight station floor, forward of the underdeck relay panel. Access to the box is through the toilet compartment.

System Operation

Figure 4-10 shows the electrical schematic for cabin temperature control. Power is applied to the temperature control switch through the AIR COND MASTER switch only when the corresponding air conditioning system is being used. When the temperature control switch is toggled to "HOT" or "COOL," power is supplied to drive the temperature control valve. If the valve is driven toward "hot" and the duct temperature reaches 150°C (300°F), the high-limit thermal switch closes and energizes the TEMP OVHT relay. When the relay is energized, it removes the "hot" signal to the valve and supplies power to drive the valve toward closed. The thermal switch resets when the duct temperature drops below 150°C (300°F). When using manual temperature control, the operator should toggle the switch momentarily: He should wait between each actuation to allow the temperature to stabilize.

In "AUTO," the temperature control switch applies power to energize the TEMP CONTROL relay. When energized, this relay applies power to the temperature control box and removes power from the TEMP OVHT relay. The temperature control box compares the signals received from the cabin sensor, anticipator and high-limit sensor, and the selector rheostat, and supplies power to drive the

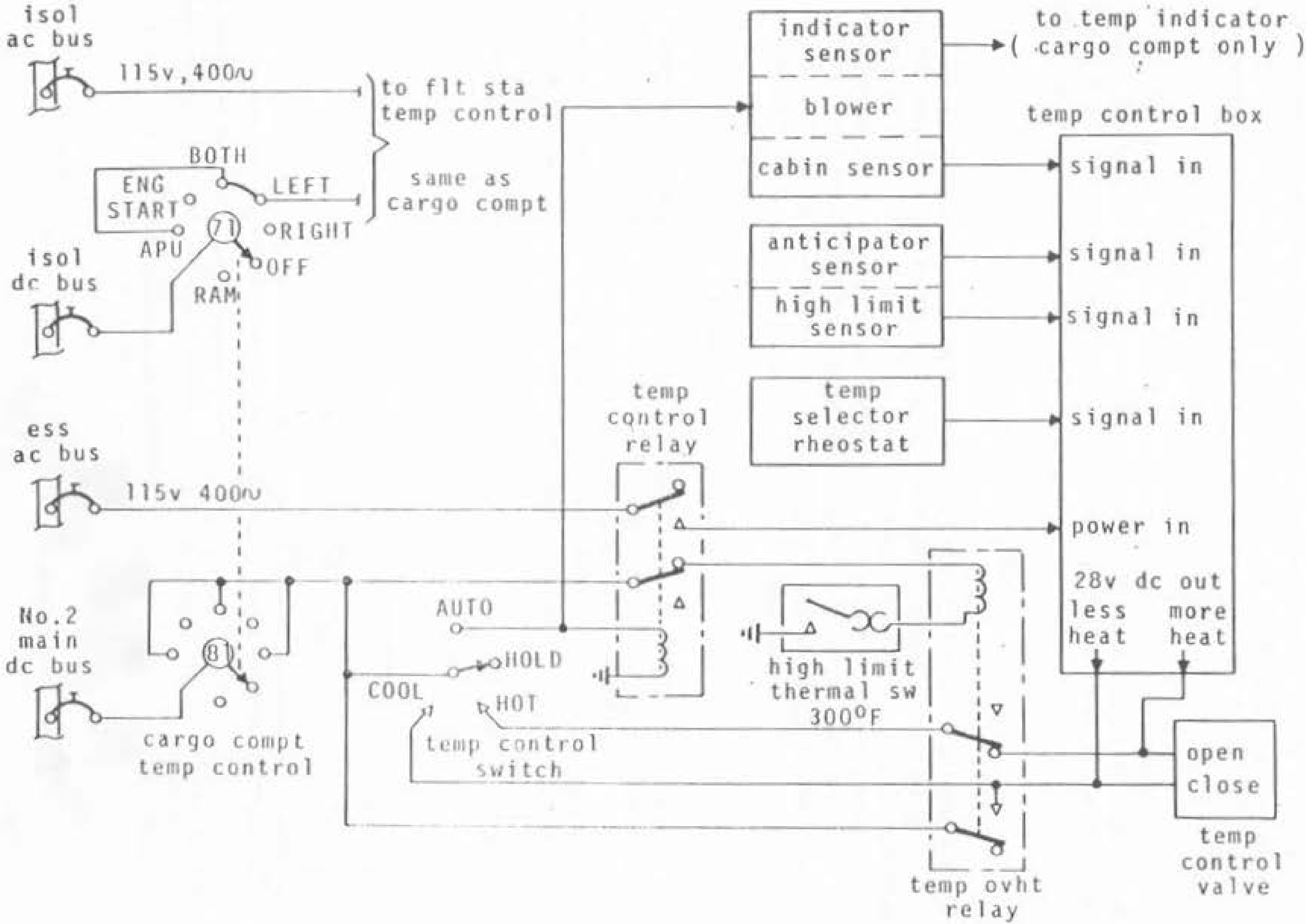



FIGURE 4-10. CABIN TEMPERATURE CONTROL

bleed air. This air mixture discharges through holes along the sides of the distribution ducts. Some of the air is recirculated by the ejector assembly; the excess flows up into the cargo compartment through louvered panels along the sides. Fiberglas cloth insulating blankets are installed under the distribution ducts to help hold the heat up under the floor as shown in Figure 4-12.


FIGURE 4-12. FLOOR HEAT AIR DISTRIBUTION

## Components

Two valves are used to control the supply of bleed air for the floor heat system: the floor heat shutoff valve, and the floor heat regulator valve. Thermostats are used to provide temperature control and overheat protection.

### Floor Heat Shutoff Valve

The floor heat shutoff valve is located in the APU and ground high-pressure supply duct where the duct tees into the bleed air manifold in the center wing section. This valve is a motor driven butterfly type, powered by 28-volts, dc. Access to the valve is through the left-hand bleed air manifold access panel in the center wing section.

### Floor Heat Regulator Valve

The floor heat regulator valve is located in the floor heat supply duct in the APU compartment. It is a solenoid-controlled, air actuated, modulating butterfly-type valve with a shutoff feature. It is energized open. Access to the valve is through the inboard APU compartment access panel. This panel is located under the forward end of the left main landing gear pod and is held in place with cam-lock fasteners. A schematic cutaway of the regulator valve is shown in Figure 4-13.

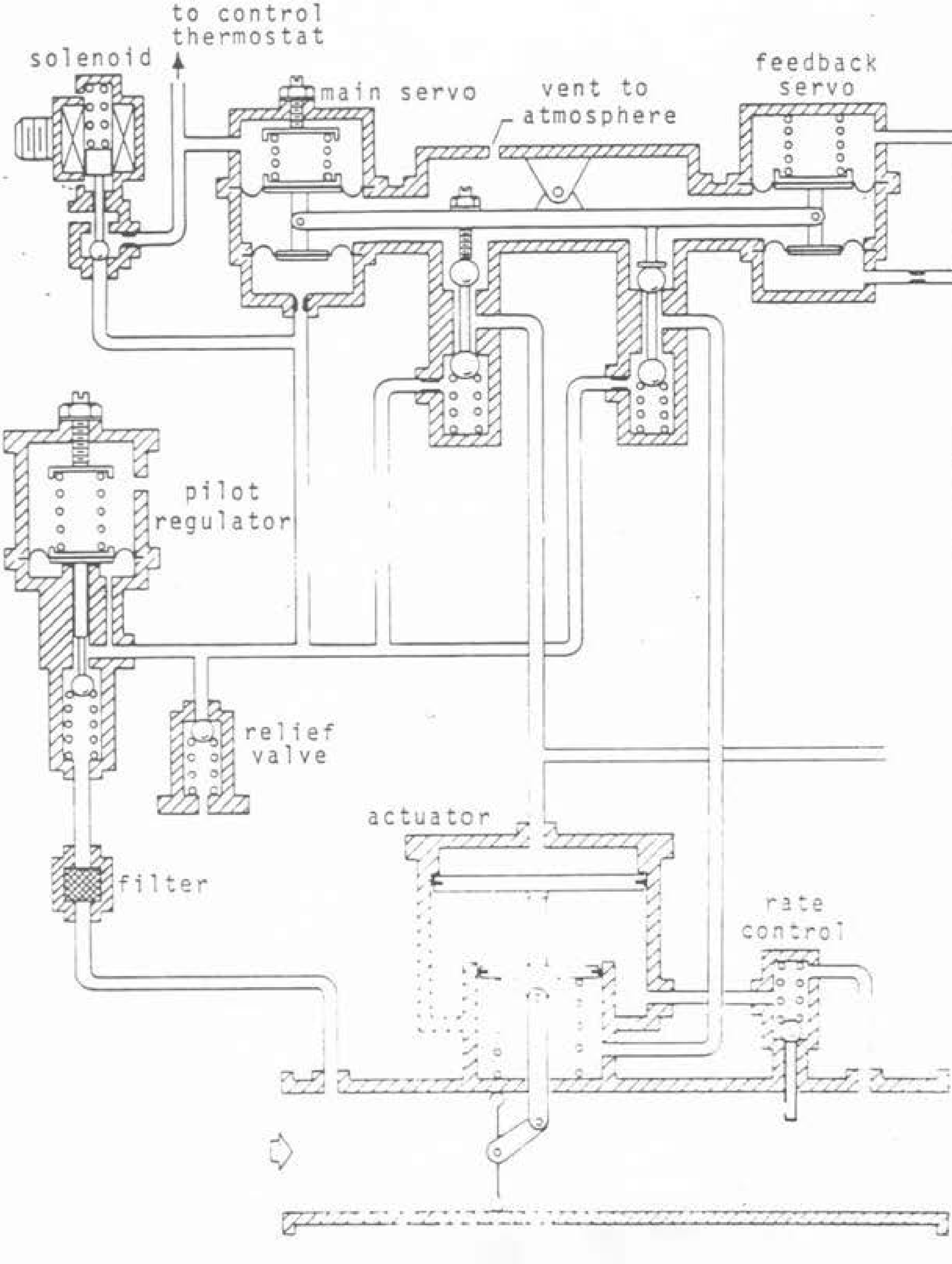



FIGURE 4-13. FLOOR HEAT REGULATOR VALVE

Pneumatic Thermostats

Two temperature sensing pneumatic thermostats are used to control the modulation of the floor heat regulator valve. Both thermostats are connected to the valve through 1/4-inch tubing. One thermostat is an anticipator sensor. It is installed in the forward end of the aft distribution duct and is sensitive to rapid changes in temperature. The other thermostat is the control sensor. It is mounted on a bracket next to the ejector assembly where it can sense the temperature of the recirculated air. It is set to operate at 18°C (65°F). A cutaway view of the thermostat is shown in Figure 4-14. The temperature

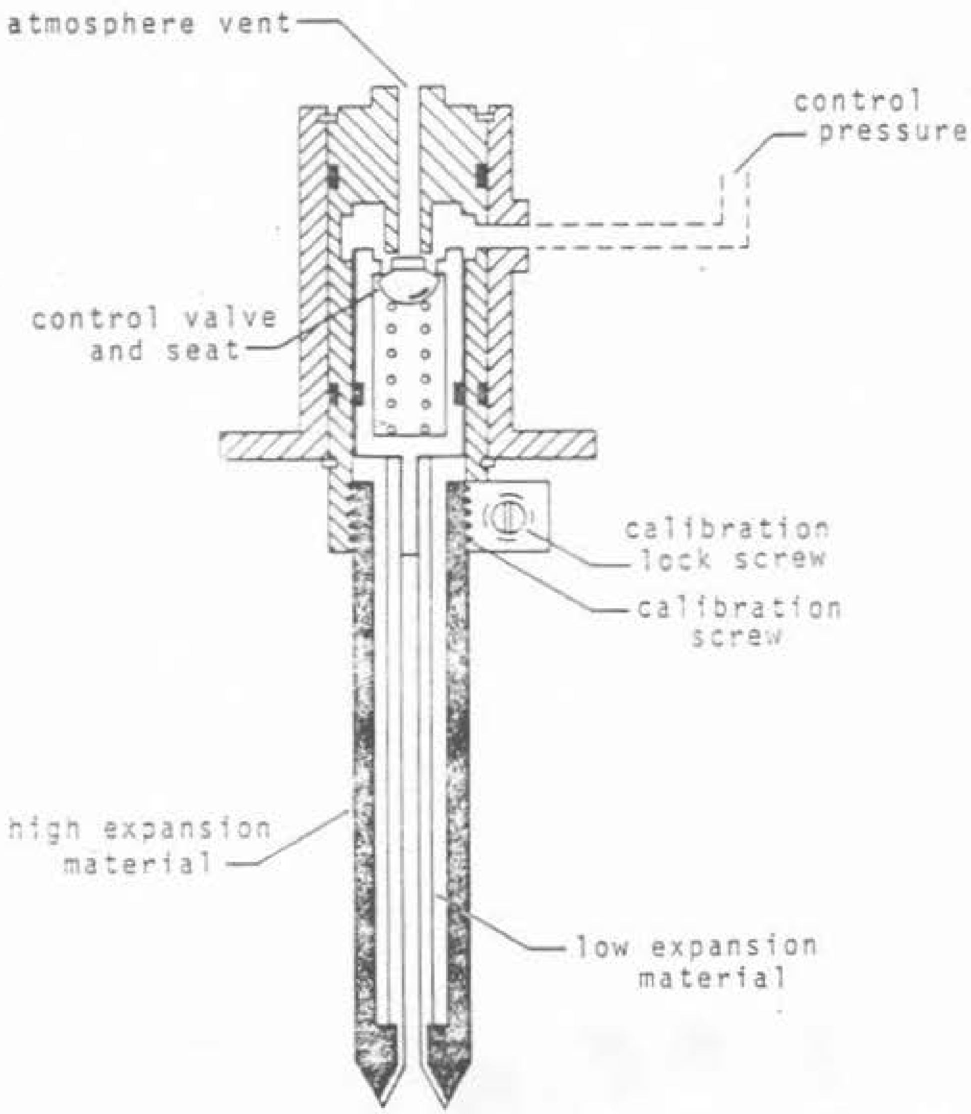



FIGURE 4-14. PNEUMATIC THERMOSTAT

sensing probe is of bimetallic construction and attaches to a spring-loaded ball-type poppet valve. When subjected to heat, the probe expands and unseats the ball. This action provides a vent for the regulator valve control pressure. When the ball valve opens, the regulator valve butterfly moves toward closed; when the ball valve moves toward closed, the regulator valve butterfly moves toward open.

Overheat Thermal Switch

A bimetallic-type overheat thermal switch is mounted on a bracket near the forward end of the aft distribution duct. It is positioned to sense the temperature of the air coming from the first outlet and actuates at 124°C (225°F). The thermal switch is wired into the APU compartment and cargo floor overheat system.

## System Operation

As shown in Figure 4-15, when the floor heat system is turned on, bleed air is supplied to the ejector assembly through the floor heat regulator valve. Modulation of the valve butterfly is controlled by the pneumatic thermostats so that the valve continuously supplies just enough hot air to maintain an underfloor temperature of 18°C (65°F).

The FLOOR HEAT switch receives power from the AIR COND MASTER switch, and the system can be operated when the master switch is in any position except "ENG START."

If an overheat condition occurs, the cargo floor overheat control relay is energized, which removes power from the regulator valve and drives it closed. A holding circuit keeps the valves closed until the system is reset. *

During emergency depressurization, the floor heat shutoff valve is closed to shut off floor heat. When the EMERG DEPRESS switch is positioned to "DEPRESS," the No. 1 CABIN PRESS DUMP RELAY energizes and removes power from the valve. "EMERG DEPRESS" does not affect the floor heat shutoff valve.

* See Bleed Air Overheat Detection System, Chapter 2.

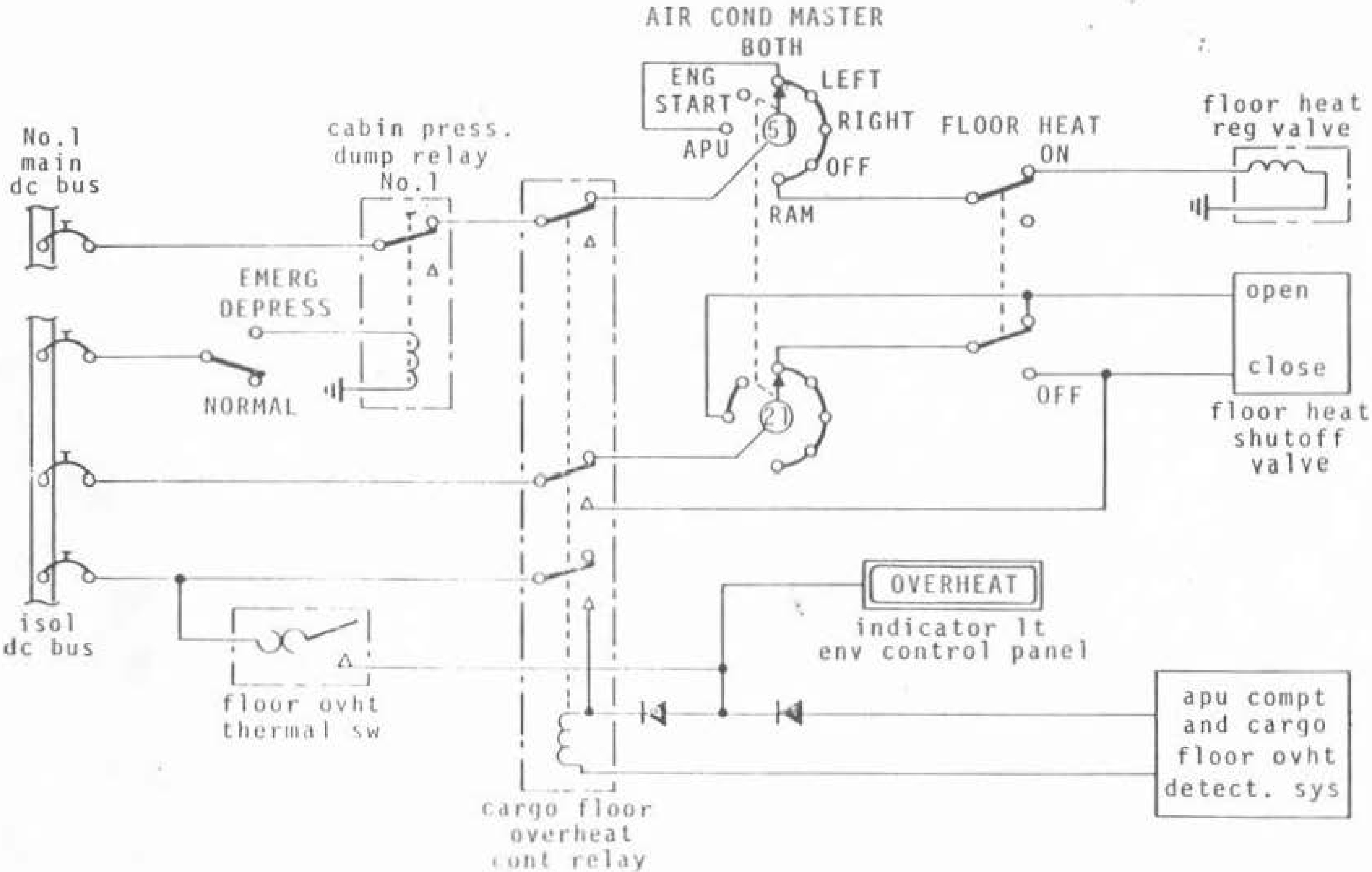



FIGURE 4-15. CARGO FLOOR HEAT CONTROL SCHEMATIC

Provisions are included for connecting a mobile ground air conditioning unit into the aircraft's conditioned-air distribution ducting. The connector is located on the right side of the fuselage at F.S. 477 as shown in Figure 4-16. A flapper-type check valve is installed in the supply duct to prevent reverse flow. The connector is protected by a circular cover plate which is fastened with nine flush-mounted Allen-head screws.

