MAY 1958 SECRET

ARROW 2
AIR CONDITIONING SYSTEM

REPORT No.72/SYSTEMS 22/48-2

ENGINEERING DIVISION

AVRO AIRCRAFT LIMITED.

ARROW 2

AIR CONDITIONING SYSTEM

Report No. 72/Systems 22/48-2

MAY 1958

This brochure is intended to provide an accurate description of the system(s) or service(s) for the ARROW 2 at the time of writing, and is not to be considered binding with respect to changes which may occur subsequent to the date of publication

Revised by ____________ Approved by ____________

Authorized by ____________

Engineering Division
Avro Aircraft Limited
Malton - Ontario

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1.0 SUMMARY

This report describes the air cycle air conditioning system installed in the ARROW 2 aircraft, the description being such, as to permit an understanding of how the system functions. Background to system design philosophy is provided by including a review of the problems involved, as well as a summary of the design requirements and objectives established.

2.0 INTRODUCTION

The ARROW 2 air conditioning system design has been influenced by the performance capabilities of the aircraft. High speed operation of the aircraft at altitudes up to 60,000 feet, in all types of weather, results in a wide variation of compartment temperatures. In addition, kinetic heating at sustained supersonic speeds and heat generated by elaborate electronic equipment create an unusually high demand on system cooling capacity. To further complicate the problem, the system must provide cockpit pressurization, and closely control the temperature of the air supplied to both the cockpit and the equipment compartments.

Apart from performance adequacy, weight and space requirements are prime considerations in system design. These are generally governed by the limitations which may be imposed on system performance and the type of system selected. Comfort requirements in military combat aircraft permit performance limitations which generally favour the design of a light-weight system with minimum space requirements.

In the design of the air conditioning system temperature and pressure are the most important factors. Humidity, ventilating air velocity, and noise, need only be considered when their effect could cause undue discomfort to the crew members. Air freshness is not a real problem on the ARROW 2 since oxygen would normally be used throughout the entire flight. A suitable crew environment can be provided and maintained when these factors are carefully weighed and considered.

With skin temperatures in the neighborhood of $+250^{\circ}F$ at maximum aircraft speed, some aircraft equipment requires cooling. Reliability of the weapon system as a whole can be assured only by temperature control of the electronic equipment and missile environment.

3.0 DESIGN REQUIREMENT AND OBJECTIVES

The general requirements for the design of ARROW 2 air conditioning system are outlined in specifications WSC 1-2, CAP 479 and ARDCM 80-1 These may be summarized briefly as the provision of a suitable cockpit environment, and the provision of an equipment environment which ensures reliable operation of all components.

3.1 COCKPIT

Limits laid down for cockpit pressure and temperature are:

(a) Pressure - a desirable maximum of 25,000 feet and a limit of 27,000 feet for cockpit pressure altitude.

(b) Temperature - a range controlled by the pilot varying from 40°F to 80°F.

No definite limits are set for humidity, and air velocity, but the combined effect of these factors must not cause undue crew discomfort. The elimination of disturbing or annoying drafts and noises is necessary to prevent fatigue of crew members and maintain their efficiency and alertness at a desirable level.

Studies have shown that pressure and temperature requirements can be met with a cockpit airflow of 27.5 lb/min, at inlet temperatures ranging from 16°F to 100°F.

Acceptability of the cockpit environment will be proven by ground and flight test.

Emergency equipment is required to restrict pressure and temperature to tolerable limits in the event of normal system failure.

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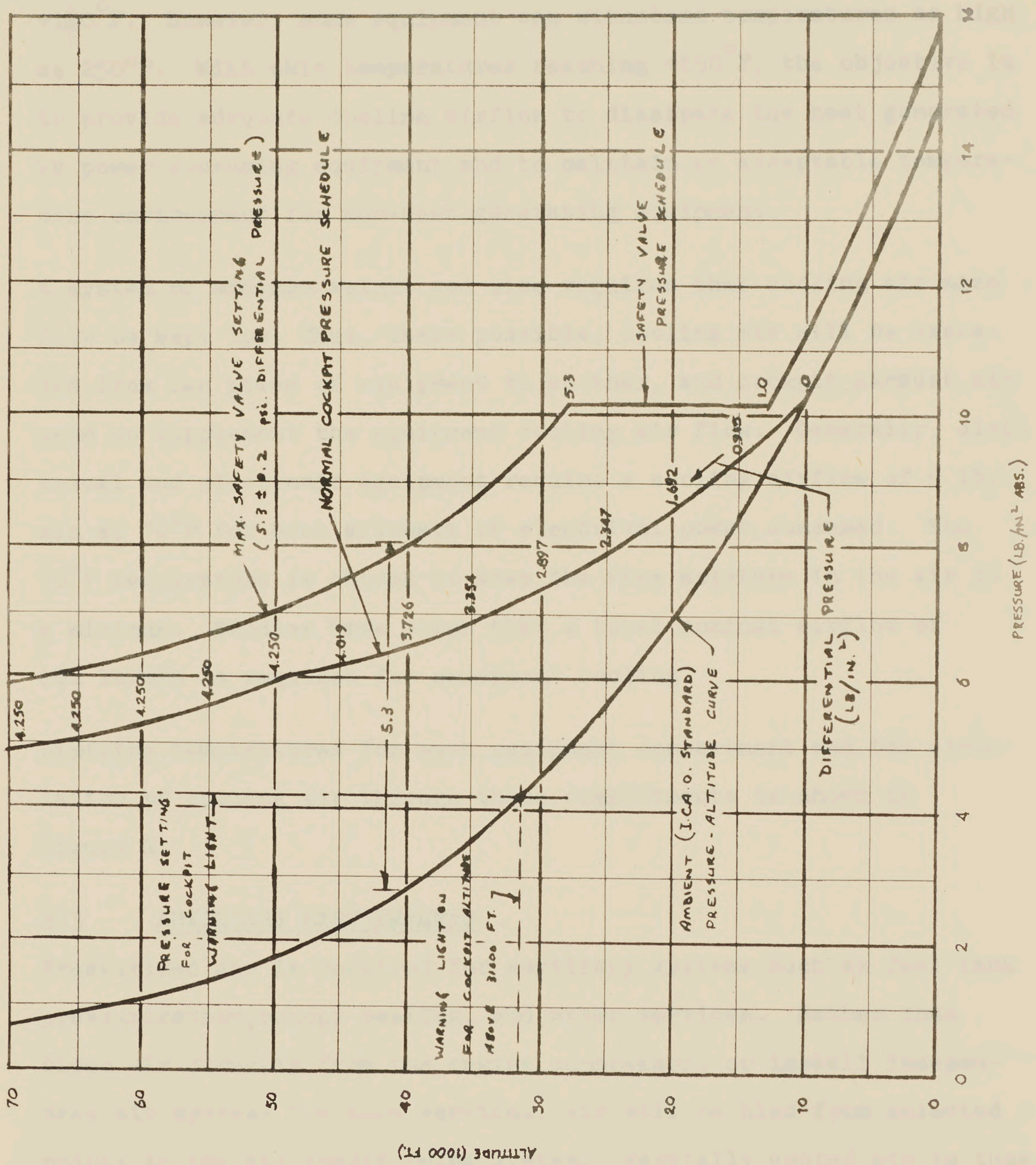


FIG. 1 VARIATION OF COCKPIT PRESSURE WITH ALTITUDE

3.2 EQUIPMENT COMPARTMENTS

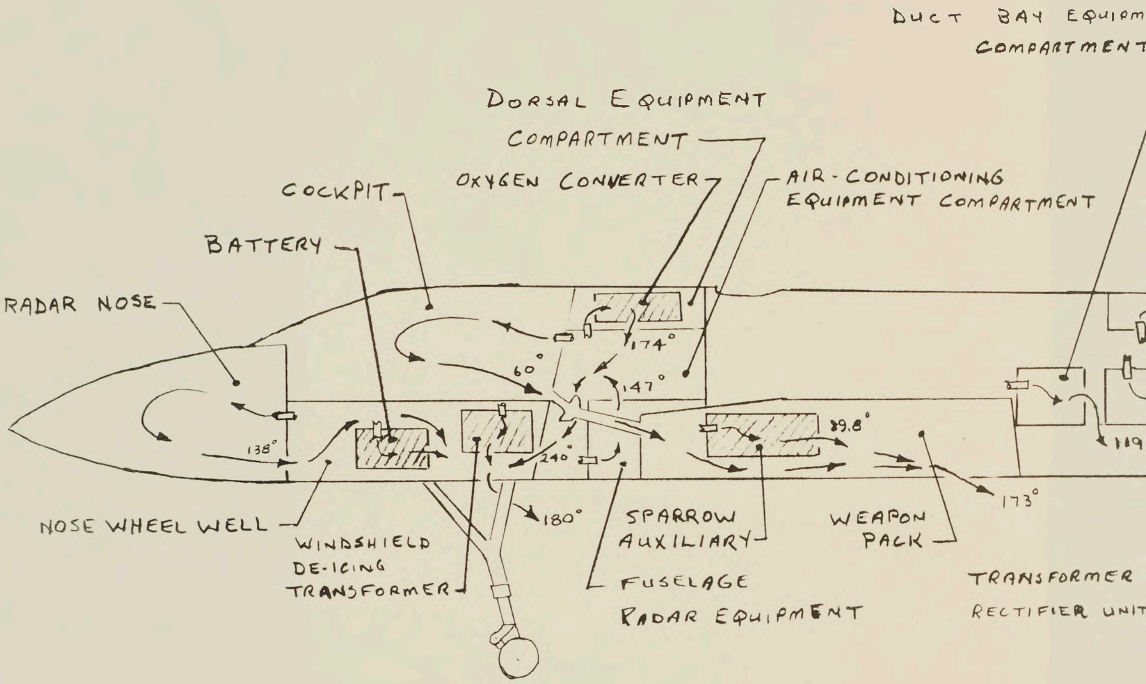
The operating temperature range for most equipment is - 65°F to +160°F. However, some equipment can withstand temperatures as high as 250°F. With skin temperatures reaching +250°F, the objective is to provide adequate cooling airflow to dissipate the heat generated by power-consuming equipment and to maintain an acceptable temperature environment for non-heat generating equipment.

A system of minimum weight and size requires that cooling air mass flow be kept low. Thus, where possible, cooling air will be cascaded from one piece of equipment to another, and cockpit exhaust air used to supplement the equipment cooling air flow. Generally, electrical and electronic equipment require a cooling airflow of 5 lb/min at 70°F for each kilowatt of electrical power consumed. The 70°F temperature is chosen to keep the free moisture in the air to a minimum. Studies have shown that a total nominal airflow of 122 lb/min is required for equipment cooling.

Limiting temperatures for each equipment compartment and the circulation of cooling air through these compartments is shown in Figure 2.

3.3 AUXILIARY REQUIREMENTS

Pressurized air is required for auxiliary systems such as fuel tank pressurization, canopy sealing, and other services. Rather than bleed air directly from the engine compressor, or install independent air systems for such services, air will be bled from selected points in the air conditioning system. Partially cooled air is thus supplied to these auxiliary systems.



NOTE - TEMPERATURES INDICATED ARE MAXIMUM EXHAUST TEMPERATURES OF COMPARTMENTS

FIGURE 2 - TEMPERATURE CON

AIR CIRCULATION A

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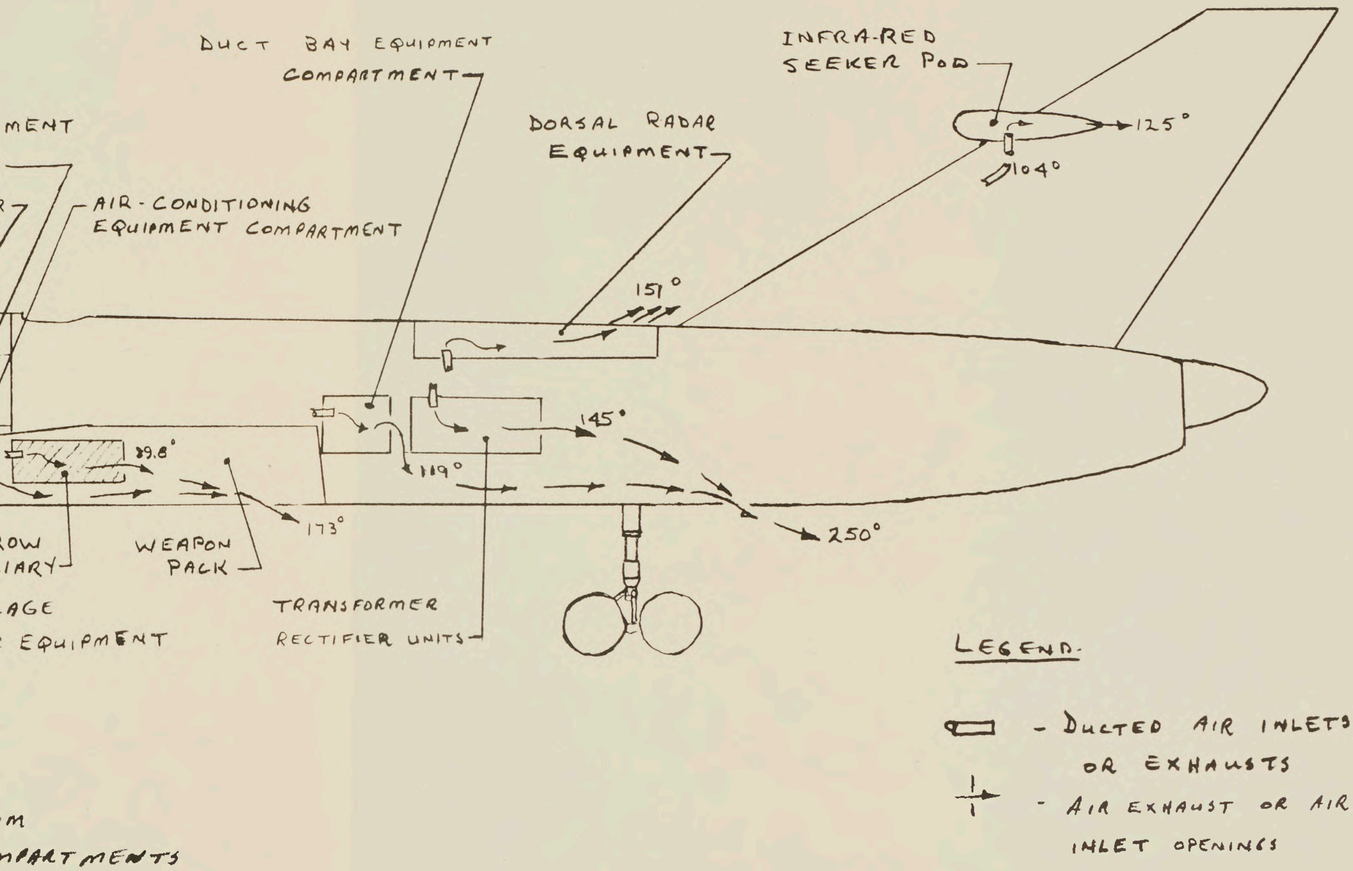