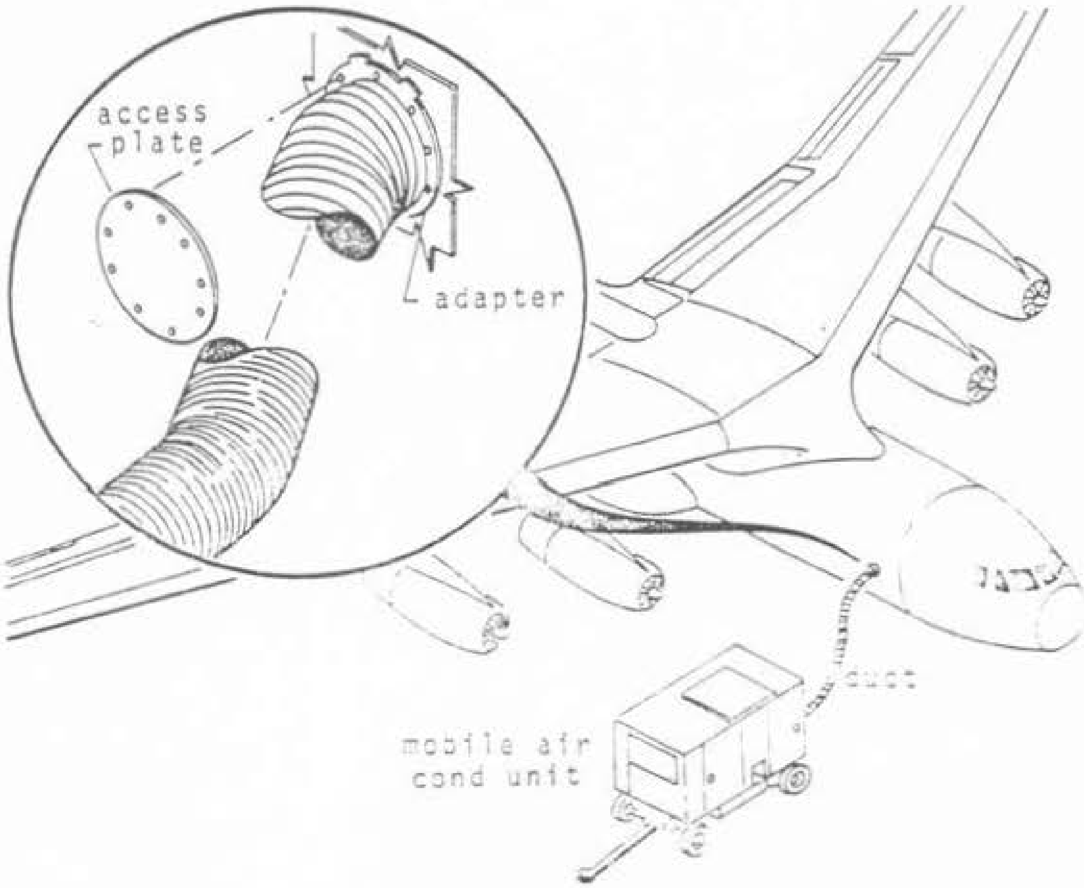



FIGURE 4-16. GROUND AIR CONDITIONING CONNECTION

## RAM AIR VENTILATION SYSTEM

Ram air may be used for ventilation in the aircraft if air conditioning and pressurization are not required or cannot be used. Air is supplied through a shutoff valve from the right-hand ram air inlet and is ducted into the aircraft through the left-hand air conditioning system distribution ducting. Through this ducting, ram air can be supplied to all of the outlets in the aircraft, including the gaspers. Approximately 500 cfm of air is supplied to the flight station and 2000 cfm is supplied to the cargo compartment. The system is shown in Figure 4-17.

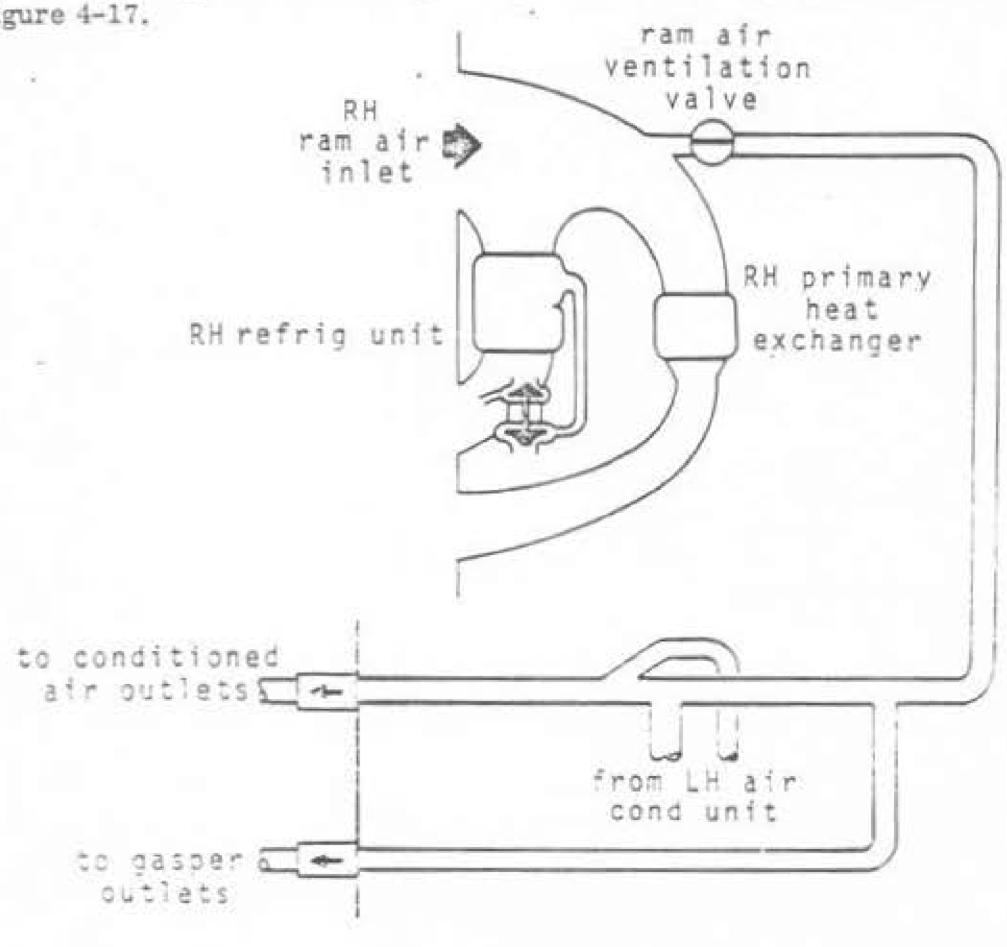



FIGURE 4-17. RAM AIR VENTILATION SYSTEM

### Ram Air Ventilation Valve

The ram air ventilation valve is located just forward of the right-hand refrigeration unit in the center wing section. It is installed in a short section of ducting which connects the right-hand ram air inlet to the left-hand system distribution duct. The valve is a motor-driven butterfly type and is controlled by the AIR COND MASTER switch.

System Control and Operation

Figure 4-18 shows the control schematic for the ram air ventilation valve. The valve is controlled directly through the master switch. When the switch is placed in the "RAM" position, the valve is driven open. In all other positions of the switch, the valve is closed.

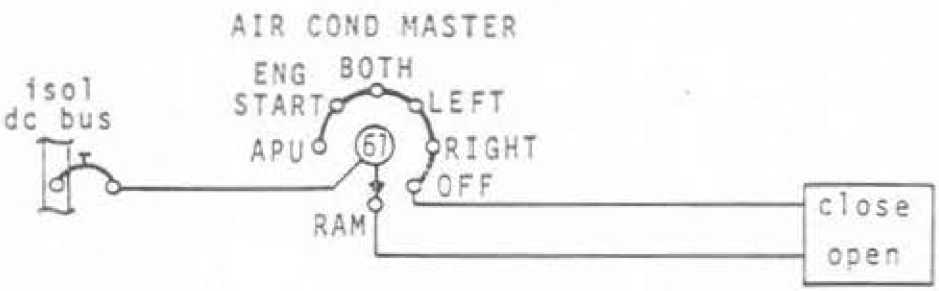



FIGURE 4-18. RAM AIR VENTILATION CONTROL SCHEMATIC

Since ram air pressure is very small (about 2 psi maximum), it is necessary to depressurize the aircraft before the ram air can enter through the check valves in the distribution ducts. For this reason, there are control circuits which cause the pressurization system outflow valves to open when the master switch is positioned to "RAM." These control circuits are discussed in the following chapter. Also, by opening the outflow valves, an outlet for the ram air is provided to ensure adequate ventilation.

ELECTRICAL AND ELECTRONICS EQUIPMENT COOLING SYSTEMS

Most of the avionics systems "black boxes" and the majority of the electrical distribution system components are located under the flight deck floor. Since these units generate a great deal of heat when operating, special cooling systems are provided to ensure adequate cooling of the components. The cooling is accomplished by circulating cabin air around the components.

## Electrical Equipment Cooling System

Two ducted fans are used to draw conditioned air from the flight station and circulate it over the electrical equipment. These fans are mounted under the floor in the aft right corner of the flight station as shown in Figure 4-19. The fans are driven by 115-volt 3-phase ac motors, and are rated at 240 cfm each. One or both fans normally operate any time power is on the aircraft. Access to the fans is through the toilet compartment.

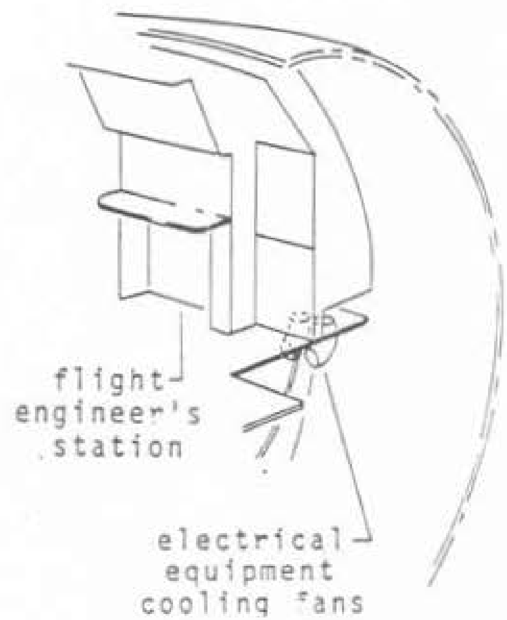



FIGURE 4-19. ELECTRICAL EQUIPMENT COOLING FAN LOCATION

### System Operation

Figure 4-20 shows the control schematic for the electrical equipment cooling fans. Whenever power is on the aircraft, the No. 1 fan normally operates and the No. 1 cooling fan current sensing relay is energized. When the aircraft is in the air, this relay supplies a ground through the deenergized contacts of the No. 2 touchdown relay to energize the No. 2 fan control relay. With this relay energized, the No. 2 fan does not operate. However, if the No. 1 fan fails, the No. 1 cooling fan sensing relay deenergizes, which removes the ground from the No. 2 fan control relay. The relay then deenergizes and applies power to the No. 2 fan. If the No. 2 fan fails also, a ground is provided through the deenergized contacts of the No. 1 cooling fan current sensing relay, the No. 2 touchdown relay, and the No. 2 cooling fan current sensing relay, to the fail indicator light at the flight engineer's console. If either fan is operating while the aircraft is in the air, there is no failure indication.

When the aircraft is on the ground, the No. 2 touchdown relay is energized, which removes the ground from the No. 2 fan control relay. With this relay deenergized, the No. 2 fan also operates. If the No. 1 fan fails, the No. 1 cooling fan current sensing relay deenergizes and supplies a ground through the energized contacts of the touchdown relay to the fail indicator light. If the No. 2

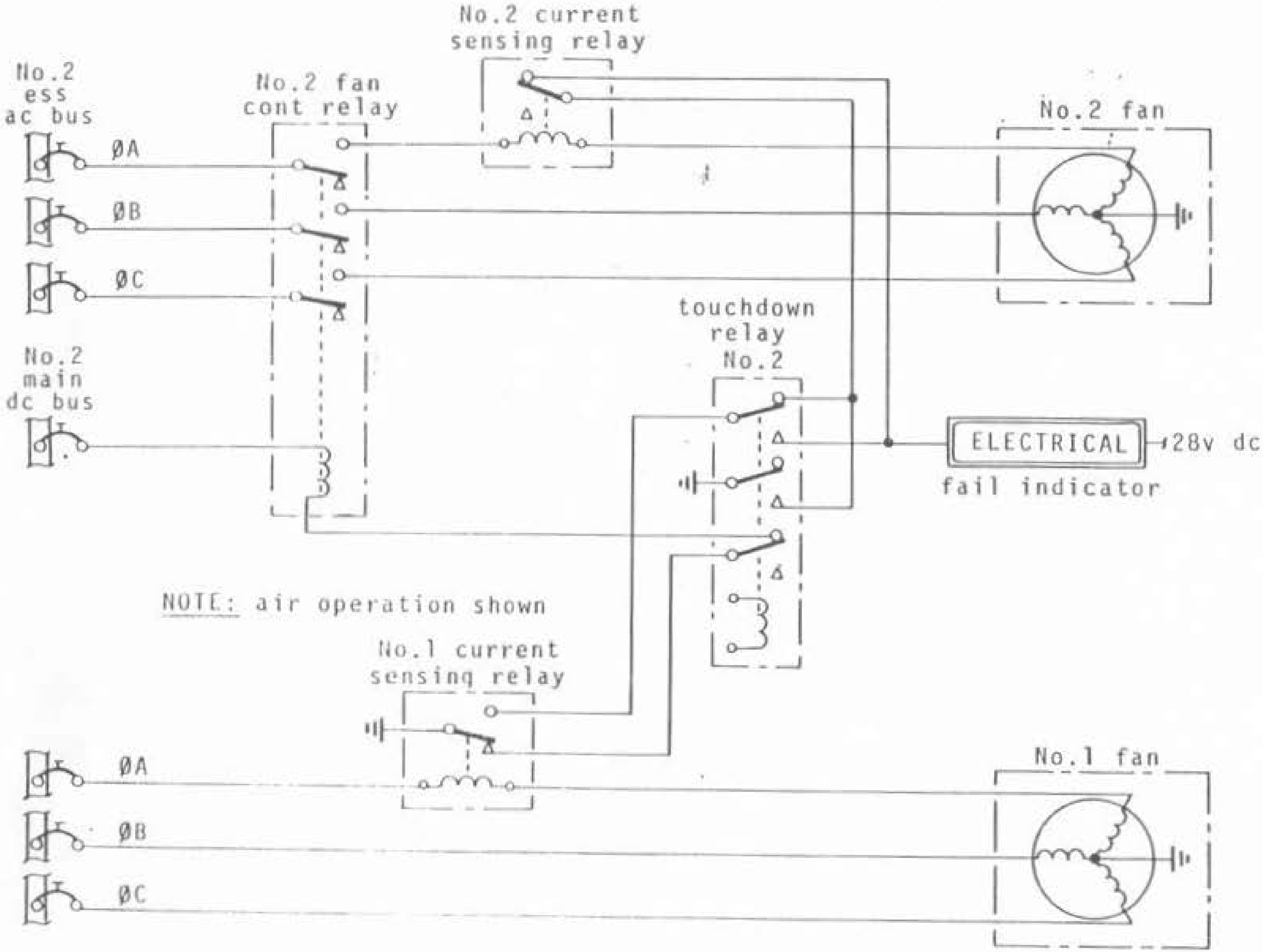



FIGURE 4-20. ELECTRICAL EQUIPMENT COOLING SYSTEM CONTROL SCHEMATIC

fan fails, the No. 2 cooling fan current sensing relay applies a ground from the energized contacts of the touchdown relay to the light. Thus, a failure indication is provided if either fan fails while the aircraft is on the ground.

## Electronics Equipment Cooling System

Figure 4-21 shows the electronics equipment cooling system flow schematic. The electronics black boxes are mounted on hollow racks which are ducted overboard through two fans and a flow control valve. The system is located in the belly of the fuselage, forward of F.S. 452. The two fans are electric-motor driven, using 115-volt 3-phase ac power and are rated at 850 cfm each. One or both fans normally operate any time power is available on the aircraft. Check valves downstream from the fans prevent reverse flow in the ducting when one fan is not operating.

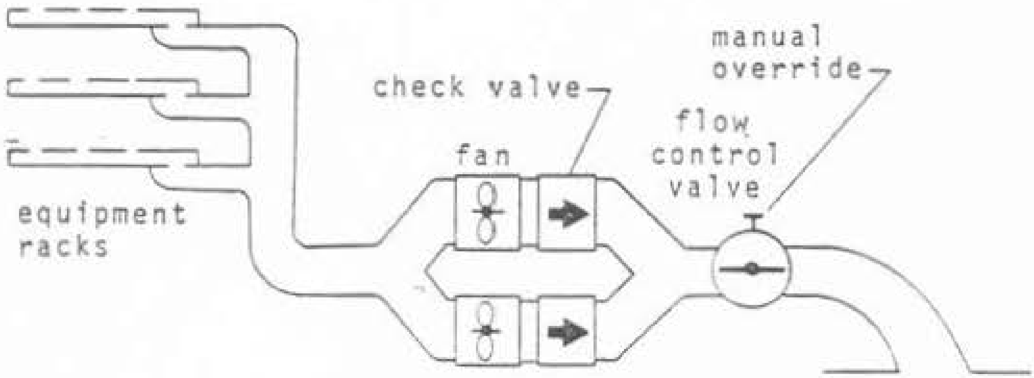



FIG. 4-21 ELECTRONICS EQUIPMENT COOLING SYSTEM

### Flow Control Valve

A cutaway view of the valve is shown in Figure 4-22. It is an air actuated "unbalanced" butterfly valve with both solenoid control and manual override features. The valve is spring-loaded open and air-actuated toward closed. When the aircraft is on the ground, the solenoid is energized to hold the butterfly fully open. When the aircraft is in the air, the butterfly modulates to provide sufficient airflow for electronics equipment cooling. At the same time, however, this airflow is not great enough to be detrimental to aircraft pressurization.

The manual override tee-handle is located to the right of the step leading down into the underdeck area just forward of the flight deck entrance ladder. When the tee-handle is pushed in to the "OPEN" position, the valve is mechanically held fully open. The "CLOSE" override position, however, will not close the valve. If the tee-handle is pulled out to the "CLOSE" position, a mechanical

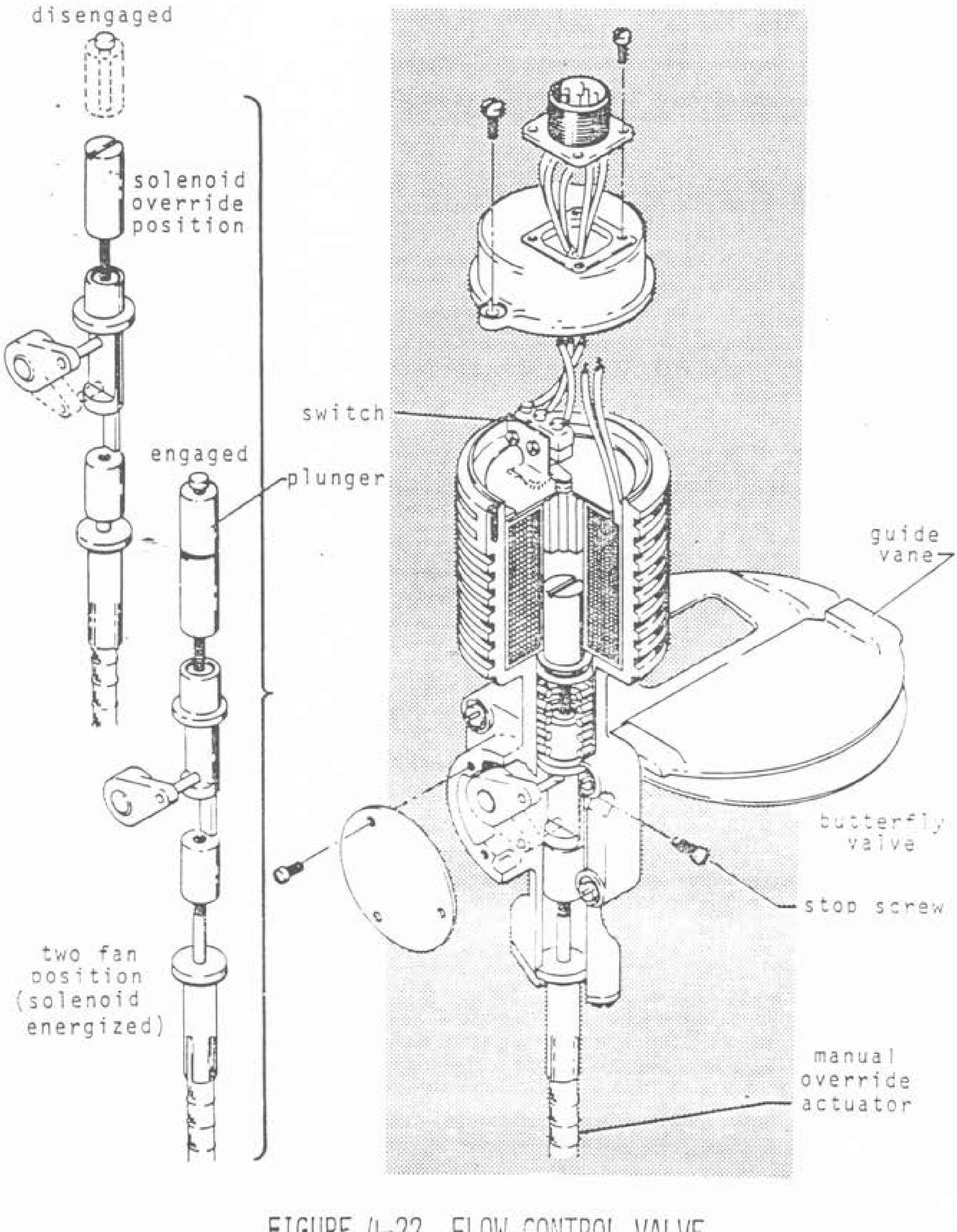



FIGURE 4-22. FLOW CONTROL VALVE

linkage overrides the solenoid and allows the valve to modulate according to the airflow.

## System Operation

System operation is similar to the electrical equipment cooling system operation. One fan normally operates when the aircraft is in the air, and both fans operate when the aircraft is on the ground. In flight, if one fan fails, the other fan is activated automatically. If both fans fail, a failure indication is provided at both navigator's station and flight engineer's station. When the aircraft is on the ground, the second fan is activated through a microswitch in the flow control valve. In this configuration, the failure indication is provided if either fan fails. The electrical schematic of the system is shown in Figure 4-23.

*NOTE **

*Modification to Electronics Equipment Cooling System*

*When the aircraft is on the ground, the flow control valve solenoid is energized to hold the valve full open and start the No. 2 fan. Power is applied to the solenoid through the energized contacts of the No. 4 touchdown relay. However, when power is removed from the system or when the aircraft takes off, the relay deenergizes to remove power from the solenoid. Due to the large size of the solenoid coil, an arc is produced across the relay contacts as the solenoid deenergizes. This arcing burns the contacts and has caused a high failure rate of the relay.*

*To solve this problem, the electrical connector to the valve has been disconnected and stowed. This action disables the function of the No. 2 fan during ground operation. Also, the wire on the touchdown relay that supplies a ground for the fail indicator light has been disconnected. This action is taken to prevent the failure indication that would otherwise be given when the No. 2 fan does not operate on the ground.*

*It is important to note that the air operation of the system is not affected by this modification. If the No. 1 fan fails, the No. 2 fan starts automatically and continues to run after touchdown, and the failure light illuminates at touchdown.*

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* This modification may not be permanent.

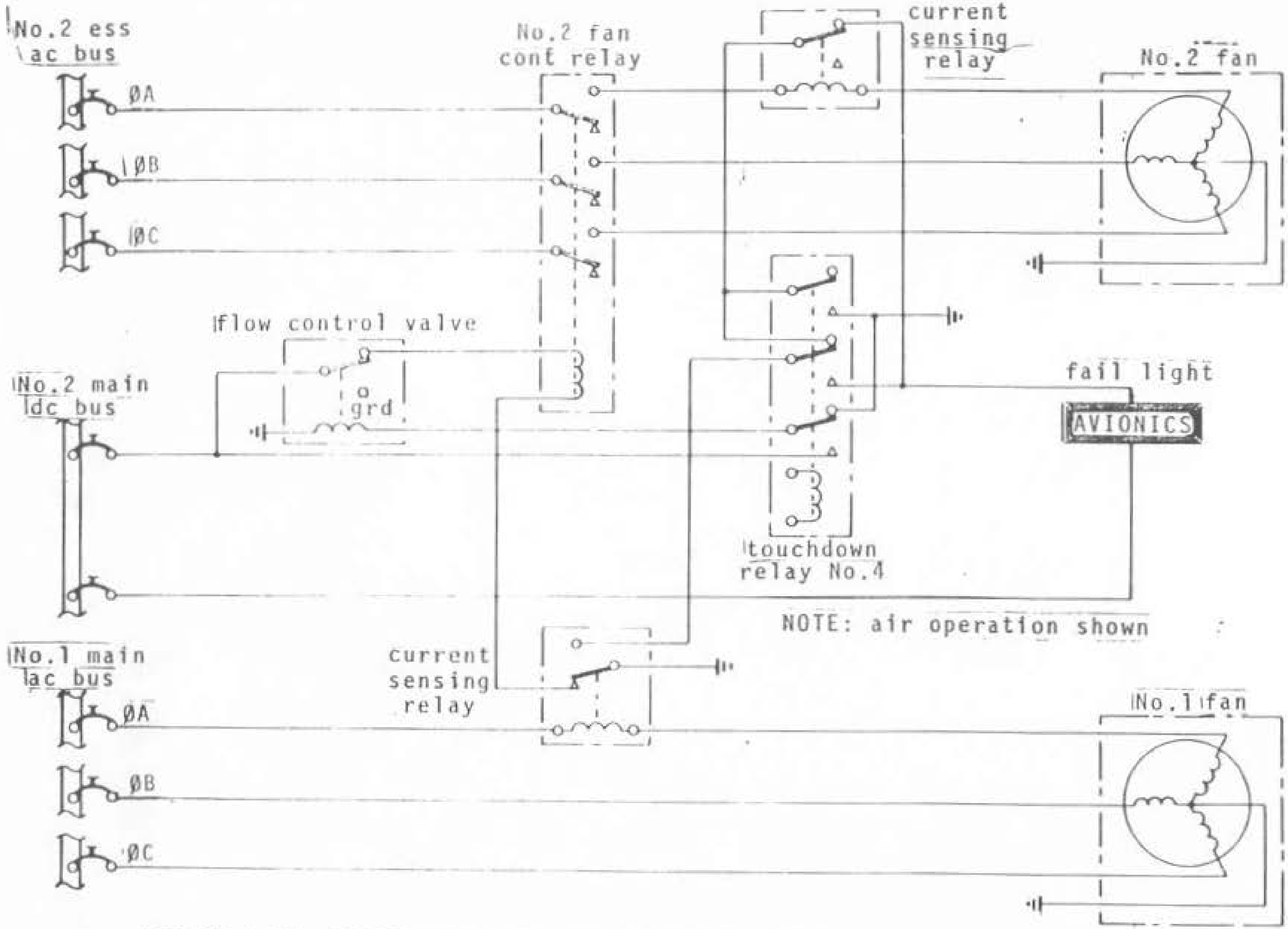



FIGURE 4-23. ELECTRONICS EQUIPMENT COOLING SYSTEM ELECTRICAL SCHEMATIC

## STUDY QUESTIONS

1. How is the hot bleed air used for air conditioning cooled? ______________________________.

2. What does "air conditioning" mean? ______________________________.

3. What is the purpose of the flow control and shutoff valve? ______________________________.

4. The flow control valve is ____________ controlled, ____________ actuated, spring-loaded ____________, and energized ____________.

5. The flow control valves are normally controlled by the ____________ switch, but can be overridden closed by ____________ and ____________.

6. What indications will be in evidence if a flow control valve fails closed? ______________________________.

7. Name the positions of the master switch in order from left to right and tell what each position controls.

______________________________

______________________________.

8. What conditions must be met in order to operate the air conditioning system on the ground? ______________________________

______________________________.

9. What does the refrigeration package consist of? ____________

______________________________.

10. What is the purpose of the heat exchanger? ____________

______________________________.

11. What is the primary purpose of the compressor fan? ____________

______________________________.

12. What is the purpose of the jet pump assembly in the refrigeration unit? ______________________________.

13. What is the purpose of the low-limit system and how does it operate? ______________________________.

14. What is the means of bearing lubrication in the cooling turbine assembly? ______________________________.

15. ______ °F is considered a turbine overheat condition.

16. How is the turbine protected from an overheat condition?

______________________________.

17. What is the purpose of the water separator?____________ ____________________________________________________.

18. How is the water separator protected from damage due to freezing if the low-limit system fails?________________ ____________________________________________________.

19. Approximately __________ percent of the "free" moisture is removed by the water separator.

20. Where are the air conditioning system components located? ____________________________________________________.

21. How is cabin temperature control accomplished?_________ ____________________________________________________.

22. What type of thermostats are used in the cabin temperature control system?________________________________________.

23. _________ °F is considered a duct overheat condition.

24. How are the ducts protected from an overheat condition? ____________________________________________________.

25. What valve is controlled by the flight station temperature control switch?_________________________________.

26. If cabin temperature (either system) cannot be controlled either automatically or manually, the probable cause is a failure of the associated____________________________.

27. How would the flight station temperature be affected if the flight station sensor becomes dirty (covered with dust)?______________________________________________.

28. How would the cargo compartment temperature be affected if the control sensor in the cargo compartment sensing unit opened?________________________________________.

29. What controls are used to regulate cargo compartment temperature if the left-hand air conditioning unit is turned off?_________________________________________.

30. What provides the signals to the compartment temperature indicator on Environmental Control Panel?______________ ____________________________________________________.

31. With the FLT STA AIR FLOW switch in "NORM" and the AIR COND MASTER switch in "BOTH," the air flow distribution from the right-hand system is____________percent to the flight station and __________ percent to the cargo compartment.

32. (TRUE - FALSE) Changing the temperature in the flight station has no effect on the cargo compartment since the two systems are independent.

33. What controls the flight station alternate air valve?
_______________________________________________.

34. The floor heat system receives air from the ___________.

35. The underfloor area is protected from overheat by______ ______________ which actuates at_______ °F and causes ______________________________.

36. The_________________ switch normally controls the floor heat system, but the valves can be overridden by ______ ____________________ and ______________________________.

37. What type of valve is the floor heat regulator valve and how is it controlled?______________________________.

38. What type of valve is the floor heat shutoff valve and how is it controlled?______________________________.

39. The air for ram air ventilation comes from the______-hand ram air inlet and is distributed through the________-hand system distribution ducts.

40. The ram air ventilation valve is controlled by _________.

41. Where is the connection for a ground air conditioning cart located?______________________________.

42. How is cooling of the electrical equipment accomplished?
_______________________________________________
_______________________________________________.

43. Where is the fail indicator light for the electrical equipment cooling system located?______________________.

44. When would the electrical equipment cooling system fail light be illuminated?______________________________.

45. How is cooling of the electronics equipment accomplished?
_______________________________________________.

46. What indication, if any, would be given if the electronics equipment cooling system flow control valve failed to energize upon touchdown?______________________________.

47. What failure indication(s) is (are) given if the No. 1 electronics equipment cooling fan fails during flight?
_______________________________________________.

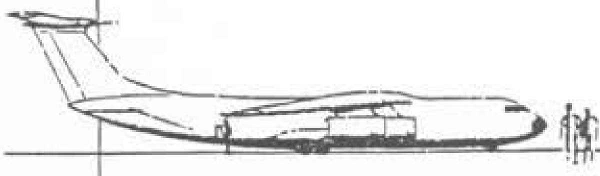
48. What component(s) would be suspect if the AVIONICS failure indicator lights illuminate upon touchdown?

________________________________________.

49. Refer to question No. 48. What would be the easiest method of determining whether or not the flow control valve has failed to energize?____________________.

50. Refer to question No. 48. What would be the easiest method of determining whether a fan has failed?

________________________________________.





PRESSURIZATION SYSTEM

Pressurizing an aircraft means keeping the pressure inside at a higher value than the pressure outside or maintaining the cabin at a lower altitude than the existing aircraft altitude. Pressurization of the Star-Lifter is accomplished by sealing the fuselage, providing a constant input of air, and regulating the outflow. The air conditioning systems provide the input; the pressurization system controls the outflow.

The metal seams, fixed windows, and similar structures in the fulelage are permanently sealed against air leakage. A rubber flap-type seal is used on the ramp and aft pressure door. A pressurized rubber seal is used on the crew entrance door. Cabin air inflates the seal through a series of small holes in the seal itself. This action ensures positive sealing of the door when the cabin is pressurized. It is necessary to maintain good sealing of the fuselage at all times to ensure good efficiency of the pressurization system. Any time repairs are made to the fuselage, care should be taken to clean and seal the repaired structure.

It is desirable to maintain the cabin altitude as near sea level as possible. However, a differential pressure of 12 pounds per square inch is required to maintain a sea level cabin pressure when the aircraft is at 40,000 feet. Even though this pressure appears small, it produces a force of 1728 pounds on each square foot of surface area. To withstand such a pressure safely, the fuselage would have to be of sufficiently heavy construction to withstand twice that amount of pressure. It is much more practical to build a lighter structure and limit the differential pressure to a lesser value. This procedure means that a sea level cabin can be maintained only until the aircraft reaches a specified altitude. Above this altitude, the cabin altitude must also rise in order to prevent further pressurization.

A normal maximum differential pressure of 8.2 psi is used in the Star-Lifter. With this pressure, a sea level cabin altitude can be maintained until the aircraft reaches approximately 21,000 feet, and an 8000-foot cabin can be maintained at 40,000 feet. Other cabin altitudes and corresponding aircraft altitudes are listed in the following table:

| Cabin Altitude | Aircraft Altitude |
|---|---|
| -1000 feet | 19,000 feet |
| 1000 feet | 23,000 feet |
| 2000 feet | 25,000 feet |
| 4000 feet | 30,000 feet |
| 6000 feet | 35,000 feet |

Cabin pressure is normally controlled automatically. However, the system permits the operator to select desired cabin altitudes and rates of change. An altitude adjustment on the automatic pressure controller, as shown in Figure 5-1, permits altitude selections of from minus 1000 feet to 10,000 feet. A rate

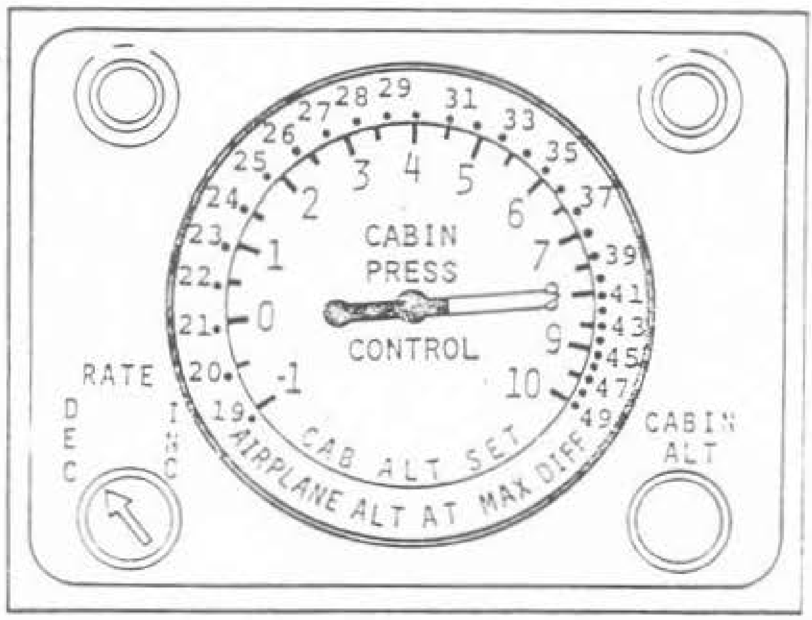



FIGURE 5-1, CABIN PRESSURE CONTROLLER

adjustment permits cabin rate-of-change selections of from 200 to 2000 feet per minute. A pointer on the face of the controller displays the selected cabin altitude and corresponding aircraft altitude at maximum differential pressure. To protect the aircraft structure from excessive differential pressure, a limiting device is built into the controller which automatically limits differential pressure to 8.3 psi, regardless of the altitude or rate selections. Figure 5-2 shows the various differential pressures for corresponding aircraft and cabin altitudes.

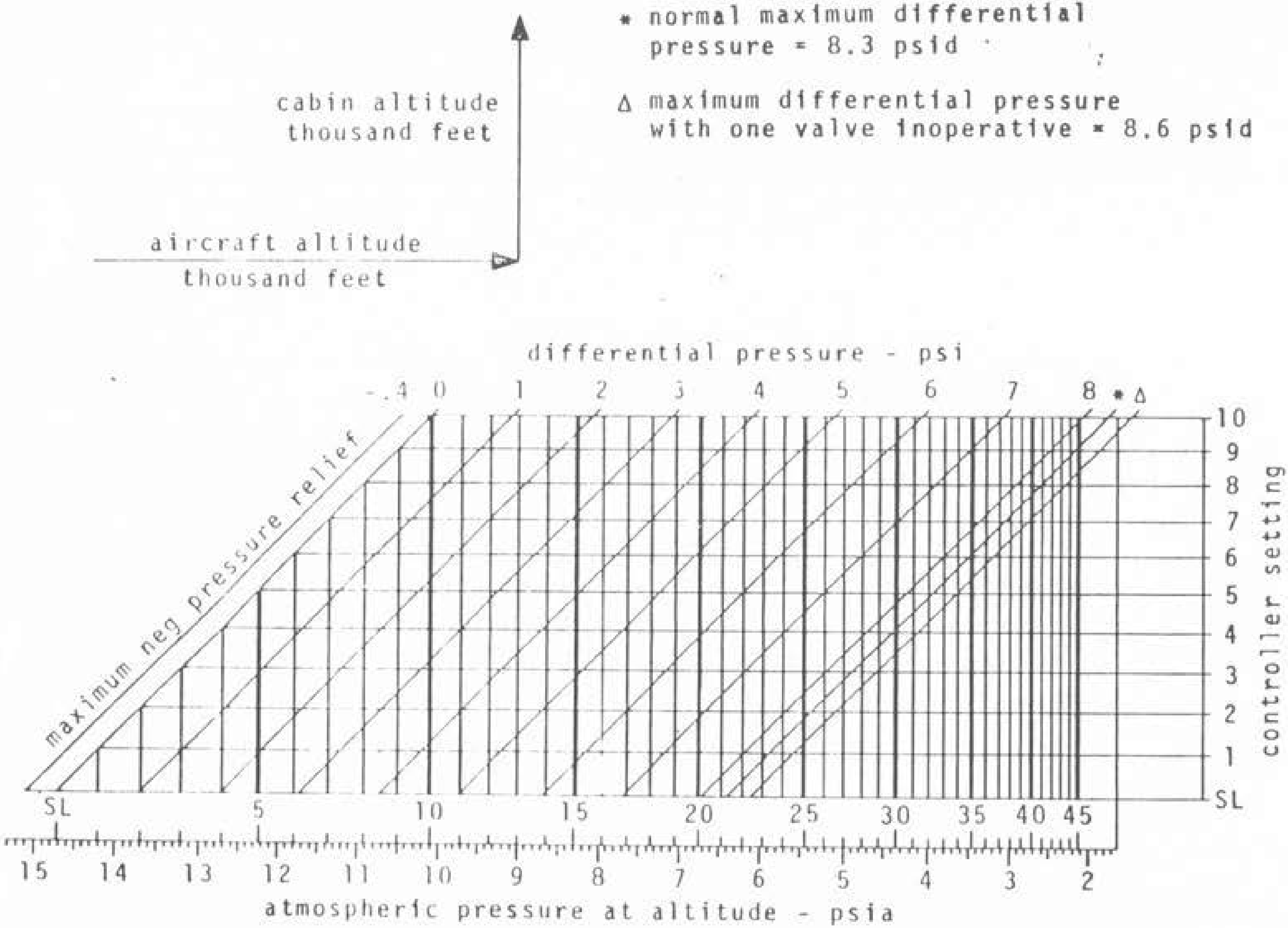



FIGURE 5-2. CABIN PRESSURIZATION CHART

Several safety features and backup devices, incorporated into both the aircraft and the systems in order to provide maximum protection for the aircraft and flight personnel in the event of a component malfunction, follow:

- In order to ensure that the fuselage structure can safely be pressurized to 8.3 psid, the structure has been proof-tested at 17 psid. In addition, every fuselage is pressurized to 12 psid after assembly.

- The aircraft pressurization system depends on the air conditioning systems for its supply of air. This air supply is sufficient to ensure a 10,000-foot cabin altitude at 40,000 feet with one system inoperative.

- The automatic pressure controller contains a high differential control which limits cabin differential to 8.3 psi any time the aircraft altitude exceeds the corresponding altitude for a given cabin altitude or rate selection.

- A manual pressure controller is included in the system and can be used to control cabin pressure if the automatic controller fails.

- Two outflow valves are used to regulate air flow out of the aircraft. Each valve contains a safety relief mechanism which actuates at 8.3 psid. A maximum differential pressure of 8.6 psid can be maintained with one valve inoperative.

- A cabin altitude limit control is also incorporated into each outflow valve. This mechanism will modulate the valve to maintain a 13,000-foot cabin altitude in the event of a system malfunction which would tend to hold the valve open.

- The fuselage is built to withstand high inside pressure pushing out - not high outside pressure pushing in. Since it is possible to obtain a negative differential pressure under certain operating conditions, two separate valves are installed in the fuselage to limit this negative differential to a maximum of 0.4 psid.

- Since cabin altitude cannot be selected over 10,000 feet on the automatic pressure controller (and would not be over 8000 feet under most normal operating conditions), a CABIN PRES LOW warning is provided whenever cabin altitude exceeds 10,000 feet.

- Automatic circuits are provided to depressurize the aircraft upon touchdown in order to prevent inadvertent pressurization on the ground.

## SYSTEM COMPONENTS

The pressurization system consists of the following:

- Two combination outflow/safety valves
- Jet pump pressure regulator
- Control venturi
- Automatic pressure controller
- Manual pressure controller
- Two negative pressure relief valves

In addition to these components, the system also contains the following components for depressurization:

- Control fan and venturi
- Low pressure dump solenoid
- High pressure dump solenoid

Indicators are provided to permit the flight engineer to monitor the system operation, as follows:

- Combination cabin altimeter and differential pressure gage
- Cabin rate-of-climb indicator
- Cabin pressure low warning light

The cabin rate-of-climb indicator and the controls for depressurization are located on the upper Environmental Control Panel. The lower panel contains the automatic and manual pressure controllers, the cabin altimeter and differential pressure indicator, and the cabin pressure low warning light.