2 - TEMPERATURE CONTROLLED AREAS

AIR CIRCULATION AND AIR TEMPERATURES

3.4 SUMMARY OF AIRFLOWS REQUIRED

Air conditioning -

Cockpit - 27.5 lb/min at 16°F to 100 °F.

Equipment - 122 lb/min at 70°F.

Auxiliary Systems -

Low pressure pneumatics - negligible flow at 250°F max.

Fuel tank pressurization - 1 to 15 lb/min at 370°F max.

4.0 SYSTEM DESCRIPTION

4.1 GENERAL

The ARROW 2 is equipped with an air cycle air conditioning system. The main engine compressors are utilized for the compression portion of the cycle. The refrigeration section consists of an air-to-air heat exchanger, a water evaporator and an expansion turbine. Equipment cooling, cockpit pressurization, and heating and cooling, constitute the air conditioning load. The flow diagram for this basic system is shown in Figure 3(b).

The basic system control circuits regulate turbine flow rate, cockpit temperature and flow rate, equipment cooling air temperature, and cockpit pressure.

These circuits are in general fully automatic and require no attention from the pilot.

Provision is made for ground air-conditioning and emergency operation of the system. Auxiliary equipment extends the operating range of the system under conditions where system performance is deficient, and automatic safety devices provide protection against failure of temperature and pressure controls. Pilot-operated controls are provided for system control under abnormal conditions.

Tapping points are provided in the system to supply compressed air for:

1. Pressurization of fuel tanks
2. The oil systems associated with the engine installation
3. Low pressure pneumatic system
4. Pressurization of miscellaneous items of equipment.

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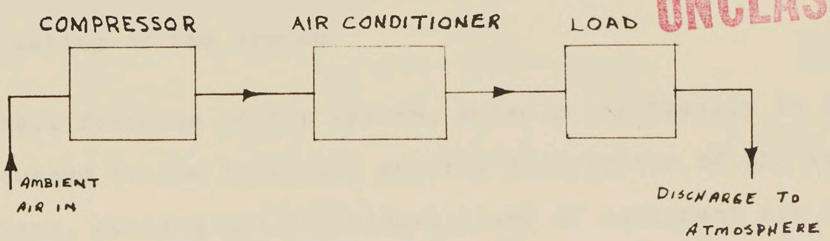

FIGURE 3 (a) - SIMPLE FLOW DIAGRAM - AIR CYCLE SYSTEM

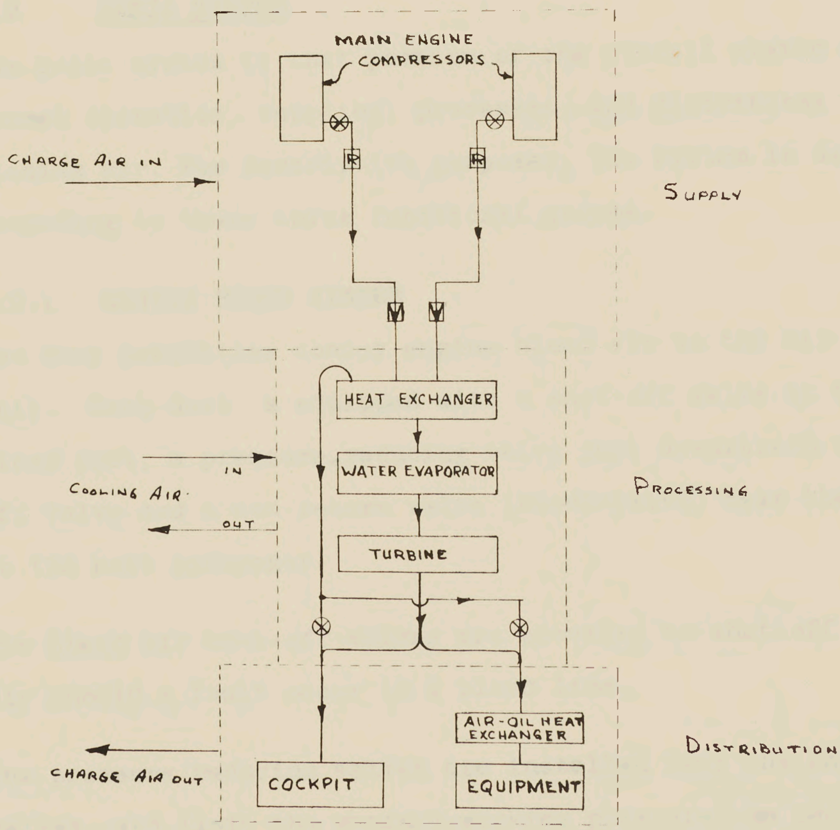

FIGURE 3 (b) - FLOW DIAGRAM - ARROW 2 BASIC SYSTEM

Pressure and temperature sensing points are provided to facilitate ground testing of the system.

The overall features of the system, shown schematically in Figure 4(a) are discussed in the following general description of the system. Sub-systems, ducting and individual items of equipment are considered in greater detail in subsequent sections of the report. Electrical control systems, for which theoretical circuits are shown in Figure 5, are also considered in the supplemental sections of the report.

4.2 BASIC SYSTEM

The basic system is that portion of the overall system which in normal operation, supplies, processes, and distributes the conditioning air. For descriptive purposes, the system is described according to these three functional groups.

4.2.1 ENGINE BLEED SYSTEM

Two duct assemblies convey engine bleed air to the air conditioning unit. Each duct is equipped with a shut-off valve at the engine bleed port, a pressure-reducing valve just downstream of the shut-off valve and a non-return valve (check-valve) near the duct entry to the heat exchanger.

The bleed air shut-off valves are provided to shut off the air supply should a fault occur in a bleed line.

The pressure reducing valves are installed near the engine bleed valves, and limit the maximum working pressures on ducting and equipment. The valves limit bleed air pressure to 60 psig.

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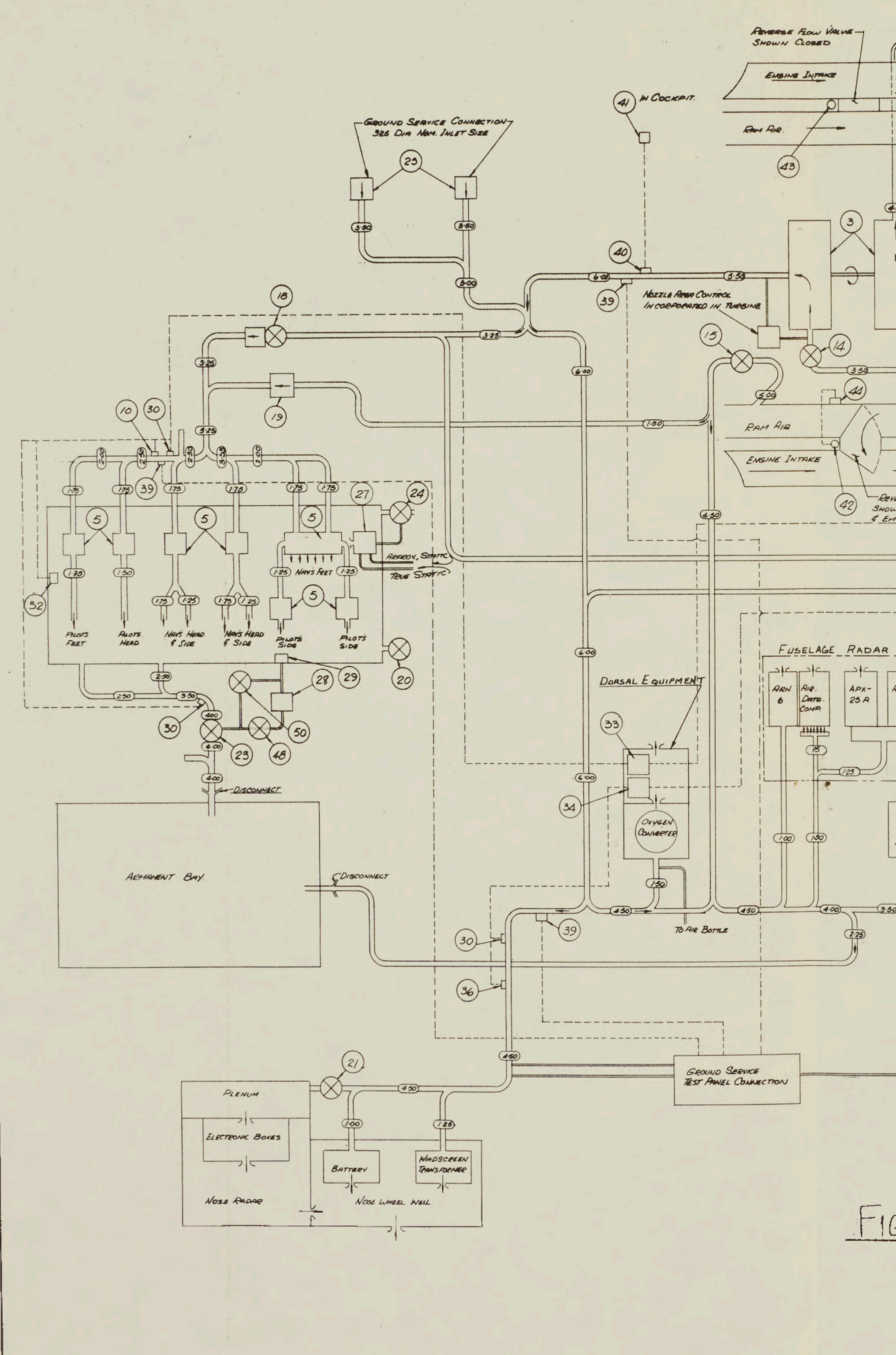

FIG

REPORT ERRORS TO DESIGN OFFICE

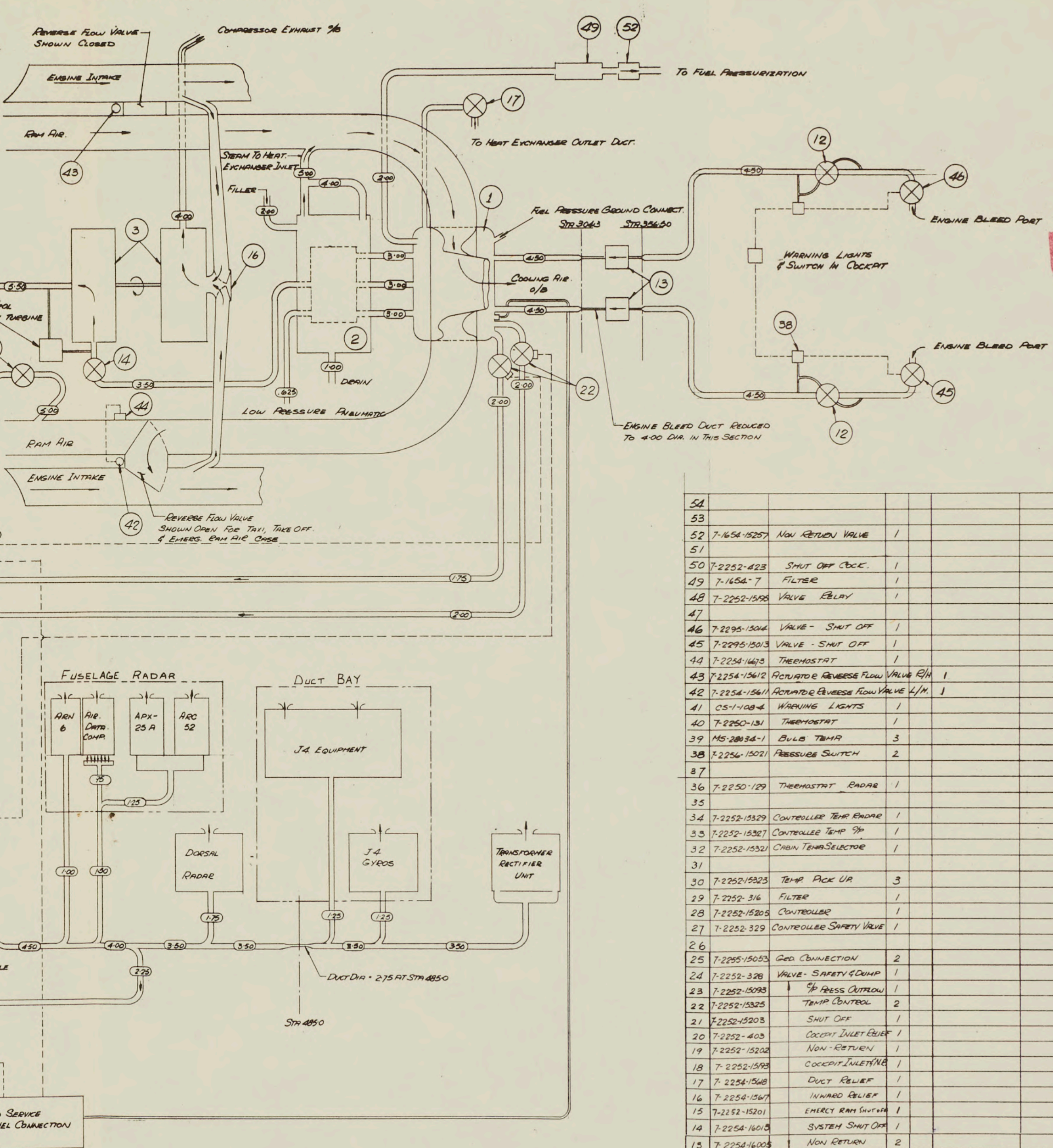

FIGURE 4(a)