### Outflow/Safety Valve

Two outflow valves are used to regulate cabin pressure by controlling the air flowing out of the cabin. Both valves are located on the bulkhead above the aft pressure door, one on each side. They are air-actuated, poppet-type valves and are spring-loaded closed. A source of negative pressure is required for control. Each valve contains a built-in jet pump, a pneumatic relay, a safety relief valve, and an aneroid valve for cabin altitude limit control, and a cabin altitude limit override diaphragm. A cutaway view of the valve is shown in Figure 5-3.

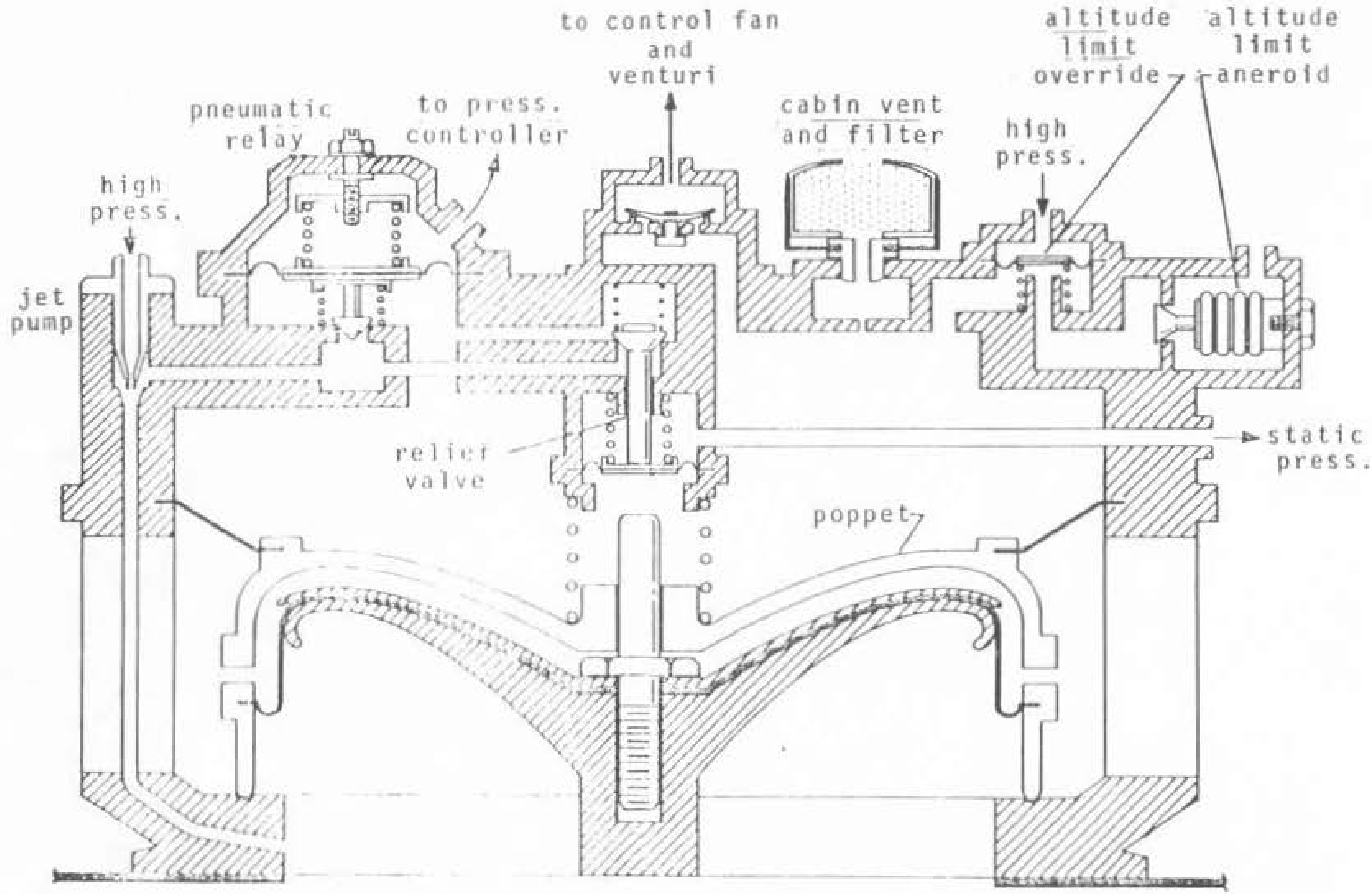



FIGURE 5-3. OUTFLOW/SAFETY VALVE

Operation

The outflow valve is normally controlled through actuation of the pneumatic relay. This mechanism is actually a small control valve which is activated by pressure signals from the pressure controller.

Cabin air is sensed in the head chamber of the valve (on top of the poppet) through a cabin vent and filter. The actuator chamber (on the bottom side of the poppet) is also open to cabin pressure through holes in the poppet. When the pneumatic relay is open, the jet pump evacuates the head chamber of the valve, which allows the higher pressure in the actuator chamber to push the poppet open against the spring. When the pneumatic relay closes, the head chamber again fills with cabin pressure through the cabin vent, and the spring closes the poppet.

Cabin pressure and static pressure are sensed on opposite sides of the safety relief valve actuator diaphragm. If cabin pressure exceeds static pressure by a differential of 8.3 psi, the diaphragm pushes against the spring to open the relief valve. This action allows the jet pump to evacuate the head chamber of the outflow valve to open the poppet. At this time, the outflow valve functions as a pressure relief valve to prevent cabin pressure from exceeding the maximum allowable limit. When cabin differential drops below 8.3 psi, the safety relief valve closes, which allows the outflow valve to revert to its normal function as a pressure regulator.

An aneroid valve is used to provide cabin altitude limit control in the event of a system malfunction which would cause the outflow valve to open and depressurize the aircraft. If such a malfunction occurs and cabin pressure decreases to an equivalent altitude of approximately 13,000 feet, the aneroid valve opens. Cabin pressure can then enter the head chamber of the outflow valve to move the poppet back toward closed in order to prevent a further decrease in cabin pressure. This altitude limit control can be overridden, however, if depressurization is desired. High-pressure air, applied to the override diaphragm, causes the diaphragm to block the passage of cabin air into the head chamber.

The head chambers of both valves are connected to the system control fan and venturi. This unit, used to open the valves when the aircraft is on the ground, is also controlled through certain positions of the AIR COND MASTER switch. A rubber flap-type check valve in each outflow valve prevents a loss of head chamber pressure through the control fan and venturi when the unit is not operating.

A cartridge type filter is used on the cabin vent in each outflow valve. The filter should be changed periodically to ensure proper operation.

## Jet Pump Pressure Regulator

The high pressure air, used by the jet pumps and cabin altitude limit control override diaphragms in the outflow valves, is supplied from the bleed air manifold. A pressure regulator is installed in the supply line to provide a source of constant pressure for the jet pumps and to protect the altitude limit override diaphragms. The regulator, shown in Figure 5-4, is located on the aft right-hand side of the center wing box beam section in the cargo compartment. It regulates at 15 psi above cabin pressure and includes a 26 psi relief valve.

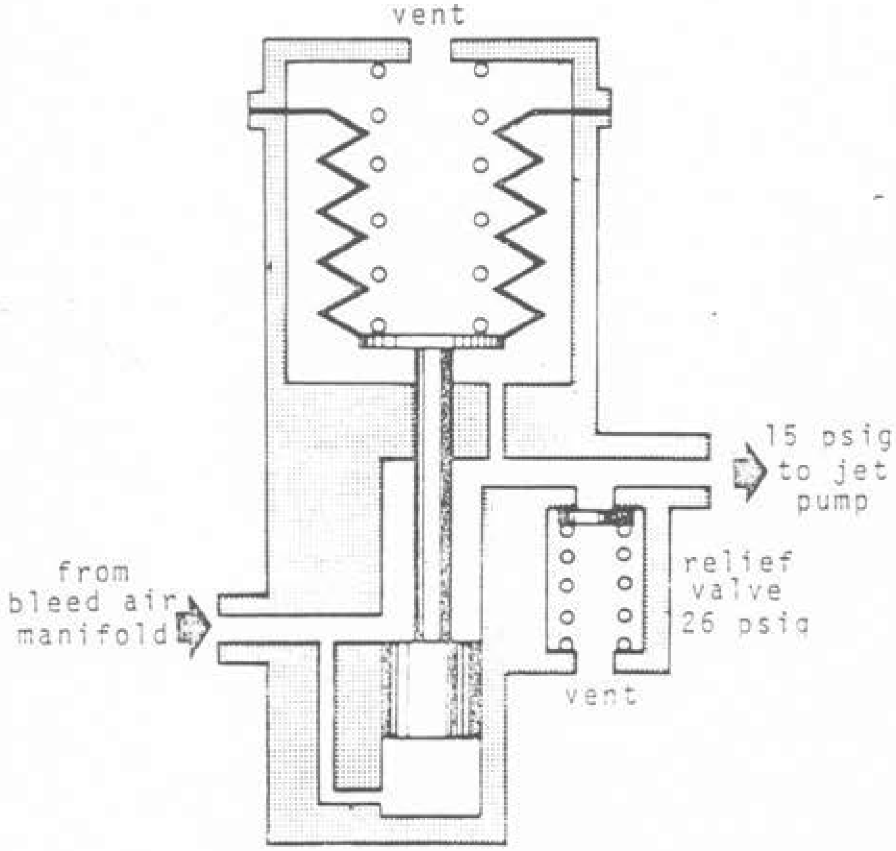



FIGURE 5-4, JET PUMP PRESSURE REGULATOR

## Control Venturi

A venturi is used to supply the negative pressure necessary for controlling the outflow valves. It is located behind the fuel control panel at the flight engineer's station and is attached to the aircraft skin. With the air conditioning systems operating, cabin air flows overboard through the venturi. This airflow creates a slight negative pressure (a few inches of water) at the throat. The negative pressure is supplied to both pressure controllers and to the low-pressure dump solenoid valve.

## Automatic Pressure Controller

The automatic pressure controller is the normal control device for cabin pressurization. Shown in Figure 5-5, the controller is divided into two main chambers: the rate chamber and the control chamber, separated by the rate control diaphragm. The two chambers are connected through a rate control needle valve by a passage which bypasses the rate diaphragm.

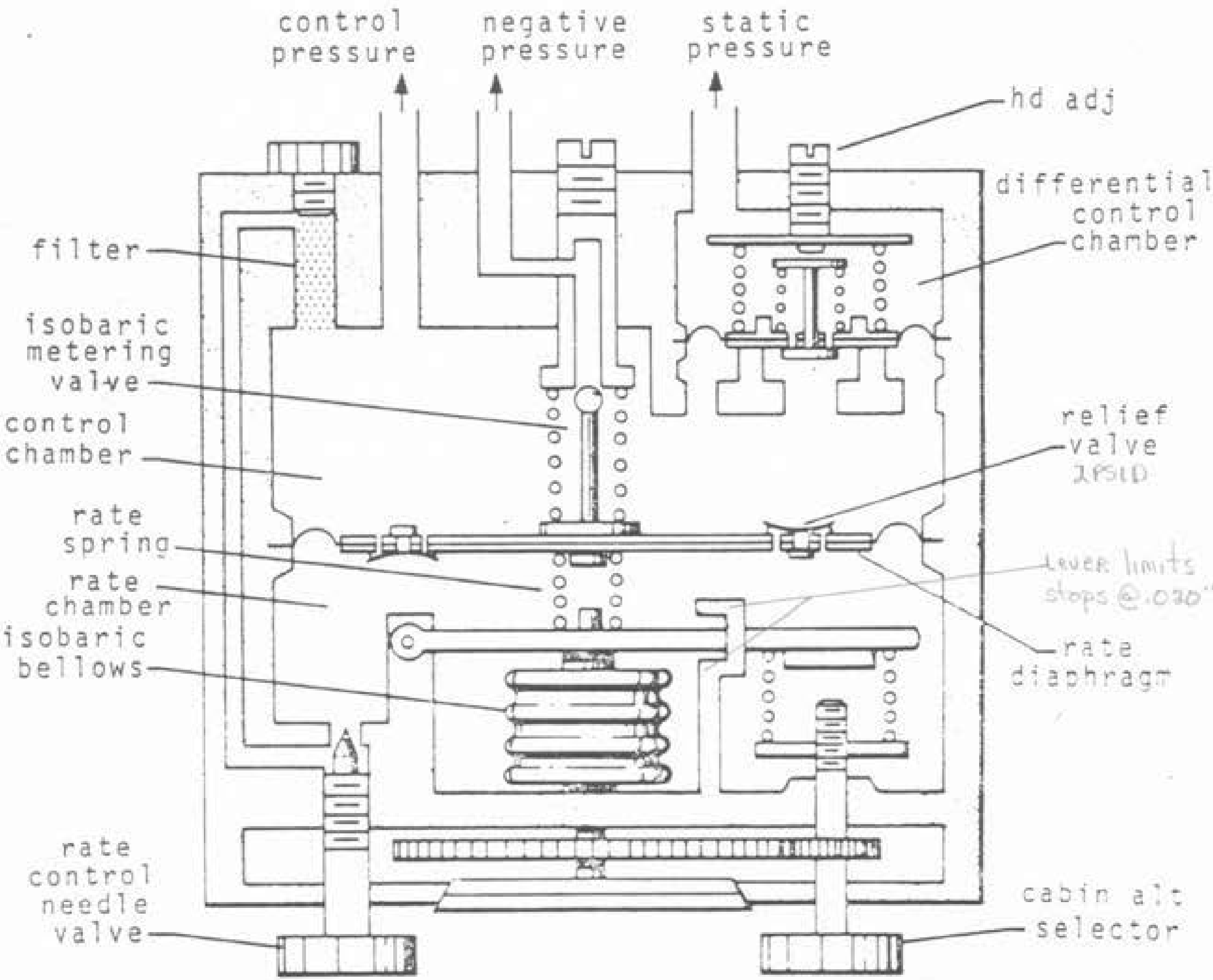



FIGURE 5-5. AUTOMATIC PRESSURE CONTROLLER

The rate chamber is in the front of the controller and contains the altitude selector control and spring assembly, the isobaric bellows, a lever assembly, and the rate control needle valve. All of the control lines connect to the control chamber on the back of the controller. This chamber houses the isobaric metering valve, the rate filter, and the differential control diaphragm and valve assembly. Springs are used to connect the isobaric metering valve to the rate diaphragm and to the lever so that the valve can be controlled independently by either the lever or the diaphragm.

A static pressure sensing line connects to the differential control diaphragm. Negative pressure from the control venturi is supplied to the isobaric metering valve. The third line is the outflow valve control line that connects the control chamber to the pneumatic relays on the outflow valves through the manual pressure controller. Cabin pressure is sensed in this line through a vent and filter on the manual controller. Thus, this line provides cabin pressure both to the pneumatic relays and to the control chamber of the pressure controller. It also provides negative pressure to the pneumatic relays when the isobaric metering valve is open.

The rate filter should be changed periodically to ensure proper operation of the controller.

Operation

Operation of the pressure controller can be divided into four categories:

- Isobaric range of operation
- Rate range of operation .
- Differential range of operation
- Unpressurized range of operation

Isobaric Range - In the isobaric range of operation, the pressure controller operates to maintain a constant cabin altitude regardless of aircraft altitude. An isobaric range of operation exists whenever cabin altitude is being maintained at the selected altitude, and the aircraft is between that altitude and the corresponding aircraft altitude at maximum differential pressure. The isobaric control mechanism consists of the altitude selector (a threaded shaft with a nut), the selector spring, the isobaric bellows (an evacuated aneroid), and the lever. Opposing forces are applied to the lever by the spring (which always pushes) and the bellows (which always pulls). Cabin pressure, from the control chamber, is admitted to the bellows through the rate filter and needle valve. Whenever cabin pressure, sensed by the bellows, is equal to the altitude selection, the lever is "balanced." When cabin pressure is less than the selected altitude, the selector spring pushes on the lever to move the metering valve toward closed. This action reduces the supply of negative pressure to the outflow valves so that they move toward closed and permit cabin pressure to increase. When cabin pressure is greater than the selected altitude, the higher pressure causes the bellows to contract, which pulls on the lever and allows the metering valve to open. This action supplies greater negative pressure to open the outflow valves and decrease cabin pressure. A mechanical stop on the lever limits the movement of the metering valve to about 0.020 inch.

Rate Range - In the rate range of operation, the controller operates to control the cabin pressure (altitude) rate of change independently of aircraft's altitude rate of change. Since the only way that cabin pressure can be sensed in the rate chamber is through the rate control needle valve, this valve can be used to control the rate at which air enters or leaves the chamber. By controlling this air flow rate between the chambers, a differential pressure is created across the rate diaphragm, which causes the diaphragm to move and position the metering valve. This action causes the outflow valves to be positioned so as to regulate the outflow of air and produce the desired rate of change. Two relief valves in the rate diaphragm limit the differential pressure on the diaphragm to a maximum of 2 psi, which is done to protect the diaphragm from excessive differential pressure during rapid changes in cabin pressure. When starting from an unpressurized condition, the rate control has no effect if the aircraft rate of change is less than the selected cabin rate during ascent or greater than the selected cabin rate during descent.

Differential Range - Whenever the aircraft goes above the isobaric range selected on the controller, the differential control causes cabin altitude to rise at a rate corresponding to the aircraft's rate of climb. Static pressure and cabin pressure are sensed on opposite sides of the differential control diaphragm. As cabin differential increases, the diaphragm pushes back against the spring until, at 8.3 psid, the valve is against the stop. Any further increase in differential pressure causes the diaphragm to move farther which opens the valve. Control chamber pressure is then vented overboard, which creates a negative pressure in the control line to open the outflow valves and decrease cabin pressure. When the differential drops back to less than 8.3 psi, the differential control valve closes.

Unpressurized Range - An unpressurized range of operation exists when the cabin altitude selection is higher than the actual aircraft altitude. Rotating the altitude selector clockwise (higher altitude) decreases the push of the selector spring. This action allows the bellows to contract and open the metering valve, If the aircraft remains below the selected cabin altitude, the pressure on the bellows cannot decrease sufficiently to let the bellows expand and close the metering valve. Thus, the outflow valves remain open to keep the aircraft unpressurized.

## Manual Pressure Controller

A manual pressure controller is located on the lower Environmental Control Panel to the left of the automatic controller. It can override the automatic controller and can be used to control cabin pressurization if the automatic controller fails. Shown in Figure 5-6, the unit contains a camshaft and two

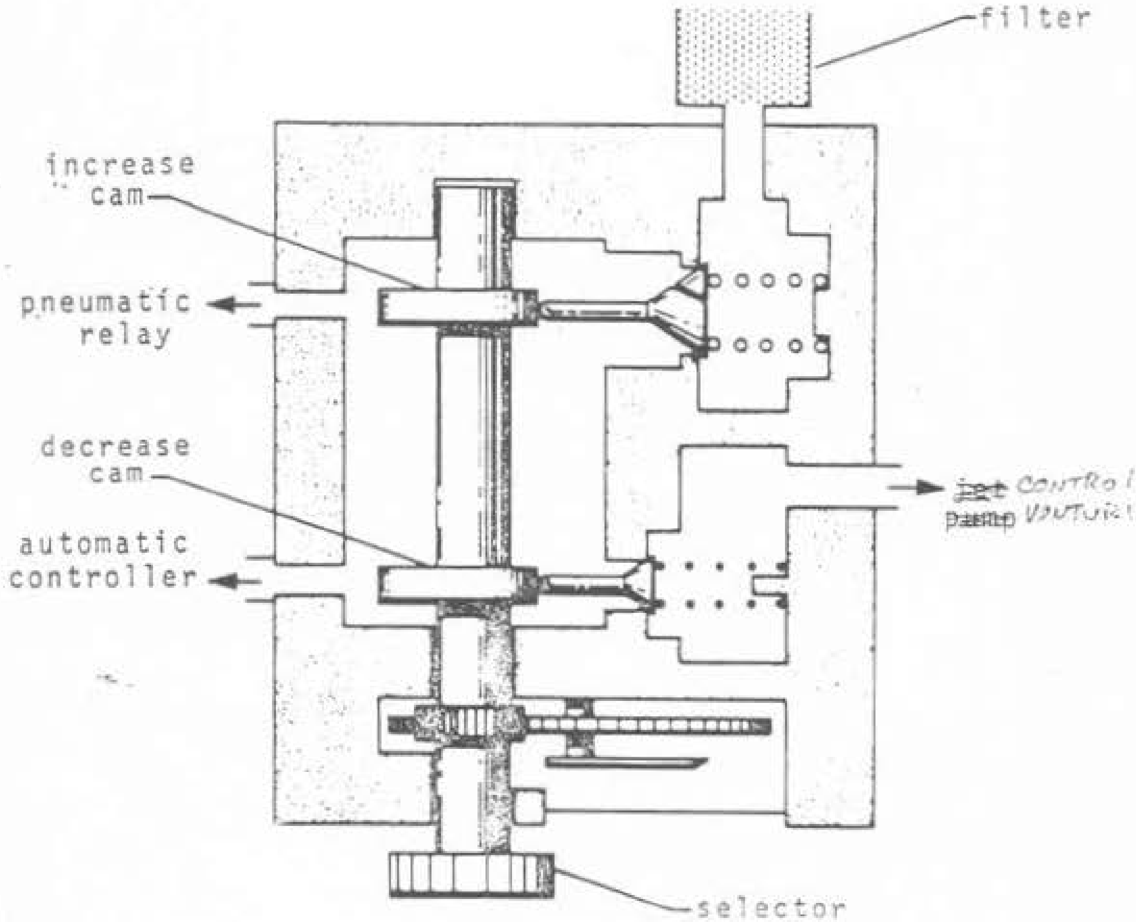



FIGURE 5-6. MANUAL PRESSURE CONTROLLER

valves. Cabin pressure is supplied to one of the valves through a vent and filter. A small port through this valve provides cabin pressure sensing to the automatic controller. Negative pressure from the control venturi is supplied to the other valve. A pointer on the face of the controller indicates "DECREASE," "AUTO," and "INCREASE." A cartridge-type filter is used on the cabin vent. It is identical to those on the outflow valves, and should be changed periodically.

<u>Operation</u>

In the "AUTO" position, both valves are closed. The control must be in this position when using the automatic controller. Rotating the control knob counterclockwise to "DECREASE" opens the negative pressure valve and supplies negative pressure to the pneumatic relays to open the outflow valves. Rotating the control knob clockwise to "INCREASE" opens the cabin pressure valve and supplies cabin pressure to the pneumatic relays to close the outflow valves. Rate of change is controlled by how far the control knob is turned.

## SYSTEM OPERATION

Figure 5-7 shows a flow schematic of the pressurization system. The following example illustrates system operation for a given set of conditions. It must be kept in mind, however, that operating conditions are constantly changing. For example, the outflow valves modulate continuously in response to changes in cabin differential pressure as the aircraft changes altitude or flies through areas of high or low atmospheric pressure. The position of the valves at any instant may depend upon several conditions which are changing simultaneously. For the purpose of this explanation, it is convenient to consider only one variable condition at a time, even through such a situation would seldom actually exist.

It is assumed that the aircraft is ready to take off with the doors closed and the air conditioning systems operating.

To start, the pressures in all the chambers are equal. With cabin air flowing through the control venturi, a negative pressure is produced in the control line to the isobaric metering valve in the automatic controller. Selecting a cabin altitude that is higher than field elevation reduces the spring load on the isobaric bellows, which allows the bellows to contract and open the metering valve. This action produces a negative pressure in the control line to the pneumatic relays to hold the outflow valves open.

As the aircraft begins to climb, the absolute pressure in the cabin starts to decrease. Since the control chamber in the automatic controller is vented to cabin pressure (through the cabin vent and filter in the manual controller), control chamber pressure also begins to decrease. This causes air to flow from the rate chamber to the control chamber, thereby decreasing the rate chamber pressure also. If the aircraft rate of climb is faster than the selected rate for the cabin, the flow of air from the rate chamber to the control chamber is restricted by the rate needle valve. This action causes the pressure drop in the rate chamber to lag behind the pressure drop in the control chamber. Thus, a differential pressure is created across the rate diaphragm to move the metering valve toward closed, which reduces the negative pressure in the control line to the pneumatic relays. The outflow valves then move toward closed to restrict the outflow of cabin air, thus maintaining a higher pressure inside the cabin in order to achieve a slower rate of change.

*NOTE*

> *Since the rate selector is not calibrated, the rate control may be set at the 12 o'clock position initially. (This setting produces a rate of change of about 500 fpm.) After a rate of change is established, it may be adjusted more accurately by monitoring the cabin rate-of-climb indicator.*

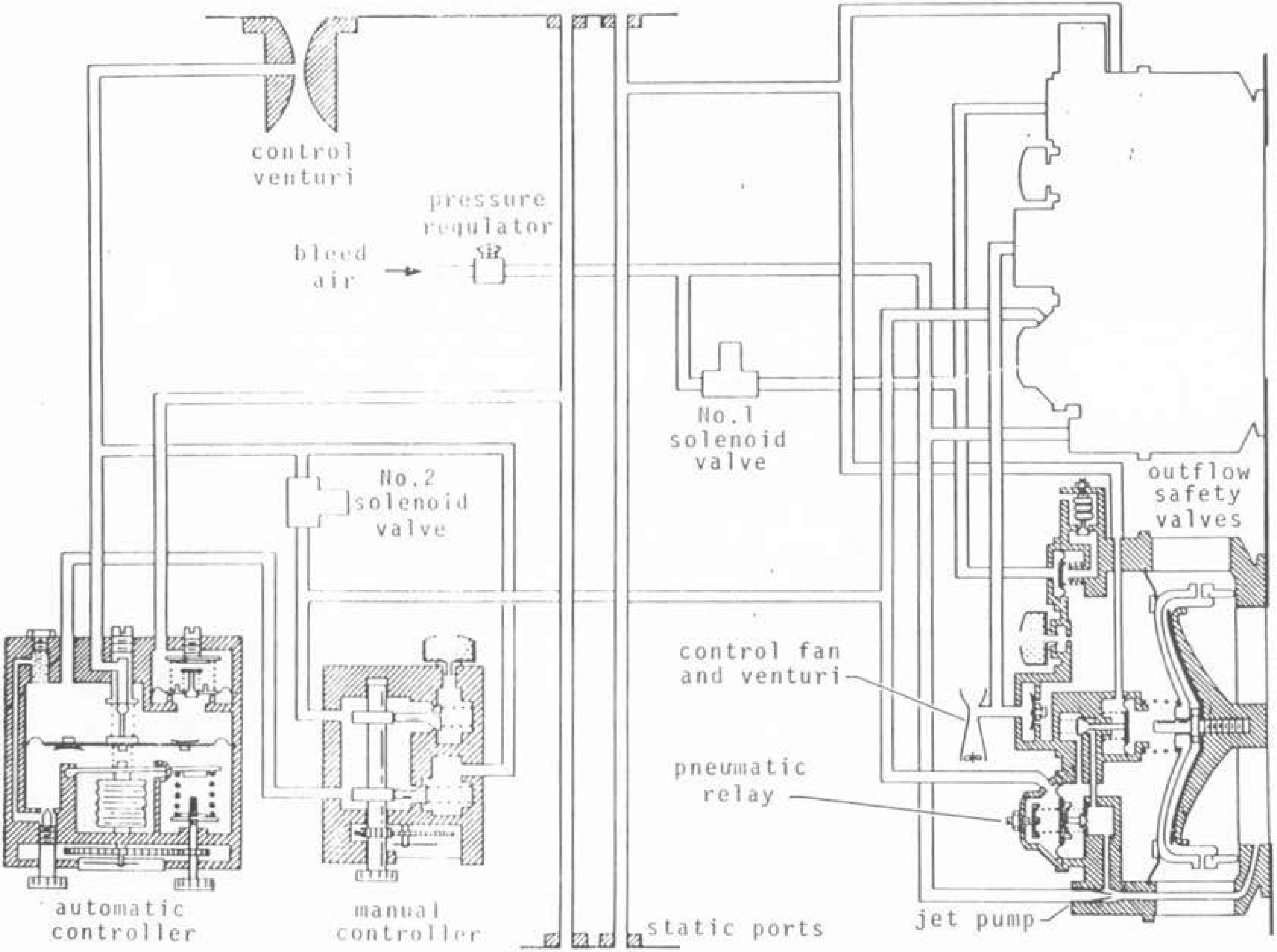



FIGURE 5-7. CABIN PRESSURE CONTROL FLOW DIAGRAM

As the cabin reaches the selected altitude, the reduced pressure in the rate chamber allows the bellows to expand and move the metering valve further closed. This action reduces the amount of air that the control venturi can draw from the control chamber; pressure equalizes across the rate diaphragm, and the metering valve seeks a balance position determined by the altitude selection. In this position, the absolute pressure maintained in the controller operates the outflow valves to hold the desired cabin altitude.

For descent, the pressure controller is set for a cabin altitude slightly higher than field elevation. When the altitude selector is rotated counterclockwise for the lower altitude selection, the selector spring is compressed so that it pushes on the lever to move the metering valve toward closed. This reduces the negative pressure to the pneumatic relays and the outflow valves move toward closed, which allows cabin pressure to increase. If the pressure increases at a faster rate than the selected rate, the rate needle restricts the flow of air into the rate chamber so that the pressure increase in the rate chamber lags behind the pressure increase in the control chamber. Higher pressure on the control side of the rate diaphragm opens the metering valve, which allows the control venturi to evacuate the control line to the pneumatic relays. The outflow valves then move toward open to reduce the pressure build-up to the desired rate.

When the pressure in the rate chamber increases to the equivalent selected altitude, the bellows contracts to move the metering valve further open. This action allows the control venturi to draw more air out of the control chamber; the pressure equalizes across the rate diaphragm; and the metering valve seeks the balance position determined by the altitude selection. Cabin pressure is then maintained at the selected altitude until the aircraft drops below this altitude at which time the aircraft becomes unpressurized.

The foregoing example assumes that the aircraft does not exceed the selected isobaric range of operation. It should be remembered, however, that the differential control overrides both the rate selection and altitude selection to limit cabin pressure to 8.3 psid.

Two conditions exist which can cause a negative cabin differential pressure (pressure inside less than pressure outside). The first of these conditions occurs when the aircraft is cruising in an isobaric range and then descends rapidly to below the selected cabin altitude. (This situation takes place if the flight engineer forgets to set the cabin altitude back down upon descent.) The second condition occurs when the cabin rate of descent is slow and the aircraft descends rapidly enough to "overtake" the cabin. In either case, the pressurization system cannot react fast enough to prevent the absolute pressure inside the aircraft from becoming less than the atmospheric pressure outside, and a condition of negative cabin differential pressure exists.

Two negative pressure relief valves are installed in the aircraft to protect the structure from excessive negative differential pressure. The valves are located on the aft pressure bulkhead just above the outflow valves, one on each side. They are 8-inch diameter dual-flapper check valves that open inward. The valves limit negative pressure to a maximum of 0.4 psid even with both air conditioning systems operating.

## DEPRESSURIZATION

### Control Fan and Venturi

Automatic depressurization upon touchdown is provided by means of a squat switch and the control fan and venturi. Figure 5-8 shows a cutaway view of the

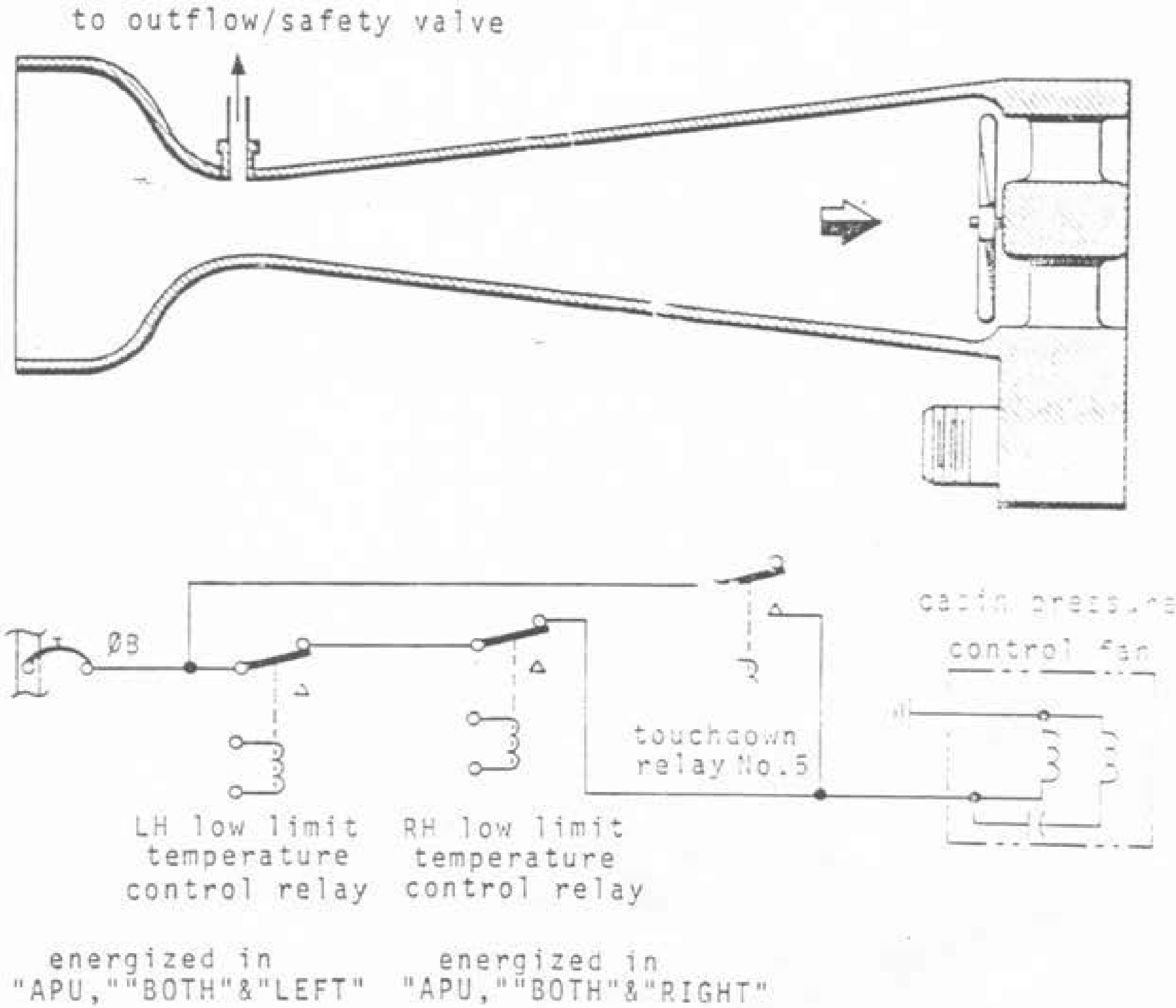



FIGURE 5-8. CABIN PRESSURE CONTROL FAN AND VENTURI

control fan and venturi and the electrical control schematic. The unit is located on the aft pressure bulkhead between the two outflow valves. The throat of the venturi is connected into the head chamber of both outflow valves through tubing. When the fan operates, cabin air is pulled through the venturi, creating a negative pressure at the throat. This negative pressure evacuates the head chambers of the valves to hold the poppets open.

As shown in the control schematic, the fan is activated through the energized contacts of the No. 5 touchdown relay. This relay is energized by a squat switch on the main landing gear strut assembly when the aircraft is on the ground. The fan is also activated through the deenergized contacts of the right-hand and left-hand low-limit temperature control relays. Since one or both relays are energized if the AIR COND MASTER switch is in "APU," "BOTH," LEFT," or "RIGHT," (as shown in Figure 4-5), the fan does not operate at this time, (unless, of course, the aircraft is on the ground). However, if the master switch is positioned to "ENG START," "OFF," or "RAM," both low-limit relays are deenergized, which applies power to the fan to open the outflow valves.

## Air Conditioning - No Pressure

Two methods of control are available to the operator if it is desired to operate the air conditioning systems with no pressurization. One method is to select a cabin altitude on the automatic controller that is higher than the aircraft altitude. This can be done, of course, only if the aircraft is below 10,000 feet. The second method is to set the manual controller to full "DECREASE." It should be remembered, however, that the cabin altitude limit control in the outflow valves does not let the cabin depressurize to an altitude of more than 13,000 feet. If, for some reason, it is desired or necessary to fly unpressurized above this altitude, the CABIN ALT LIMIT ORIDE switch must be used in conjunction with the manual controller. This switch is located on the upper Environmental Control Panel next to the AIR COND MASTER switch. It is covered by a red guard. Placing the switch in the "ORIDE" (override) position energizes the No. 1 DEPRESS SOLENOID valve. When energized, this valve admits high-pressure air to the cabin altitude limit override diaphragms in the outflow valves.

## Emergency Depressurization

Two red-guarded EMERG DEPRESS switches are provided for use if it becomes necessary to depressurize the aircraft rapidly. One switch is located in the lower right corner of the upper Environmental Control Panel. The other switch is located on the overhead console. Both switches are wired in parallel so that emergency depressurization is accomplished if either switch is actuated. In "EMERG DEPRESS," both the No. 1 and No. 2 dump solenoid valves are energized open as shown in Figure 5-7. The No. 2 valve permits the control venturi to evacuate the control line to the pneumatic relays to open the outflow valves. The No. 1 valve provides for cabin altitude limit override, which allows the cabin to depressurize completely. Depressurization time from maximum differential pressure is about 90 seconds. Figure 5-9 shows the electrical schematic for emergency depressurization.

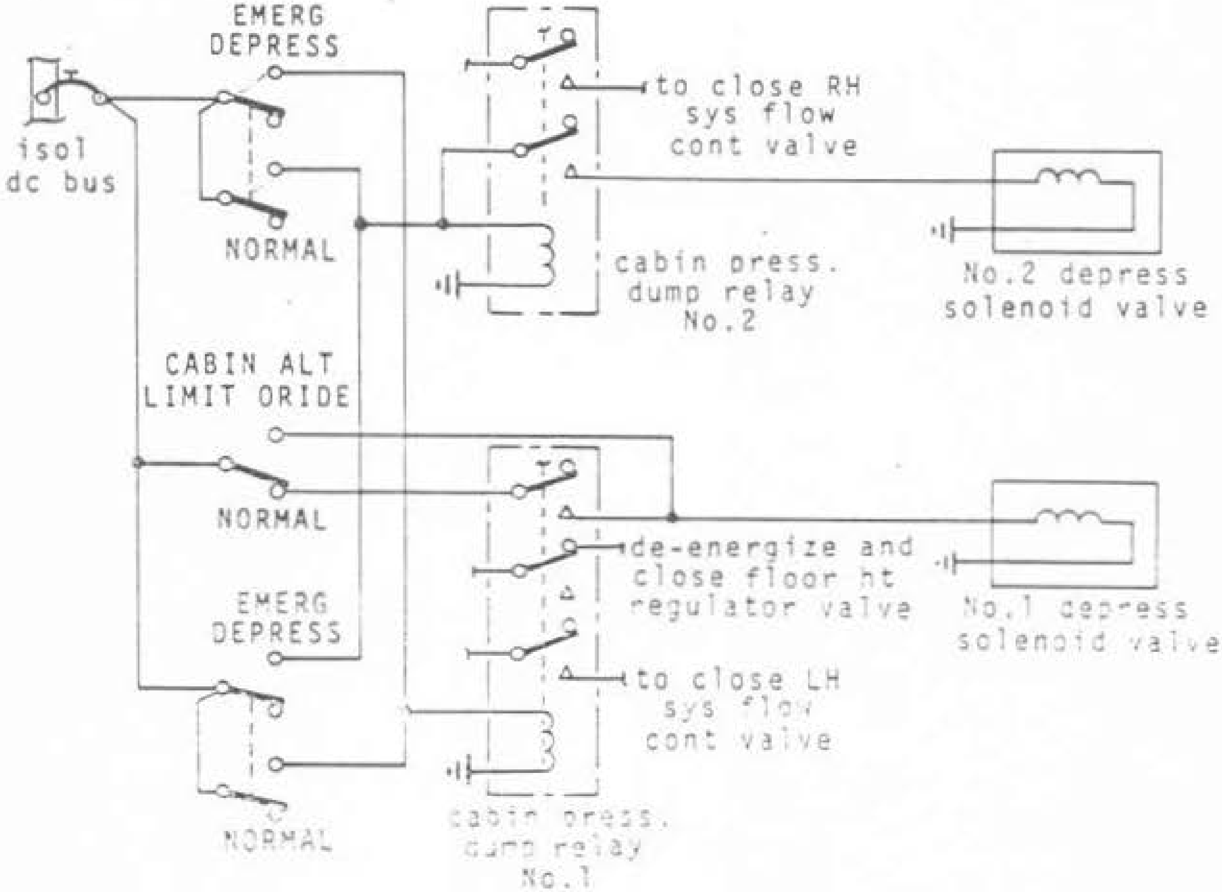



FIGURE 5-9. EMERGENCY DEPRESSURIZATION CONTROL SCHEMATIC

## Manual Emergency Depressurization

A depressurization hatch is installed overhead in the forward end of the cargo compartment as shown in Figure 5-10. The hatch is cable-actuated open by a tee-handle on the overhead console. It may also be opened from the cargo compartment. The hatch is hinged on the forward side so that it opens into the airstream. When the hatch is opened, the aircraft depressurizes from maximum differential pressure in approximately 15 seconds.