AIRCRAFT APPLICABILITY
25206
25207

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REF.	PART No.	DESCRIPTION	L.H.	R.H.	DESCRIPTION	SPEC^N – COND^N	LOFT REF.	EST.	ACT.
			UNIT No. OFF		FINISHED PART SPECIFICATION			WEIGHT/PART LB.	
54									
53									
52	7-1654-15257	Non Return Valve	1						
51									
50	7-2252-423	Shut Off Cock.	1						
49	7-1654-7	Filter	1						
48	7-2252-15198	Valve Relay	1						
47									
46	7-2295-15014	Valve - Shut Off	1						
45	7-2295-15013	Valve - Shut Off	1						
44	7-2254-16673	Thermostat	1						
43	7-2254-15612	Actuator Reverse Flow Valve R/H			1				
42	7-2254-15611	Actuator Reverse Flow Valve L/H.			1				
41	CS-1-108-4	Warning Lights	1						
40	7-2250-131	Thermostat	1						
39	MS-28034-1	Bulb Temp	3						
38	7-2256-15021	Pressure Switch	2						
37									
36	7-2250-129	Thermostat Radar	1						
35									
34	7-2252-15329	Controller Temp. Radar	1						
33	7-2252-15327	Controller Temp C/P	1						
32	7-2252-15321	Cabin Temp Selector	1						
31									
30	7-2252-15323	Temp. Pick Up.	3						
29	7-2252-316	Filter	1						
28	7-2252-15205	Controller	1						
27	7-2252-329	Controller Safety Valve	1						
26									
25	7-2255-15053	Grd. Connection	2						
24	7-2252-328	Valve - Safety & Dump	1						
23	7-2252-15093	C/P Press Outflow	1						
22	7-2252-15325	Temp. Control	2						
21	7-2252-15203	Shut Off	1						
20	7-2252-403	Cockpit Inlet Relief	1						
19	7-2252-15202	Non-Return	1						
18	7-2252-15193	Cockpit Inlet & NB	1						
17	7-2254-15618	Duct Relief	1						
16	7-2254-15617	Inward Relief	1						
15	7-2252-15201	Emercy Ram Shut off	1						
14	7-2254-16015	System Shut Off	1						
13	7-2254-16005	Non Return	2						
12	7-2256-15023	Valve - Press. Reducing	2						
11									
10	7-2250-15081	Thermostat	1						
9									
8									
7									
6									
5		Silencers	7						
4									
3	7-2254-1002	Turbine & Compressor	1		Airesearch	202640			
2	7-2254-1003	Water Evaporator	1		Surface Combustion SK 7124				
1	7-2254-1001	Heat Exchanger Air To Air	1		Airesearch 170140	SHT 1			

DRAWING PARTS LIST

TARGET WEIGHT LB.

REDRAWN

ISSUE No.	6	5	4	3	2	1
MOD. No.	X74-	X74-036	X74-036	X74-036	X74-036	X74-036
E.R.N. No.		74-36/273	74-36/108	74-36/1	74-36/8	
DRAWN BY	J. [illegible]	V. Brunwood	A.F. Brett	O'Connor	P. Syter	O'Connor
DATE	11 June 58	11 Mar 58	10 Oct 57	14 June 57	29 Mar 57	11 Jan 57
CHECKED						
STRENGTH APP.						
DESIGN APP.	G. Shaw	G. Shaw	G. Shaw	G. Shaw	G. Shaw	G. Shaw
MEMO-No						F 1472