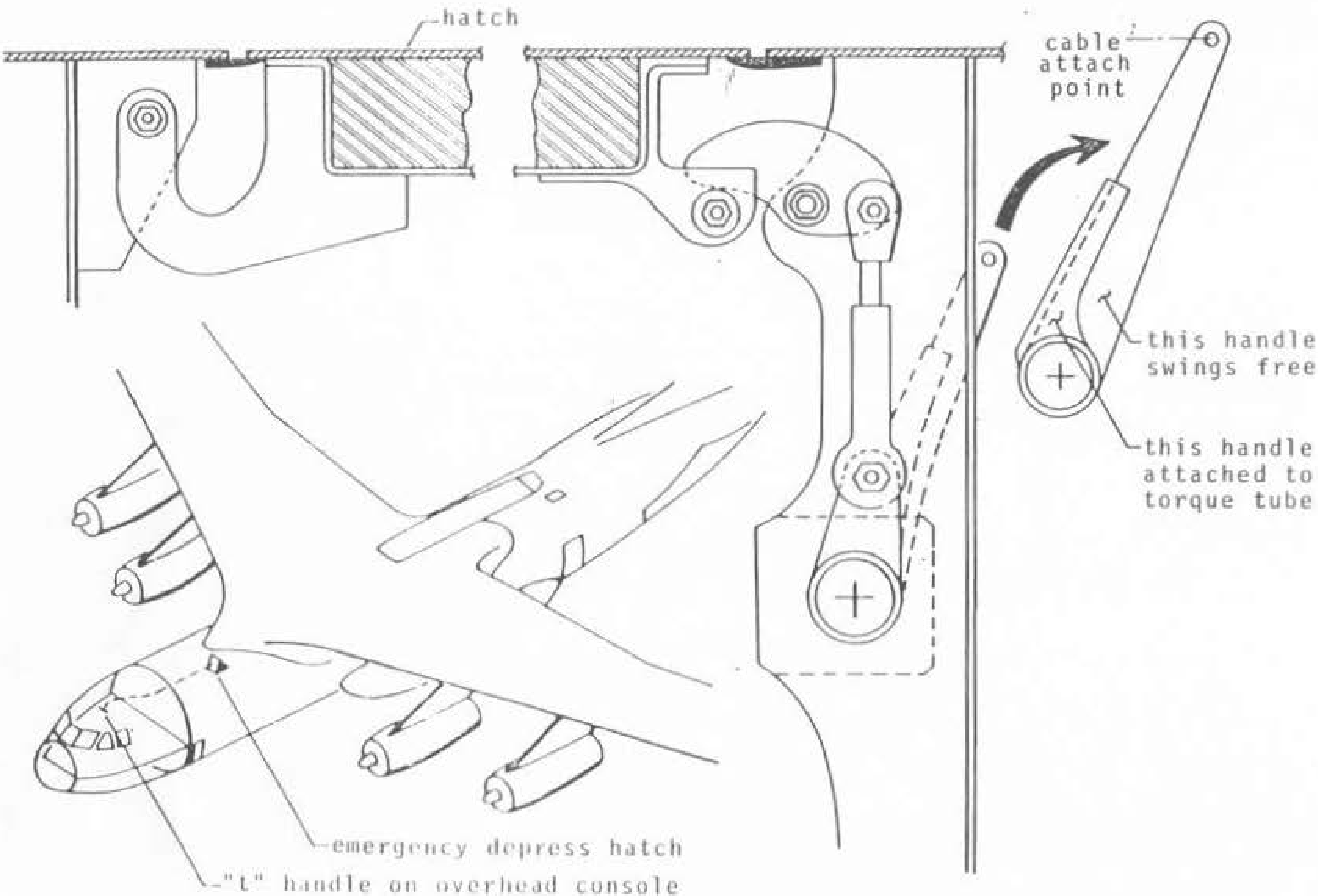



FIGURE 5-10. MANUAL DEPRESSURIZATION SYSTEM

## Low-Pressure Warning

Two CABIN PRESS LOW warning lights are provided to warn the crew whenever cabin altitude exceeds 10,000 feet. One light is located next to the automatic pressure controller. The other light is included on the pilot's annunciator panel. Both lights are activated by a pressure switch located under the flight station floor near the electrical equipment cooling fans. When the absolute pressure in the cabin drops to 10.1 psia, the switch actuates and supplies an electrical ground to illuminate the warning lights as shown in Figure 5-11.

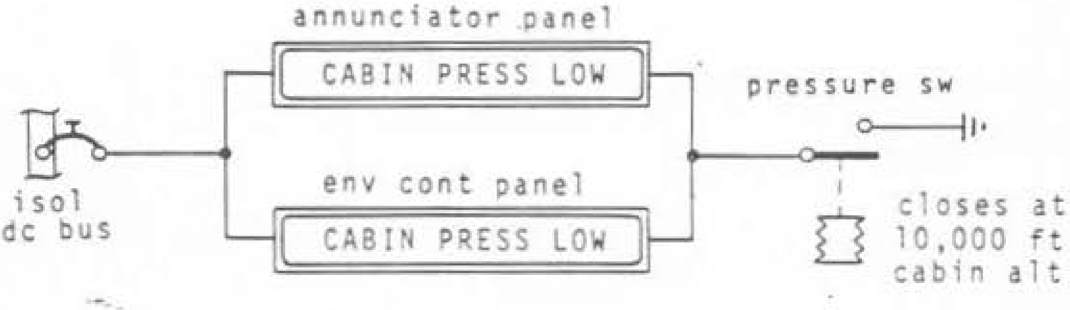



FIGURE 5-11. CABIN PRESSURE LOW WARNING

## GROUND PRESSURIZATION

A ground pressure test should be made whenever a major component of the pressurization system, such as a controller or an outflow valve, is replaced. This test ensures proper operation of the component. Pressurization to maximum differential should be accomplished whenever any structural repairs are made to the fuselage to ensure the structural integrity of the repair. Also, a fuselage leakage test may be accomplished whenever it is deemed necessary to ensure that the fuselage is adequately sealed against leakage.

A source of compressed air is necessary to operate the air conditioning systems. The engines, the APU, or a mobile ground compressor may be used for this purpose. The circuit breaker for the control fan and venturi must be opened (pulled) to allow the outflow valves to close.

### Component Check-Out

Operation of the automatic pressure controller may be checked by the selection of a cabin altitude that is lower than the field elevation. Cabin pressure should increase at the selected rate to a value of 1 psi for each 2000 feet. When the controller is reset for a cabin altitude above field elevation, the cabin should depressurize at the selected rate.

Operation of the manual controller may be checked by rotating the control knob to "INCREASE" and then "DECREASE." Cabin pressure should increase and decrease according to the selection at a rate determined by how far the knob is rotated.

Either controller may be used for a check of the outflow valves. Cabin pressure should increase and decrease according to the selections. During the test, a visual check should be made to ensure that both valves are operating.

## Pressure Test for Structural Repair

To check the integrity of a structural repair to the fuselage, the cabin should be pressurized to maximum differential pressure. The manual pressure controller must be used for this test. The control knob is set for a confortable rate of increase, and the differential pressure indicator is monitored. The pressure should increase to, and stabilize at, 8.3 psid. It may be necessary to operate the engines (two) in order to have sufficient airflow to obtain maximum differential pressure. When maximum differential is reached, the controller is set for a confortable rate of decrease to depressurize the aircraft. Emergency depressurization may be checked at this time, if desired.

## Cabin Leakage Check

To ensure proper sealing of the fuselage, a leakage test may be made whenever it is deemed necessary. For this test, the electronics equipment cooling system flow control valve must be removed and the discharge duct must be capped. The fuselage is then pressurized as in the test for structural repair. When the pressure reaches maximum differential, the air conditioning should be shut off with the SYSTEM SHUTOFF switches. The pressure drop from 7.5 psi to 5.5 psi should be timed with a stop watch. If the time required for the 2 psi pressure drop is less than 2 minutes, there is excessive leakage and corrective action should be taken.

## External Pressurization

The aircraft can be pressurized from outside, if, for some reason, it is undesirable to do so from inside. An external ground pressure test fitting is provided in the nose wheel well for this purpose. A mobile ground compressor can be used to supply compressed air directly into the fuselage. Gages may be connected so that the differential pressure and rate of change can be monitored.

## *STUDY QUESTIONS*

1. *The term "isobaric" means ______________________________.*
2. *"Pressurizing an aircraft" means ________________________.*
3. *During flight, the air used to pressurize the StarLifter is obtained from __________________________________.*
4. *Cabin pressure is controlled by ____________________________.*
5. *The StarLifter can maintain sea level pressure in the cabin until the aircraft reaches ______________ feet.*
6. *An _________ foot cabin altitude can be maintained at at 40,000 feet.*
7. *A normal maximum differential pressure of _________ psid is used in the StarLifter.*
8. *What pressure should the manifold pressure indicator show if the aircraft is at 21,000 feet and climbing? Ans: Approximately _______________ psi.*
9. *What is the force exerted against the crew entrance door (approximately 30 x 60 inches) at a differential pressure of 8 psi? Ans: ____________________ pounds.*
10. *What is the purpose of the outflow valves _____________________________________________________________.*
11. *What is the purpose of the control venturi? _________________________________________________________.*
12. *Where is the control venturi located? _________________________________________________________.*
13. *What is the purpose of the control fan and venturi? _________________________________________________________.*
14. *Where is the control fan and venturi assembly located? _________________________________________________________.*
15. *The isobaric range of the pressure controller is selective from ________ feet to ________ feet cabin altitude.*
16. *The cabin rate selection limits are _________ to ______ fpm.*
17. *What is the function of the differential control in the automatic pressure controller? _________________________________________________________.*

18. Refer to No. 17. At what pressure does it operate? ______________ psid.

19. At what pressure do the safety valves relieve?_____ psid.

20. What is the purpose of the cabin altitude limit control? ______________________________.

21. Refer to 20. How does it operate?____________________.

22. How do the safety valves operate to provide overpressure relief?______________________________.

23. What is the purpose of the pneumatic relay in the outflow valve?______________________________.

24. Does the AIR COND MASTER switch in any way control pressurization? If so, how?____________________ ______________________________.

25. What units in the automatic pressure controller regulate the movement of the isobaric metering valve?__________ ______________________________.

26. How would cabin pressurization be affected if the rate filter becomes clogged?____________________.

27. How would cabin pressurization be affected if a pneumatic relay diaphragm ruptured?____________________.

28. List the actions that would take place if an emergency depressurization switch is positioned to "DEPRESS."

______________________________

______________________________

______________________________.

29. Where is the cabin pressure low warning switch located?

______________________________.

30. The manual emergency depressurization hatch is actuated by______________ located on ____________________.

31. Assume that the aircraft is cruising in a normal, pressurized condition. Suddenly, the CABIN PRESS LOW warning lights illuminate. What should the crew do?

______________________________

______________________________.

## WING LEADING EDGE ANTI-ICING SYSTEM

The StarLifter wing is protected by an evaporative anti-icing system which uses engine bleed air as the primary heat source. Basically, the system heats the leading edge surface by using a jet pump to circulate a mixture of bleed air and leading edge plenum air through double-skin heat transfer passages.

Figure 6-1 shows a cross-sectional view of a typical wing leading edge section.

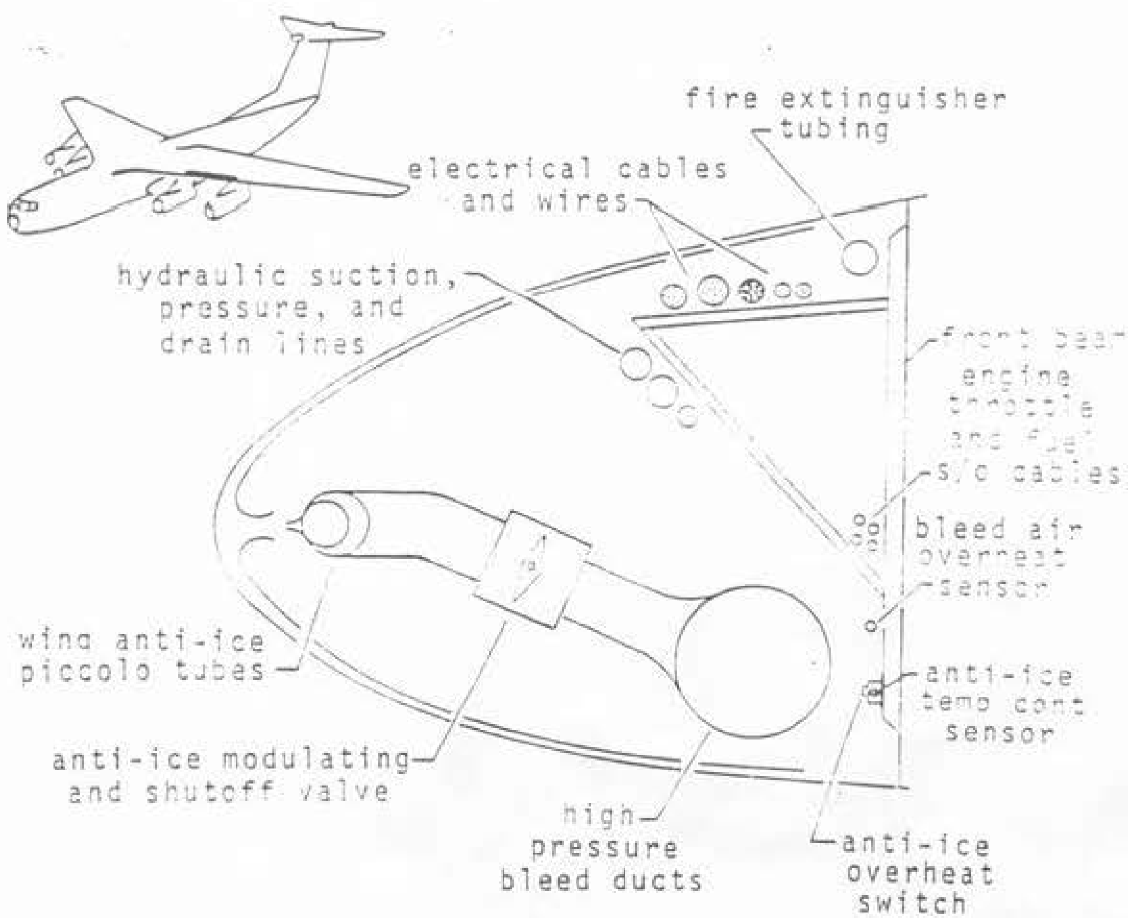



FIGURE 6-1. WING LEADING EDGE SECTION

The bleed air manifold supplies air to a modulating control valve which regulates the airflow to the jet pump. The jet pump is comprised of a long tube with a forward-facing row of 0.040-inch diameter nozzles, spaced 40 per foot. This tube, called a "piccolo tube," distributes the air throughout the leading edge section. Figure 6-2 shows a typical piccolo tube installation.

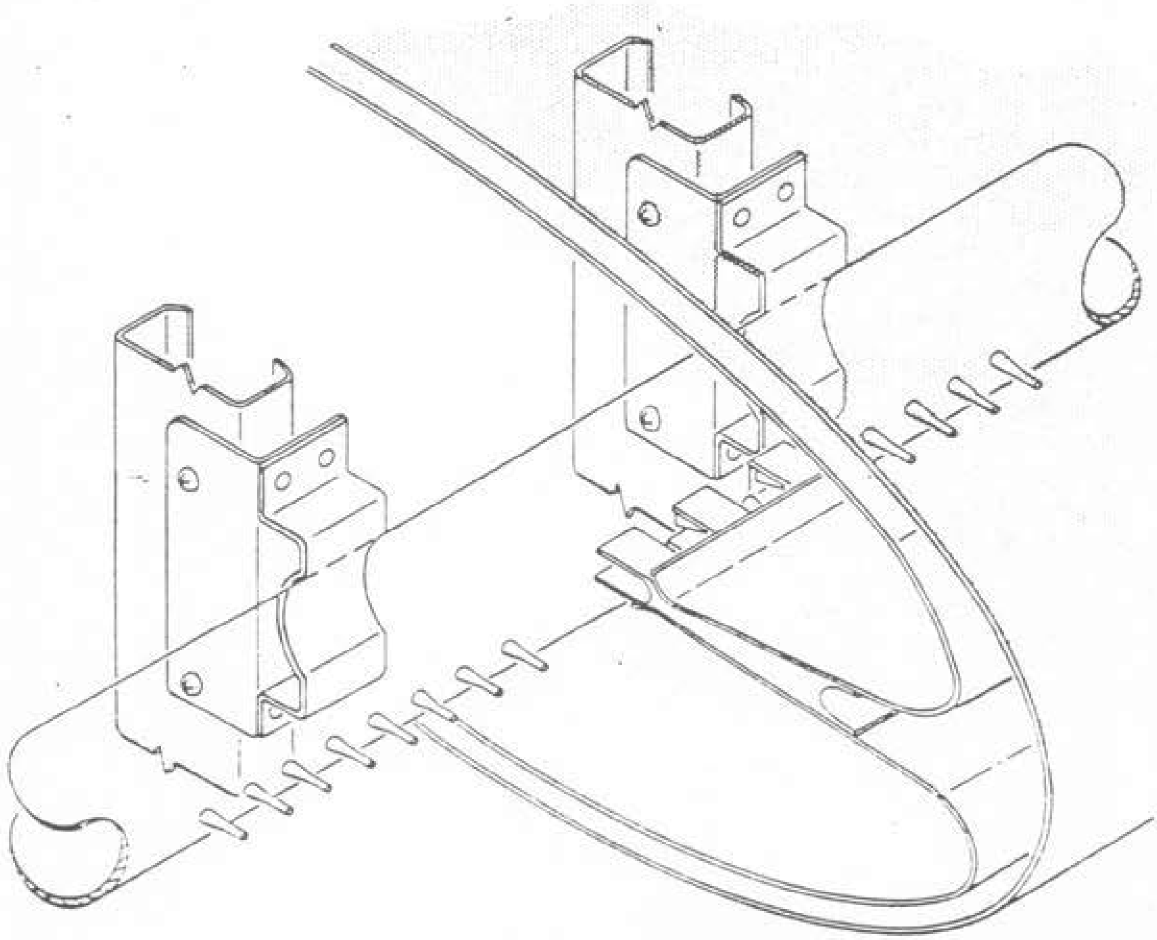


FIGURE 6-2. ANTI-ICING PICCOLO TUBE - WING

From the piccolo tube, the bleed air discharges through the nozzles into the mixing section, where it mixes with ambient leading edge plenum air drawn in by the jet pump effect. The resulting mixture flows into the double-skin heat transfer passages which extend along the upper and lower leading edge surfaces to about 2 inches forward of the front wing beam. As the air circulates through the leading edge, it flows outward and discharges through a hole provided in the wing tip.

The anti-iced surfaces consist of three leading edge sections on each wing: one section between the engine pylons, and two sections outboard of the No. 1 and No. 4 pylons. The leading edge section between the pylons is called the mid-section; the section immediately outboard of the outboard pylon is called the inner-outboard section; and the section nearest the wing tip is referred to as the outboard section. The inboard wing sections, between the inboard pylons and the fuselage, have no anti-icing provisions. Each anti-iced section is protected by a piccolo tube supplied by a control valve. Bleed air is supplied to the inboard end of each piccolo tube. Figure 6-3 shows the anti-icing system component locations for the left wing. Overheat thermal switches are mounted on the wing spar in each section along with control thermostats for the valves.

## ANTI-ICING CONTROL VALVE

All six anti-icing control valves are identical. A schematic cutaway view of the valve is shown in Figure 6-4. It is solenoid-controlled, air-actuated, spring-loaded closed, energized open, and modulated by a temperature sensing pneumatic thermostat. The valve serves as a shutoff valve and as a modulating temperature control valve. All of the valves are controlled by switches on the Anti-Icing Control Panel.