REFERENCE DRAWINGS	
DWG. No.	DESCRIPTION

DESCRIPTION: SCHEMATIC AIR CONDITIONING PARTIAL ASTRA

SCALE —
FINISH TO DWG. —
LIMITS UNLESS NOTED —

ARROW 2
TYPE/MARK | SHOWN ON DRAWING

AVRO AIRCRAFT LIMITED
MALTON ONTARIO

DRAWING NUMBER: 7-2200-15002

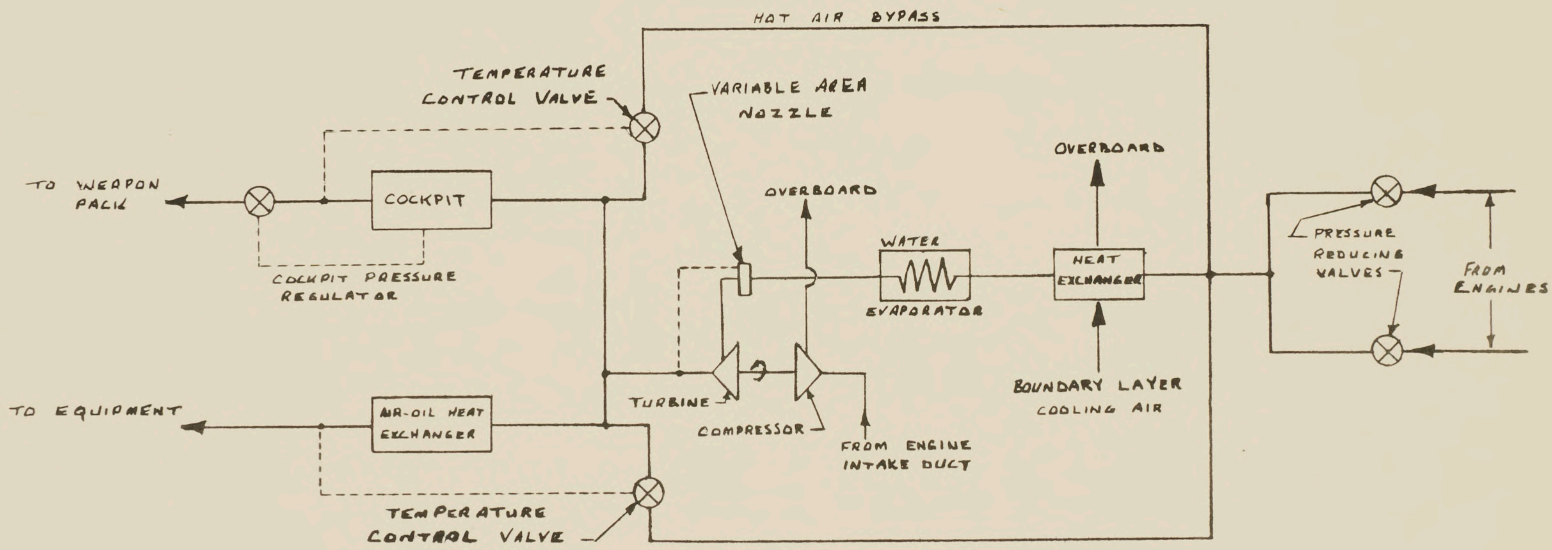

FIGURE 4(b) - SIMPLIFIED SCHEMATIC - ARROW 2 AIR CONDITIONING SYSTEM

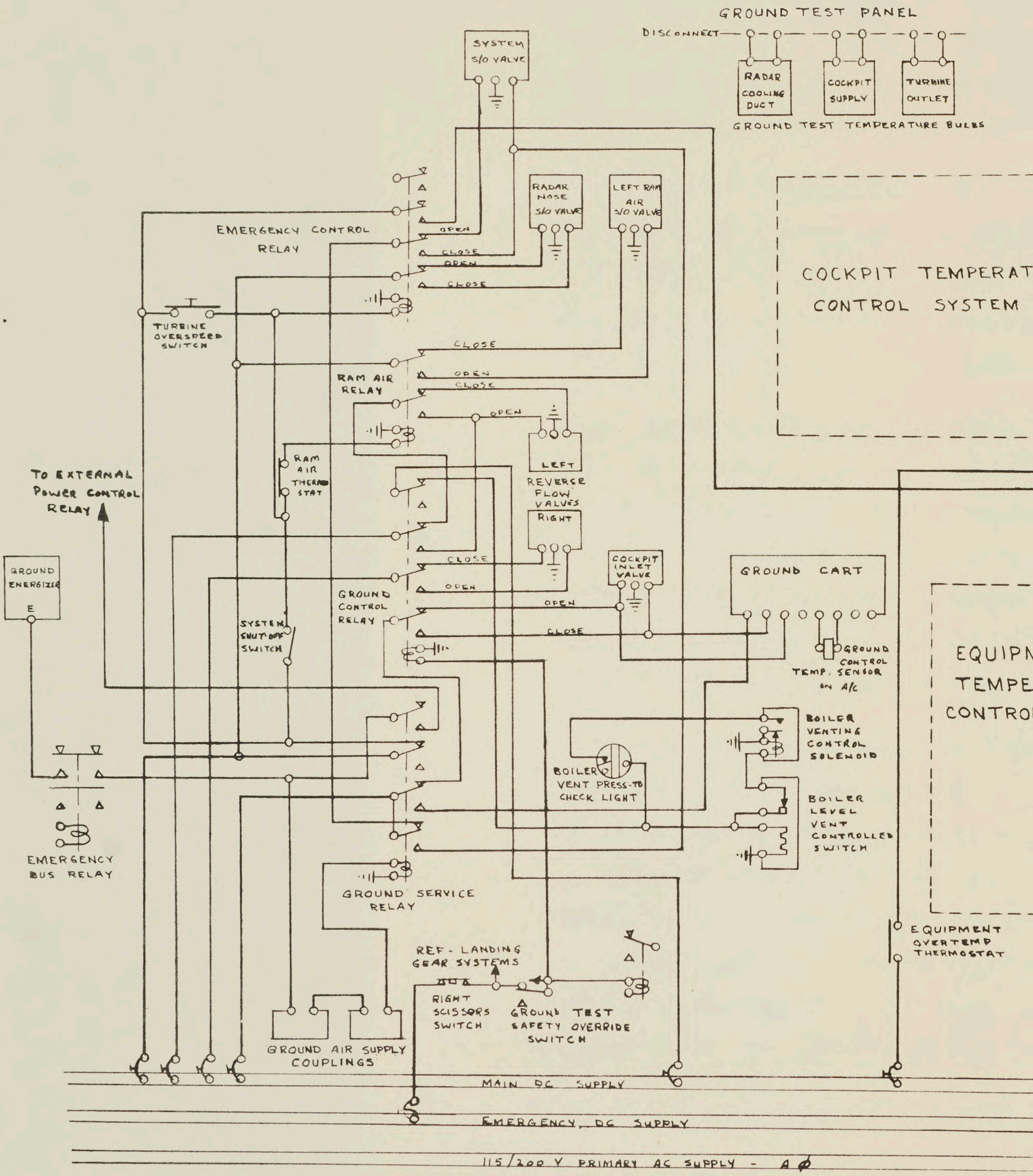

FIGURE 5 - THEORETICAL CIRCUITS - ELECTRICAL CO

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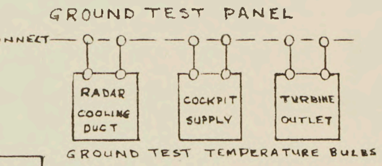
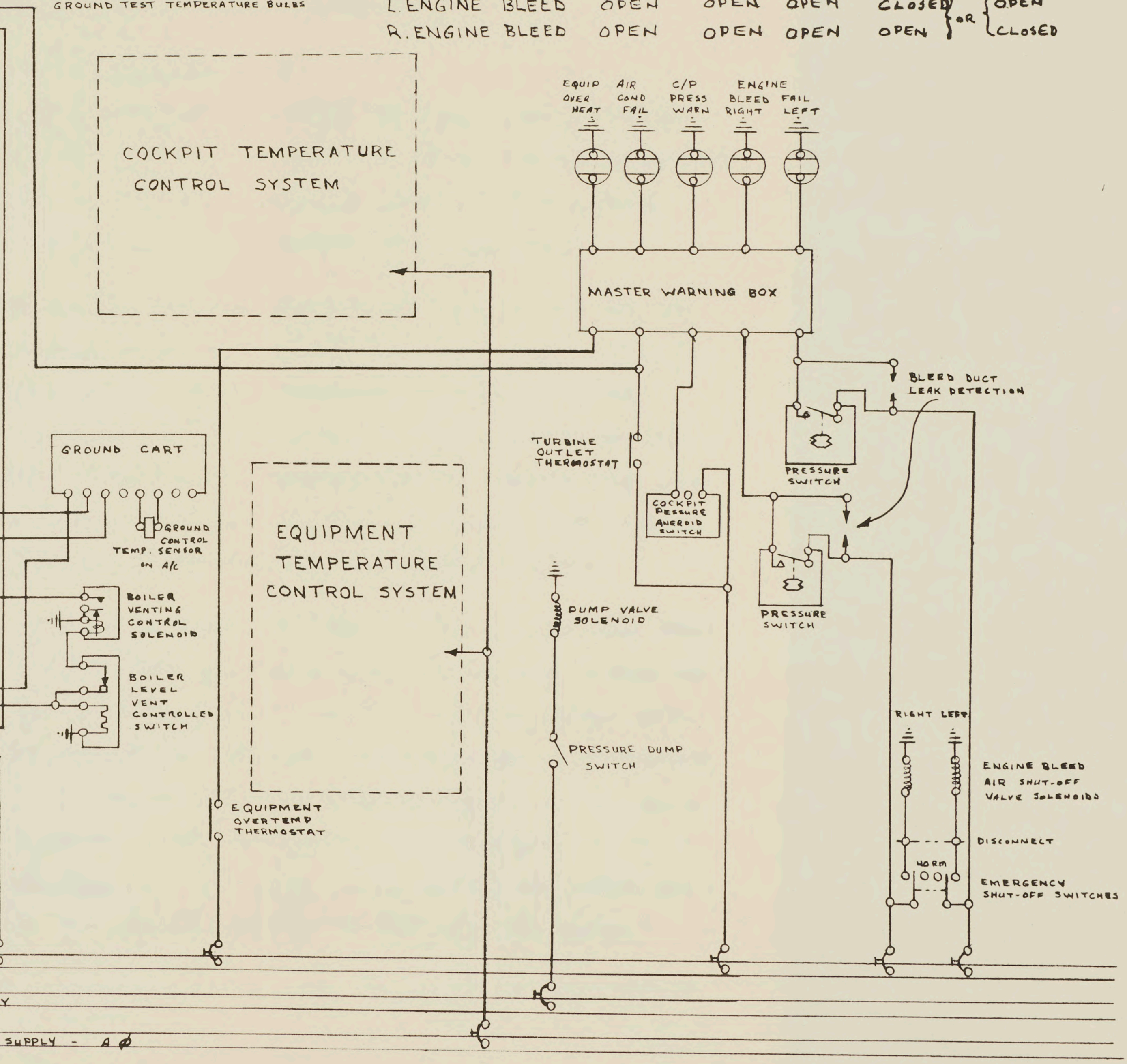
VALVE	NORMAL SERVICE	NORMAL TAXI	NORMAL FLIGHT	PILOT'S SELECTION (EMERGENCY)
RAM AIR	CLOSED	CLOSED	CLOSED	OPEN (BELOW 100°F)
RADAR NOSE	OPEN	OPEN	OPEN	CLOSED
SYSTEM SHUT-OFF	CLOSED	OPEN	OPEN	CLOSED
L. REVERSE FLOW	OPEN	OPEN	CLOSED	OPEN (BELOW 100°F)
R. REVERSE FLOW	OPEN	OPEN	CLOSED	CLOSED
COCKPIT INLET	CLOSED OR OPEN	CLOSED	OPEN	OPEN
L. ENGINE BLEED	OPEN	OPEN	OPEN	CLOSED } OR { OPEN
R. ENGINE BLEED	OPEN	OPEN	OPEN	OPEN } OR { CLOSED





L CIRCUITS - ELECTRICAL CONTROL SYSTEMS - ARROW 2 AIR CONDITIONING

The non-return valves installed adjacent to the heat exchanger prevent reverse flow of bleed air in a closed bleed duct. This precaution is necessary to conserve engine power and to avoid the fire hazards created by leakage of hot air.

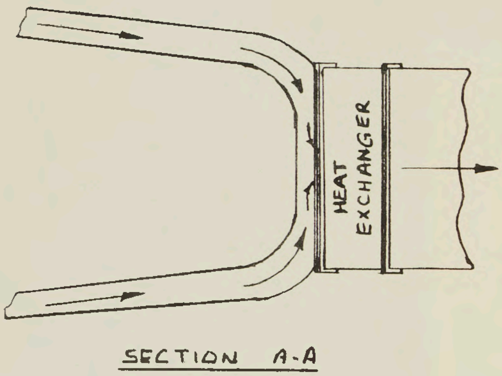
4.2.2 THE AIR CONDITIONING UNIT

The ram air heat exchanger, the water evaporator and the expansion turbine are the basic components in the air conditioning unit. The components are grouped together to form a compact package which is installed in the air conditioning compartment.

High temperature air from the engine bleed ducts enters the ram air heat exchanger where it undergoes its first stage of cooling. It them passes into the water evaporator for further cooling. The air is subjected to a final stage of cooling in the expansion turbine. Some of the hot air bypasses the air conditioning unit. This air is combined with the cold air discharged by the turbine to give the desired temperature for the conditioning air.

Cooling in the heat exchanger is achieved with ram air taken from the boundary layer bleed air ducts, which are located between the fuselage sides and the engine air intakes. Air from these ducts is routed through the heat exchanger and discharged to atmosphere through a dorsal exhaust nozzle as shown in Figure 6. The extent of cooling achieved in the heat exchanger is dependent on the relative temperatures and flow rates of the cooling and charge air. These in turn are directly related to the aircraft's speed.

The evaporator makes use of the high latent heat of vaporization



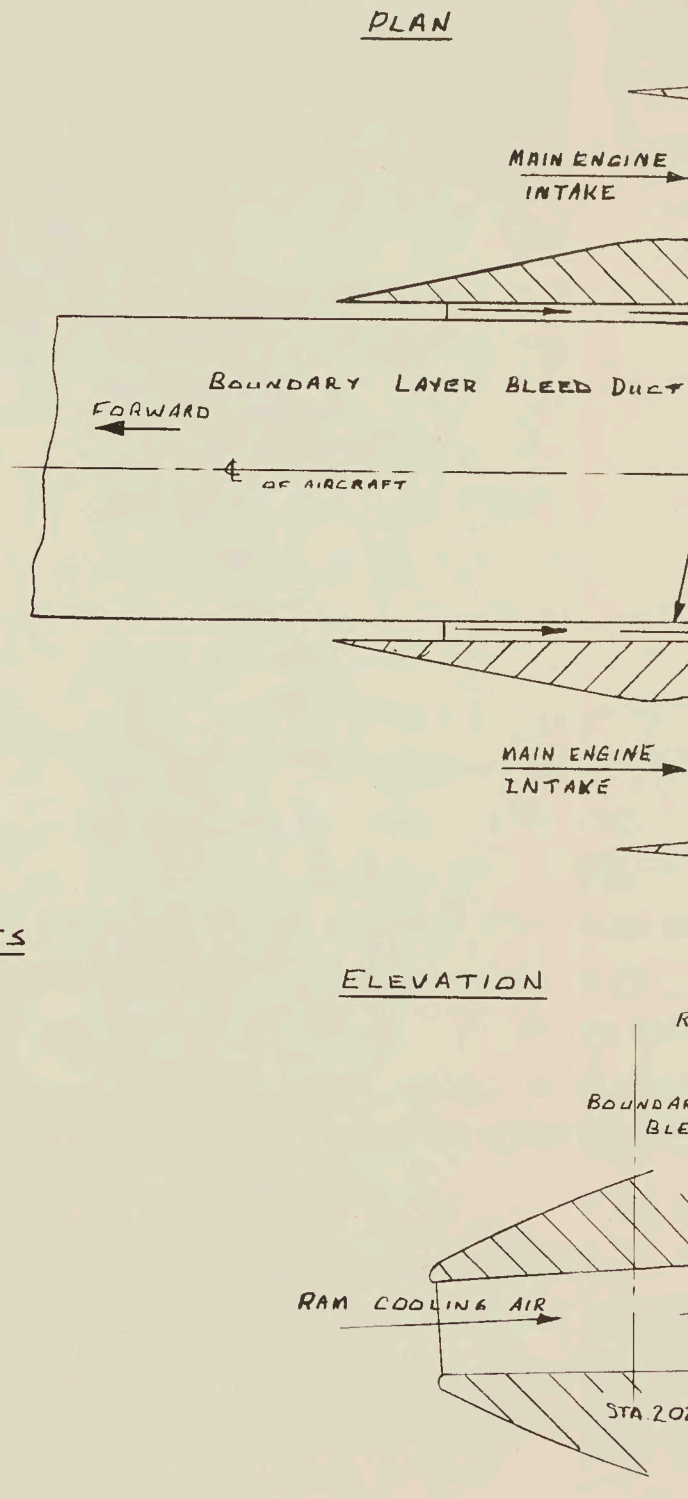


FIGURE 6

COOLING AIR CIRCUITS

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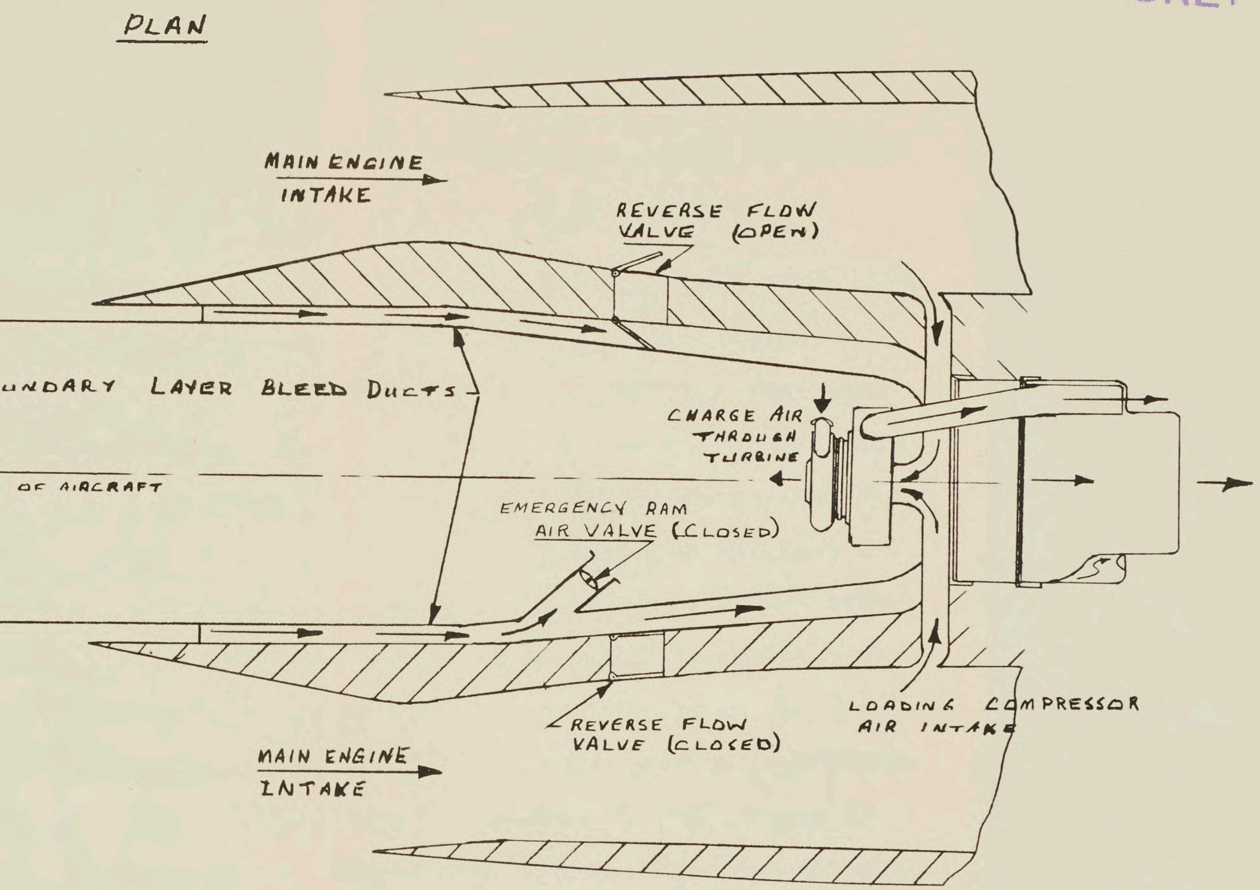
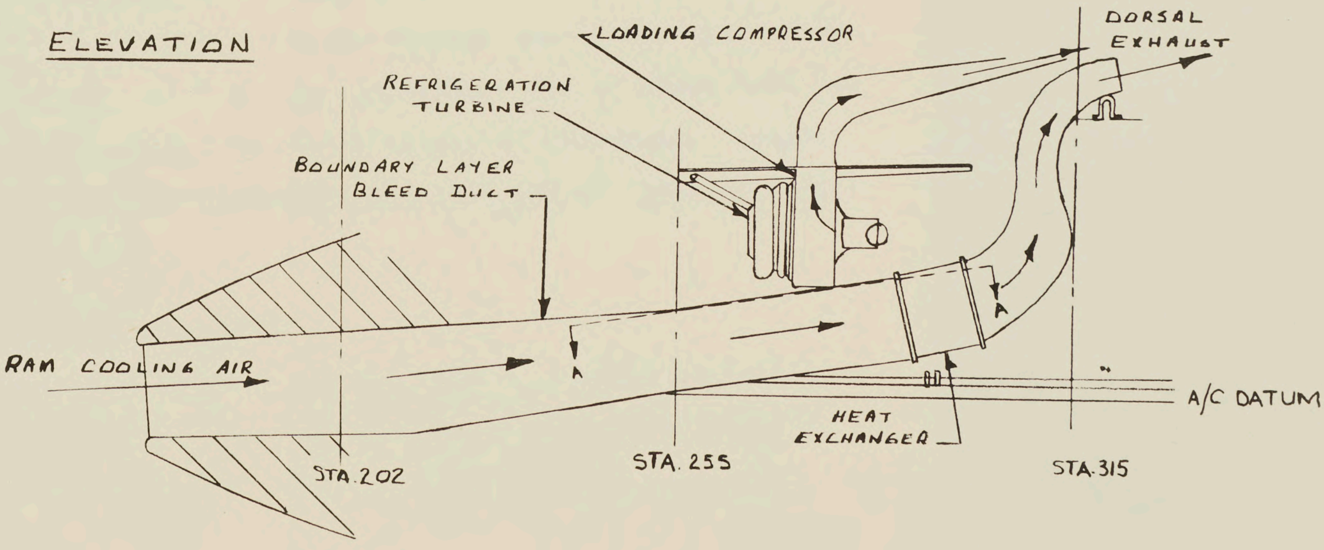