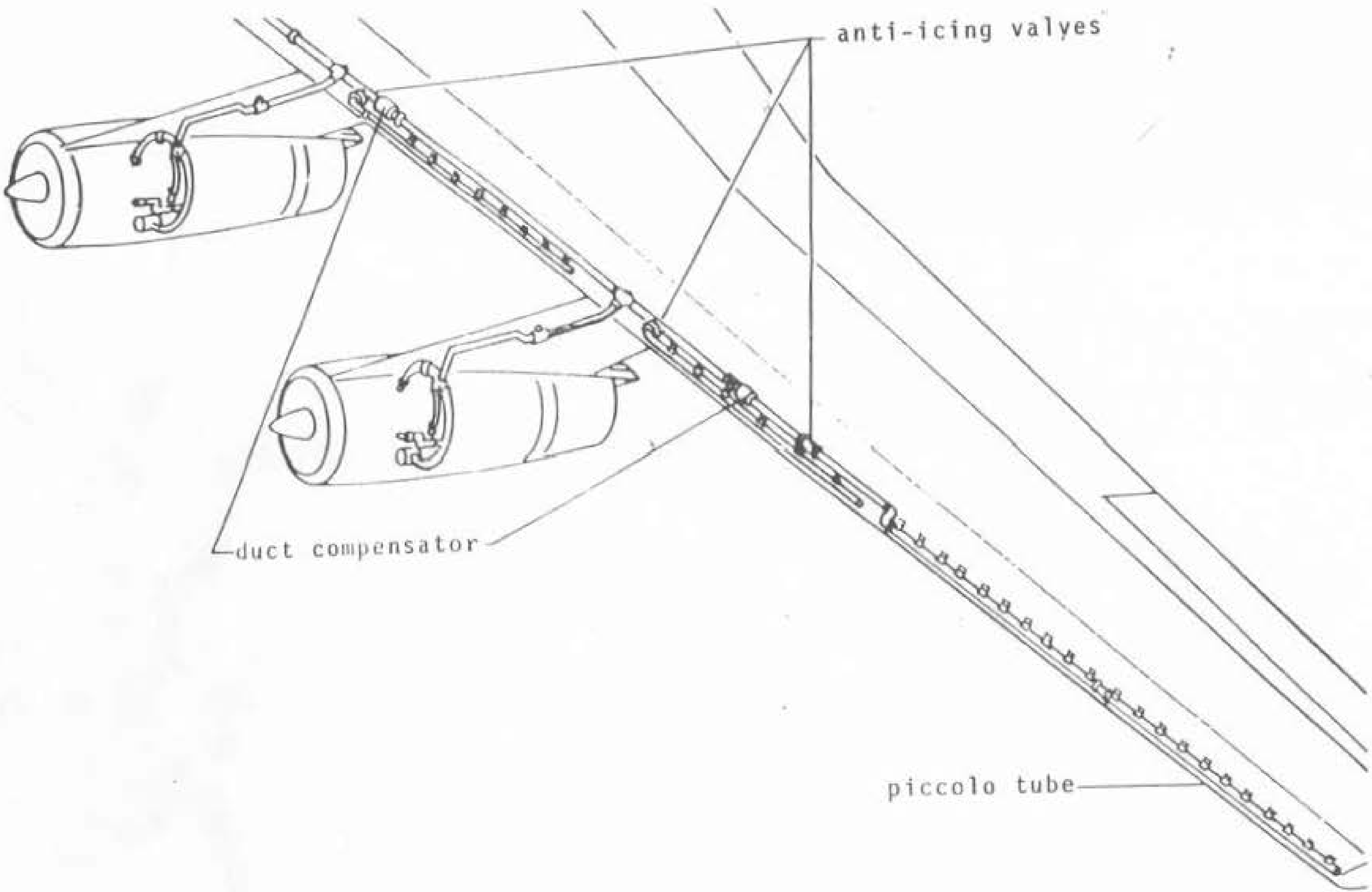
## ANTI-ICING CONTROL PANEL

The Anti-Icing Control Panel is shown in Figure 6-5. It is located on the left side of the overhead console. In addition to the wing leading edge anti-icing controls, it contains the controls for the ice detector, engine anti-icing, empennage de-icing (which is electric), angle-of-attack de-icing, pitot heat, and anti-icing of the total temperature probe. Three switches for wing leading edge anti-icing are located along the bottom left edge of the panel. Just above each switch is a group of four annunciator lights which allows the pilot to monitor system operation.

## SYSTEM OPERATION

Figure 6-6 shows a flow schematic of the system for the right wing. Operation is manual in that the control switches must be placed in the "ON" position to activate the system. When anti-icing is no longer required, the system must be turned off by placing the control switches in the "OFF" position. However, when the system is operating, each valve is automatically controlled by its own control thermostat.

Activation of the valves is accomplished in pairs: Two valves located at the same wing station in opposite wings are energized by the same switch. Therefore, symmetrical ice protection is provided by each switch if the pilot elects to anti-ice only a portion of the wing.




WING LEADING EDGE ANTI-ICING COMPONENT LOCATIONS

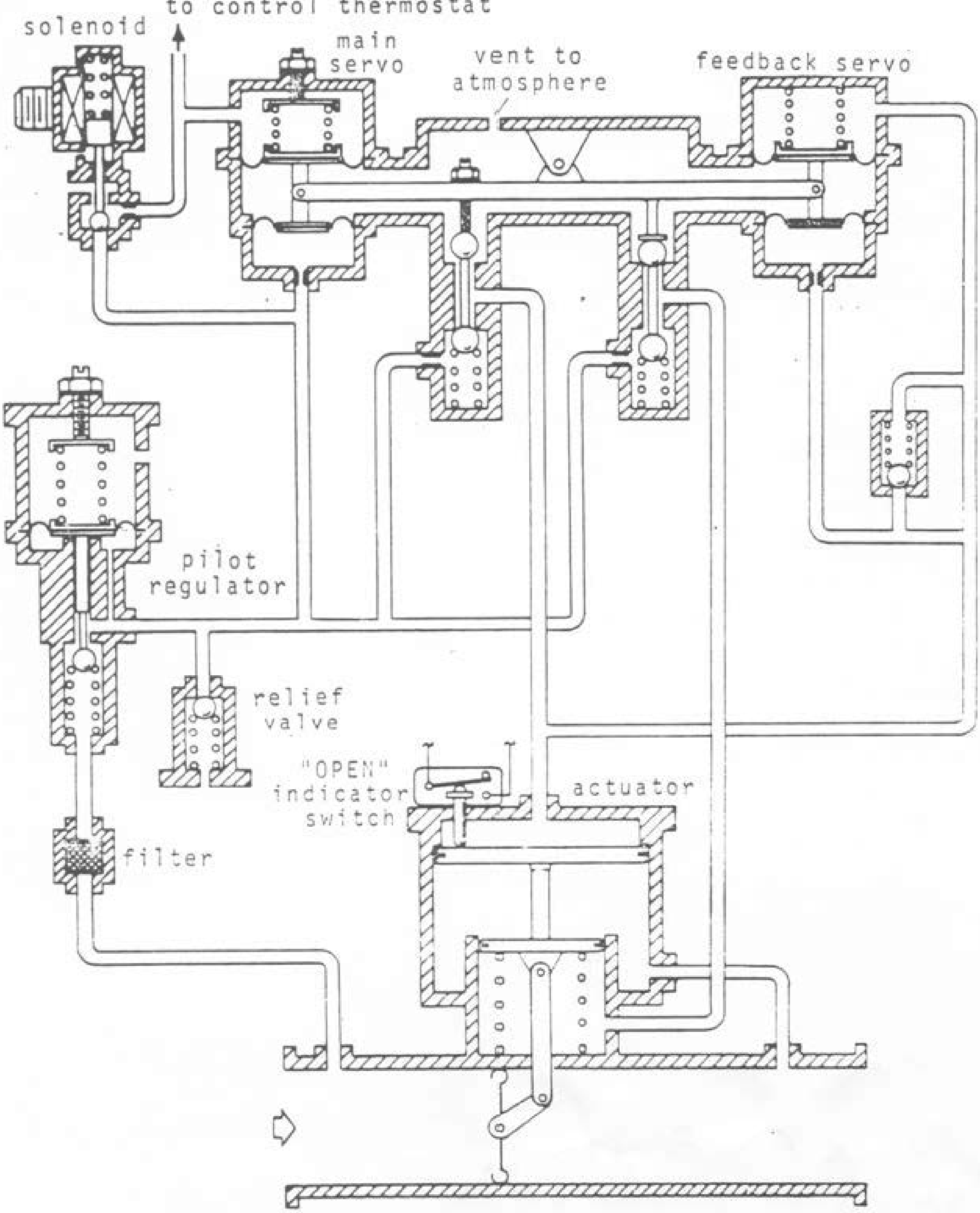



FIGURE 6-4. ANTI-ICING CONTROL PANEL

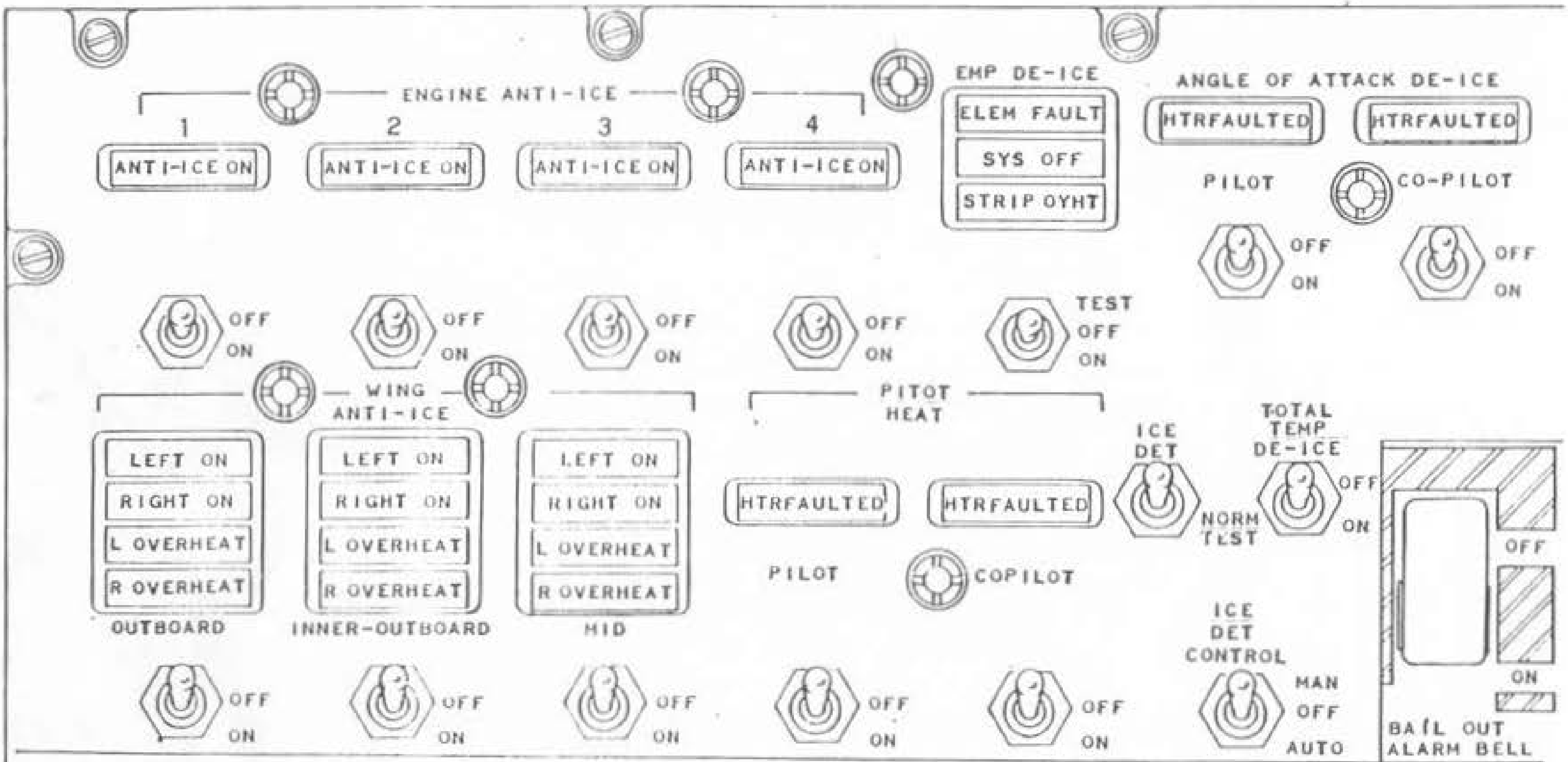



FIGURE 6-5. ANTI-ICING CONTROL PANEL

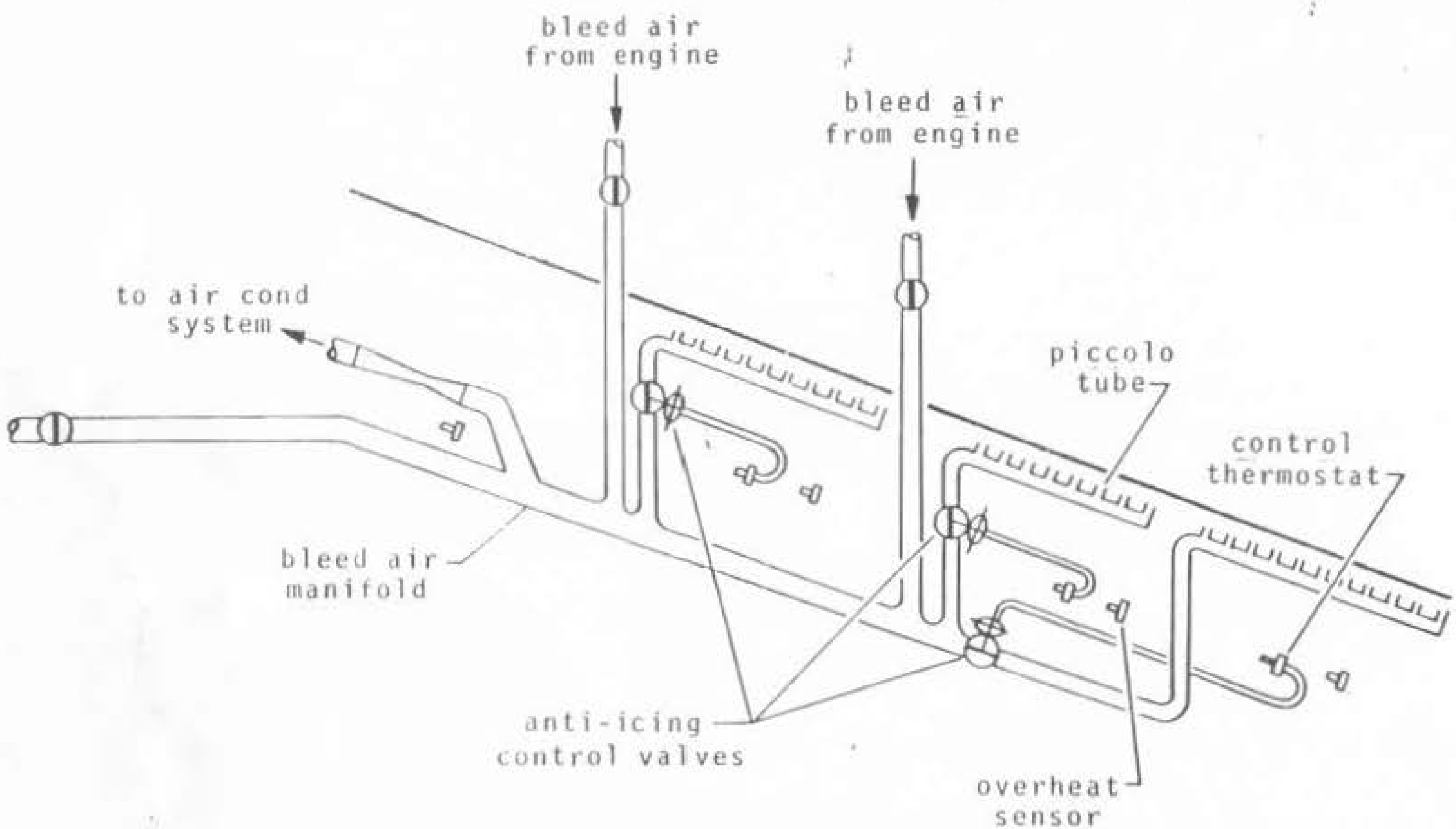



FIGURE 6-6. RIGHT WING LEADING EDGE ANTI-ICING

During operation, each valve modulates in response to temperature signals from its thermostat, which regulates the flow of air into its respective leading edge section in order to maintain the specified temperature for that section. The control settings for the thermostats are as follow:

| | |
|---|---|
| Mid-Section | 57°C (135°F) |
| Inner-Outboard Section | 71°C (160°F) |
| Outboard Section | 79°C (175°F) |

When the control switches are placed in the "ON" position, the LEFT ON and RIGHT ON indicator lights above each switch should illuminate. These lights are illuminated through microswitches in the individual valves. If any one of the lights fails to illuminate, it is an indication that the corresponding valve has failed to open.

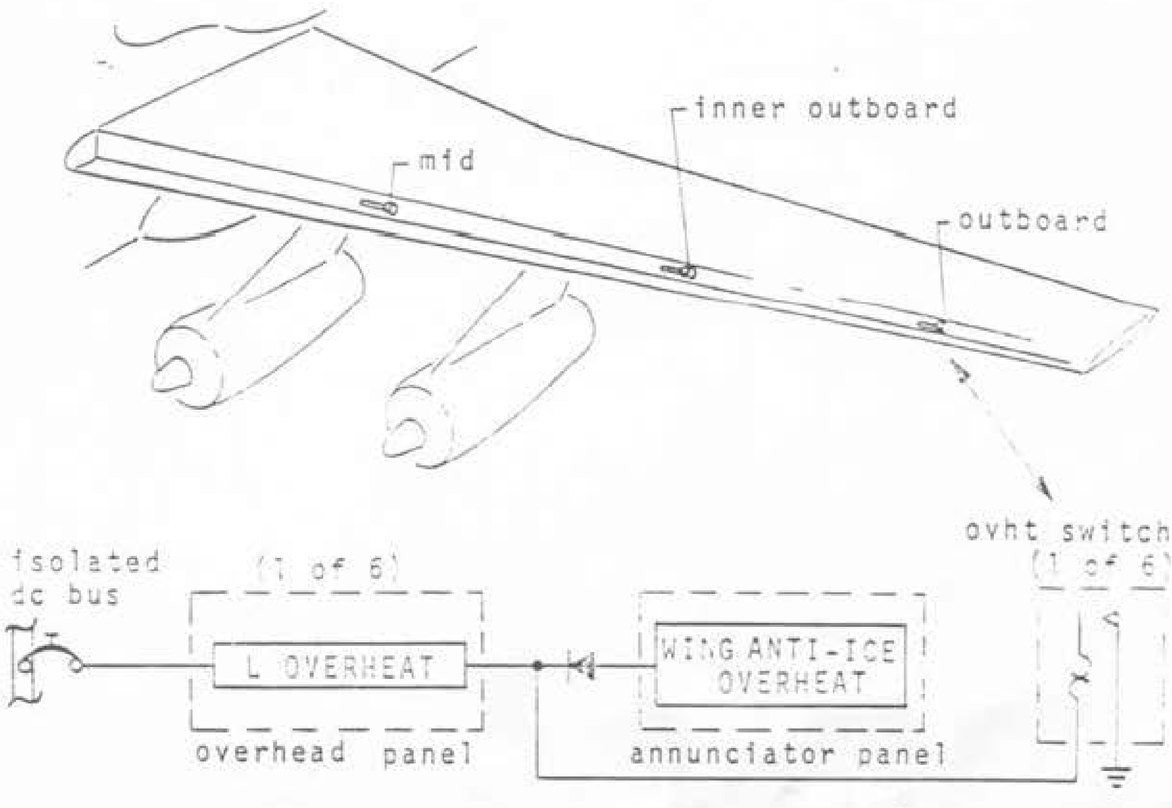



FIGURE 6-7. WING LEADING EDGE OVERHEAT WARNING SYSTEM

Excessively high temperatures within the leading edges could cause damage to surrounding equipment (wiring, sealing, etc.). To guard against such a condition, a bimetallic type thermal switch is installed in each section to provide a warning to the pilot if an overheat occurs as shown in Figure 6-7. The temperature settings of the thermal switches are 88°C (190°F) for the midsection and 105°C (220°F) for the two outboard sections. If a malfunction of a valve or thermostat allows the temperature within a leading edge section to reach the overheat themperature specified for that section, the thermal switch actuates to illuminate warning lights on the anti-icing control panel and the pilot's annunicator panel. When an overheat occurs, the pilot must shut off the anti-icing for the affected section.

*CAUTION*

*DO NOT OPERATE THE SYSTEM ON THE GROUND. When the system is first turned on, the control valves open fully for a few seconds before the control thermostats can sense the temperature and start controlling the valves. Since there is no cooling air flowing over the wings to dissipate the heat, the high temperature of the bleed air supplied during the initial opening of the valves may cause structural damage to the leading edge sections.*

*STUDY QUESTIONS*

1. *Anti-icing for the wing leading edges mixes bleed air with ambient air to provide ice control. (true or false)*

2. *What type of thermostats are used to control the anti-icing valves?* ____________________.

3. *What are the control temperature settings for the various leading edge sections?* ____________________.

4. *What temperature is considered an overheat within the respective leading edge sections* ____________________.

5. *Wing leading edge anti-icing is turned on automatically if ice is detected. (true or false).*

6. *Wing leading edge anti-icing is turned off automatically if an overheat occurs. (true or false).*

7. *Where is the outboard section anti-icing control valve located________________________________________.*

8. *What indication is given if an overheat occurs within a leading edge section?______________________________.*

9. *What indication is given if an anti-icing valve fails to open when the system is turned on?__________________.*

10. *What access is provided to the anti-icing system components for maintenance purposes?_________________________.*

# MISCELLANEOUS SYSTEMS

## WINDSHIELD RAIN REMOVAL SYSTEM

The StarLifter is equipped with a jet blast rain removal system. The pilot's and copilot's windshields are cleared by high-temperature, high-velocity air supplied through slot-type nozzles at the base of the windshields. Bleed air is supplied from the output of the primary heat exchangers. The system is controlled by a switch on the overhead console which provides individual selections for the pilot and copilot. Figure 7-1 shows the rain removal system control panel.