PLAN
MAIN ENGINE INTAKE
REVERSE FLOW VALVE (OPEN)
UNDARY LAYER BLEED DUCTS
CHARGE AIR THROUGH TURBINE
OF AIRCRAFT
EMERGENCY RAM AIR VALVE (CLOSED)
REVERSE FLOW VALVE (CLOSED)
LOADING COMPRESSOR AIR INTAKE
MAIN ENGINE INTAKE



ELEVATION
LOADING COMPRESSOR
DORSAL EXHAUST
REFRIGERATION TURBINE
BOUNDARY LAYER BLEED DUCT
RAM COOLING AIR
A
A
A/C DATUM
HEAT EXCHANGER
STA. 202
STA. 255
STA. 315

of water to produce cooling. The evaporator is in fact an air-to-water heat exchanger, frequently referred to as a boiler. Steam is generated in the boiler when the heat extracted from the air by the water is sufficient to produce boiling. The heat extracted is rejected to the atmosphere with the steam discharge.

In passing through the heat exchanger and the water evaporator, the air pressure is only slightly decreased. Thus, at the inlet to the expansion turbine, the air is still at a relatively high pressure but moderate temperature. Cooling in the turbine is achieved by expanding this high pressure air to the lower pressure existing in the air conditioned compartments. In the expansion process, external work must be done by the turbine if a balance between input and output energy is to be maintained. The energy extracted from the air by the turbine is transformed into shaft work by the turbine wheel, and is dissipated through a turbine loading compressor driven from the turbine output shaft. Loading of the turbine is necessary to prevent overspeeding of the turbine wheel which would result in the eventual destruction of the turbine. No attempt is made to obtain useful work from the turbine due to the wide variation in its output. To load the compressor, air is drawn from the engine air intake ducts, and is discharged to atmosphere through a dorsal exhaust in the neighborhood of the ram air exhaust nozzle as shown in Figure 6.

4.2.3 AIR DISTRIBUTION SYSTEM

Conditioned air is distributed to the various compartments by a system of supply ducts. From the air conditioning unit, the air is fed to a main transition point where the ducting separates into two main distribution systems. A system supplies the cockpit and the other supplies the equipment compartments. Mixing of hot and cold air for temperature control takes place in this transition region.

All equipment cooling air first passes through an air-oil heat exchanger. This heat exchanger cools oil from the ASTRA electronic system's magnetron cooling circuit and the radar scanner's hydraulic drive system. Where possible, the cooling air is cascaded from one piece of equipment to another, and from one compartment to another, in order to reduce the total required airflow. Cockpit exhaust air is used to supplement the cooling air flow to the weapon pack.

4.3 CONTROL SYSTEMS

4.3.1 COCKPIT PRESSURE CONTROL

Cockpit pressure is regulated by means of a valve in the cockpit exhaust duct. This valve is operated by a control unit which, with the valve, maintains the cockpit pressure to a fixed schedule with altitude (see Figure 1). This control is independent of cockpit flow. The cockpit is unpressurized from sea level to 10,000 feet. From 10,000 feet to 50,000 feet the pressure differential is increased from zero to 4.25 ± 0.25 psi. Above 50,000 feet a fixed differential of 4.25 ± 0.25 psi is maintained.

4.3.2 COCKPIT TEMPERATURE CONTROL

Cockpit temperature control is achieved by mixing hot air, ducted from upstream of the heat exchanger, with the cold air discharged by the turbine. The cockpit temperature is controlled by the pilot to give a temperature of from 40°F to 80°F, at the cockpit outlet. An additional control (toggle-switch) permits the pilot to select an air inlet temperature of 90°F as a method of preventing fog. Other than the pilot selecting the desired temperature, the operation of the system is completely automatic.

4.3.3 EQUIPMENT TEMPERATURE CONTROL

Equipment temperature control is also achieved by the controlled mixing of hot and cold air. Equipment cooling air temperature is controlled to a constant 70°F. The sensing point, which controls the temperature, is located in the main duct, downstream of the air-oil heat exchanger. Operation of the system is completely automatic.

4.3.4 SYSTEM FLOW CONTROL

Total air flow through the system is regulated by varying the inlet nozzle area of the refrigerating turbine. The nozzle area is controlled to maintain a turbine outlet pressure scheduled against altitude. This schedule is chosen to give a constant 27.5 ± 2.5 lb/min air flow through the cockpit. The pressure drop in the equipment branch has been selected so that for a constant flow of 27.5 lb/min through the cockpit, the equipment flow will be 122 $^{+20}_{-0}$ lb/min.

4.4 AUXILIARY EQUIPMENT

The operation of the refrigeration turbine is dependent on engine bleed pressure and cooling in the heat exchanger depends on ram pressure (forward speed). When these pressures are very low the system performance will be deficient. For prolonged operation under such conditions, the operating range has been extended by the addition of some auxiliary equipment.

4.4.1 COMPRESSOR INLET RELIEF VALVE

When the engines are operated on the ground at full power, a large negative pressure region is developed in the engine intakes. This creates a negative pressure differential across the refrigeration turbine's loading compressor, causing it to surge. A relief valve, installed at the compressor inlet, opens whenever the compressor inlet pressure is below ambient pressure, and prevents the occurrence of this surge.

4.4.2 REVERSE FLOW VALVES

To create a flow of cooling air through the heat exchanger while the aircraft is taxiing, advantage is taken of the pressure depression occurring in the main engine intakes at low forward speed. Reverse flow valves are installed between the boundary layer bleed ducts and the main engine intakes, allowing cooling air to flow through the heat exchanger in a direction opposite to normal flow.

4.4.3 COCKPIT INLET RESTRICTION

Again during taxiing, total air flow in the basic system is low. To insure adequate flow to the fire control system during these conditions, a valve is installed at cockpit inlet to restrict cockpit flow.

4.4.4 COCKPIT BYPASS (Not in basic airframe).

At extreme altitudes and low speeds, engine bleed pressure is insufficient to maintain cockpit pressure to the desired schedule.

Under these conditions, the cockpit pressure discharge valve will close, reducing cockpit discharge flow to zero, thereby maintaining available cockpit pressure. This case would probably be of short duration, since due to the very poor fuel economy, it is far from an optimum cruise condition. Of significance in this situation, however, is the reduction of air flow to the weapon pack with the cockpit exhaust closed. To insure cooling of the weapon pack under these conditions, a cockpit bypass system, controlled by a differential pressure operated valve, will be tested and installed in the aircraft if required.

4.5 EMERGENCY AND SAFETY PROVISIONS

The system contains various warning and emergency devices to give as complete protection as possible to the crew, equipment and the system. Numerous safety devices are incorporated in the system, some of which operate automatically, others are operated at the pilot's discretion when a system malfunction is indicated by a warning signal.

4.5.1 SYSTEM SHUT-OFF

An electrically-actuated shut-off valve is installed at the turbine inlet. In normal operation the valve is always open. It closes when the pilot selects the emergency mode of system operation, or automatically when a ground air supply is connected to the aircraft.

4.5.2 EMERGENCY RAM AIR SUPPLY

An emergency ram air system is provided and supplies equipment cooling air and cockpit pressurizing air in the event of normal air supply malfunction. Emergency ram air is obtained from the left hand boundary layer bleed duct, and is ducted to the cockpit and aft equipment air supply ducts. The ram air is admitted through the normally-closed emergency ram air shut-off valve when the pilot selects the emergency mode of system operation.

Selection of emergency ram air, apart from opening the ram air shut-off valve, operates the left-hand reverse flow valve to isolate the boundary layer bleed duct (see Figure 6), thus increasing ram pressure. It also shuts down the fire control system, and closes the radar nose shut-off valve, reducing ram air requirements. A thermostat prevents the ram air valve from opening if the ram air temperature is above 100°F.

4.5.3 EMERGENCY TEMPERATURE CONTROL

The cockpit and equipment are further protected with overheat thermostats. Should the temperature controllers fail to operate the temperature control valves, the thermostats will cycle the valves to give a crude form of temperature control.

If turbine outlet temperature exceeds 80°F, a warning light in the cockpit is illuminated, indicating one of the following conditions:

(a) A low bleed air pressure at turbine inlet (this condition can occur during hot day taxi).

(b) The water evaporator (boiler) has run dry.

(c) The expansion turbine has seized.

Corrective action for (b) and (c) is to reduce engine power. If this does not clear the fault, the system should be shut down and emergency ram air used.

4.5.4 COCKPIT PRESSURE PROTECTION

The cockpit is protected from over-pressurization by means of a safety valve which operates to a predetermined schedule (See Figure 1). An override switch permits the pilot to dump cockpit pressure at any time. An inward relief valve prevents the possibility of a negative differential pressure occurring.

Non-return valves in the main and emergency ram air cockpit inlets will retain the cockpit pressure in the event of loss of normal air supply.

4.5.5 ENGINE BLEED DUCT PROTECTION

Due to its size and large nominal flow, the main pressure-reducing valve will not control bleed air pressures with a flow of less than 20 lb/min. A duct relief valve is provided to guarantee a total flow of 40 lb/min when duct pressure rises to 75 psig. This situation can occur when the main system shut-off valve is closed. Bleed duct faults are indicated by two warning lights, (one for each duct) in the pilot's cockpit (see para. 4.6.1).

To shut off the bleed air flow in the event of a fault, a pilot-controlled shut-off valve is installed in each bleed duct. Non-return valves in the downstream end of each duct serve to isolate a duct when it is shut down. A leak detection system is provided for each bleed air duct, and will combine pressure and temperature sensing devices to operate the cockpit warning lights.

The theoretical circuit for each bleed duct is shown in Figure 7. The pressure and temperature sensing devices are arranged in parallel to operate the same warning light.

The pressure sensing portion of the leak detection system is used in the dorsal region where the bleed ducts are close together, since at this point a temperature sensing device could not discriminate between a leak in the left-hand or right-hand duct. The temperature sensing portion of the system is used in the aircraft's duct bay region where the bleed ducts are far enough apart to permit positive identification of bleed duct leak.

4.5.6 PRESSURE SENSING DEVICE

The pressure sensing device is a double walled duct, which consists of two concentric tubes, with the annular space between them serving as a leakage air collecting chamber. A pressure switch is connected to the annular space. If leakage from the inner tube occurs, the pressure build-up in the leakage chamber operates the pressure switch to close the warning-light circuit as shown in Figure 7). To prevent excessive pressure build-up within the annular space, the outer duct is vented to its ambient environment through a controlled leakage port.

4.5.7 TEMPERATURE SENSING DEVICE

A Fenwal continuous wire heat detector forms the basis of the temperature-sensing portion of the system. Together with the control unit, the detector forms a bridge circuit which operates to illuminate a warning light.