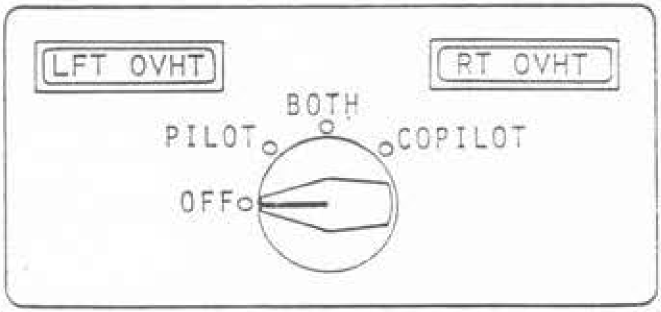



FIGURE 7-1. RAIN REMOVAL SYSTEM CONTROL PANEL

### System Components

A flow schematic of the rain removal system is shown in Figure 7-2. Four valves are used to control the supply and distribution of air to the nozzles. A venturi is installed in each supply line to limit airflow to a maximum of 72 ppm in the event of a ruptured duct or component malfunction. The two supply ducts join together in the center wing section to form a single duct which then carries the air forward through the cargo compartment and under the flight station floor. A 3-inch diameter check valve is installed in each supply duct just upstream of the junction.

### Pressure Regulator and Shutoff Valves

A pressure regulator and shutoff valve is installed in each rain removal supply duct in the center wing leading edge section. Figure 7-3 shows a schematic cutaway of the valve. It is solenoid-controlled, air-actuated,

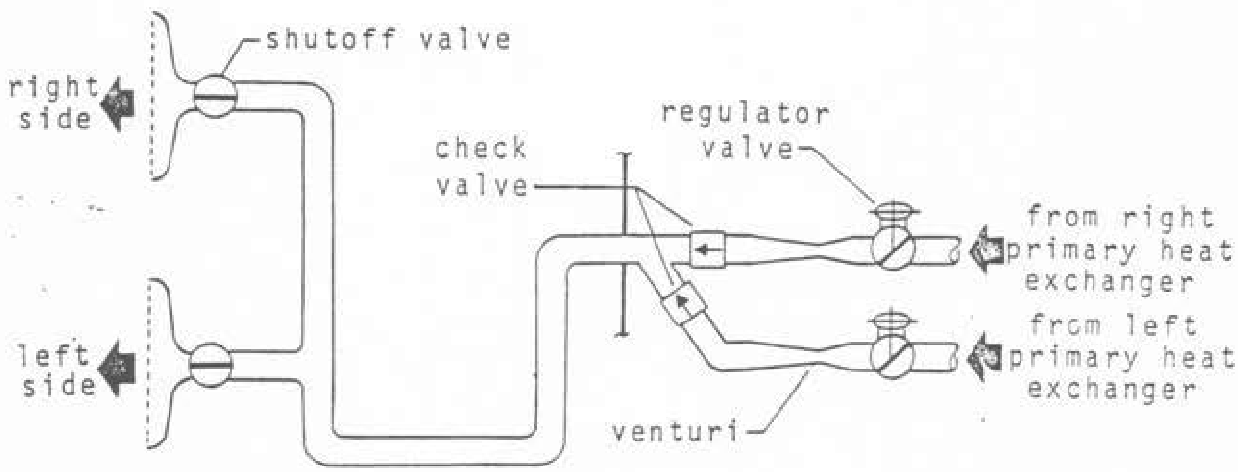



FIGURE 7-2. RAIN REMOVAL SYSTEM

spring-loaded closed, and energized open. When open, the valve regulates air pressure to 20 psig. Both valves are identical, and both valves are opened when the rain removal system is turned on.

Nozzle Shutoff Valves

Individual nozzle shutoff valves are installed in the system to provide rain removal for the pilot's and copilot's windshields separately or together. They are motor-driven butterfly valves, powered by 28-volt dc, and are controlled by the rain removal selector switch. The valves are located in the nozzle supply ducts under the pilot's and copilot's side consoles. Access panels are provided in the sides of the consoles at floor level.

## System Operation

The electrical control schematic for the system is shown in Figure 7-4. When the selector switch is positioned to "PILOT," only the left-hand nozzle shutoff is driven open. In the "COPILOT" position, only the right-hand nozzle shutoff valve is driven open. In the "BOTH" position, both shutoff valves are driven open. In all three of the "on" positions, both pressure regulator valves are energized open to ensure a supply of air as long as there is an output from either one of the primary heat exchangers.

Any time the system is turned on, power is removed from the NESA heat system for the affected windshield(s) in order to prevent a windshield overheat condition. However, if an overheat condition does occur, a warning is provided, and the pilot should shutoff the air supply to the affected panel. Temperature sensing thermistors, imbedded in the windshield panels, activate the overheat warning

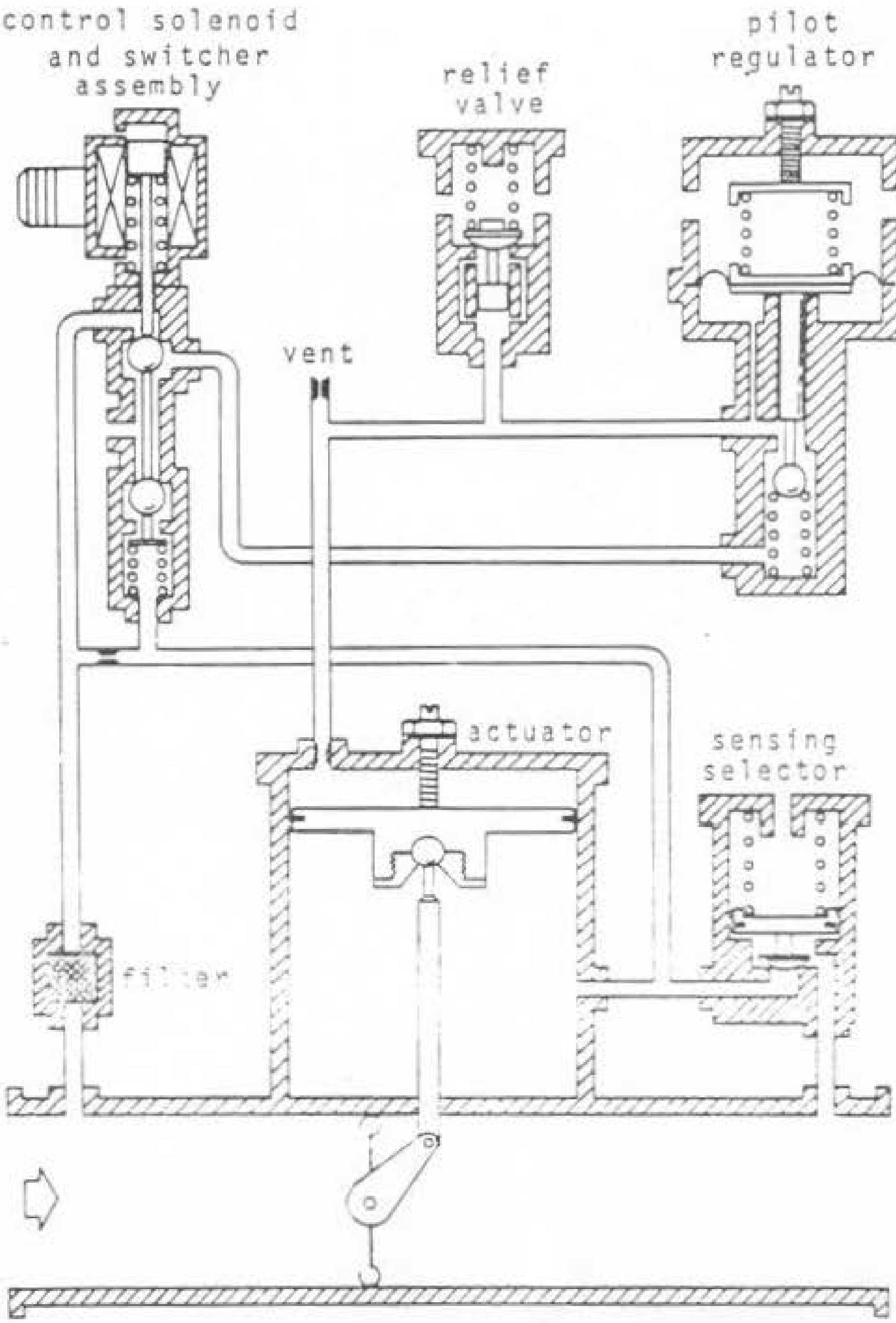



FIGURE 7-3. RAIN REMOVAL PRESSURE
REGULATOR AND SHUTOFF VALVE

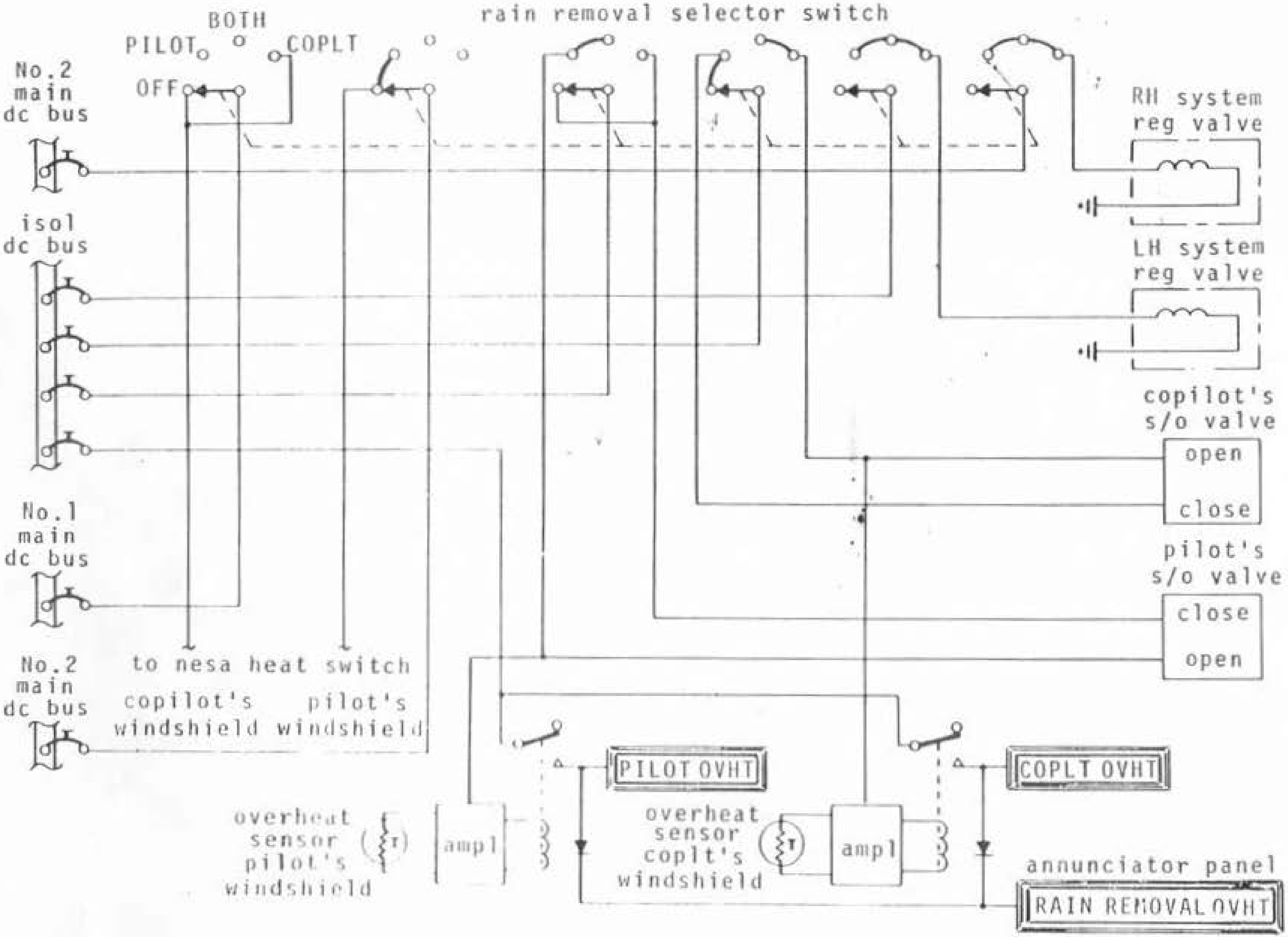



FIGURE 7-4. RAIN REMOVAL SYSTEM CONTROL SCHEMATIC

system at a windshield temperature of 82°C (180°F). When activated, the over-heat warning system illuminates appropriate indicator lights on the rain removal control panel and the pilot's annunicator panel.

## SMOKE DETECTION SYSTEM

A smoke detection system is installed in the aircraft to provide a warning if a smoke-producing, potential fire condition exists. Five smoke detectors are strategically located throughout the fuselage. If smoke is detected by any one of the units, warning lights are illuminated on the Smoke Detector Test Panel and on the Pilot's Annunciator Panel.

### Components

The smoke detector system consists of five detector units, a control amplifier, and the test panel. The test panel is located at the flight engineer's station and contains a selector switch and a CARGO SMOKE indicator light as shown in Figure 7-5. The control amplifier is located under the flight station floor on the left side.

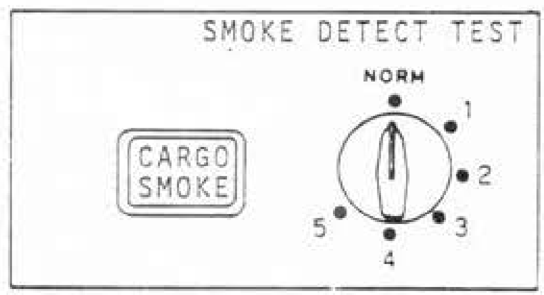
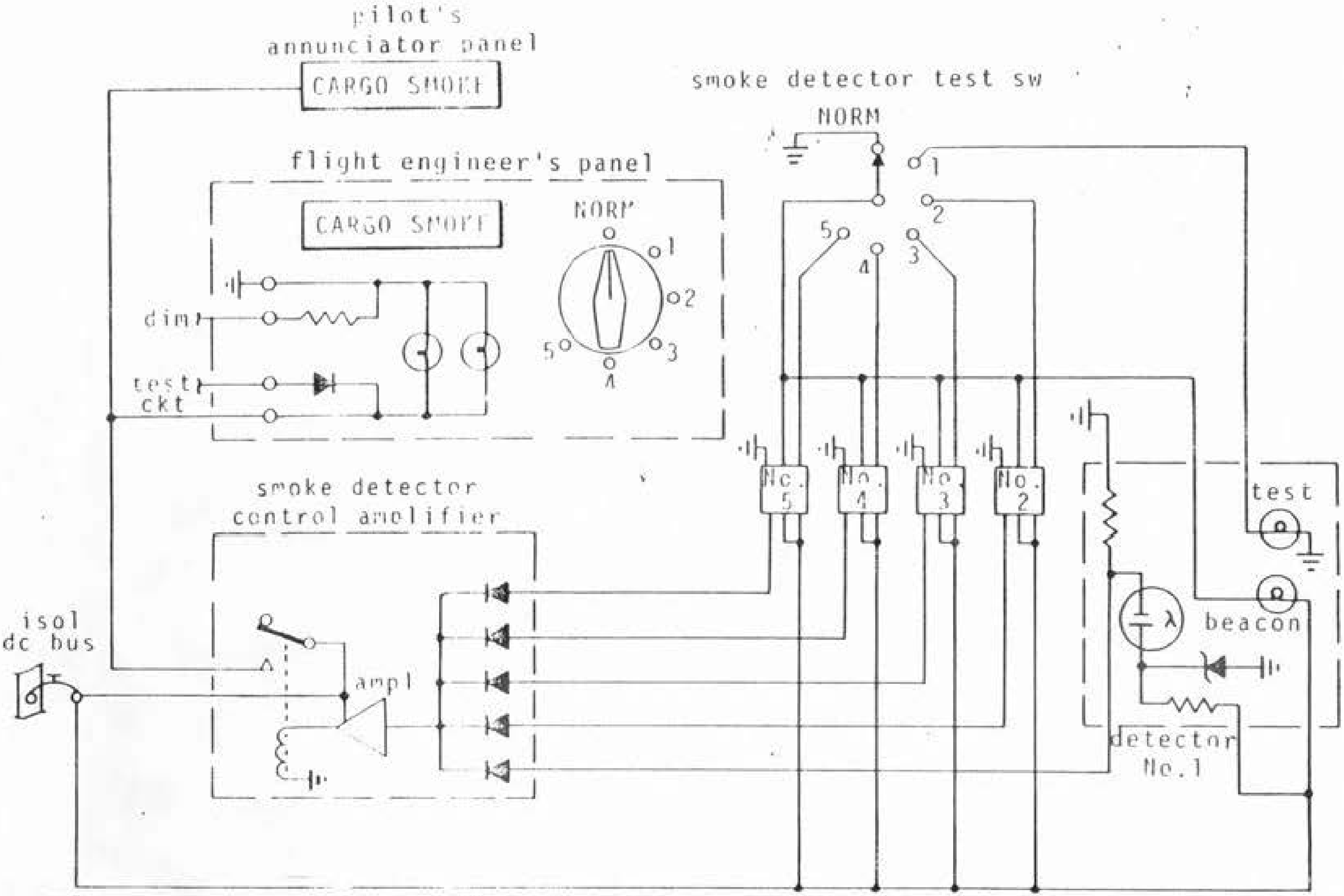



FIGURE 7-5. SMOKE DETECTION TEST CONTROL PANEL

### Operation

Figure 7-6 shows the electrical schematic of the smoke detection system and the locations of the detectors. The detector contains two lamps, a photo-electric cell, and a voltage divider circuit. The illumination from the beacon lamp is shielded from the photo-cell. When smoke enters the detector, it causes the light to diffuse and strike the photo-cell. Figure 7-7 shows the arrangement of the lamps and photo-cell. When light strikes the photo-cell, it conducts to provide a signal to the control amplifier. This signal triggers a transistor circuit which then energizes a relay to provide power for the indicator lights.

To test the system, the selector switch is rotated through the test positions "1" through "5." In test, the test lamp is illuminated to shine directly on the photo-cell and produce the required signal to the control amplifier. The warning lights should illuminate when the switch is rotated to the first test position and should remain illuminated through subsequent test positions until




| | | | | | |
|---|---|---|---|---|---|
| detector location: | 1 - FS 498 | 2 - FS 1098 | 3 - FS 1378 LH | 4 - FS 1378 RH | 5 - FS 395 |

FIGURE 7-6. SMOKE DETECTION SYSTEM SCHEMATIC

the switch is returned to the "NORM" position. The photo-cell continues to conduct for three or four seconds after power has been removed from the lamp. It is therefore necessary to pause at each test position to give the previous detector time to de-activate. The detectors may also be tested by holding a burning cigarette directly under the unit.

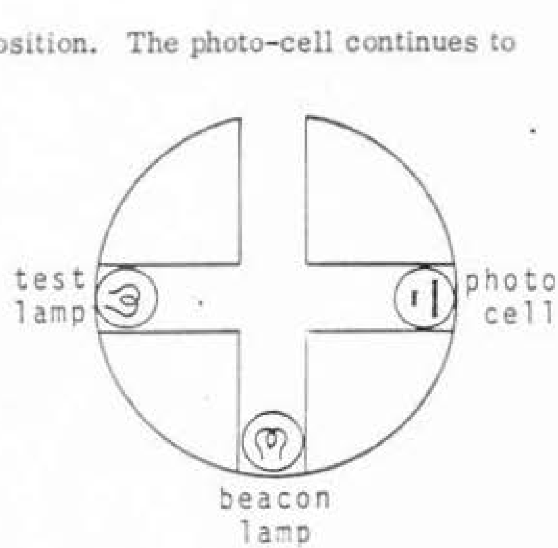



FIGURE 7-7. SMOKE DETECTOR

Smoke Evacuation

To evacuate a heavy accumulation of smoke from the cabin, the flight engineer should select "RAM" on the AIR COND MASTER switch. This action opens the outflow valves to depressurize the aircraft for rapid evacuation of smoke, and, at the same time, provides fresh air ventilation. A small, manually controlled panel just aft of the pilot's windshield may also be opened to help clear smoke from the flight station.

*STUDY QUESTIONS*

1. *Air for rain removal is supplied from ________________.*

2. *Rain removal air is supplied to the nozzle shutoff valves at a pressure of ____________________ psig.*

3. *The pilot does not need to shut off the windshield NESA heat when the rain removal system is operating (true or false).*

4. *The rain removal system is automatically shut off if an overheat occurs. (true or false).*

5. *Where are the rain removal system nozzle shut off valves located? ________________________________.*

6. *Where are the rain removal system pressure regulator valves located? ____________________________.*

7. Name the positions of the rain removal selector switch and list the valves that are open in each position.

______________________________________________

______________________________________________.

8. The smoke detection system activates the fire extinguishing system when smoke is detected. (true or false).

9. What is the procedure for testing the smoke detection system? ______________________________________________.

10. What is the procedure for smoke evacuation? ____________

______________________________________________.