The Fenwal detector consists of an Inconnel tube enclosing a single wire embedded in a salt base core material. The resistance of the core material to current flow is dependent on temperature. At a temperature near that of the bleed air, the core material becomes

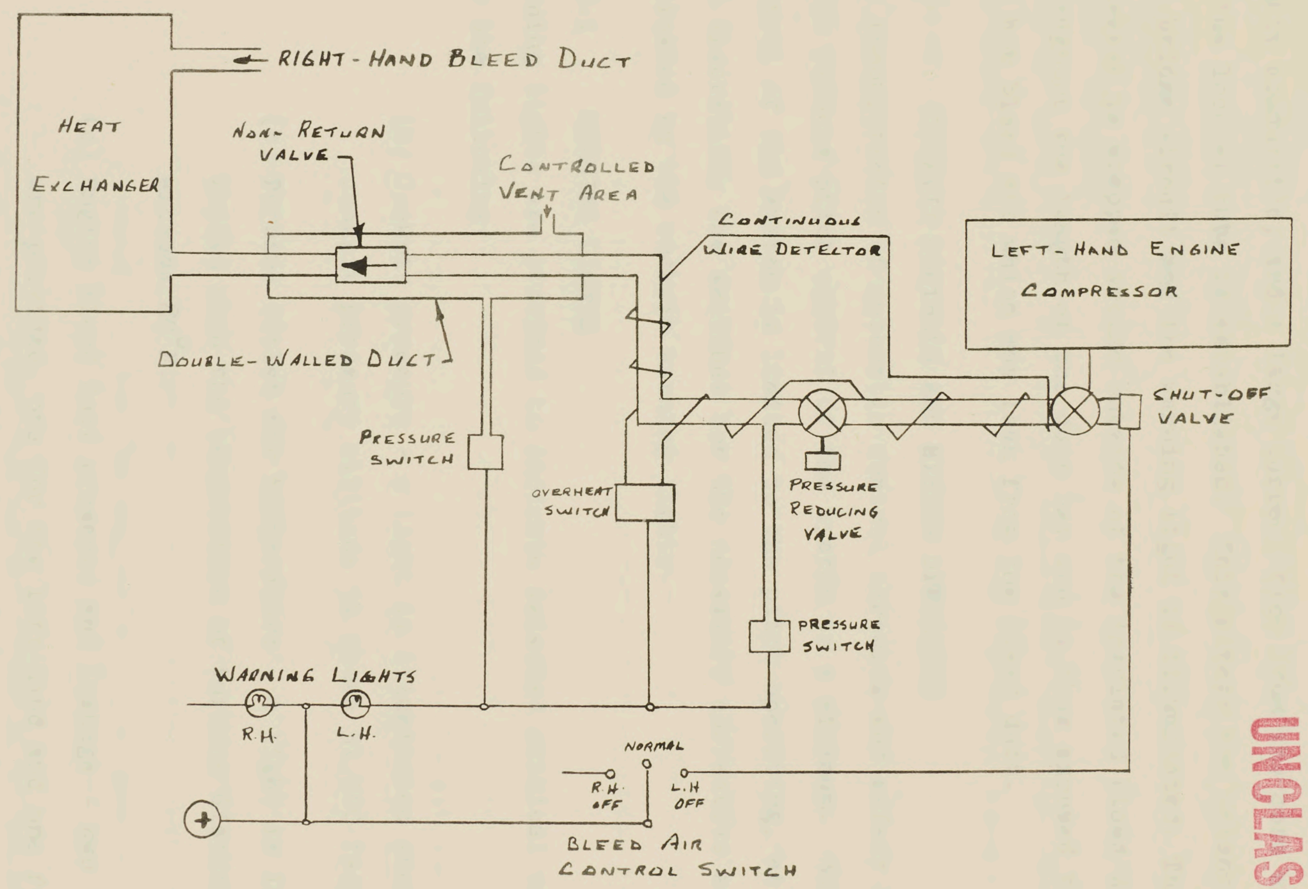


FIGURE 7 - SCHEMATIC - ENGINE BLEED DUCT LEAK DETECTION SYSTEM

highly conductive, and a large current flow from the core wire to the Inconel tube is established. This alters the balance of the bridge circuit and the warning light is illuminated. The detector is wrapped around the outside of the insulated bleed duct, throughout the length of the duct bay and is thus exposed to any hot bleed air which may leak from the bleed duct.

4.6 COCKPIT CONTROLS AND SYSTEM OPERATION

The incorporation of automatic control circuits and safety devices reduces pilot control of the system to a minimum. Manual control of the system is limited to the pilot operating, at his own discretion, the switches for the necessary corrective action indicated by the cockpit warning lights.

4.6.1 WARNING LIGHTS

Warning lights are provided to indicate selected critical values for the following:

(a) Cockpit pressure - a light is illuminated when cockpit pressure altitude is above 31,000 feet.

(b) Turbine outlet air temperature - a light is illuminated when the temperature of turbine discharge exceeds 80°F.

(c) Engine bleed duct pressure and leakage - two lights are provided, one for the left-hand and one for the right-hand bleed duct. These lights are illuminated when either the bleed pressure exceeds 90 psig or a leak occurs anywhere along the length of the bleed duct.

4.6.2 **SWITCHES**

With the exception of the cockpit temperature selector, the following switches may be operated during emergency conditions as indicated:

(a) System shut-off switch in normal operation, the switch is in the "NORM" position. Selecting the "EMERG" position closes the shut-off valve and opens the emergency ram air valve. The emergency mode of operation will generally be selected when the turbine outlet temperature warning light is illuminated.

(b) Emergency shut-off switch - This is a three position toggle switch, normally in the "NORM" position. The switch is operated in conjunction with the engine bleed duct warning lights. If the left-hand light is illuminated, the left-hand closed position is selected; and if the right-hand light is illuminated, the right-hand closed position is selected. The switch operates to close the engine bleed air shut off valves.

(c) Cockpit pressure dump switch - This is a two-position switch. Selecting the "DUMP" position opens the safety dump valve if the cockpit pressure should become excessive.

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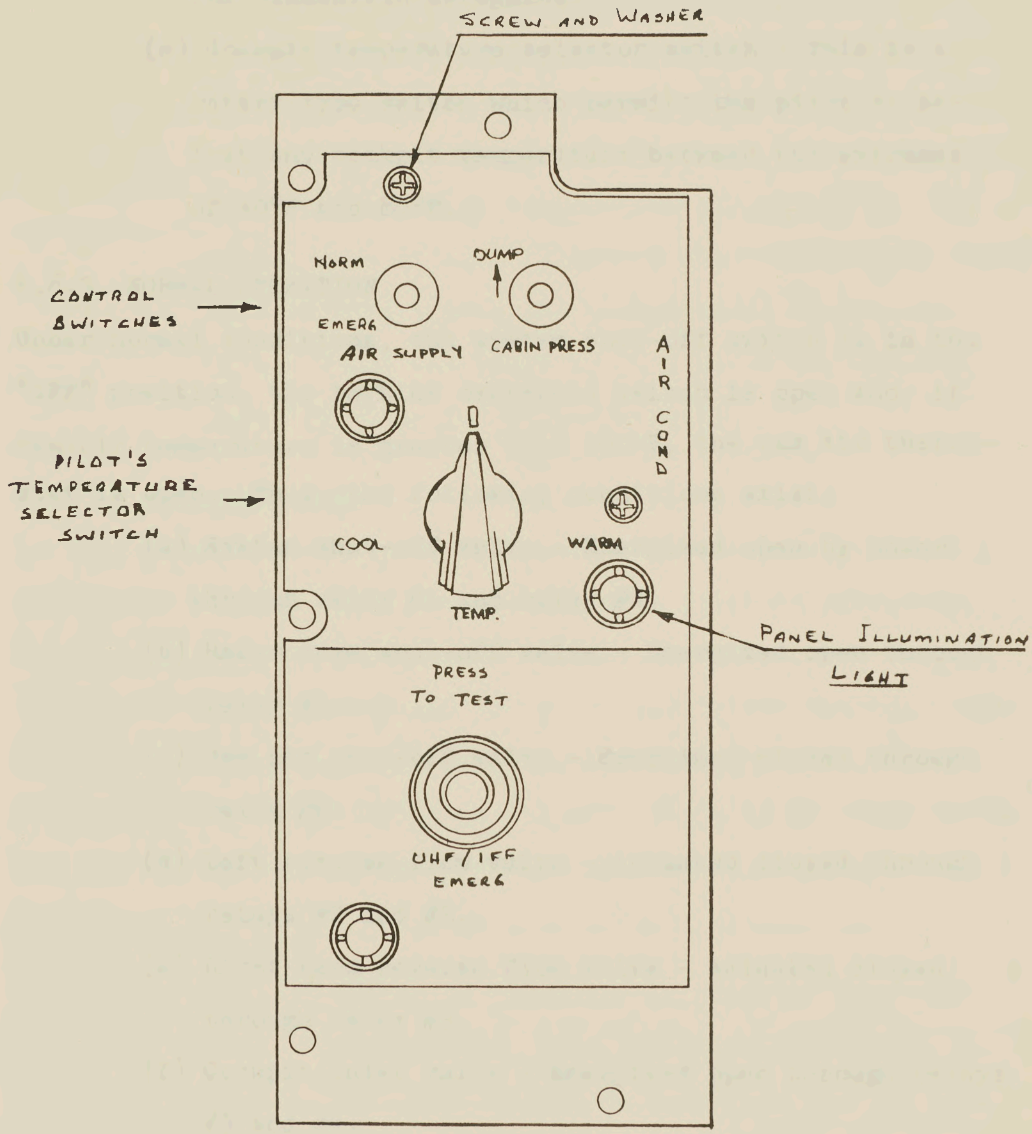

FIGURE 8 - COCKPIT CONTROL PANEL

(d) Defog switch is a two-position toggle switch which is normally in the "OFF" position. Selecting the "DEFOG" position admits 90°F air into the cockpit for windshield defogging.

(e) Cockpit temperature selector switch - This is a rotary type switch which permits the pilot to select any cockpit temperature between the extremes of 40°F and 80°F.

4.6.3 NORMAL OPERATION

Under normal conditions, the system shut-off switch is in the "OFF" position, the turbine overspeed switch is open and, if ram air temperature is greater than 100°F, the ram air thermostat is open. Thus, the following conditions exist:

(a) System shut-off valve - Energized open by power through relay #1 and relay #4.

(b) Radar nose shut-off valve - Energized open through relay #1

(c) Ram air shut-off valve - Energized closed through relay #2.

(d) Left reverse flow valve - Actuated closed through relays #2 and #3.

(e) Right-hand reverse flow valve - Actuated closed through relay #3

(f) Cockpit inlet valve - Energized open through relays #3 and #4.

4.6.4 EMERGENCY OPERATION

Two emergency modes of system operation can be established.

These are:

(1) Automatic mode which is initiated by overspeeding of the refrigeration turbine.

(2) Manual mode which is initiated by selecting the emergency position for the system shut-off switch. This is initiated when the air conditioning system fail warning light is illuminated, indicating that the turbine outlet temperature exceeds 80°F. The manual mode is also initiated when both engine bleed duct warning lights are illuminated, indicating either bleed air leaks or failure of the pressure reducing valve in the bleed ducts.

4.6.4.1 Automatic Mode

In this mode, the overspeed switch closes, energizing #1 relay (emergency control relay) solenoid. With relay #1 energized, the system shut-off valve and the radar nose valve are both closed and power is supplied to the system failed warning light. If ram air temperature is less then 100°F the ram air thermostat is closed and #2 relay is tripped. Tripping #2 relay opens the ram air valve and the left-hand reverse flow valve.

4.6.4.2 Manual Mode

The system shut-off switch is connected in parallel with the overspeed switch. Consequently, when the emergency switch position is selected, the same conditions described for the automatic mode will be obtained.

4.7 GROUND SERVICING PROVISIONS

The system has been designed to permit ease of maintenance and servicing of system components. To facilitate maintenance and servicing requirements, provision has been made in the system for ground air conditioning when the engines are shut down, and checking of system performance when the engines are running.

4.7.1 GROUND AIR SUPPLY

Ground air-conditioning is required to permit ground servicing of the electronic equipment and to allow pre-flight air conditioning of the cockpit. Since the aircraft system can supply cooling air only while the aircraft engines are running, provision is made for connecting a ground air-supply to the air craft system.

Provision in the aircraft for ground air supply consists of two ground service couplings and the associated ducting. Cooling air is ducted to the downstream side of the turbine, where it enters the aircraft's normal air distribution system, and is then routed to the cockpit and the various equipment compartments.

The two ground service couplings are located on the underside of the aircraft between nosewheel well and the weapon pack. Each coupling is provided with a microswitch which is normally open. When the ground supply is connected, the two switches, which are wired in series, close to trip the ground service relay and set-up the aircraft system for ground air conditioning. The system shut-off valve is closed by this operation.

4.7.2 SYSTEM GROUND TESTING

Pressure and temperature taps, connected to a ground test panel in the nose wheel well permits checking of the following:

(1) Pressure reducing valve - A single pressure tap on the high temperature side of the heat exchanger checks bleed air pressure.

(2) Refrigeration turbine - A single temperature tap at turbine ouulet checks turbine discharge air temperature.

(3) Temperature controls - A temperature sensor in the radar nose air supply duct and a temperature pick-up in the cockpit air-distribution system check performance of the corresponding temperature control circuits.

(4) Flow controls

4.7.3 EQUIPMENT SERVICING

Installation of the air conditioning system has been designed to permit filling and checking the water level in the water evaporator and lubrication of the refrigeration turbine.

Provision is also made to allow leakage checks of the engine bleed ducting and the cockpit. The engine bleed ducts carry air at high temperature and pressure and consequently require leakage checks at regular intervals. Due to the extreme altitude reached by the aircraft and the fact that cockpit exhaust air is used to cool equipment, a close check of cockpit leakage is necessary. The controllers for both the cockpit pressure regulator and the safety valve are provided with means for closing them at sea level and for checking their maximum pressure settings.

4.8 OPERATION ON THE GROUND

When the aircraft is on the ground, it's weight is on the landing gear and the scissors switch contacts are closed thus energizing the ground control relay.

4.8.1 OPERATION DURING TAXIING

When the aircraft is being taxiied, ram air heat exchanger cooling air flow and total system flow are low (Ref. section 4.4). With the ground control relay tripped, both reverse flow valves are open, providing a cooling air flow through the heat exchanger, and the cockpit inlet valve is closed to divert system flow to the equipment sections.

4.8.2 GROUND SERVICING

A single ground service vehicle provides both external electrical power and external air conditioning air. Both the ground energizer and the ground air supply must be connected to the aircraft if either electrical power or air conditioning is to be provided in the aircraft.

The ground service relay is energized by power from the ground energizer. The microswitches in the ground service couplings close the relay's solenoid circuit when the external air supply hoses are properly connected to the aircraft. With the relay energized, power is supplied to the aircraft's electrical system, the air conditioning system shut-off valve is closed and the cockpit inlet valve is closed. A switch on the ground service vehicle permits the cockpit inlet valve to be selected either open or closed.

5.0 EQUIPMENT DETAILS

5.1 RAM AIR HEAT EXCHANGER

The ram air heat exchanger serves as a first stage cooler in the system and is located at the aft end of the air conditioning compartment. For a given turbine temperature drop, the discharge air temperature is dependent on turbine inlet temperature. By reducing the temperature of the air entering the turbine, lower discharge temperatures may be obtained with a consequent increase of system cooling capacity.

The unit is an air-to-air heat exchanger consisting of tubes to transport the hot engine bleed air, and a casing which guides the ram cooling air over the bleed air tubes. Cooling in the unit is achieved by simple heat transfer from the engine bleed air to the tubes, and from the tubes to the cooling ram air. The heated ram air is discharged to atmosphere, so that a continuous flow of cooling air is maintained in the unit.

5.2 TURBINE - COMPRESSOR UNIT

The refrigeration turbine and its loading compressor are supplied as a packaged unit.

5.2.1 REFRIGERATION TURBINE

The refrigeration turbine is the heart of the air conditioning system, and is the basic cooling device around which the entire system has been designed. Overall system flow rate and conditioning air temperature is primarily dependent on the turbine's operation.

The refrigeration turbine is a single stage radial flow machine with a variable area inlet nozzle and an axial discharge nozzle. The primary function of the turbine is to provide cold air. The unit is located in the air conditioning compartment, and discharges air directly into the distribution system.

Operation of the turbine is based on the principle that a gas subjected to expansion, experiences a temperature drop. The pressure drop between turbine inlet and turbine outlet allows an airflow through the turbine which causes the turbine wheel to rotate, transforming the energy extracted from the inlet air into external work. The decrease in internal energy of the air passing through the turbine lowers the temperature of the working air. Turbine pressure drop, speed of rotation and temperature drop are related as follows:

> The larger the pressure drop, the higher the turbine speed; the higher the turbine speed the greater the temperature drop.

Thus, the extent of cooling which occurs in the turbine is directly dependent on the pressure drop across the turbine.

To prevent overspeeding of the turbine, the work available from the turbine must be dissipated. For this reason, a turbine loading compressor is coupled directly to the output shaft of the turbine.

5.2.2 LOADING COMPRESSOR

The centrifugal loading compressor is mounted directly to the turbine output shaft. The unit absorbs and dissipates the mechanical energy developed by the turbine.

The compressor is driven by the turbine and loaded by air drawn from the main air intakes. The compressed air is discharged to atmosphere through a dorsal exhaust nozzle.

5.3 WATER EVAPORATOR

Above 30,000 feet, under maximum speed conditions, the ram air heat exchanger does not provide adequate cooling of the bleed air. A water evaporator is therefore installed as an additional heat sink.

The unit is located in the air conditioning compartment, between the ram air heat exchanger and the expansion turbine.

The water evaporator is basically a tank or boiler with air tubes passing through it. The total capacity of the tank is 265 pounds of water (26.5 Imperial gallons) of which 250 pounds is useable (i.e. can be evaporated). This quantity of water is adequate for the mpst severe mission.

The design of the evaporator is such that freezing of the water has no effect on its structure or operation. Normally, with bleed air passing through the unit continuously it is unlikely that water freezing would occur.

In operation high temperature bleed air flows through the air tubes continuously. With the water level in the tank normally above the tubes, cooling of the air is simply a matter of heat exchange between the air, the tubes and the water. Due to its high latent heat of vaporization, the water is an excellent heat absorber. Boiling of the water coincides with the additional cooling requirements at high speeds, thus no controls are required.

A filler is provided which automatically shuts off when the boiler is full.

5.4 GROUND SERVICE COUPLING

Two ground-service couplings are located on the underside of the aircraft to permit a ground air supply to be connected to the aircraft air conditioning system. These couplings are the only equipment items in the ground air supply duct system and are located at the upstream end of the duct system.

The coupling is a female adaptor to which the ground air conditioning unit's air supply hose is connected. It's overall length is 5.55 inches and it's maximum diameter is 5.0 inches. An electrical connector mounted externally to the basic coupling, and connected to a built-in micro-switch, results in a maximum diametral length of 6.25 inches. The microswitch is mechanically linked to a valve assembly within the adaptor housing.

The spring-loaded valve assembly within the adaptor is normally closed to air flow. When the ground air supply hose is connected, the valve opens and at the same time closes the microswitch. The microswitches of the two ground supply couplings are wired in series, ensuring that both ground air supply hoses are properly connected to the aircraft before the ground service relay in the aircraft is energized.

6.0 DUCTING

Ducting is described under the three main groups: bleed ducting, distribution ducting, and ram cooling air ducts. There are also the minor groups of emergency ram air ducts and ground air supply ducting.

6.1 BLEED DUCTING

The bleed ducting transports high temperature, high pressure engine bleed air to the air conditioning equipment. The ducting is 4 1/2 inches in diameter and is made of 0.016 to 0.020 inch thick stainless steel. Bolted flanges and Janitrol 'V' band clamps are used for duct connection. The ducts are insulated with 5/8 inch of fiberglass type insulation and protected with a stainless steel foil sheath, The ducting is mounted on rollers which permits free movement during duct expansion and fuselage structure deflection. Flexible sections are used where necessary to allow for relative motion due to thermal expansion. The two bleed ducts extend from the engine compressor bleed ports to the ram air heat exchanger.

Steel ducts are also used to interconnect the heat exchanger, water evaporator and the expansion turbine. Hot air bypass ducts to the cockpit and equipment air distribution systems are also of steel construction.

6.2 DISTRIBUTION DUCTING

The distribution ducting conveys conditioned air from the air conditioning units to the compartments which require air conditioning. The distribution ducting is of aluminum alloy with beaded ends. Both Marman and Wiggins connections are used for duct joints. The ducts are wrapped with fibreglass insulation blankets to maintain near-constant thermal properties of the conditioning air during its transportation in the distribution system. The distribution system is described in two groups as follows:

(a) Cockpit supply and exhaust ducting

(b) Equipment supply ducting.

6.2.1 COCKPIT SUPPLY DUCTING

The cockpit supply ducting originates at the combined cockpit inlet and non-return valve, just aft of the OBS/AI seat bulkhead. It separates into two ducts. One of the two ducts supplies air to the pilot's and OBS/AI's feet, and the other supplies air at the pilot's seat. Air at the OBS/AI's seat is supplied by a flexible hose from each of the two supply ducts. Air is discharged into the cockpit through silencers designed to minimize the transmission of air conditioning system noise to the cockpit.

6.2.2 COCKPIT EXHAUST DUCTING

Cockpit air is exhausted through floor exhaust grilles, located in each cockpit, to an exhaust duct which discharged it into the weapon pack.

6.2.3 EQUIPMENT SUPPLY DUCTING

Downstream of the air-oil heat exchanger, the equipment cooling air supply duct separates into two main branches, one supplying air to the radar nose and the other supplying air to the aft equipment compartments. The radar nose duct extends forward beneath the cockpit floor to a plenum chamber located at the forward end of the cockpit. The air is then circulated by natural convection into the various compartments in the nose and is finally exhausted into the nose wheel well. Two small diameter ducts are connected into the main radar nose duct to cool the windscreen de-icing transformer and the electrical system's battery.

The aft equipment compartments supply duct runs aft from the OBS/AI's seat bulkhead, with feeder ducts branching out to supply air to the following compartments and equipment

(a) Dorsal equipment compartment

(b) Aft radar compartment

(c) Weapon pack

(d) Dorsal radar compartment

(e) Duct bay equipment compartment

(f) Electrical system transformer rectifier units

All conditioned compartments exhaust to atmosphere by normal air leakage through the structure.

6.2.4 TURBINE OUTLET TRANSITION DUCT ASSEMBLY

The transition duct assembly connects directly to the turbine discharge duct. The transition duct initiates the distribution of air for the cockpit and equipment groups and provides for the mixing of hot and cold air. The basic features of the duct are represented in Figure 9

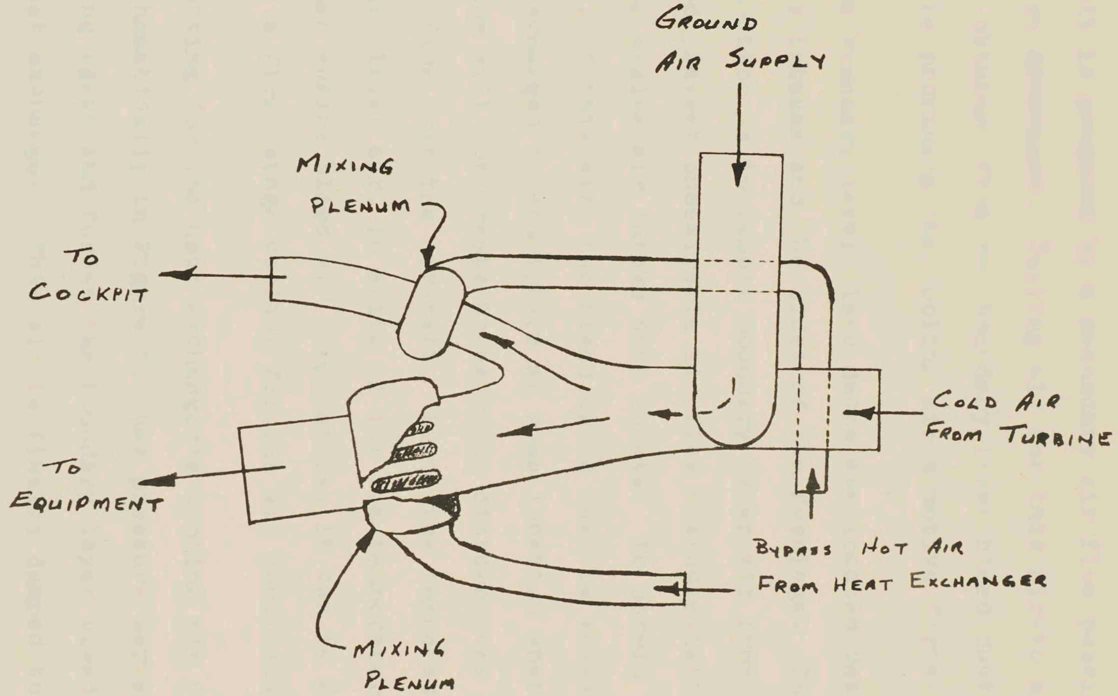

FIGURE 9 DIAGRAMMATIC - TURBINE OUTLET TRANSITION DUCT

6.3 COOLING AIR DUCTS

First stage cooling of the charge air in the air conditioning unit is produced by a secondary air flow passing through a heat exchanger. Cooling air for this air-to-air heat exchanger is obtained from the boundary layer bleed ducts with ram pressure providing the cooling air's motive force.

The boundary layer bleed ducts are located between the engine air intakes and the sides of the fuselage. Their primary function is to remove boundary layer air from the fuselage sides and prevent undesirable air flow characteristics developing at the engine air intake duct inlets. To permit continuous removal of this air, the bleed ducts must be scavenged, and the air discharged to atmosphere at some location where the discharge flow will not create undesirable disturbances in the normal airflow over the aircraft. Since the temperature of the boundary layer air, in spite of the ram temperature rise, is lower than engine bleed air temperature, it can be effectively used as a first stage coolant for the air conditioning system air.

Ducting for the heat exchanger's cooling air flow is shown schematically in Figure 6. Ram pressure serves as the scavenging agent and forces the boundary layer bleed air through the heat exchanger. This air is finally dumped to atmosphere through a dorsal discharge nozzle.

6.4 COMPRESSOR AIR SUPPLY DUCTS

An air source is required for the refrigeration turbine's loading compressor. For this purpose, air is bled from the main intakes and ducted directly to the compressor inlet. This ducting is shown schematically in Figure 6.

6.5 EMERGENCY RAM AIR DUCTING

Ram air from the left-hand boundary layer bleed duct is used to provide an emergency air supply for cockpit pressurization and equipment cooling. The opening of the shut-off valve, at the origin of the emergency ram air ducting, establishes flow in the emergency system.

The emergency air ducts are located just aft of the OBS/AI seat bulkhead. A common air duct, originating at the shut-off valve, separates into two branches, one supplying air to the equipment air distribution system, and the other to the cockpit air supply system. The equipment branch is a 4-1/2 inch diamter duct feeding directly into the aft equipment air supply duct. The cockpit branch is a 1-1/2 inch diameter duct connected into the cockpit air supply duct just downstream of the combined inlet and non-return valve. A non-return valve is installed in the 1-1/2 inch duct to prevent loss of cockpit pressure.

6.6 GROUND AIR SUPPLY DUCTING

Ducting is installed in the aircraft to convey conditioning air from a ground air supply to the aircraft's air distribution system. This permits cooling or heating of the cockpit and equipment compartments before flight.

Air is admitted through two ground service couplings located on the underside of the aircraft and just aft of the rear cockpit. The couplings, described in greater detail in section 5.4, are located one on each side of the aircraft.

A 3-1/2 inch aluminum alloy duct originates at each ground service coupling. To facilitate installation and assembly, three Marman joints are used in the left-hand duct assembly and two in the right-hand duct assembly. The two ducts feed into a short U-shaped duct which connects to the turbine outlet transition duct assembly (see para. 6.2.4).

7.0 SYSTEM PERFORMANCE ANALYSIS

To fully investigate the performance of the air conditioning system, the results of a comprehensive flight and ground test program must be analyzed. The system was first analyzed using data from preliminary estimates for engine bleed conditions, cooling air requirements, duct losses and equipment performance. This yielded an initial estimate of duct sizes, limiting duct pressures and temperatures, bought-out equipment requirements and system performance limitations.

The variables which can alter the original analysis are:

(a) Variations in engine bleed pressure and temperature.

(b) Variations in bought out equipment performance.

(c) Variations in duct pressure loss characteristics (duct runs).

(d) Changes in system loads.

Since the variables listed change from time to time, system analysis is in a continuous state of change. To allow the effect of changes to be checked quickly, the analysis has been programmed for a digital computer.

Results of system analysis for a few cases is given in Table 8.1. These cases outline the flight envelope of the system and are based on steady state conditions.

Although the system has been designed to operate over the flight envelope of the aircraft, its performance will deteriorate when engine bleed pressure is low. Performance will

TABLE 8.1 – PERFORMANCE DAT
BASED ON SYSTEM A

Case No.		000 x 45	000 x 62	000 x 61	004 C 41	004 C 00
A/C Mach No.		0	0	0	.4	.4
Pressure Altitude	Ft.	S.L.	S.L.	S.L.	S.L.	S.L.
Flight Condition		Taxi	Taxi	Taxi	Cruise	Cruise
Ambient Temperature	^oR	563	535	520	563	400
Stagnation Temperature	^oR	563	535	520	581	413
Engine Bleed – H.E. Inlet Temp	^oR	720	705	686	780	555
Engine Bleed Pressure	Lb/In^{2}Abs	24.78	30.4	30.67	38.40	38.40
Total Bleed Flow	Lb/Min.	144.1	151.4	151.9	153.5	148.3
H.E. Outlet – Boiler Inlet Temp.	^oR	600	576	554	602	415
Cooling Air Mass Flow	Lb/Min.	233	226	229.6	482	588
Fuel Pressurization Mass Flow	Lb/Min.	1.0	1.0	1.0	1.0	1.0
Boiling Temperature of Water	^oR	672	672	672	675	675
Rate of Water Consumption	Lb/Min.	0	0	0	0	0
Boiler Outlet – Turbine Inlet Temp.	^oR	600	576	554	602	415
Turbine Inlet Pressure	Lb/In^{2}Abs	21.12	27.53	28.21	35.79	37.70
Bearing Cooling Mass Flow	Lb/Min.	7.0	7.0	7.0	7.0	7.0
Turbine Mass Flow	Lb/Min.	135.9	135.2	122.5	142.9	36.0
Turbine Speed	RPM	15,613	18,837	18,226	22,290	6,000
Turbine Nozzle Area	In^2	7.0	4.37	3.73	3.33	0.65
Turbine Outlet Temperature	^oR	567	513	492	507	391
Turbine Outlet Pressure	Lb/In^{2}Abs	15.70	15.73	15.70	15.73	15.65
Cockpit Total Flow	Lb/Min.	25.8	27.5	27.5	27.5	27.5
Cockpit Turbine Flow (Cold)	Lb/Min.	25.8	27.5	26.4	27.5	6.7
Cockpit HE Bypass Flow (Hot)	Lb/Min.	0	0	1.1	0	20.8
Cockpit Inlet Temp.	^oR	567	513	500	507	515
Cockpit Outlet Temp.	^oR	582	532	520	534	520
Cockpit Pressure	Lb/In^{2}Abs	15.27	15.30	15.29	15.30	15.31
Cockpit Bypass Flow	Lb/Min.	0	0	0	0	0
Equipment Total Flow	Lb/Min.	110.3	115.9	116.4	118.0	112.8
Equipment Turbine Flow (Cold)	Lb/Min.	110.3	107.7	96.1	115.4	29.3
Equipment HE Bypass Flow (Hot)	Lb/Min.	0	8.2	20.3	2.6	83.5
Equipment Inlet Temp.	^oR	571	530	530	530	530

SECRET

TABLE 8.1 – PERFORMANCE DATA FOR SELECTED CASES BASED ON SYSTEM ANALYSIS

000 x 45	000 x 62	000 x 61	004 C 41	004 C 00	004 D 40	420 G 41	409 C 40	409 C 00	409 D 40	409 C 41	509 C 41	620 G 41	615 C 40	619 G 21
0	0	0	.4	.4	.4	1.97	.92	.92	.92	.92	.92	1.916	1.5	1.90
S.L.	S.L.	S.L.	S.L.	S.L.	S.L.	40,000	40,000	40,000	40,000	45,000	50,000	60,000	60,000	65,000
Taxi	Taxi	Taxi	Cruise	Cruise	Descent	Max. Speed	Cruise	Cruise	Descent	Cruise	Cruise	Max. Speed	Cruise	Max. Speed
563	535	520	563	400	563	416	416	375	416	418	421	426	426	390
563	535	520	581	413	581	740	486	438	486	489	493	740	617	672
720	705	686	780	555	732	1257	901	821	760	1024	1032	1252	1155	1200
24.78	30.4	30.67	38.40	38.40	30.60	89.20	29.20	29.95	14.58	27.20	21.83	31.5	23.99	28.06
144.1	151.4	151.9	153.5	148.3	151.7	171.6	172.2	170.3	115.7	162.6	131.9	155.4	142.3	153.5
600	576	554	602	415	597	796	610	510	524	698	680	919	832	900
233	226	229.6	482	588	485	517	211	228	223.6	154.9	137.9	161.6	130.4	126.3
1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0
672	672	672	675	675	675	643	611	611	611	601	592	598	589	589
0	0	0	0	0	0	5.2	0	0	0	3.3	2.5	10.2	7.3	9.9
600	576	554	602	415	597	658	610	510	524	611	600	629	610	618
21.12	27.53	28.21	35.79	37.70	27.39	60.41	24.54	27.08	11.21	21.70	17.34	26.63	18.60	22.70
7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
135.9	135.2	122.5	142.9	36.0	143.7	148.5	154.8	114.7	89.7	154.4	123.3	142.3	133.2	141.6
15,613	18,837	18,226	22,290	6,000	19,545	33,056	38,381	34,058	24,460	39,305	38,492	40,840	39,009	40,668
7.0	4.37	3.73	3.33	0.65	4.77	2.09	5.70	3.29	7.0	7.0	7.00	4.74	7.00	5.75
567	513	492	507	391	533	436	490	388	462	517	511	481	515	496
15.70	15.73	15.70	15.73	15.65	15.77	7.31	7.38	7.28	5.95	6.99	6.10	6.37	5.99	6.22
25.8	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	1.29	24.6	9.6	27.5	20.9	27.5
25.8	27.5	26.4	27.5	6.7	27.5	26.4	26.6	19.7	1.29	24.6	9.6	27.5	20.9	27.5
0	0	1.1	0	20.8	0	1.1	0.9	7.8	0	0	0	0	0	0
567	513	500	507	515	533	468	503	510	462	517	511	481	515	496
582	532	520	534	520	554	520	520	520	641	533	550	530	552	535
15.27	15.30	15.29	15.30	15.31	15.32	6.45	6.45	6.45	5.93	6.16	5.93	5.29	5.29	5.07
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110.3	115.9	116.4	118.0	112.8	116.2	135.1	136.7	134.8	106.4	130.0	114.3	119.9	112.4	117.0
110.3	107.7	96.1	115.4	29.3	116.2	122.1	128.2	94.9	88.7	130.0	113.9	114.8	112.4	114.1
0	8.2	20.3	2.6	83.5	0	13.0	8.5	39.9	17.7	0	0.4	5.1	0	2.9
571	530	530	530	530	549	530	530	530	530	532	530	530	532.6	530

be marginal when taxiing on a hot day, during descent, and at extreme altitudes (particularly when combined with low speeds).

Maximum air conditioning loads and the corresponding cooling air flow requirements, on which system analysis has been based, are shown in Figure 10.

In addition to the theoretical analysis, a full-scale system rig test will be conducted. This rig will contain all ducting and equipment which is used in the system. The purpose of these tests is to check the theoretical analysis and behaviour of the system as much as possible, before the system is air tested. The final stage will be a flight test program to prove the system.

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FIGURE 10

Air Conditioning System Cooling Loads.

Not Available.

APPENDIX 'A'

EQUIPMENT LIST

The following list covers all the bought-out equipment used in the air conditioning system with the exception of hardware and ducting.

Item No.	Description	Qty. per A/C	Avro Dwg. No.	Avrocan Spec. No.	Weight (ea)	Supplier
1	Ram Air Heat Exchanger	1	7-2254-1001	E.483	129.50	AiResearch
2	Turbine and Compressor	1	7-2254-1002	E.484	89.0	"
3	Water Evaporator	1	7-2254-1003	E.486	106.0	Surface Combustion
4	Pressure Reducing Valve	2	7-2256-15023	E.552		AiResearch
5	Cockpit Temperature Controller	1	7-2252-15327	E.619	1.75	
6	Cockpit Temperature Sensing Element	1	7-2252-15323	E.619	0.09	
7	Cockpit Temperature Rheostat	1	7-2252-15321	E.619	0.20	
8	Cockpit Temperature Control Valve	1	7-2252-15325	E.619	3.20	
9	Equipment Temperature Controller	1	7-2252-15329	E.619	1.75	
10	Equipment Temperature Sensing Element	1	7-2252-15323	E.619	0.09	
11	Equipment Temperature Control Valve	1	7-2252-15325	E.619		
12	Cockpit Pressure Controller	1	7-2252-15205	E.298	2.00	Normalair
13	Cockpit Pressure Relay Valve	1	7-2252-15195	E.298	1.00	Normalair
14	Cockpit Pressure Filter	1	7-2252-316	E.298	1.50	Normalair
15	Cockpit Pressure Discharge Valve	1	7-2252-15093	E.298	4.25	Normalair
16	Cockpit Pressure Ground Test Shut-Off Valve	1	7-2252-423	E.298	0.25	
17	Reverse Flow Valve Actuator - L.H. - R.H.	1 1	7-2254-15611 7-2254-15612	E.474 E.474	4.50 4.50	
18	Cockpit Inlet and Non-Return Valve	1	7-2252-15193	E.239	3.50	
19	Cockpit Bypass Valve	1			2.80	
20	Compressor Inlet Relief Valve	1	7-2254-15617	E.550	3.50	

Item No.	Description	Qty. per A/C	Avro Dwg. No.	Avrocan Spec. No.	Weight (ea)	Supplier
21	Thermostat - Turbine Outlet Warning	1	7-2250-131			
22	System Shut-off Valve	1	7-2254-16013	E.487	3.00	
23	Emergency Ram Air Shut-Off Valve	1	7-2252-15021	E.489	4.50	
24	Radar Nose Shut-off Valve	1	7-2252-15203	E.492	3.60	
25	Emergency Ram Air Non-Return Valve - Cockpit	1	7-2252-15202	E.490		
26	Duct Relief Valve - Bleed Pressure	1	7-2254-15618	E.551	7.00	
27	Cockpit Safety Valve	1	7-2252-328	E.572		AiResearch
28	Cockpit Safety Valve Controller	1	7-2252-329	E.572	1.74	"
29	Cockpit Inward Relief Valve	1	7-2252-403	E.572	3.50	"
30	Cockpit Pressure Warning Switch	1				
31	Bleed Duct Overpressure Switch	2	7-2256-15021	E.298	0.50	Parmatic
32	Bleed Duct Thermal Leak Detector					
33	Engine Bleed Shut-off Valve - L.H. - R.H.	1 1	7-2295-15013 7-2295-15014	E.617 E.617	7.00 7.00	
34	Engine Bleed Non-Return Valve	2	7-2254-16005	E.488	2.80	
35	Cockpit Overheat Thermostat	1	7-2250-15081			
36	Equipment Overheat Thermostat	1	7-2250-129			
37	Ground Test Engine Bleed Pressure Pickup					
38	Ground Test Turbine Outlet Temperature Pickup	1	7-2254-16673			

Item No.	Description	Qty. per A/C	Avro Dwg. No.	Avrocan Spec. No.	Weight (ea)	Supplier
39	Ground Test Flow Pick-up Radar Nose	2				
40	Ground Test Temperature Pick-up (Cockpit inlet)	1				
41	Ground Test Temperature Pick-up (Radar Nose)	1				
42	Ground Service Coupling	2				
43	Ram Air Thermostat	1				